Water Resource Management at the Mpala Conservancy (Laikipia District, Kenya)

Chelsea Ransom
Steven Rippberger
Alicia Ritzenthaler

A project submitted in partial fulfillment
of the requirement for
the degree of Master of Science
(Natural Resources and Environment)
at the University of Michigan
July 2012

Abstract

The Mpala Conservancy, located in Kenya's semi-arid Rift Valley, faces the pressure of water scarcity and the challenge of using that resource sustainably. This report provides the Mpala Conservancy with recommendations on how to increase their water security by quantifying water demand, assessing the availability of water sources, and improving water quality.

Demand was measured quantitatively by metering flow at 26 strategic locations throughout the property, spanning the research center, Ranch, and distribution system at large. Daily bednight records were used to normalize demand per capita. The current water demand of the Mpala Research Centre (MRC) is approximately 400L/day/person. Kenyans living in the MRC Village use significantly less water with a demand of approximately 15L/day/person. The total water demand at the Ranch, including the Top Spray Race, was measured at about 30,000L/day. To meet this demand, Mpala draws from water sources that include the Ewaso Nyiro River, the Miocene Aquifer, rooftop harvested rainwater, and the Nanja weirs. Assuming average rainfall, the Nanja weirs can meet Mpala's water demand throughout the year. However, evaporation and rainfall patterns strongly influence whether or not the weirs can capture and store enough water during the rainy season to provide sufficient water through a drought. Demand prediction and weir volume estimation tools were developed to aid future monitoring and management.

Water quality analysis was conducted during both the rainy and dry seasons at primary sources, rainwater storage tanks, and main points of use such as showers, kitchen faucets, and potable water units. Measured water quality parameters included: total and fecal coliforms, nitrate, phosphate, hardness, total suspended solids (TSS), total dissolved solids (TDS), turbidity, and dissolved oxygen (DO). Based on high turbidity and biological contamination in weir and river water, full water treatment is recommended for drinking and cooking. Pre-treatment such as roughing filtration is sufficient for bathing, and when followed by slow sand filtration and disinfection, will provide high quality drinking and cooking water.

Based upon the analysis of Mpala's water resources presented here, a suite of behavioral, managerial, and technical recommendations are provided regarding future water use and management at Mpala. These recommendations include relying on the Nanja weirs as the primary water source and installing storage tanks and roughing filters on the supply lines to MRC and the Ranch. Mpala should also link projected demand at MRC, based on expected bednights, with current water storage in the Nanja weirs to predict and plan for potential water shortages. Monitoring of water quality, availability, and use should be continued.

Acknowledgements

We would like to give a special thank you to our client, funders, and advisors:

The Mpala Research Centre & Wildlife Foundation

The Graham Environmental Sustainability Institute

School of Natural Resources & Environment at the University of Michigan

Donald Scavia & Steven J. Wright, University of Michigan

This project would not have been possible without their dedicated and continuous support.

We would also like to say thank you to the following individuals that contributed time and/or resources to help make this project a success:

Melissa Antokal - University of Michigan

Andrew Atuka - Mpala

Bilal Butt – University of Michigan

Laura Budd – Mpala

Kent Campbell – CILER, University of Michigan

Rachel Fletcher – University of Michigan

Keith Fritschie – University of Michigan

Edward Gachanja – Mpala

Drew Gronewold – NOAA, GLERL

Nick Gutshchow – University of Michigan

Karen Houghtaling – Graham Institute, UofM

Jackson – Mpala

Tom Johengen – CILER, University of Michigan

Kanyare – Mpala

Karanja - Independant

Margaret Kinnaird - Mpala

JoesphLeting – Mpala

Mike Littlewood – Mpala

Kevin Olmstead – TetraTech

Jenny Pfaff – University of Michigan

Caitlin Ryan - University of Michigan

Nagapooja Seeba - University of Michigan

Gary Stoops - Fort Wayne Children's Zoo

Tom Traexler – Rural Focus, Ltd

Mburu Tuni – Mpala

Njogo – Mpala

Pedro – Mpala

Tanai – Mpala

Veronica Teresa – Mpala

Rima Upchurch – University of Michigan

Ajay Varadharajan - University of Michigan

Mike Wiley – SNRE, University of Michigan

Table of Contents

List of Tables

List of Figures

List of Appendices

Abbreviations

$CaCO_3^-$	calcium carbonate
CFU	colony forming units
cms	cubic meters per second
d	day
in	inches
IWA	International Water Association
KEBS	Kenya Environmental Bureau of Standards
km	kilometers
Ksh	Kenyan Shilling
L	liters
LU	livestock unit
m	meters
m^2	square meters
m^3	cubic meters
µS/cm	microsiemen per centimeter
mg/L	milligrams per liter
MCL	maximum contaminant level
mm	millimeters
mL	milliliters
MRC	Mpala Research Centre (Centre, River Camp, & Village)
Ranch	Mpala Ranch, Ltd.
MWI	Ministry of Water & Irrigation (Republic of Kenya)
n.d.	undated source
$NO2^-$-N	nitrite nitrogen
$NO3^-$-N	nitrate nitrogen
NTU	nephelometric turbidity unit
$PO4^{2-}$	phosphate
PtCo	platinum cobalt color unit
TDS	total dissolved solids
TNTC	too numerous to count
TSS	total suspended solids
USEPA or EPA	United States Environmental Protection Agency
VT	village tank
WASREB	Water Services Regulatory Board
WHO	World Health Organization
wk	week
yr	year

Introduction

"Mpala facilitates and exemplifies sustainable human-wildlife co-existence and the advancement of human livelihoods and quality of life. We do this through education, outreach, and by developing science-based solutions to guide conservation actions for the benefit of nature and human welfare. Mpala…a living laboratory."

– Mpala Mission (Mpala Wildlife Foundation & Mpala Research Trust, 2009)

In the arid and semi-arid regions of Kenya, water management and conservation is of the utmost importance. Kenya is listed as "chronically water-scarce" by UN-WATER with an annual renewable freshwater supply of 647 cubic meters per capita, one of the lowest in the world (2006). Although located within the Inter-Tropical Convergence Zone, experiencing two rainy seasons each year, rainfall is highly variable and excess water during the rainy season often creates temporary flooding which is then followed by severe drought during the dry season (Mogaka et al., 2006). Ultimately, the scarcity and variability of water throughout Kenya has profound social, economic, and political impacts, and it is crucial that focus be placed on increasing water security.

The Mpala Conservancy is located in the Laikipia District of Kenya, approximately 30 miles north of the equator and near Mount Kenya (Figure 1). It covers over 49,000 acres of unfenced property and is home to an abundance of wildlife, including lions, elephants, and the endangered Grevy zebra. In addition to providing sanctuary for biodiversity in the area, Mpala has on its premises a research center (Mpala Research Centre or MRC), which hosts hundreds of students, researchers, and professionals annually from all across the globe, as well as a working ranch (Ranch). The MRC and Ranch are located approximately 4.5 km apart (Figure 2).

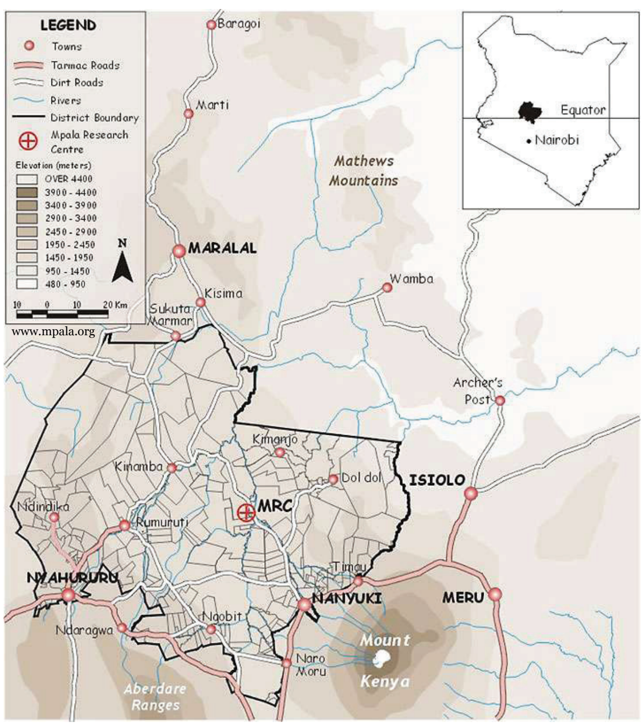


Figure 1: Map of Laikipia District, Kenya

Mpala Research Centre consists of housing, administration, and research facilities for guests at the research center (Centre; Figure 3), as well as River Camp, located on the bank of the Ewaso Nyiro River. River Camp provides housing for large groups visiting Mpala and features tent-type housing structures, restrooms with bucket showers, and on-site dining. Together, the Centre and River Camp can host approximately 85 guests at once. The Ranch consists of a maintenance workshop, guesthouse, administrative buildings, health clinic, garden, and small school. Its primary function is to lead the operations and handling of approximately 2,500 head of livestock living on the property. In addition to the facilities already mentioned at MRC and the Ranch, both of these locations have an on-site village providing year-round housing for staff and their families. Other Mpala facilities located throughout the property include security outposts, bomas, and Clifford House.

Mpala is confronted with a variety of hurdles resulting from operation in such a unique and variable environment. With humans co-existing intimately alongside wildlife, operations are often disrupted. For instance, elephants occasionally uproot water pipes, particularly during the dry seasons, to gain access to the precious resource. Since 2009, when the Ewaso Nyiro River ran dry for the first time in recorded history, Mpala has become increasingly concerned about their overall water security. To better understand Mpala's current water situation, and with the goal of increasing Mpala's overall water security, our team spent 19 months, including two on-site visits, collecting and analyzing data on three issues considered essential to developing valuable and comprehensive recommendations for Mpala: water demand, supply, and quality.

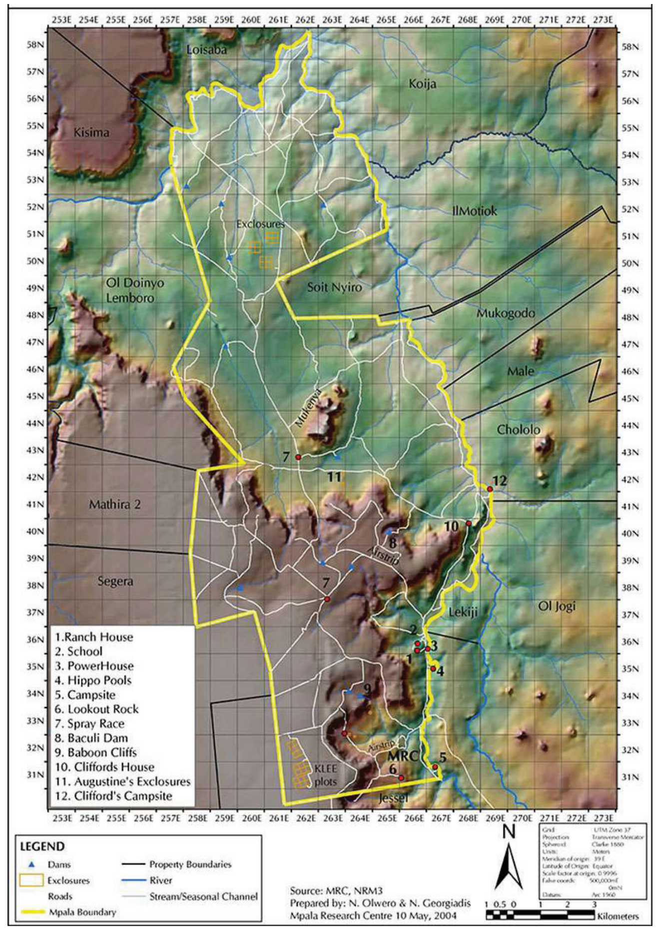


Figure 2: Map of the Mpala Conservancy

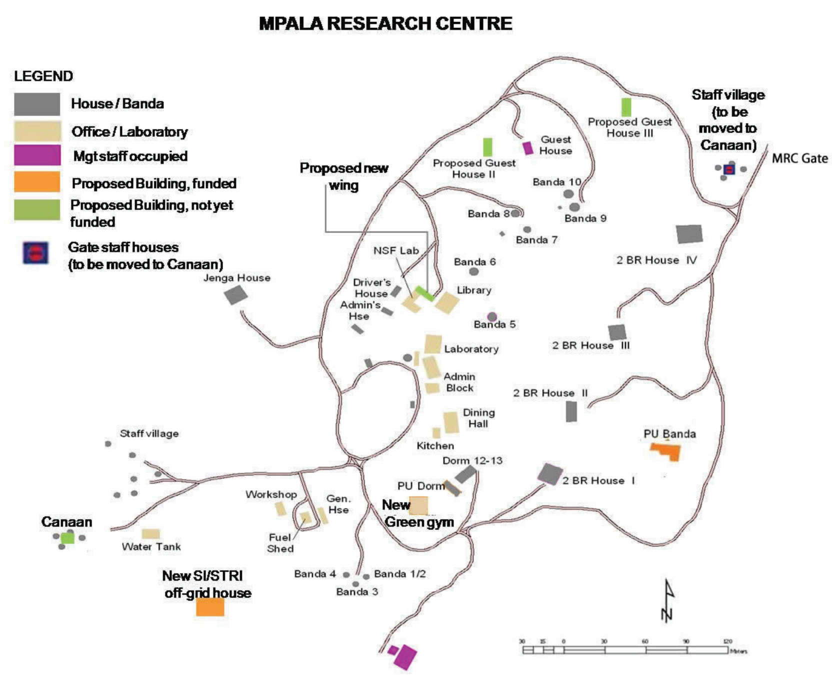


Figure 3: Map of Mpala Research Centre (river camp not shown)

Water Demand

Introduction

Purpose

To provide recommendations to enhance Mpala's water security, a clear understanding of water demand must be established. This includes not only knowing the total amount of water used on the property, but also where and how it is being used. Equipped with such information, Mpala will be able to reduce or eliminate inefficiencies, as well as design and implement water use policies and procedures that will have the greatest likelihood of improving their water security.

Background: Population

At Mpala, and for the purposes of this report, the total population can be divided into the following sub populations: the MRC Village, the Ranch Village, researchers/visitors, boma/ security personnel, and livestock. Wildlife is excluded from this list of subpopulations as this water use was considered beyond the scope of this report. Although the exact populations are unknown for the two villages, several surveys indicate that the MRC and Ranch Village populations range from 149-258 and 232-441 people, respectively (Table 1). The Village populations reach the high ends of their proposed ranges when school is not in session and children return home (April, August, December, and part of January). Antokal et al. (2011) estimated the combined year-round population of the two Villages to be 550 people, and applying Kenya's 2009 population growth rate of 2.69% per year, projected that the total population of the Villages will reach over 950 people by 2030 (Table 2).

Table 1: Population estimates for the MRC & Ranch Villages, 2009-2010 (Antokal et al., 2011)

	Mpala Population Estimates		
	MRC	**Ranch**	**Total**
Aquasearch Ltd. report	149	367	516
2009 census	239	367	606
Director estimate	-	-	~600
Administrator estimate	-	-	~450-500; ~650 during summer
Operations Manager estimate	~225	-	-
Undated communication	191; 258 during summer	232; 441 during summer	423; 699 during summer

Table 2: Projections of combined MRC & Ranch Village populations using different initial populations (Antokal et al., 2011)

Mpala Population Projections (2010-2030) Using Various Initial Populations

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2025**	**2030**
400	411	422	433	445	457	469	482	495	508	522	536	612	699
500	513	527	541	556	571	586	602	618	635	652	670	765	873
550	565	580	596	612	628	645	662	680	698	717	737	841	961
600	616	633	650	667	685	704	723	742	762	782	804	918	1048
700	719	738	758	778	799	821	843	866	889	913	937	1071	1223

The visitor population includes researchers and guests staying at MRC (Centre and River Camp) and the Ranch guest house. This population varies considerably throughout the year and is documented by recording daily bednights (one bednight is one visitor staying one night). Using bednight data from August 2007 to August 2010, Antokal et al. (2011) reported the average number of visitor bednights at MRC for each month (Table 3). Their report also indicated that the highest number of bednights in a month at the MRC bandas and guesthouses (i.e. Centre or MRC proper) was 1,112 (~37 visitors, June 2010) and 846 (~27 visitors, March 2009) at River Camp. The visitor population at the Ranch guest house was deemed insignificant, as the average was less than 1 person per month. Antokal et al. (2011) also indicated in their report that Mpala management requested that future population projections be 200% of the current average visitor population and 133% of the current MRC Village population.

Table 3: Average monthly visitor population at Mpala, 2007-2010 (Antokal et al., 2011)

	Average Monthly Visitor Bednights	Average Monthly Visitor Population (bednights/days)
January	584	19
February	433	14
March	608	20
April	520	17
May	311	11
June	493	16
July	648	22
August	541	17
September	332	11
October	497	16
November	220	7
December	88	3
Average	**440**	**14**

Population estimates for boma and security personnel at Mpala are scarce. These individuals live in various locations across the entire property, and some boma staff frequently move from one location to another. According to the Mpala Director, it's estimated that 96 boma personnel live in temporary houses, 18 staff live in blockhouses at locations like the borehole pump and Top Spray Race, and 15 security personnel live in permanent homes. Based on these estimates, there are a total of 129 Boma/security personnel (Kinnaird, 2010).

The current livestock population at Mpala consists of ~2,500 grade Boran cattle, ~100 camels, and ~100 sheep/goats (Aquasearch Ltd, 2010).

Background: Water Demand and Use

There are several existing reports that discuss water consumption at Mpala to varying degrees. Most of the water demand/use values in these reports are rough estimates, with the exception of some reported by Antokal et al. (2011) and Aquasearch Ltd (2010), which were based on water meter readings. Specifically, most of the demand/use estimates appear to be inferred from rough supply estimates or based on general water use data not specific to Mpala. The per capita demand estimates used to estimate water consumption at Mpala come from the [Republic of Kenya] Ministry of Water and Irrigation's (MWI) "Practice Manual for Water Supply Services in Kenya" (2005) (Table 4).

Table 4: Estimates of per capita water demand in Kenya (MWI, 2005)

	Rural area estimates (l/c/d)			Urban area estimates (l/c/d)		
	High	Medium	Low	High	Medium	Low
People w/individual connections	60	50	40	250	150	75
People w/o connections	20	15	10	-	-	20
Livestock unit	50	50	50	-	-	-

These reports estimate per capita water use by Mpala staff and villagers to be between 20–75 liters/capita/day, while per capita water use of guests staying at the Centre and River Camp is estimated to range between 80–200 liters/capita/day (Airy, n.d.; Antokal et al., 2011). Odhiambo et al. (n.d.) provide one of the more unique per capita demand estimates, reporting that researchers and management use 8 liters/capita/day of rainwater for drinking, brushing teeth, and cooking. The requirement of 8 liters/capita/day of clean water is also discussed in the paper by Antokal et al. (2011), but instead of brushing teeth, they state that this 8 liters/capita/day includes: 2.5 liters for both drinking and cooking, and 3 liters for laundry/bathing.

In addition to domestic water demand, water is also required for livestock and, during dry periods, for irrigation at the Ranch. Livestock get much of their drinking water from small, man made reservoirs scattered throughout the property or directly from the river, and this demand is beyond the scope of this report (Aquasearch Ltd, 2010). Water must be supplied year round to the Top Spray Race, where livestock are sprayed down to rid them of ticks; currently this water is supplied by the Ewaso Nyiro River via a pump located near the Ranch. Overall, the estimated total water demand/use at Mpala has been estimated to be ~45 m^3/d, with the Ranch using twice as much water as MRC (Aquasearch Ltd, 2010). Appendix 1 presents a comprehensive overview of the demand/use estimates found in previously published reports.

In 2010, Antokal et al. (2011) installed the following volumetric water meters:

- **Borehole (Pump)**: measure all water pumped from the borehole before it enters Tank 1. Approximate installation date: July 2010.

- **MRC (Tank 4)**: measures all borehole water entering Tank 4 for use by MRC. Approximate installation date: before August 10, 2010; new meter installed on October 28, 2010.

- **Ranch House (Ranch Field Meter)**: measures all borehole water delivered to the Ranch. Approximate installation date: August 2010.
- **Lister Turbine (Ranch)**: measures all water pumped from river for use at the Ranch and Top Spray Race. Approximate installation date: December 2010.
- **Nanja**: measures all water leaving Nanja weirs for use by the Ranch. Approximate installation date: November 2010.

Results presented by Antokal et al. (2011) represent the most comprehensive instance in which meter data at Mpala has been formally analyzed to determine water use/ demand or water loss,and their analyses have been important in both identifying system inefficiencies and in helping to provide a more accurate understanding of Mpala's water use. For example, Antokal et al. (2011) reported use of borehole water was calculated using the Borehole, Ranch, and Ranch House meters. Based on readings between August 2010 and December 2010, they concluded that, on average, 37.67 m^3/d was pumped from the borehole, with 6.14 m^3/d delivered to the Ranch and 18.98 m^3/d delivered to MRC (Table 5). These numbers led them to conclude that 12.55 m^3/d (~33% of water pumped) was being lost in the distribution system, and that this loss was most likely due to leakages in the underground pipes (Antokal et al., 2011). As of the beginning of this project, it appears that no analyses of the Lister Turbine or Nanja meter readings have been conducted.

Antokal et al. (2011) also discussed ways to reduce water consumption by guests and visitors, including the installation of low-flow fixtures at the Centre. Antokal et al. (2011) estimated that average washroom water use per bednight using standard taps, toilets, and showers, is 5.5 gallons (~20 liters), 17.5 gallons (66 liters), and 25 gallons (95 liters) respectively. By their calculations, replacing all the existing fixtures with low or reduced flow fixtures could result in reductions of water use of up to 90 liters/ capita/day (see Table 5 in their publication for cost estimates of low-flow fixtures) and reduce MRC's total demand by ~14%. When that report was published, a major deterrent to installing more low-flow fixtures at Mpala was that they can be more difficult to repair and maintain than standard fixtures, and the Centre had problems in the past with being able to keep such fixtures operating effectively.

Table 5: Results from meter data analysis (Antokal et al., 2011)

	Ranch House (m^3)	MRC (m^3)	Borehole (m^3)
Average Daily	6.14	18.98	37.67
Percent of total	24%	76%	
Share of total borehole if no losses	**9.21**	**28.46**	
Missing/Discrepancy	**3.07**	**9.48**	

Another approach taken by MRC to reduce demand was to install timers on the showers in the Princeton Dorm that limited showers to eight minutes. Survey data shows that guests generally take a 10-minute shower once or twice a day, and the savings of 90 liters/capita/day mentioned above included reducing shower times to eight minutes (Cole et al., 2012 & Antokal et al., 2011). These timers, which automatically shut off the water after eight minutes, were intentionally broken shortly after installation, and therefore were not a sustainable method of reducing shower water consumption (M. Kinnaird, personal communication, 2012).

Water Meters and Distribution System

During our first visit to Mpala, we conducted a detailed assessment of Mpala's piping network to gain a more complete understanding of the water distribution system. We broke the distribution network down into three subsystems to reduce complexity. The first subsystem includes the line from the borehole up to Tank 4 at MRC and to Don Graham's Tank and the Ranch House Tank at the Ranch. The second subsystem includes all of the lines at MRC. The third subsystem includes all lines servicing the Ranch. We then identified gaps in the existing water flow data and selected strategic locations for installing additional meters. In total, we replaced one existing meter at Tank 4 and installed 21 new meters: 14 at MRC and 7 at the Ranch (Appendix 2). Each meter was installed with its own filter to prevent damage from coarse materials in the water, except for meters #4 Gabriel, #5 Village, and #6 Ranch House Tank which all share a filter located at the outlet of the Village Tank at the Ranch.

Water Meters

Two types of flow meters were installed. All 0.5", 0.75", 1", and 1.5" meters were volumetric rotary piston meters, and the 2" and 3" meters were H4000 Woltman-type meters. Both meters measure cumulative flow with reported accuracy to the liter. These meters were chosen primarily because they can be installed both vertically and horizontally, as opposed to multi-jet meters that must be installed horizontally (Ironmongers Ltd., personal communication, 2011). Additionally, volumetric water meters were chosen because of their high level of accuracy across a wide range of flow rates (Yaniv, 2009). These meters meet the ISO 4064 standard and have a permissible error of ±5% at minimum flow and ±2% at overload, permanent, and transitional flows (ISO, 2005).

Borehole Distribution System

Currently, the only distribution system shared between MRC and the Ranch is the pipeline delivering water from the borehole. Recently, however, there has been discussion about building a pipeline to deliver water from the Nanja weirs to MRC (currently only the Ranch receives water from Nanja). Starting at the borehole, water is first pumped into two above ground storage tanks, Tanks 1 and 2, located immediately next to the pump house (see Appendix 3 for more information on the major storage tanks at Mpala). From there, water is transported to Tank 3, more commonly referred to as the Break Pressure Tank (10 m^3 storage capacity). Two separate pipelines leave the Break Pressure Tank, one to Tank 4 (25 m^3) located in the field by the MRC Village, and another that splits at the Ranch feeding the Ranch House Tank (25 m^3) and Don Graham's Tank. The Ranch and MRC are approximately 4,309m and 5,702 m (Aquasearch Ltd, 2010) from the borehole, respectively, so it can be estimated that the total length of pipeline for the borehole is within that range. Current meters on the main borehole line (Table 6) are:

- **Borehole**: a multi-jet meter that measures water pumped from the borehole into Tank 1. Approximate installation date: July 2010.

- **#1 Tank 4**: installed on the borehole line at the inlet of Tank 4 at MRC. A new meter was installed on August 26, 2011 to replace a multi-jet meter that was installed vertically on October 28, 2010.

- **Field**: a multi-jet meter located on the borehole line in the field by the Ranch Village, just before the split to Don Graham's Tank. This meter was installed in August 2010 and measures all borehole water delivered to the Ranch. This meter is called Ranch House meter in the report by Antokal et al. (2011).

Table 6: Meters for borehole system

Meter Number	Meter Name
-	Borehole
1	Tank 4
-	Field

On January 25, 2012, two leaks were reported on the borehole line between the Break Pressure Tank and Tank 4 at MRC. The leaks occurred a few hundred meters apart on a segment of pipe that is downward sloping, just before the line levels out and then gains elevation to reach Tank 4. Due to the relatively low elevation, this segment of the pipeline experiences high pressure, causing stress on the pipe. This additional stress was considered when the pipeline was installed because it changes from PVC to stronger galvanized iron (GI) just before the line levels out; the leaks occurred on the PVC section just before this switch.

MRC Distribution System

The MRC distribution system includes all water distributed to the Centre, River Camp, and the MRC Village. Figure 4 provides an overview of the distribution hierarchy at MRC and Figure 5 shows known parts of the distribution network, excluding branches to stand alone spigots at the Centre, and the locations of installed meters (refer to Table 7 or Appendix 2 for meter information). GIS maps of the network were also created and sent to Mpala's GIS specialist. MRC primarily uses borehole water via Tank 4, which feeds the Smithsonian House and Tank 5. Tank 5 feeds the Village, Centre, and River Camp. River water is typically pumped into the Black Tank for use by the Village, but when the borehole pump is broken, river water is pumped into Tank 5 and used by all of MRC.

The meters installed at MRC are as follows:

- **#1 Tank 4**: see above in "Borehole Distribution System."

- **#2 Black Tank:** installed on the spigot, this meter measures all water drawn from the Black Tank. When the borehole pump is working, this should account for all river water used at MRC. A meter installed August 28, 2011 was damaged January 3, 2012 and a replacement was installed February 26, 2012. There is no data for this location from January 4, 2012 to February 25, 2012.

- **#3 Village**: measures water distributed to MRC Village via Tank 5. Meter installed on August 26, 2011.

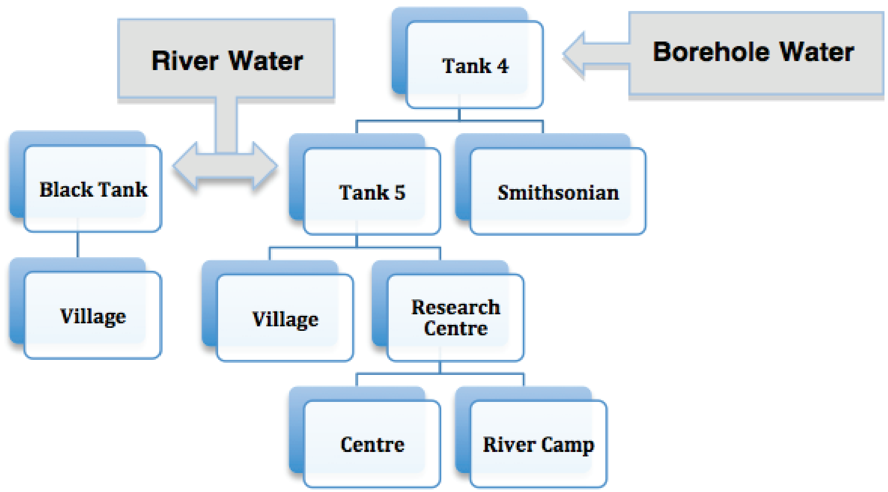


Figure 4: MRC water distribution hierarchy

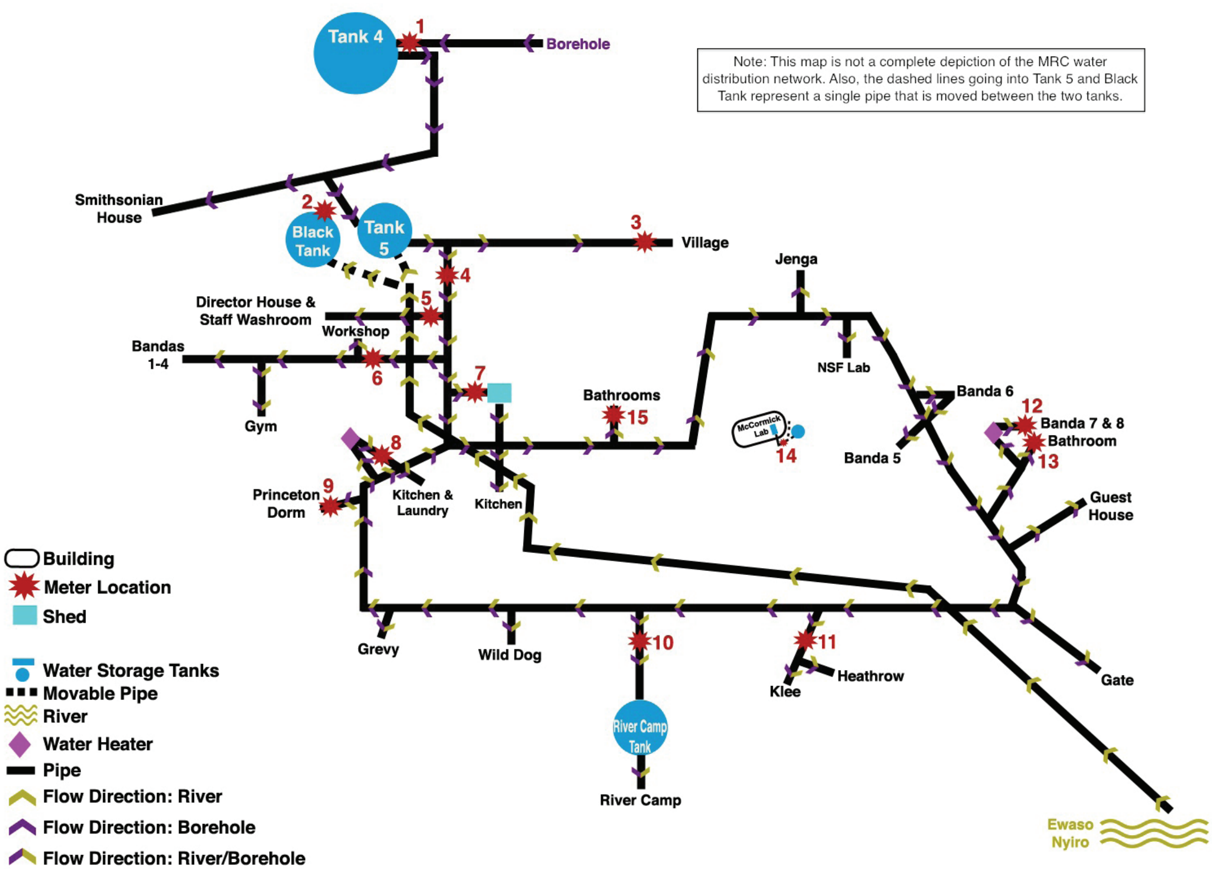


Figure 5: MRC water distribution system & meter locations

Table 7: MRC meter numbers & names

MRC Meters

Number	Name
1	Tank 4
2	Black Tank
3	Village
4	Bush Meter
5	Margaret
6	Garage/Bandas
7	Kitchen Filter
8	Kitchen Hot
9	Princeton Dorm
10	River Camp
11	Klee/Heathrow
12	Bathroom Hot
13	Bathroom Cold
14	Lab
15	Guest Toilet

- **#4 Bush Meter**: located on the 3 inch main line from Tank 4 to MRC, this captures all demand at the Centre and River Camp. Meter installed on August 25, 2011.
- **#5 Margaret**: measures all piped water to the Director's house, which has an irrigated garden, as well as water used at a new staff bathroom completed in February 2012. Meter installed on August 27, 2011.
- **#6 Garage/Bandas**: measures all water used by the garage, Bandas 1-4, and the gym. Meter installed on August 27, 2011.
- **#7 Kitchen Filter**: measures water entering the shed across from the parking area before being used by the kitchen and for laundry. Meter installed on August 27, 2011.
- **#8 Kitchen Hot**: located on the inlet to the elevated hot water storage tank, this measures potentially heated water used at the kitchen and for laundry. Meter was installed on August 30, 2011, but at the time of installation, the hot water heater was broken (fixed on September 9, 2011).
- **#9 Princeton Dorm**: installed along the back of the dorm on the inlet to the bathrooms, this meter measures all water used by the Princeton Dorm. Meter installed on August 28, 2011.
- **#10 River Camp:** measures all water from the main pipeline to River Camp. Meter installed on August 28, 2011.
- **#11 Klee/Heathrow**: this captures water entering both Heathrow and Klee houses. Meter installed on August 29, 2011.
- **#12 Bathroom Hot**: measures all hot water piped to the banda 7 and 8 shared bathroom. Meter installed on August 30, 2011.
- **#13 Bathroom Cold**: located next to meter #12 Bathroom Hot, this measures all cold water piped to the banda 7 and 8 shared bathroom. Meter installed on August 30, 2011.
- **#14 Lab**: measures all water pumped to the indoor storage tank at the McCormick Lab. The system is designed to pump water from the NE rainwater storage tank, but at the time of installation, water was being pumped to the indoor tank from a spigot coming off the main line. Meter installed on August 30, 2011.

- **#15 Guest Toilet:** located across the road from the admin building, this measures all water piped to the communal bathroom, which contains two toilets and two hand washing sinks. Meter installed on August 28, 2011.

Although captured by the #3 Bush meter, water use at the following locations cannot be teased out: Grevy and Wild Dog houses, the guest house, Jenga, NSF Lab, Banda 6 bathroom, Banda 5 bathroom, Banda 9 and 10 shared bathroom, staff houses/bathroom near the labs, the gate, and the other dorm. With these installed meters, #2 Black Tank and #3 Village together capture all water piped to the Village; meters#4 Bush Meter and #3 Village meters capture all water leaving Tank 5; meters #7 Kitchen Filter and #8 Kitchen Hot should capture all water (excluding rainwater) used for cooking and laundry; meters #12 Bathroom Hot and #13 Bathroom Cold measure all water used by the shared banda 7 and 8 bathroom.

The Ranch Distribution System

The borehole, river, and Nanja weirs supply water to the Ranch; Figure 6 shows this distribution network and meter locations (see Table 8 for Ranch meter information).

Historically at the Ranch, borehole water was distributed for use at the Ranch House via the Ranch House Tank, and at Don Graham's house via Don Graham's Tank. With the completion of the Nanja weirs in late 2010, the Ranch has almost entirely stopped using borehole water. Nanja water is gravity fed from the bottom of the lowermost weir (Weir 1) into the Ranch Village Tank and is used to meet the majority of water demand. In the event that Nanja is unable to meet demand, then it is supplemented with water pumped from the river. As previously discussed, river water must be pumped to the Top Spray Race year-round due to it's high elevation (Figure 6).

Table 8: Ranch meter numbers & names

Ranch Meters	
Number	**Name**
1	Garden
2	Workshop/Clinic
3	Nanja into Village Tank
4	Gabriel
5	Village
6	Ranch House Tank
7	River into Village Tank
-	Field
-	Ranch River
-	Nanja

The Ranch Village Tank (Village Tank) has two inlets, one that was designed to carry only river water and the other for Nanja water. On occasion, Nanja water enters the Village Tank through both of these inlet pipes (not simultaneously), which we observed during our stay. We also observed water draining from the Village Tank overflow pipe and being used for irrigation. The Village Tank has two outlet pipes in addition to the overflow pipe; one to the workshop, clinic, and administration building, and another to the Ranch Village, Ranch House Tank, and Don Graham's Tank.

The meters within the Ranch distribution subsystem are as follows:

- **#1 Garden**: measures all water used for the garden and the game pool. Installed on August 23, 2011.
- **#2 Workshop/Clinic**: located on an outlet pipe from the Ranch Village Tank, this measures water demand at the workshop, clinic, and the administration building. Installed on August 25, 2011.

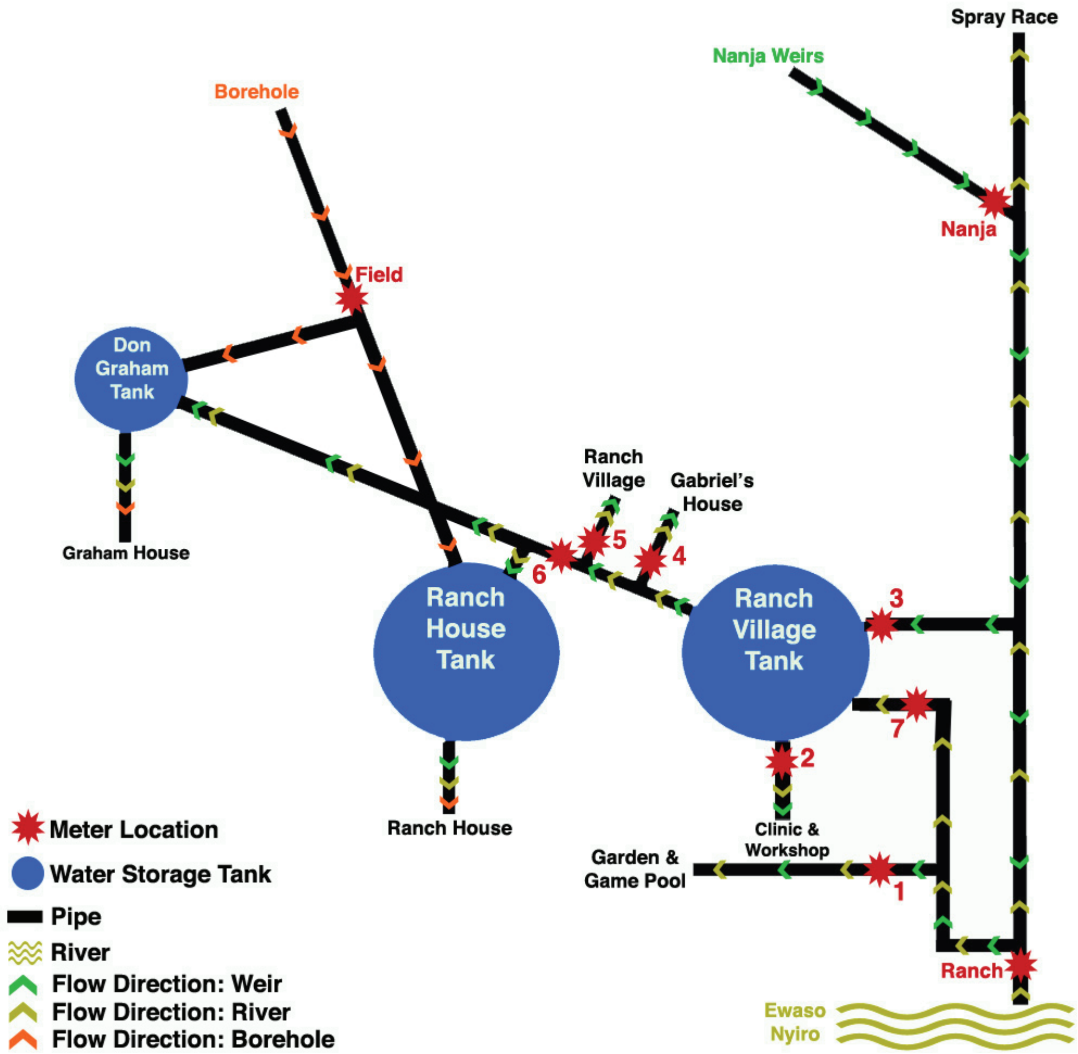


Figure 6: Ranch water distribution system & meter locations

- **#3 Nanja into Village Tank (Nanja into VT)**: located on the Nanja line inlet to the Ranch Village Tank, this meter was intended to capture Nanja demand at the Ranch, but as discussed above, sometimes Nanja water enters via the other inlet pipe (see #7 River into Village Tank). Installed on August 26, 2011.

- **#4 Gabriel**: measures water leaving the Village Tank that is delivered to, what staff refer to as, "Gabriel's House" in the Ranch Village. Installed on August 25, 2011.

- **#5 Village**: measures water leaving the Village Tank for use in the Ranch Village. Installed on August 25, 2011.

- **#6 Ranch House Tank**: measures water piped from the Village Tank to the Ranch House Tank and on to Don Graham's Tank. Installed on August 25, 2011.

- **#7 River into Village Tank (River into VT)**: located on the inlet to the Ranch Village Tank, this meter was intended to capture all River water entering the Village Tank. As observed during our visit, on occasion this pipe carries Nanja water entering the Village Tank. Installed on August 26, 2011.

- **Field**: see above in "Borehole Distribution System."

- **Ranch River**: located on the Ewaso Nyiro River, it measures all water pumped from the river for use by the Ranch. As told by Ranch Manager, when Nanja weirs have water in them, river water is pumped only when needed at the spray race. Installed in December 2010 (M. Littlewood, personal communication, 2011).

- **Nanja**: located on the outlet pipe coming from the bottom of Weir 1, this multi-jet meter measures flow from the Nanja weirs to the Ranch. Water from Nanja is gravity fed to the Ranch in the same pipe that carries river water pumped up to the Top Spray Race. Installed in November 2010.

Together, meters #3 Nanja into VT and #7 River into VT measure all water entering the Village Tank, and meters #2 Workshop/Clinic, #4 Gabriel, #5 Village, and #6 Ranch House Tank measure all water leaving the Village Tank (not including overflow). Meters #4 Gabriel and #5 Village measure all water delivered to the Ranch Village. With the above water meters, the only distributed water known to be unmetered at the Ranch is the river water pumped to the TopSpray Race.

Additional Water Demand

Both MRC and the Ranch have rainwater catchment/storage systems, and the amount of rainwater used on a daily basis is uncertain. Additionally, water is transported in bowsers (a truck with a water tank on it) to various locations, such as the bomas and security posts. According to the Ranch Manager, the Ranch bowser (6.3 m^3 capacity) has been taking water from a small, recently formed reservoir (thought to be a by product of Nanja but perhaps a result of the heavy rains experienced in November and December 2011) and has not drawn water from any storage tanks. The MRC bowser (1 m^3 capacity) has been regularly drawing water from rainwater storage tanks and delivering it to River Camp for drinking and cooking.

Table 9: Mpala bednight data, January '08 - February '12

	2008			2009			2010			2011		
	Total	**Centre**	**Camp**	**Total**	**Centre**	**Camp**	**Total**	**Centre**	**Camp**	**Total**	**Centre**	**Camp**
January	420	414	6	884	449	435	1243	841	402	1205	802	403
February	397	397	0	872	636	236	796	551	245	647	647	0
March	467	467	0	1749	903	846	1389	866	523	899	711	188
April	497	435	62	843	780	63	970	734	236	1385	1049	336
May	405	405	0	875	426	449	793	660	133	1096	828	268
June	716	527	189	811	618	193	1321	1112	209	1523	1354	169
July	651	523	128	1182	872	310	1259	1047	212	1686	1638	48
August	563	563	0	960	695	265	1318	943	375	1754	1153	601
September	437	437	0	522	456	66	548	548	0	840	792	48
October	579	531	48	598	518	80	929	551	378	1186	850	336
November	419	382	37	560	560	0	601	521	80	521	521	0
December	-	-	-	319	319	0	489	489	0	343	343	0
Total	**5551**	**5081**	**470**	**10175**	**7232**	**2943**	**11656**	**8863**	**2793**	**13085**	**10688**	**2397**
Average	**505**	**462**	**43**	**848**	**603**	**245**	**971**	**739**	**233**	**1090**	**891**	**200**

Data Collection and Methods of Analysis

Bednight Data

All reported researcher/guest populations have been derived from daily MRC bednight records from January 1, 2008 to March 1, 2012. These records contain the number of guests each day, as well as the building/location that each guest was assigned to (see Appendix 4 for an example bednight record sheet). These records also include bednight data for the Mpala Director,which previous studies did not include in their analyses of bednight/population data (Antokal et al. 2011 & Aquasearch Ltd. 2010). Note that the terms "bednight" and "population" cannot be used interchangeably; the total number of guest bednights at MRC (Centre and River Camp), divided by the number of days, yields the average guest population over the time period. To identify broader trends in guest populations over time we performed analyses of monthly bednights at the Centre (encompassing the bandas, dorms, and houses), River Camp, and total bednights across Mpala. This process was done for all months in the dataset except December 2008, which was omitted due to incomplete data (Table 9).

To pair bednight data with water meter data, monthly bednights were calculated for individual bandas and dorms at the Centre from September 2011 thru February 2012 (Table 10). All the locations listed in the top two sections of Table 10, as well as Total Bednights and Guest Population, were locations or groups for which demand data was recorded by a water meter, while water use at locations in the third section of Table 10 were not being directly measured. Table 11 shows the link(s) between bednight groups and individual water meters.

To explore potential relationships between bednights/population and water use, a correlation matrix was constructed using monthly water meter and bednight data. In addition to monthly bednights, an analysis was performed on monthly population to eliminate variability in the number of days each month. These results (Appendix 11) do not differ markedly from results using bednights (Appendix 9). For paired variables with high correlation (r value close to ±1), regression analysis was run (α = .05) with monthly bednights/population as the independent variable and water use as the dependent variable. The results of these regressions are presented and discussed in the Analysis & Results section of the Demand section.

2012			Average (month)		
Total	Centre	Camp	Total	Centre	Camp
1660	1140	510	1082	729	351
924	733	189	727	593	134
-	-	-	1126	737	389
-	-	-	924	750	174
-	-	-	792	580	213
-	-	-	1093	903	190
-	-	-	1195	1020	175
-	-	-	1149	839	310
-	-	-	587	558	29
-	-	-	823	613	211
-	-	-	525	496	29
-	-	-	384	384	0
-	**-**	**-**	**10117**	**7966**	**2151**
-	**-**	**-**	**854**	**673**	**180**

Table 10: Detailed bednight data, September '11 - February '12

	September-11	October-11	November-11	December-11	January-12	February-12
Centre	792	850	521	343	1140	733
Campsite	48	336	0	0	510	189
Smithsonian	0	0	0	0	10	2
Bandas 1-4	87	64	41	37	158	47
Bandas 7 & 8	32	91	90	57	96	82
Princeton Dorm	149	168	71	51	203	100
Director	68	38	28	0	62	42
Klee	45	30	2	24	15	72
Heathrow	85	89	68	3	69	83
Banda 5	28	27	6	15	13	13
Banda 6	23	4	1	0	0	0
Bandas 9 & 10	2	31	16	19	78	36
Banda 11	25	16	3	0	14	4
Dorm 12 & 13	131	210	180	125	330	198
Jenga	22	30	9	0	75	16
Grevy	39	21	4	8	25	25
Wild Dog	56	31	2	4	2	15
Total Bednights	**840**	**1186**	**521**	**343**	**1660**	**924**
Guest Population	**28**	**38**	**17**	**11**	**54**	**32**

Table 11: Linked bednight groups & water meters

Bednight Group	MRC Water Meter
Total Bednights	#4 Bush
Centre	#7 Kitchen Filter; #8 Kitchen Hot; #15 Guest Toilet
Campsite	#10 River Camp
Bandas 1-4	#6 Garage/Bandas
Bandas 7 & 8	#12 Bathroom Hot; #13 Bathroom Cold
Princeton Dorm	#9 Princeton Dorm
Director	#5 Margaret
Klee	#11 Klee/Heathrow
Heathrow	#11 Klee/Heathrow
Banda 5	Specific water use can't be determined; summed bednights should show strong correlation with "unmeasured consumption" at MRC
Banda 6	
Bandas 9 & 10	
Banda 11	
Dorm 12 & 13	
Jenga	
Grevy	
Wild Dog	
Smithsonian	

Water Meter Data

Calculations of water use are derived from daily meter readings between August 27, 2011 and March 1, 2012 (see Appendix 5 and Appendix 6 for raw meter data). At the request of Mpala management, most consumption figures are presented on a monthly basis. However, analysis of both daily and weekly consumption was carried out as well to help identify any irregularities in the data.

There were a number of instances where meter readings were missing or incorrectly recorded (Appendices 5 and 6). In some cases it was clear what the missing/incorrect value should be, such as when the next recorded reading showed no change over the time period. When the correct reading was not immediately apparent, it was estimated by interpolating across the time period in question. Readings calculated in this way are estimates and were not used when calculating water use. In this particular analysis, where monthly demand was calculated on the first of each month, an adjustment was only necessary for September 2011. For September 2011, the meter readings on 8/31/11 were used as the starting values, since 9/1/11 had several missing readings and because September has 30 days. As mentioned previously, meter #2 Black Tank was broken for most of January and February 2012, and not enough data was available to perform an analysis. The total monthly water volumes recorded by each meter at MRC and the Ranch can be seen in Table 12 and Table 13 respectively.

As previously discussed, meter readings were also analyzed at daily and weekly time intervals to uncover irregularities. To accomplish this, the highest 10 percent of daily changes were identified for all meters. Using the dates of these readings, bednight data and the daily field notes taken by Mpala's plumber were referenced to explore explanations. Abnormally high readings were typically due to a large number of guests at MRC or to leakages in the system, but some irregularities could not be easily determined (Table 14). High readings observed at #4 Bush Meter from January 14th to January 18th were some such irregularities that could not be easily explained. It is possible that MRC was at full capacity (84-88 bednights recorded) and was in fact using this much water, but over 80% of this use was not accounted for by meters #5 – #15. It is also possible that the pipe became filled with air, as Mpala was having difficulties supplying water at a fast enough rate, and this air interfered with the meters.

During analysis, the readings reported in Table 14 were handled differently depending on what was being determined. For per capita consumption/demand (e.g. water use at Princeton Dorm based on the dorm's population), readings known to include leakages were replaced with average use. This average was derived from daily use values on days with an equal number of bednights of the day being replaced. Regarding the irregular readings for #4 Bush Meter, analyses were run both with and without January. No adjustments were made to readings when assessing overall water demand requirements because such leakages are a part of operating and maintaining a water distribution system. Lastly, total consumption at the MRC Village was estimated based on use at the Ranch Village for January '12 and February '12, because the readings for meter #2 Black Tank were missing for this time period. For September '11 through December '11, use at the MRC Village and Ranch Village were highly correlated (r = .992). The average monthly fractional use (MRC Village / Ranch

Table 12: Monthly total for MRC meters

Monthly Meter Totals at MRC (m^3)	September '11	October '11	November '11	December '11	January '12	February '12	Average
#1 Tank 4	516	745	424	398	546	423	**509**
#2 Black Tank	12	9	10	11	-	-	**11**
#3 Village	81	83	76	117	88	87	**89**
#4 Bush Meter	377	470	229	222	764	436	**417**
#5 Margaret	16	13	13	12	24	25	**17**
#6 Garage/Bandas	38	22	17	23	29	37	**28**
#7 Kitchen Filter	41	30	28	22	41	31	**32**
#8 Kitchen Hot	11	26	13	14	28	16	**18**
#9 Princeton Dorm	30	29	22	34	46	18	**30**
#10 River Camp	40	188	12	25	68	64	**66**
#11 Klee/Heathrow	17	14	11	4	15	17	**13**
#12 Bathroom Hot	1	3	2	2	3	3	**2**
#13 Bathroom Cold	2	6	4	3	5	5	**4**
#14 Lab	0	0	1	2	2	2	**1**
#15 Guest Toilet	11	12	9	6	20	10	**11**

Table 13: Monthly totals for Ranch meters

Monthly Meter Totals at Ranch (m^3)	September '11	October '11	November '11	December '11	January '12	February '12	Average
#1 Garden	110	192	149	280	159	27	**153**
#2 Workshop/Clinic	115	104	71	97	113	121	**103**
#3 Nanja into VT	0	138	25	136	306	590	**199**
#4 Gabriel	18	18	19	25	21	16	**19**
#5 Village	113	102	97	152	136	128	**122**
6 Ranch House Tank	68	18	55	49	34	57	**47**
#7 River into VT	915	352	368	389	209	0	**372**
Field	0	0	33	0	0	0	**6**
Ranch River	141	249	170	73	623	66	**220**
Nanja	1332	705	674	1058	677	928	**896**
Borehole Pump	619	828	628	501	645	685	**651**

Village) was ~0.721, and this was multiplied by the Ranch Village's total use for January '12 and February '12, yielding an expected water use by the MRC Village of 113.14 m^3 and 104.52 m^3 respectively for these months. These values, minus the amount recorded by meter #3 Village, yield the estimated amount taken from the Black Tank (January = 25.30 m^3 and 17.87 m^3). This matches the notes by Mpala's plumber indicating use at the Black Tank was higher during these months than during previous months.

Demand Calculations and Balance Equations

Water Balance Standards

International Water Association (IWA) water audits and balance equation standards were developed for municipal water utilities and have been adapted for use in this project (American Water Works Association, 2012). Balance equations for a distribution system are tabulated from known and calculated volumes of water over time (Figure 7) (Federation of Canadian Municipalities & National Research Council, 2003).

To explain this flow chart, the borehole distribution system at Mpala will be used as an example. The "system input volume" is the quantity of water supplied to the system, i.e. the amount of water pumped from the borehole (Borehole Pump meter), and is equal to the sum of "authorized consumption" and "water loss."

Authorized consumption is the sum of metered consumption,i.e. water delivered to MRC (#1 Tank 4 meter) and the Ranch (Field meter), and unmetered consumption, such as water taken from Tanks 1 or 2 by staff living at the borehole.

Table 14: Irregular meter readings

Date	Bednights	#10 River Camp Daily Change (m³)	Explanation
10/3/11	16	12	
10/4/11	16	11	
10/5/11	16	17	
10/6/11	16	21	
10/7/11	0	16	Pipe reported broken
10/8/11	0	6	
10/9/11	0	0	Pipe Repaired
10/10/11	16	9	
Date	**Bednights**	**#3 Village Daily Change (m³)**	**Explanation**
12/23/11	-	7	
12/24/11	-	10	
12/25/11	-	9	
12/26/11	-	15	Bathroom pipe reported broken
12/27/11	-	4	
Date	**Bednights**	**#9 Princeton Daily Change (m³)**	**Explanation**
12/25/11	1	1	
12/26/11	1	5	
12/27/11	1	4	Toilet overflowing
12/28/11	2	1	
1/5/12	2	2	
1/6/12	9	6	Toilet overflowing
1/7/12	9	3	
Date	**Bednights**	**#4 Bush Meter Daily Change (m³)**	**Explanation**
10/4/11	51	21	
10/5/11	50	25	
10/6/11	54	30	
10/7/11	15	36	Pipe to river camp broken
10/8/11	14	43	
10/9/11	15	16	Pipe to river camp repaired
11/28/11	15	7	
11/29/11	13	28	Outlet at new tank 5 installed
11/30/11	14	5	
1/10/12	82	17	
1/11/12	82	18	
1/12/12	86	16	
1/13/12	82	21	
1/14/12	84	44	[estimate]
1/15/12	83	44	[estimate]
1/16/12	86	98	
1/17/12	85	136	
1/18/12	88	81	
1/19/12	89	17	
1/20/12	54	14	

Water loss is the difference between the system input volume and the authorized consumption, and is broken into two categories: apparent losses and real losses. Apparent losses are due to meter inaccuracies (±2%) and water that is in storage tanks (i.e. water measured by the Borehole Pump meter and residing in storage tanks 1, 2, or 3, so not measured yet by the #1 Tank 4 meter or Field meter). When estimating how much of calculated water loss is attributable to apparent losses, the general rule of thumb is that apparent losses are 20% of calculated water loss (Kayaga, n.d.). Real losses consist of water lost due to leaks in the distribution system and leakage/overflow at storage tanks. Total water loss can be expressed as a percentage of water supply (Department of Environment and Resource Management, 2011), and for large water utilities water loss of 10% or less is considered acceptable while for smaller utilities like Mpala (systems with less than 500 connections), up to 20% water loss is deemed acceptable (Washington State Department of Health, 201; MWI, 2005).

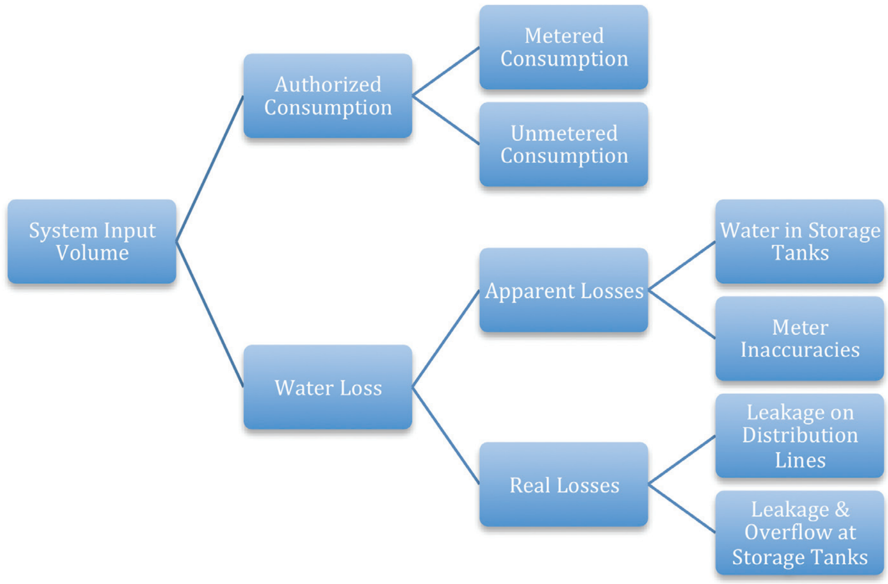


Figure 7: Simplified IWA water balance flow chart

Borehole Water Balance and Associated Equations

<u>Input</u> = Borehole Pump meter

<u>Metered Consumption</u> = Field meter + #1 Tank 4 meter

<u>Unaccounted</u> = Input – Consumption

Table 15: Borehole water balance

Borehole Water Balance (m^3)							
	September '11	October '11	November '11	December '11	January '12	February '12	Total
#1 Tank 4	516	746	423	398	546	423	**3051**
Field	0	0	33	0	0	0	**33**
*Metered Consumption	516	746	456	398	546	423	**3084**
Borehole Pump	619	828	628	501	645	685	**3906**
*Unaccounted Water	103	82	172	103	99	262	**822**
% Supply Missing	17%	10%	27%	21%	15%	38%	**21%**

MRC Demand Calculations and Balance Equation

Table 16: Calculated demands & water balance at MRC

MRC Demands and Water Balances (m^3)							
	September '11	October '11	November '11	December '11	January '12	February '12	Average
*Total Banda 7/8 Bathroom	3	8	7	4	7	7	**6**
*Total Kitchen Use	52	56	42	36	69	48	**51**
*Total MRC Village Use	94	92	86	128	113	105	**96**
*Unaccounted Use at MRC	170	127	97	75	483	209	**194**
*Centre	337	282	217	197	696	372	**350**
*Total Centre & Village Use	471	562	316	350	877	541	**425**

Input: #4 Bush Meter

Metered Consumption: #5 Margaret, #6 Garage/Bandas, #7 Kitchen Filter, #8 Kitchen Hot, #9 Princeton Dorm, #10 River Camp, #11 Klee/Heathrow, #12 Bathroom Hot, #13 Bathroom Cold, #14 Lab, #15 Guest Toilet

Unaccounted: Input – Metered Use

Water Loss (% supply) = (Unaccounted / Input) * 100

Total MRC Village Use = #3 Village + #2 Black Tank

Total MRC Use = #4 Bush Meter + #3 Village + #2 Black Tank

Total Centre Use = #4 Bush Meter – #10 River Camp

Kitchen Total Use = #7 Kitchen Filter + #8 Kitchen Hot

Banda 7/8 Bathroom Total Use = #12 Bathroom Hot + #13 Bathroom Cold

Ranch Demand Calculations and Balance Equation

Ranch Water Balance Equation

Input: Nanja, Field, Ranch River

Metered Consumption: #1 Garden, #3 Nanja into VT, #7 River into VT

Unaccounted: Input – Metered Use

Overflow at Village Tank

Input: #3 Nanja into VT, #7 River into VT

Metered Use: #2 Workshop/Clinic, #4 Gabriel, #5 Village, #6 Ranch House Tank

Max in Storage: 30 m^3

Overflow: Input – (Metered Use + Storage)

Total Ranch Village Consumption = #4 Gabriel + #5 Village

Table 17: Calculated demands & water balance at Ranch

Ranch Demand and Water Balances (m^3)	September '11	October '11	November '11
***Overflow at Village Tank**	571	217	121
***Unaccounted Use at Ranch**	448	273	335
***Total Ranch Village Use**	131	121	116

	December '11	January '12	February '12	Average
***Overflow at Village Tank**	174	181	237	**250**
***Unaccounted Use at Ranch**	326	626	377	**398**
***Total Ranch Village Use**	176	157	145	**141**

Unmetered Water Consumption

The only estimate available regarding individual rainwater use is the 8 liters/capita/day reported by Odhiambo et al. (n.d.). Estimates for water use at several of the bomas and security posts were obtained through conversations with on-site staff (Table 18).

Table 18: Water use at bomas & security posts as reported by Mpala staff

	People at site	Reported Water Use
Boma 1	7	~ 2,000 l/wk
Boma 2	6 – 7	NA
Boma 3	9	~ 2,000 l/wk
Satima Boma	9	~ 1,200 l/wk
Reese's Boma	7 – 8	~ 1,200 l/wk
Top Spray Race	1	NA
Security Post	13	~ 2,750 l/wk
Kiberan's Security Post	NA	~ 2,000 l/wk
River Camp	NA	~ 2,000 l/wk
Clifford House	NA	NA

	Notes on Water Source(s)
Boma 1	River water only
Boma 2	Tap coming off main pipeline near storage tank
Boma 3	
Satima Boma	Nanja/river water delivered once a week
Reese's Boma	
Top Spray Race	Tap from storage tank; river water
Security Post	Nanja/river water delivered once a week
Kiberan's Security Post	6,500L storage tank for rainwater; Nanja/river water delivered when needed
River Camp	1,000L of rainwater (from MRC) delivered every 3-4 days for drinking & cooking
Clifford House	15 m^3 storage tank filled once per week

Results and Analysis

Borehold Distribution System

As discussed earlier, this system was analyzed by Antokal et al. (2011) and it was reported that this system was experiencing high water loss. In reanalyzing the meter data presented in their report, several errors were identified that led them to report a higher water loss than actually existed (Appendix 7). For instance, instead of analyzing all meter data over the same time period, their analysis used data between August 10, 2010 and December 27, 2010 for the MRC meter (#1 Tank 4) and data between August 14, 2010 and December 28, 2010 for the Borehole meter (Borehole Pump). Table 19 shows the adjusted calculations that indicate approximately 22%, not 33%, of total supply was unaccounted for between August 14, 2010 and December 27, 2010.

Meter readings from August 31, 2011 to March 1, 2012 reveal that 822 m^3 of water (21% of total water pumped from the borehole) was unaccounted for. Not accounting for potential meter

Table 19: Analysis of borehole readings - Aug. '10 to Dec '10

	Ranch House (m^3)	MRC (m^3)	Borehole (m^3)
Average Daily	4.99	19.05	30.87
Percent of total	21%	79%	
Share of total borehole if no losses	**6.41**	**24.46**	
Missing/Discrepancy	**1.42**	**5.41**	

inaccuracies, up to 115 m^3 could be apparent losses from water being held in storage tanks 1, 2, and 3 and water still in the pipeline. It's unlikely that this would be the case, but it means that losses during this time period were between 18% (706 m^3) and 21% (822 m^3) of total supply. However, due to the previously mentioned leaks on the borehole line, this calculated loss is slightly higher than what would be expected under normal operating conditions. In February 2012, after repairing one of the leaks, elephants tore up the line and a lot of water was lost (Figure 8). This event is noticeable in the monthly balance table (Table 15) as losses were much higher in February 2012 than in the previous months. When this month is excluded and potential apparent losses are considered, water loss in this system was between 13.8% (444 m^3) and 17.4% (559 m^3) (Table 20; Figure 9).

Figure 8: Picture of reservoir created by 'lost' borehole water

Given the above calculations, there do not appear to be unreasonably high water losses in the borehole system. This is particularly true given the possibility of overflow from tanks 1, 2, and 3, and the fact that some water is taken from the tanks by those living near the borehole pump.

Table 20: Borehole system water balance, September '11 through January '12

	Borehole Water Balance (m^3)		
	September '11	**October '11**	**November '11**
#1 Tank 4 (to MRC)	516	746	423
Field (to Ranch)	0	0	33
***Metered Consumption**	516	746	456
Borehole Pump	619	828	628
***Unaccounted Water**	103	82	172
% Supply Missing	17%	10%	27%

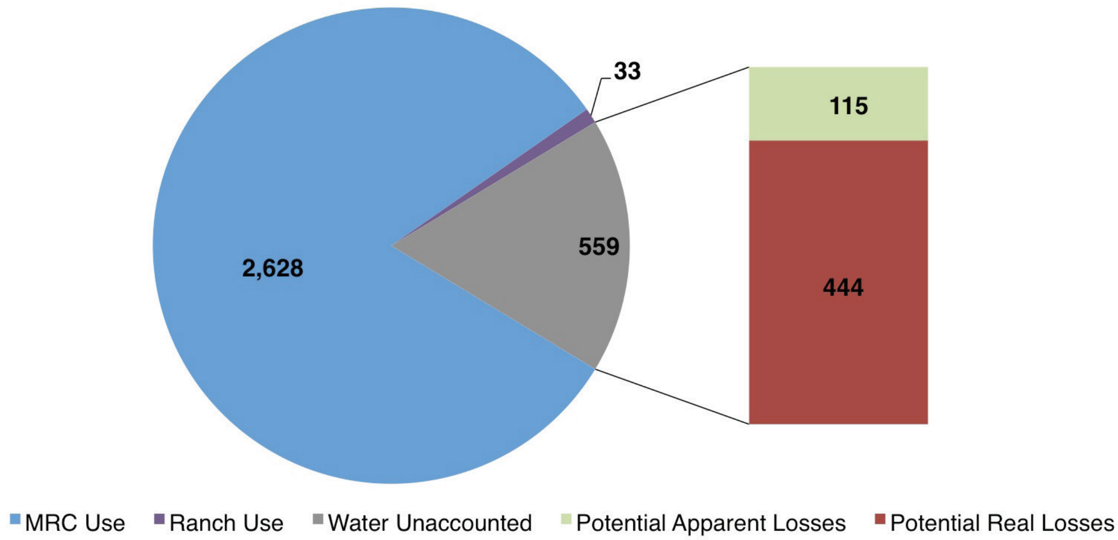


Figure 9: Borehole water balance, August '11 through January '12

Bednights

Table 21 shows the recorded bednights and equivalent monthly population from January 2008 through February 2012. For all years except 2008, which had no bednight data for the month of December, the three months with highest bednight counts and population are highlighted in green and the three months with lowest bednight counts and population are highlighted in red. It's clear that the number of guests visiting Mpala has been increasing (Figure 10); a trend that's expected to continue. The months with the most visitors are March, July, and August, as seen by the 2009-2012 averages (Table 21). The months with the least number of visitors are September, November, and December.

Borehole Water Balance (m^3)		
December '11	January '12	Total
398	546	**2629**
0	0	**33**
398	546	**2662**
501	645	**3221**
103	99	**559**
21%	15%	**17%**

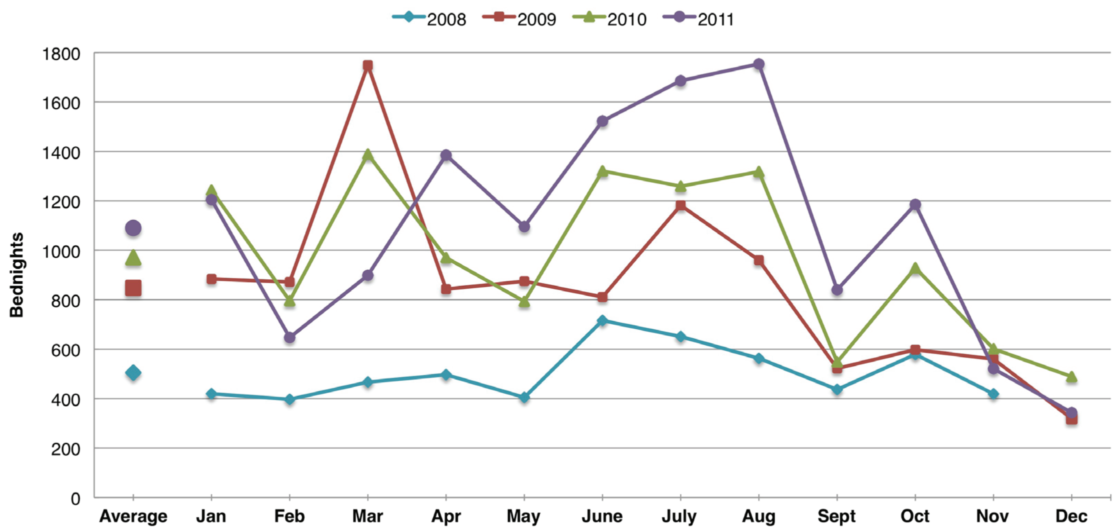


Figure 10: Historic monthly bednights at MRC, 2008 through 2011

Table 21: Historic monthly bednight & population data at Mpala

	Days	2008		2009		2010	
		Bednights	Population	Bednights	Population	Bednights	Populatior
January	31	420	14	884	29	1243	40
February	28*	397	14	872	31	796	28
March	31	467	15	1749	56	1389	45
April	30	497	17	843	28	970	32
May	31	405	13	875	28	793	26
June	30	716	24	811	27	1321	44
July	31	651	21	1182	38	1259	41
August	31	563	18	960	31	1318	43
September	30	437	15	522	17	548	18
October	31	579	19	598	19	929	30
November	30	419	14	560	19	601	20
December	31	-	-	319	10	489	16
Total (year)	-	**5551**	**182**	**10175**	**334**	**11656**	**382**
Average	-	**505**	**17**	**848**	**28**	**971**	**32**

*February 2008 and February 2012 were leap years and had 29 days

	2011		2012		2008-2012 Average		2009-2012 Average	
	Bednights	Population	Bednights	Population	Bednights	Population	Bednights	Population
January	1205	39	1660	54	1082	35	1248	40
February	647	23	924	32	727	26	810	29
March	899	29	-	-	1126	36	1346	43
April	1385	46	-	-	924	31	1066	36
May	1096	35	-	-	792	26	921	30
June	1523	51	-	-	1093	36	1218	41
July	1686	54	-	-	1195	39	1376	44
August	1754	57	-	-	1149	37	1344	43
September	840	28	-	-	587	20	637	21
October	1186	38	-	-	823	27	904	29
November	521	17	-	-	525	18	561	19
December	343	11	-	-	384	12	384	12
Total (year)	**13085**	**429**	**-**	**-**	**10406**	**341**	**11814**	**387**
Average	**1090**	**36**	**-**	**-**	**867**	**28**	**985**	**32**

Bednights and Water Use

We established strong correlations between bednights and water use (Table 22) at all but the following locations: Director's House, Princeton Dorm, Bandas 1–4,and River Camp. The Director's House has a garden that requires watering and the director travels periodically, so this could be why bednights were not highly correlated with water use. For Bandas 1–4, the majority of water use recorded by meter #6 (Garage/Bandas) is attributable to use by the garage and/or at the gym, a demand that isn't necessarily tied to occupancy at these bandas.

Regression analyses of bednights and water use at both River Camp and Princeton Dorm showed higher correlations when identifiable leakages were accounted for, however they were still lower than would be expected. For River Camp, this could be attributable to the use of rainwater that is routinely taken down from the Centre with a bowser. Also, the campsite is typically occupied by a single visiting group at a time, and some groups are likely more aware of their water consumption than others. If such inter-group variability in water use habits exists, it could explain the observed low correlation. Informal interviews conducted with researchers at MRC indicated that Princeton Dorm is the preferred place to shower due to the reliable hot water supply from the solar heating system. The weaker correlation at Princeton Dorm could be attributed to the tendency of guests to use the Princeton Dorm facilities even if not residing there.

Table 22: MRC bednight & water use correlations

Correlations	
Total Bednights	
vs #4 Bush Meter	0.977
vs #15 Guest Toilet	0.944
Campsite Bednights	
vs #10 River Camp	0.610
vs #10 River Camp (adjusted)	0.746
Centre Bednights	
vs #4 Bush Meter	0.950
vs #15 Guest Toilet	0.933
vs *Total Kitchen Use	0.989
Bandas 1- 4 Bednights	
vs #6 Garage/Bandas	0.329
Bandas 7 & 8 Bednights	
vs #12 Bathroom Hot	0.976
vs #13 Bathroom Cold	0.898
vs *Total Banda 7/8 Bathroom	0.950
Princeton Dorm Bednights	
vs #9 Princeton Dorm	0.559
vs #9 Princeton Dorm (adjusted)	0.815
Director Bednights	
#5 Margaret	0.521
Klee & Heathrow Bednights	
#11 Klee/Heathrow	0.912
Unaccounted Bednights	
vs *Unaccounted Use at MRC	0.901

Regression analyses were conducted to understand total water requirements at MRC (excluding the Village), water use at the bathrooms, and the relationship between kitchen water use and bednights. The regression analysis showed that bednight data is a strong predictor of water consumption at MRC (Figure 11); additional results from this analysis can be found in Appendix 9, including regression analysis excluding January '12 (Appendix 10), and regression analysis of average population versus water consumption can be found in Appendix 11.

The result of this analysis was paired with the 2009-2012 average monthly bednight data presented earlier (Table 21) to estimate future water demand at MRC (excluding the Village). Table 23 shows these estimates and monthly water demand predictions for a range of bednight values can be viewed in Appendix 12.

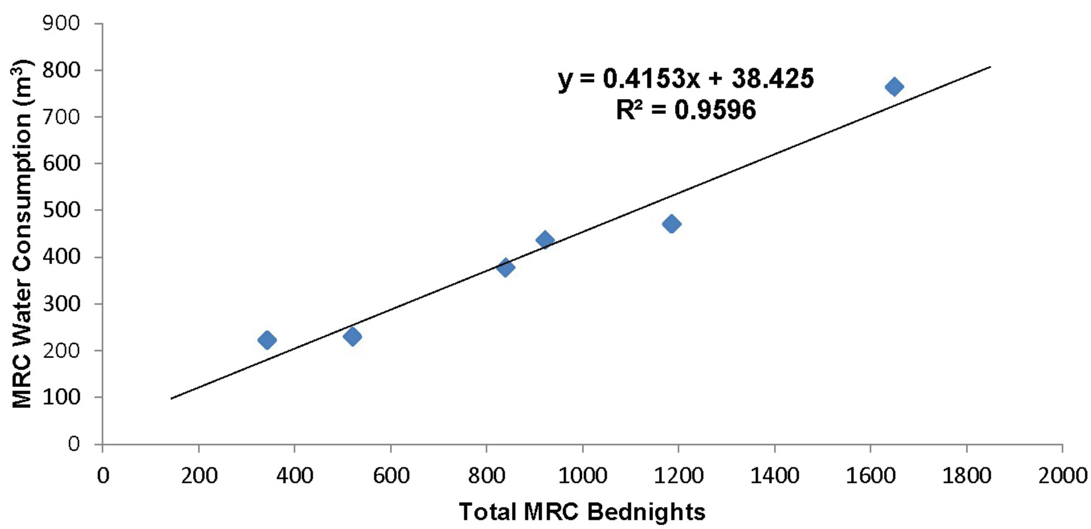


Figure 11: Monthly MRC bednights vs monthly MRC water consumption

Table 23: Average monthly bednights and predicted water consumption for Centre and River Camp combined

	Average Bednights	Predicted Total Water Use (m^3)
January	1248	557
February	810	375
March	1346	597
April	1066	481
May	921	421
June	1218	544
July	1376	610
August	1344	597
September	637	303
October	904	414
November	561	271
December	384	198
Total (year)	**11814**	**5368**
Average	**985**	**447**

This water use at MRC was examined more closely by conducting a regression analysis with Centre bednights and total kitchen water use (excluding rainwater use; Figure 12; Appendix 13), Banda 7 & 8 bednights and Banda 7 & 8 Bathroom water use (Figure 13; Appendix 15), as well as Princeton Dorm bednights and [adjusted] Princeton Dorm water use (Figure 14; Appendix 17).

When paired with the average bednight data from 2009-2012, water use at the MRC centre kitchen accounts for 9-18% of the predicted total water used by MRC (excluding MRC Village) each month (Appendix 14).

The analysis of water use at the Banda 7/8 Bathroom (Figure 13) indicates that, in a month, one person would use 2.6 m^3 of water, or 8 liters of water per day. Of this water use at the bathroom, hot water makes up, on average, 33% of the total water use (Appendix 16).

As mentioned previously and seen in Figure 13, the correlation between bednights and water use at Princeton Dorm is not as strong as expected (coefficient of determination is 0.66). This is a probable indicator that guests staying at places other than Princeton Dorm are using the facilities, which could impact the results described above regarding the Banda 7/8 Bathroom;

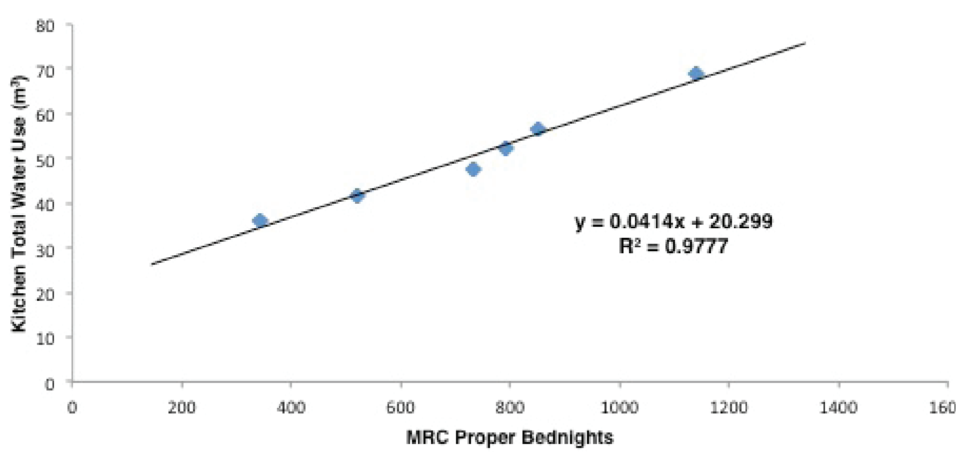


Figure 12: Monthly Centre bednights vs monthly water use at kitchen

these guests use Princeton Dorm shower facilities and the Banda 7/8 Bathroom for hand washing and toilet use. Using 60 bednights, per capita water demand at Banda 7/8 Bathroom is 80 liters/capita/day and 330 liters/capita/day at the Princeton Dorm. This gives further support to the postulation that guests staying at locations other than the Princeton Dorm are using the Princeton Dorm facilities.

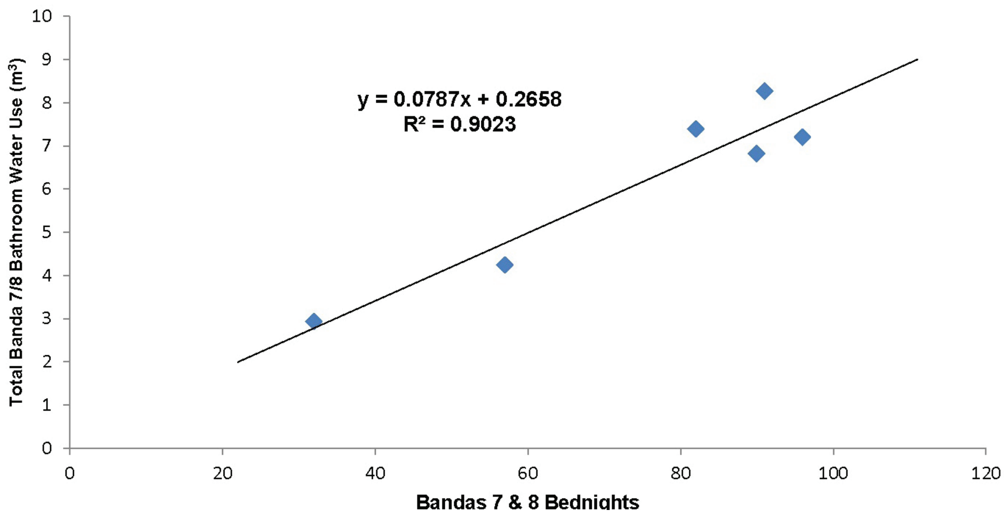


Figure 13: Banda 7/8 bathroom, monthly bednights vs monthly water use

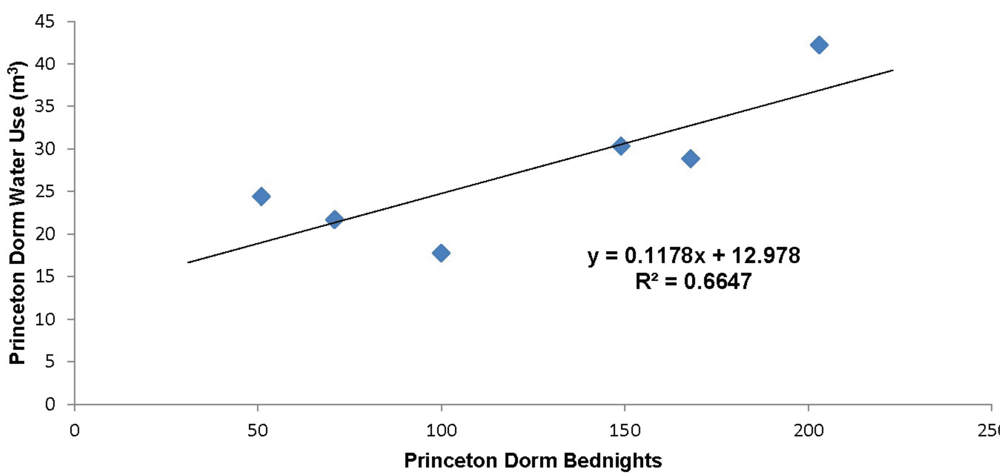


Figure 14: Princeton Dorm, monthly bednights vs monthly water use

MRC Water Use

To develop a complete understanding of MRC's water demand, water use at the Village must be accounted for as well. Population was estimated at 191 people when children are in school and 258 when children are not in school (Kinnaird, 2010b). Estimates of whether children were back from school or not were determined based on meter readings and monthly water use values. The population was estimated to be 191 people for September, October, and November, and 258 people in December, January, and February. Population was converted to bednights, which showed strong correlation with water use (r = 0.9658). Regression analysis showed bednights was significant in predicting Village water use ($p = .001$, Figure 15, Appendix 18).

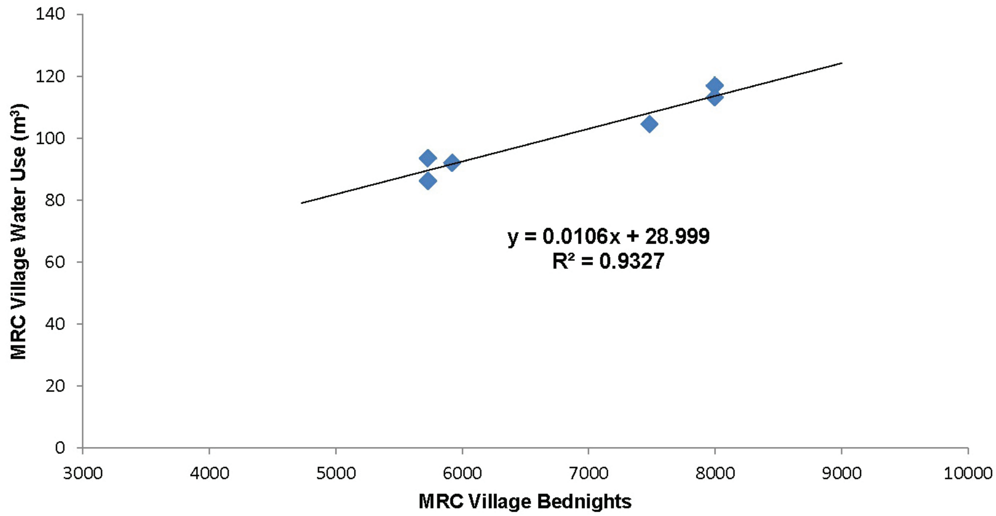


Figure 15: MRC Village , monthly bednights vs monthly water use

Based on this analysis, predicted monthly water use for the Village can be calculated assuming that children are not in school from December – February and June – August. Predicted monthly water use is 15 liters/capita/day at the Village, as shown in Table 24. Another way to calculate water use at the Village is to take the highest water use values for when children are in school (94 m^3) and when they're out of school (117 m^3) and apply these values to each month. These values are very close to the predicted values obtained from the regression equation (Table 24), so the predicted values were used to calculate total water consumption at MRC (Table 25 and Figure 16).

Overall, MRC is predicted to use 6,583 m^3 of water in a year given average bednights from 2009-2012 and the current MRC Village population, with highest demand in July (723 m^3) and lowest in December (311 m^3). The predicted total monthly water use at MRC, assuming a 100% guest increase and a 33% Village increase of current monthly averages, is shown in Table 26 and Figure 16. The number of guest bednights for July in Table 26 is equivalent to a monthly population of 89, representing a month of Mpala being at full capacity for the entire month (given current capacity).

Table 24: Predicted monthly water use at MRC Village

	Days	Village Population	Village Bednights
January	31	258	7998
February	28	258	7224
March	31	191	5921
April	30	191	5730
May	31	191	5921
June	30	258	7740
July	31	258	7998
August	31	258	7998
September	30	191	5730
October	31	191	5921
November	30	191	5730
December	31	258	7998

Table 25: Predicted monthly water use at MRC

	Predicted MRC Village Water Use (m^3)	Predicted Research Centre Water Use (m^3)	Predicted Total MRC Water Use (m^3)
January	114	557	**670**
February	105	375	**480**
March	92	597	**689**
April	90	481	**571**
May	92	421	**513**
June	111	544	**655**
July	114	610	**723**
August	114	597	**710**
September	90	303	**393**
October	92	414	**506**
November	90	271	**361**
December	114	198	**311**
Total (year)	**1215**	**5368**	**6583**
Average	**101**	**447**	**549**

Table 26: Total predicted MRC water use, 200% guest bednights & 133% village population

	Village Bednights	Water Use (m^3)	Guest Bednights	Water Use (m^3)	Total MRC Water Use (m^3)
January	10664	**142**	2496	**1075**	**1217**
February	9632	**131**	1620	**711**	**842**
March	7895	**113**	2691	**1156**	**1269**
April	7640	**110**	2132	**924**	**1034**
May	7895	**113**	1843	**804**	**916**
June	10320	**138**	2437	**1050**	**1189**
July	10664	**142**	2751	**1181**	**1323**
August	10664	**142**	2688	**1155**	**1297**
September	7640	**110**	1273	**567**	**677**
October	7895	**113**	1809	**790**	**902**
November	7640	**110**	1121	**504**	**614**
December	10664	**142**	767	**357**	**499**
Total (year)	109212	**1504**	23628	**10275**	**11779**
Average	9101	**125**	1969	**856**	**982**

Predicted Water Use (m^3)	33% Population Increase	Predicted Water Use (m^3)
114	10664	**142**
105	9632	**131**
92	7895	**113**
90	7640	**110**
92	7895	**113**
111	10320	**138**
114	10664	**142**
114	10664	**142**
90	7640	**110**
92	7895	**113**
90	7640	**110**
114	10664	**142**

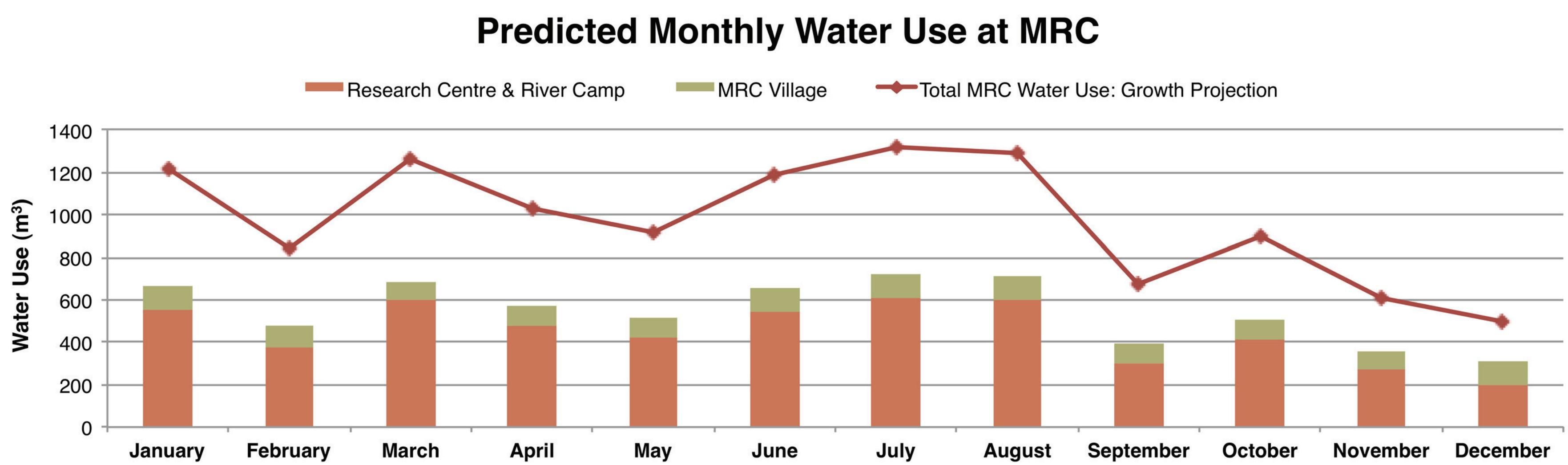


Figure 16: Total monthly water use at MRC, average & growth predictions

Ranch Water Use

Table 27 presents calculations over the months for which meter data were collected. These calculations include: the total amount of water supplied to the Ranch each month, the total amount of metered water use, known overflow from the Village Tank, unmetered water use (should represent water sent to Top Spray Race), and the total monthly water demand at the Ranch (Figure 17).

Table 27: Calculated total monthly water use at Ranch

	Total Ranch Water Use (m³)		
	September '11	**October '11**	**November '11**
***Total Water Supplied to Ranch**	1473	954	877
***Metered Water Use**	1025	681	575
***Unmetered Water Use**	448	273	302
***Village Tank Overflow**	571	217	121
Total Ranch Water Use	902	737	756
Total Ranch Water Use (m³)	30	24	25

	December '11	January '12	February '12	Total	Average
***Total Water Supplied to Ranch**	1131	1300	994	**6729**	**1122**
***Metered Water Use**	805	674	617	**4377**	**730**
***Unmetered Water Use**	326	626	377	**2352**	**392**
***Village Tank Overflow**	174	181	237	**1650**	**275**
Total Ranch Water Use	957	1119	757	**5229**	**871**
***Daily Ranch Demand (m³)**	31	36	26	**-**	**29**

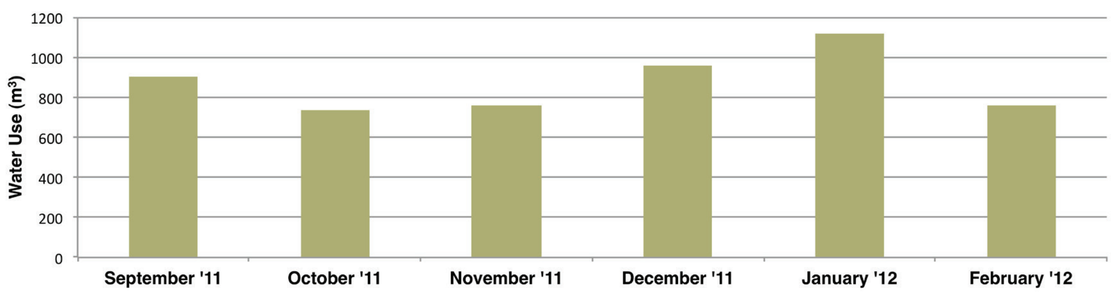


Figure 17: Total water use (without known overflow) at Ranch

Figure 18 presents a breakdown of water demand and use at the Ranch. Most notable is the large amount of overflow at the Village Tank. As explained by the Ranch Manager, this overflow only occurs when the weirs are full and the water is used to irrigate the grounds, but clearly this is a substantial amount of water. Over the six-month period, the total amount of water that overflowed from the Village Tank equaled almost two months of average total water demand at the Ranch.

In analyzing water use at the Ranch Village, the same assumptions and processes used in the MRC Village analysis were applied. Estimates for population at the Ranch Village are 232 people when children are at school and 441 people when children are out of school (Kinnaird, 2010b). Compared to the MRC Village analysis, the correlation between estimated population sizes and water use was weaker for

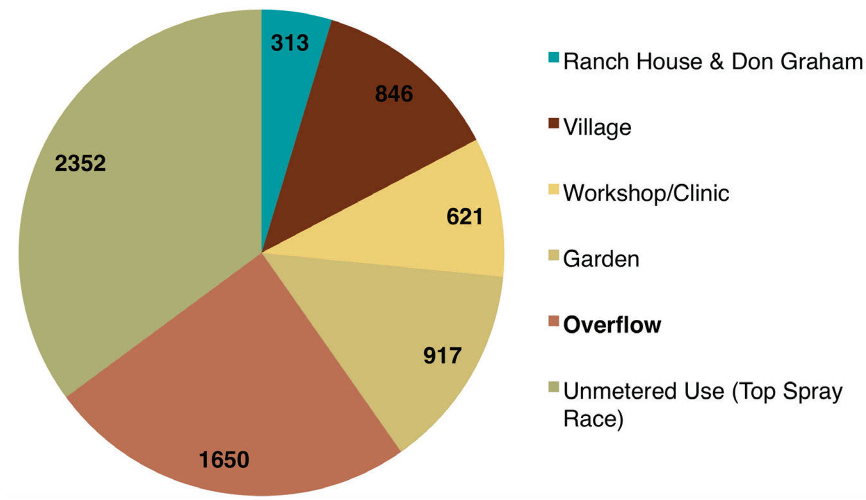


Figure 18: Breakdown of water use at Ranch, August '11 through February '12

the Ranch Village (r = 0.9034) (Figure 19; Appendix 19) and could be a result of this location having more variability in the actual day-to-day population.

Due to the lower coefficient of determination in the analysis of Ranch Village bednights compared to water use, other approaches were taken to understand water use. The minimum demand by the Ranch Village was in November 2011 (116 m^3), the maximum demand was in December 2011 (176 m^3), and the average demand over the six-month period was 141 m^3. Another approach was to take the average use during months when children are in school and an average of use when children are not in school. The average for September through November 2011 was 123 m^3 and the average use from December 2011 through February 2012 was 159 m^3. For the Ranch as a whole, average monthly water use was 871 m^3, with the lowest use occurring in October 2011 (737 m^3) and the highest in January 2012 (1,119 m^3). January 2012 showed an increase in "unmetered use" (i.e. water sent to the Top Spray Race), which is possibly due to the drier conditions experienced during that month. For instance, cattle may require more thorough and lengthy cleanings due to the dustier conditions experienced during dry periods. As there was no rainfall in January 2012, more water would have needed to be pumped from the river up to the Top Spray Race.

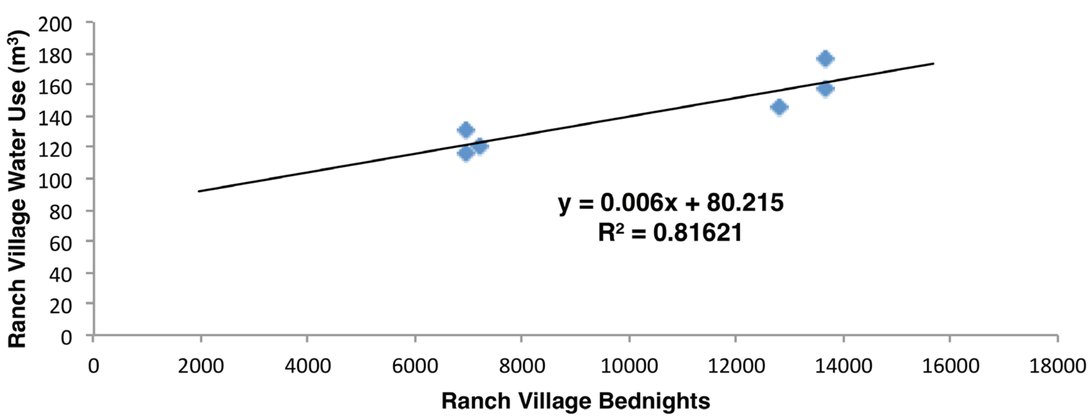


Figure 19: Ranch Village, monthly bednights vs monthly water use

There is an indication of unmetered water use at the Ranch in addition to demand at the Top Spray Race. To get water to the Top Spray Race it must be pumped from the river, and the amount of unmeasured water use exceeded the amount of water that was pumped from the river (Table 28) each month from September 2011 through February 2012. January 2012 is the only month in which the amount of water pumped from the river is almost equal to unmetered use (Table 28).

Table 28 :Difference between river water pumped & unmetered water use at Ranch

	September '11	October '11	November '11	December '11
Water Pumped from River (m^3)	141	249	170	73
***Unmetered Water Use (m^3)**	448	273	302	326
***Unmetered (-) Pumped (m^3)**	307	24	132	253

	January '12	February '12	Total	Average
Water Pumped from River (m^3)	623	66	**1322**	**220**
***Unmetered Water Use (m^3)**	626	377	**2352**	**392**
***Unmetered (-) Pumped (m^3)**	3	311	**1030**	**172**

Unmetered Demand

Table 18 shows the reported water use at bomas and security posts obtained in August 2011. Due to uncertainties around these quantities and where this water was taken from, it is not incorporated into our overall demand calculations. With the exception of River Camp, which receives water from a 1 m^3 bowser filled with rainwater from MRC, the Ranch Manager stated that from August 31, 2011 to March 1, 2012, water taken to boma/security personnel has not been taken from the pipelines or storage tanks. While on-site, it was observed that staff living by the MRC river pump were being supplied with river water. They have a 1 m^3 tank which is filled when water is pumped up to the Black Tank at the MRC Village.

Using the 8 liters/capita/day of rainwater use reported by Odhiambo et al. (n.d.) and Antokal et al. (2010), rainwater use by MRC guests was estimated for both the average number of monthly MRC bednights (2009-2012) and double the average number of monthly MRC bednights (Table 29). Given the high degree of uncertainty around these estimates, they have not been included in any calculations of total water demand at MRC, the Ranch, or the Mpala Conservancy as a whole.

Water Use at the Mpala Conservancy

Table 30 and Figure 20 show the total calculated water demand for all of Mpala. The monthly demand at the Ranch was calculated using the monthly average from available data, 871 m^3 per month, which was then rounded to 900 m^3. Actual Ranch water use can vary between 651 – 1,136 m^3 (approximately 7-9 m^3 per day). This is roughly equivalent to the amount of water used by the MRC and Ranch Villages combined.

If the number of visitors at MRC doubles and the MRC Village population increases by a third, then predicted water use at MRC increases to 11,779 m^3 per year, averaging 982 m^3 per month. As the Ranch operates somewhat independently of MRC, an increase in visitors at MRC would not necessarily result in an increase in the population at the Ranch. Keeping the Ranch demand the same, the resulting total demand for Mpala, as seen in Table 31, would be 22,579 m^3 per year, or 1,882 m^3 per month, excluding rainwater demand.

Table 29: Estimated rainwater use by MRC Guests

	Average Bednights	Estimated Rainwater Use (m^3)	100% Increase in Bednights	Estimated Rainwater Use (m^3)
January	1248	**10**	2496	**20**
February	810	**6**	1620	**13**
March	1346	**11**	2691	**22**
April	1066	**9**	2132	**17**
May	921	**7**	1843	**15**
June	1218	**10**	2437	**19**
July	1376	**11**	2751	**22**
August	1344	**11**	2688	**22**
September	637	**5**	1273	**10**
October	904	**7**	1809	**14**
November	561	**4**	1121	**9**
December	384	**3**	767	**6**
Total (year)	11814	**95**	23628	**189**

Table 30: Predicted total water use at Mpala Conservancy, current conditions

	Predicted Total MRC Water Use (m^3)	Predicted Total Ranch Water Use (m^3)	Predicted Total Mpala Water Use (m^3)
January	670	900	**1570**
February	480	900	**1380**
March	689	900	**1589**
April	571	900	**1471**
May	513	900	**1413**
June	655	900	**1555**
July	723	900	**1623**
August	710	900	**1610**
September	393	900	**1293**
October	506	900	**1406**
November	361	900	**1261**
December	311	900	**1211**
Total (year)	**6583**	**10800**	**17383**
Average	**549**	**900**	**1449**

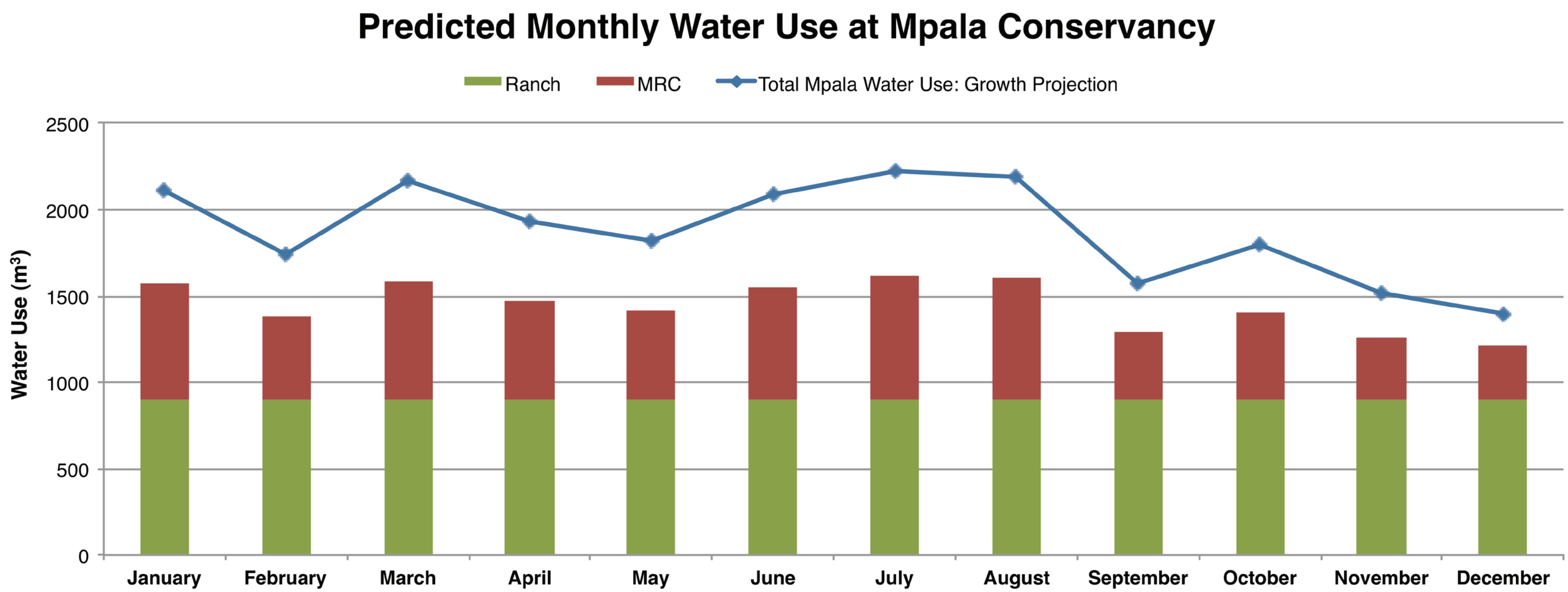


Figure 20: Predicted water use at the Mpala Conservancy, average & growth predictions

Table 31: Predicted total water use at Mpala, 200% average MRC bednights & 133% MRC Village population

	Predicted Total MRC Water Use (m^3)	Predicted Total Ranch Water Use (m^3)	Predicted Total Mpala Water Use (m^3)
January	1217	900	**2117**
February	842	900	**1742**
March	1269	900	**2169**
April	1034	900	**1934**
May	916	900	**1816**
June	1189	900	**2089**
July	1323	900	**2223**
August	1297	900	**2197**
September	677	900	**1577**
October	902	900	**1802**
November	614	900	**1514**
December	499	900	**1399**
Total (year)	**11779**	**10800**	**22579**
Average	**982**	**900**	**1882**

Water Supply

Introduction

Mpala currently has 3 primary sources of water presently available: groundwater, surface water, and rainwater. Surface and rainwater sources include the Ewaso Nyiro River, the Nanja weirs, and rooftop harvested rainwater. Groundwater is supplied to Mpala from a pump located at the borehole. Due to the semi-arid environment, Mpala must carefully manage its water resources to ensure a reliable water supply throughout the year. The current and future availability of these resources will be discussed in this section.

River Water

The Ewaso Narok and Ewaso Nyiro Rivers border Mpala on the north and east respectively. Mpala currently pumps water from two locations along the Ewaso Nyiro to deliver water to the research center and Ranch. Rivers can be described using a vast number of hydrologic, hydraulic, and ecological characteristics, and while it is important to note that rivers function as unique, complex systems, a fully comprehensive study of the Ewaso Nyiro River is beyond the scope of this report. Characteristics were therefore selected based upon their ability to effectually describe river water availability throughout the year.

Low-flow and flow stability are two characteristics used here to describe the availability of river water on both time and volumetric scales. Together, they indicate the volume of water available and how availability fluctuates over time. For the purposes of this study, low-flow describes the minimum statistically expected flow while stability describes flow fluctuations. Characteristics of river flow were examined at the Ewaso Nyiro Junction monitoring station (Figure 21) both annually and seasonally during the most recent 6-year record period available

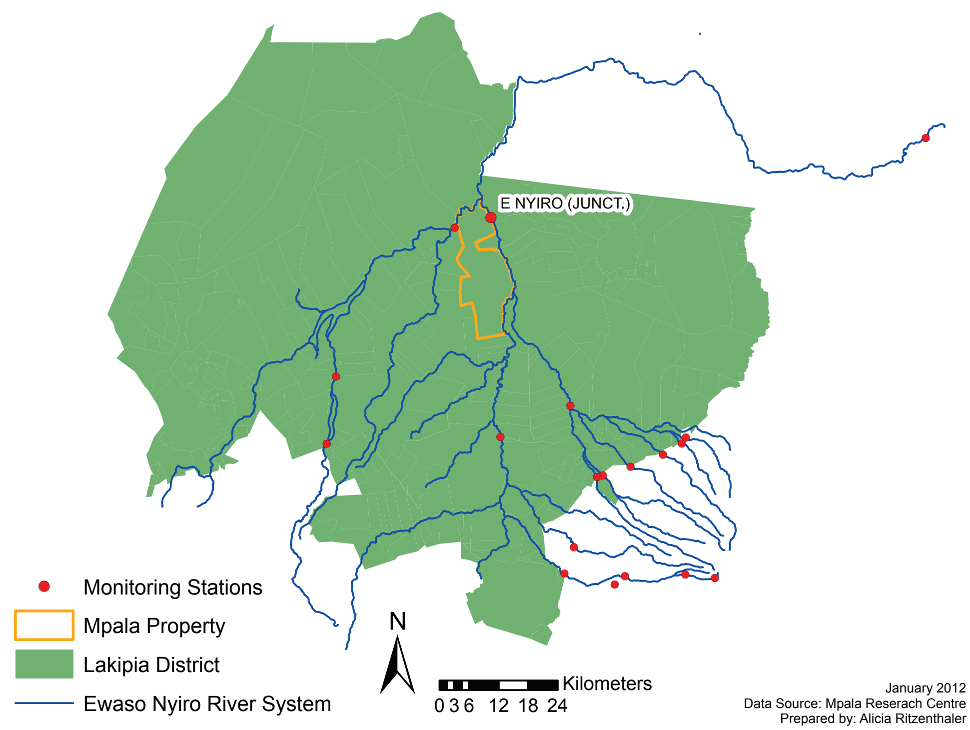


Figure 21: Ewaso Nyiro River system with selected monitoring stations

(1997-2002) as well as over the entire 42-year time record in order to qualitatively assess availability. These time periods were selected so that the recent trends could be compared to historical trends.

Low-flow

Low-flow indicates the volume of river water consistently available over a given period of time. The measure used to indicate low-flow varies across disciplines, but one common measure is 90% exceedance flow. Flow exceedance is the statistical probability that a given flow will occur based on observed historical flow records. The 90% exceedance flow indicates that the flow is expected to be greater than that value 90% of the time. While no previous detailed assessment has been completed at the Ewaso Nyiro Junction monitoring station, our analysis is similar to analyses that have been conducted for other points along the Ewaso Nyiro River, both upstream and downstream (Leibundgut, 1986; Thomas & Liniger, 1994). The 90% exceedance flow is significantly less during the 1997-2002 record period than it was prior to 1997 ($p<0.05$; Table 32) indicating that the volume of water available 90% of the time now is less than it has been historically.

Table 32: 90% exceedance flow 1960-2001

	90% Exceedance Flow (cms)					
	Annual	Long Dry[1]	Long Rains[2]	Int. Rains[3]	Short Dry[4]	Short Rains[5]
1997-2002	0.71	0.32	0.26	0.828	0.899	2.21
1960-1996	1.38	1	1.02	2.314	1.807	2.33

1. December, January, and February 2. March, April, and May 3. June, July, and August 4. September 5. October and November

It is interesting and important to note that between 1997 and 2002, the smallest low-flows do not necessarily occur during the driest seasons. This delay between rainfall and observed flow could be a result of channel storage and delay but is also often an indication of groundwater contribution. If the flows at the beginning of the dry season are much greater than the rest of the season, then channel storage and delay is a reasonable cause. If, however, low-flow is observed during the long rainy season, indicating that rainfall contributes little to flow, then it is likely that groundwater contributes significantly. Comprehensive hydrological reports of other basins in the Mt. Kenya region, including extensive studies on the nearby Naro Maru River, suggest that a combination of both lag time and groundwater contribute to higher than expected dry season flows (Decurtins, 1992).

One influence on low-flow which cannot be ignored is that of upstream users, but it is difficult to determine which changes in observed flow are factors of hydrology, and which can be attributed to withdraws from upstream users. Even with a comprehensive understanding of the hydrology and hydraulics of the Ewaso Nyiro River system, the influence of withdraws from upstream water users acts as a 'wild card' in the effort to quantify and predict river water availability. With the creation of the Water Users Association the river is being viewed as a shared resource that many individuals and stakeholders depend on. Mpala's participation in one or more Water Users Associations would indicate to other users their concern for the rivers' future and would provide an opportunity to influence management of the shared resource.

Stability

While the low-flow parameter represents the volume of water available, water stability describes when this water is available. The instability of flow is illustrated in the Ewaso Nyiro hydrographs (Figure 22a; Figure 22b). While significant flow variability is evident in the 42-year hydrograph (Figure 22a), the 6-year hydrograph helps visualize fluctuations with more detail, showing not just intra-annual fluctuation but also inter-annual variation (Figure 22b).

Stability ratios are the ratio of 90% to 10% exceedance flows and are used as the measure of stability (Equation 1). These ratios range from zero (unstable, highly fluctuating flow) to 1 (stable, consistent flow). The stability of the Ewaso Nyiro flow exhibits extreme fluctuation. Stability ratios were consistently lower in the time period 1997-2002 than they were from 1960-1996 (Table 33) ($p<0.05$), indicating that current fluctuations are more extreme than they have been historically.

Equation 1:

$$\text{Stability Ratio} = \frac{\text{90\% exceedance flow}}{\text{10\% exceedance flow}}$$

Table 33: Stability Ratios 1997-2002 compared to 1960-1996

	Stability Ratio					
	Annual	Long Dry[1]	Long Rains[2]	Int. Rains[3]	Short Dry[4]	Short Rains[5]
1997-2002	0.029	0.009	0.007	0.062	0.155	0.061
1960-1996	0.069	0.056	0.038	0.171	0.133	0.094

1. Dec, Jan, and Feb 2. Mar, Apr, and May 3. June, July, and Aug 4. Sept 5. Oct and Nov

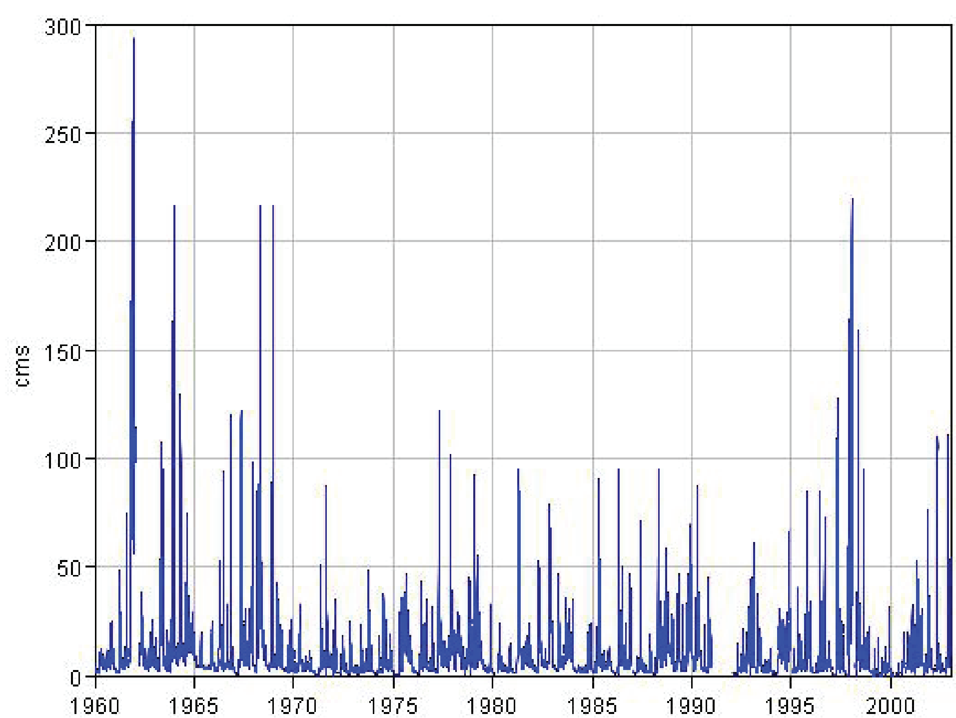


Figure 22a: 42-year hydrograph of the Ewaso Nyiro River

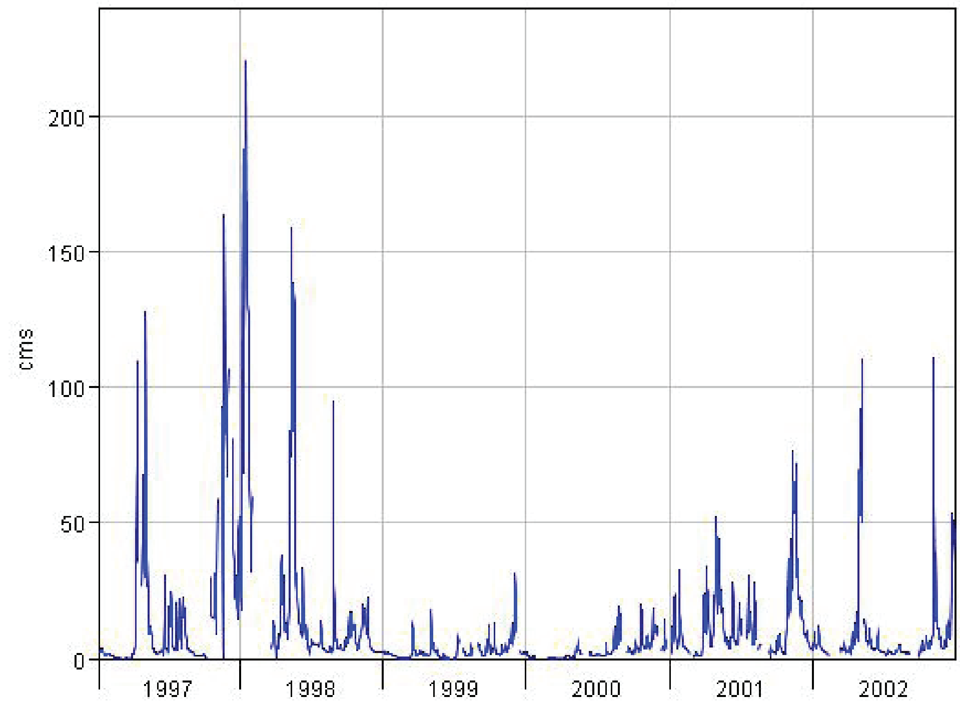


Figure 22b: 6-year hydrograph of the Ewaso Nyiro River

Rainwater

Total rainfall is influenced in part by elevation and in part by latitude. It decreases northward across the Laikipia Plateau and, just north of the Ewaso Narok/Ewaso Nyiro confluence, mean annual rainfall falls below 500 mm (Berger, 1989). A number of monitoring stations in the Laikipia Plateau, shown in Figure 23, have long-term historical rain records. Long term mean annual rainfall at these stations is similar to the mean annual rainfall observed at the Mpala Research Centre and Mpala Ranch (record period 1999-2011). The similarity of the short term mean annual rainfall at Mpala with the long term mean annual rainfall at surrounding locations strongly suggests that quantity of rainfall observed at Mpala is similar to that across the region (Figure 24).

Characteristic of the region, Mpala receives most of its rainfall distributed unevenly throughout the year in short, intense rainfall events. Regional climatic studies demonstrate increasing amounts of rainfall during individual rain events, with a decreasing number of total events (Franz, 2007). In an analysis of 50 years of rainfall data from monitoring stations in the Ewaso Nyiro River basin, 75% of the stations showed increasing total annual rainfall. The same analysis revealed that 50% of the stations showed a decreased time interval between storm events (Franz, 2007). It is interesting to note that monitoring stations with the greatest total annual rainfall were not the stations which had the greatest number of days on which rain was observed (Berger, 1989). This further supports the notion that rainfall occurs in brief, intense events as opposed to steadily over a longer period of days. While the Mpala Research Centre receives a mean annual rainfall of 638 mm, just over half of this rainfall occurs during the long and intermittent rainy seasons. Just 11% of the total annual rainfall at the MRC falls during the dry seasons. The Mpala Ranch, slightly further north than MRC, receives a mean annual rainfall of 555 mm, only 14% of which falls during the dry seasons (Table 34, Figure 25). Such unequal distribution throughout the year necessitates a mechanism for Mpala to store water during the rainy seasons for use in the dry seasons if they are to stop using the borehole and river water sources.

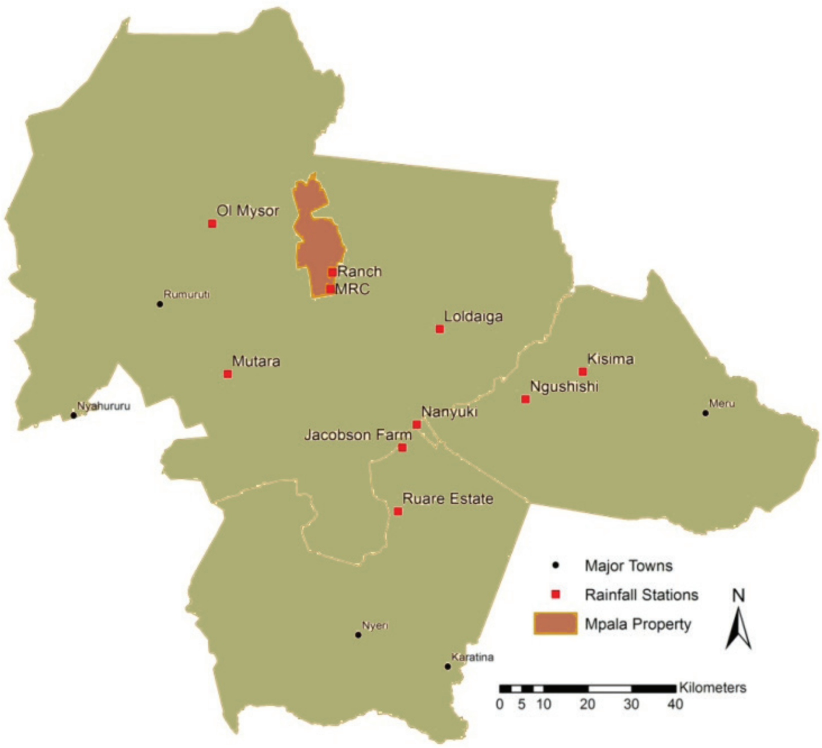


Figure 23: Rainfall monitoring stations in the Laikipia Plateau

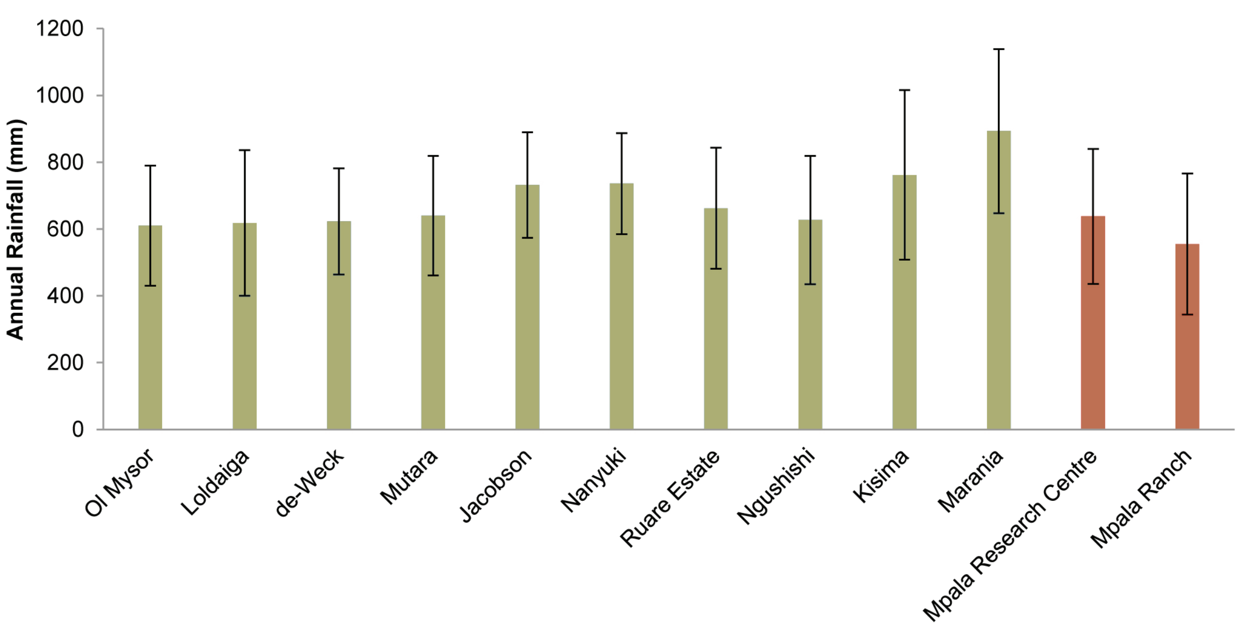


Figure 24: Annual rainfall at selected monitoring stations in the Laikipia District

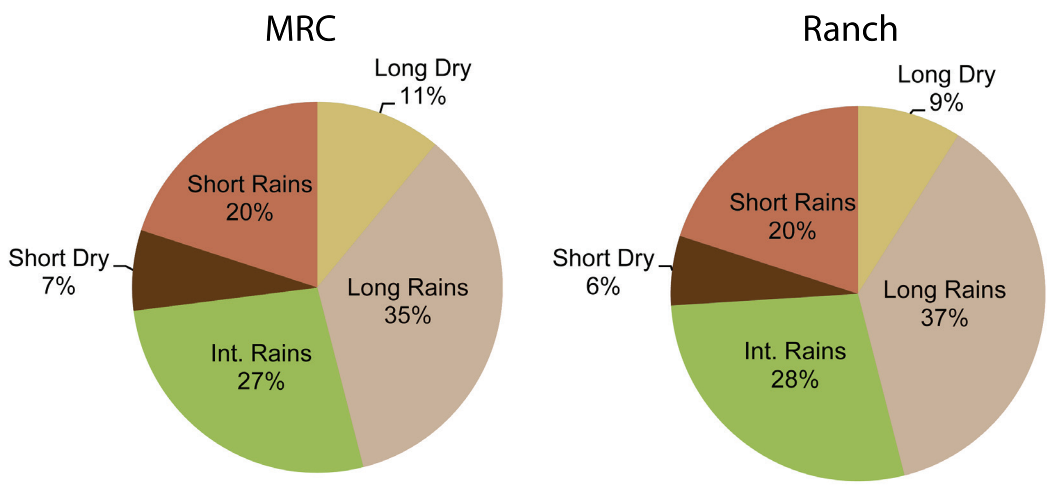


Figure 25: Rainfall variation at MRC compared to Mpala Ranch

Table 34: Rainfall at the Mpala Ranch

	Average Rainfall (mm)					
	Long Dry[1]	Long Rains[2]	Int. Rains[3]	Short Dry[4]	Short Rains[5]	Annually
MRC	**70.0** ± 67.5	**215.1** ± 98.0	**162.9** ± 81.7	**39.5** ± 39.1	**124.9** ± 79.1	**637.7** ± 201.6
Ranch	**46.9** ± 50.8	198.5 ± 86.1	149.7 ± 89.1	30.1 ± 33.1	**106.8** ± 64.0	555.1 ± 221.3

1. December, January, and February 2. March, April, and May 3. June, July, and August 4. September 5. October and November

When preparing water management plans that include rainwater as a source of drinking and domestic water, the pattern of rainfall is equally as important as volume of rainfall. Rainfall patterns define the capture and storage requirements necessary to use rainwater throughout the year, but it is important to recognize that they are inherently uncertain. Temporal patterns of rainfall variation are observable on a yearly, seasonally, and daily basis.

Yearly Variation

Rainfall varies from year-to-year (Figure 26; Table 35), and when planning for future water availability using the historical record, it is important to select a period recent enough to represent the current environment, yet also long enough to capture both high and low rainfall extremes. Within the Laikipia District, extreme rainfall years are designated as those in which the entire district receives a total annual rainfall greater than 750 mm or less than 500 mm (Berger, 1989). During the 13-year (1999-2011) rainfall record period at the Mpala Research Centre and Mpala Ranch, a number of extreme rainfall years (both high and low) were observed. Extremely high rainfall was observed in 2010 with 1,000 mm (MRC), while extremely low rainfall was observed in 2000 with only 187 mm (Ranch). Year-to-year rainfall patterns are at least partially controlledby El Niño and La Niña events, resulting in abnormally wet (El Niño) or dry (La Niña) conditions every 3-6 years (Franz, 2007).

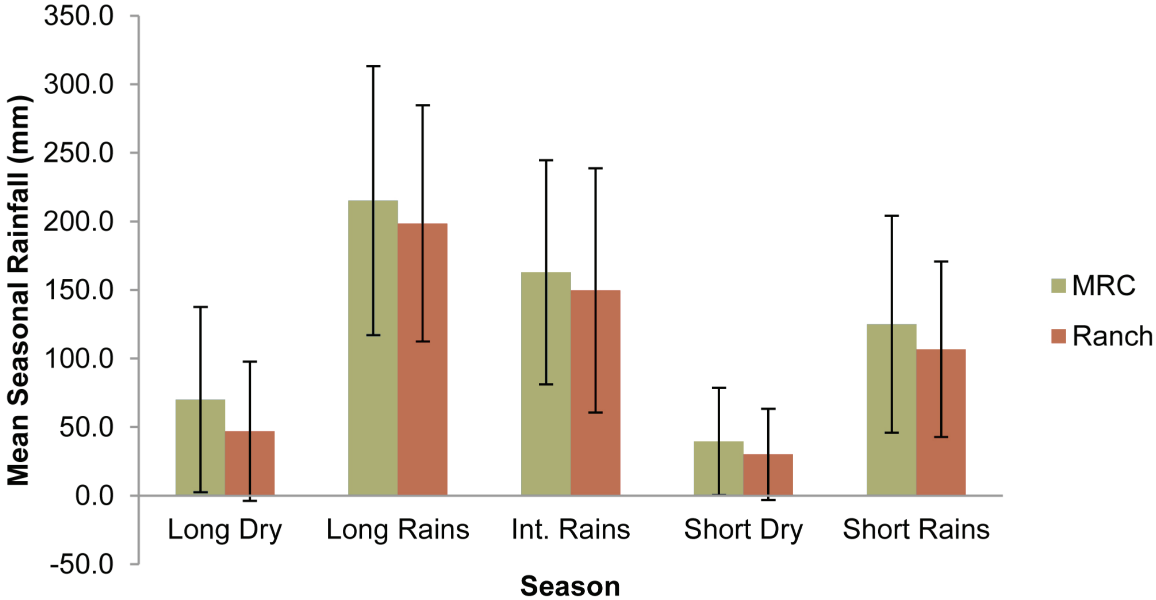


Figure 26: Mean seasonal rainfall at MRC and the Ranch. Significant standard deviation (shown by black bars) indicates that rainfall varies greatly from year to year. If years did not vary the standard deviation would be very small.

Table 35: Rainfall variation between 1999-2011

	Mpala Research Centre				Mpala Ranch			
	Range (mm)	Standard Deviation (mm)	Record Min (mm)	Record Max (mm)	Range (mm)	Standard Deviation (mm)	Record Min (mm)	Record Max (mm)
Jan	73	28.6	0	73	59.4	22.8	0	59.4
Feb	68.4	18.7	0	68.4	22.1	7.7	0	22.1
Mar	76.4	30.4	0	76.4	100.3	35.5	0	100.3
Apr	200.7	67.3	3.6	204.3	160	60.9	0	160
May	102.4	32	26	128.4	118.6	4..3	5.6	124.2
Jun	128.9	45.7	2.2	131.1	157	31.2	0	157
Jul	94.9	27.2	5.4	100.3	93.7	29.6	7.4	101.1
Aug	121.2	44.9	3.7	124.9	120.5	38.1	1	121.5
Sep	106.8	39.1	0	106.8	103	27.5	0	103
Oct	121.6	45.7	17.5	139.1	134.8	48.7	0.8	135.6
Nov	216.7	67.1	15.4	232.1	196.6	64.8	16	212.6
Dec	91.1	34.6	0	91.1	80.4	26.3	0	80.4
Long Dry	212.6	67.5	15.1	227.7	143	246.4	5.1	148.1
Long Rains	297.5	98	36.2	333.7	331.2	167.3	5.6	336.8
Int. Rains	175.9	81.7	18.1	197	243.4	70.6	20.3	263.7
Short Dry	106.8	39.1	0	106.8	103	40.8	0	103
Short Rains	221.8	79.1	20.8	242.6	220.5	108.2	16	236.5
Annual	692.1	201.6	324.3	1016.4	658.9	221.3	186.9	845.8

Seasonal Variation

For the purpose of examining rainwater availability, the year was divided into five (5) seasons:

- Long dry (December, January, and February)
- Long rainy (March, April, and May)
- Intermittent rains (June, July, and August)
- Short dry (September)
- Short rains (October and November)

This division of the year into rainfall-based seasons is consistent with other studies in the greater Ewaso Nyiro River Basin and the Laikipia District of Kenya, but some maintain September as unclassified and/or recognize two distinct rainy seasons instead of three (Berger, 1989; Franz et al., 2010). The most commonly accepted seasonal division, besides the five season division used here, designates four seasons: Long rains from March 1st – June 15th, Continental rains from June 16th –September 15th, short rains from September 16th – December 31st, and a dry season lasting all of January and February (Berger, 1989).

Although there is little statistical variation between the observed rainfall during the long dry and long rainy seasons ($p>0.05$), that does not mean that the differences which are seen are not meaningful. Because there is such great fluctuation in the amount of rainfall observed year-to-year, variation could in fact simply be masking even more important differences seasonally. The distinct seasonal rainfall variation Mpala observes is well illustrated in Figures 27 and 28.

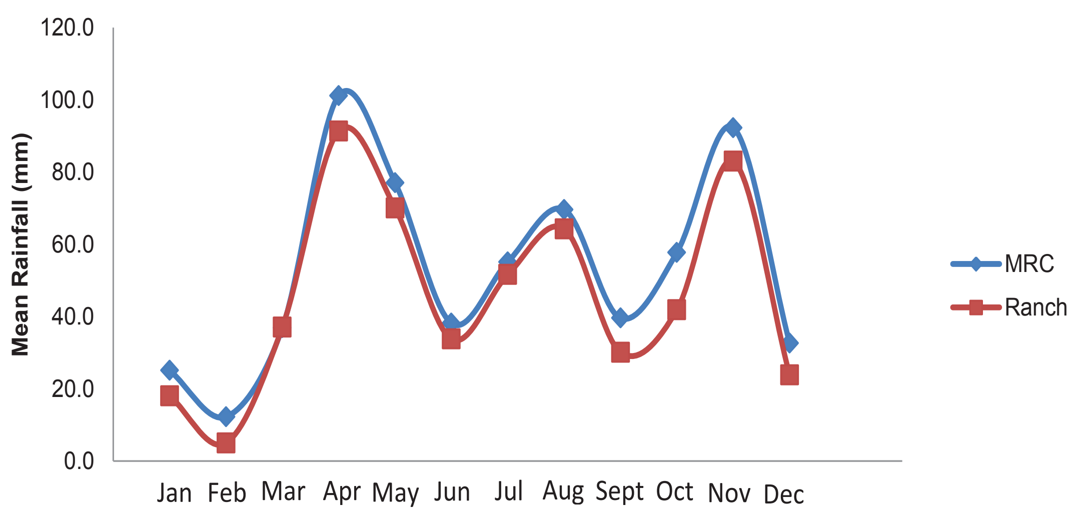


Figure 27: Distinct seasonal rainfall variation

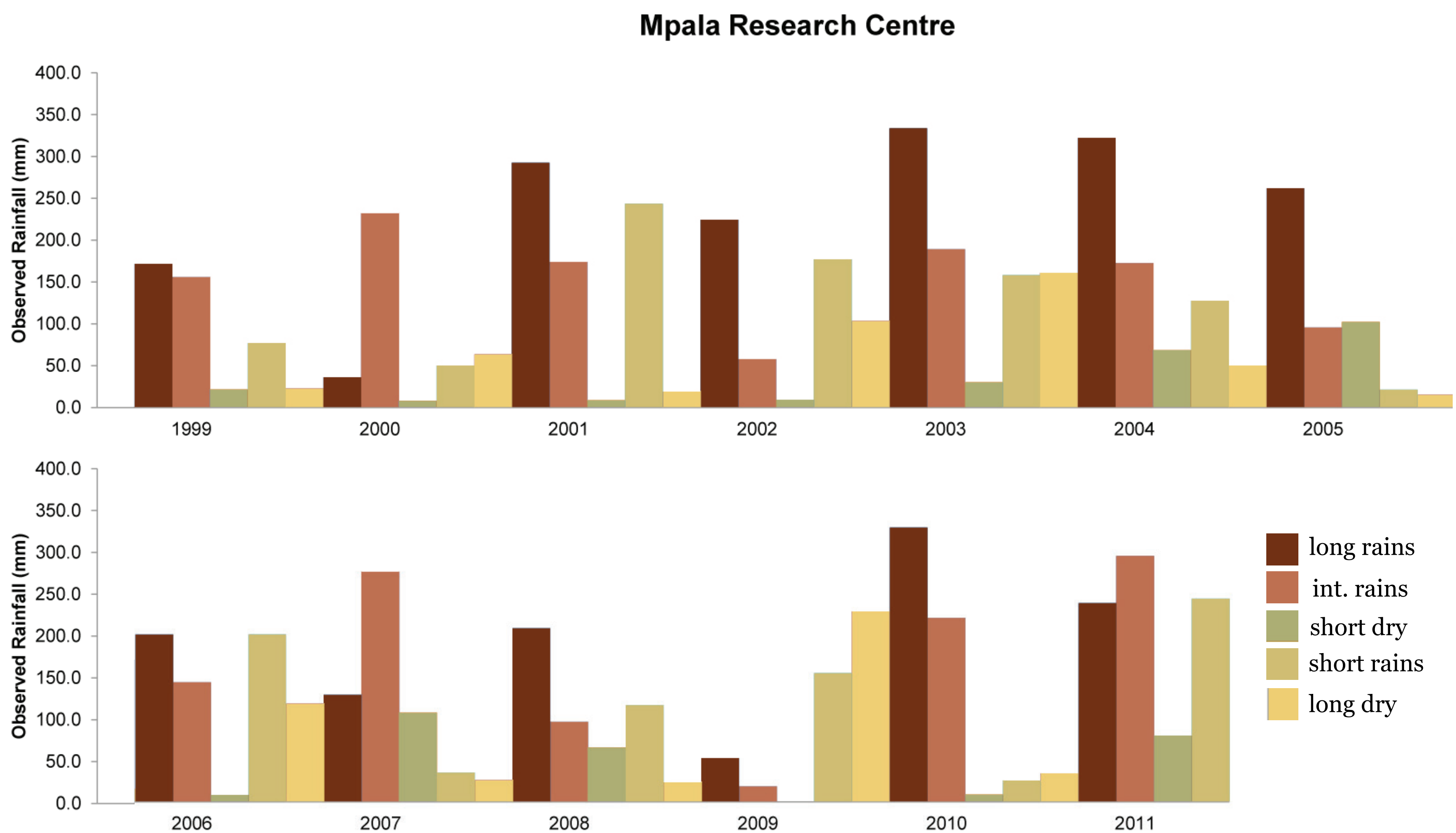


Figure 28: Distinct seasonal rainfall variation (multiple year)

Daily Variation

Rainfall also varies day-to-day and planning for capture and storage should incorporate this daily variation. Based on rainfall records from 1961-1982 at nearby Jacobson Farm, the likelihood of rain on any given day varies considerably year-to-year. Even during the rainiest periods, rain one day does not ensure rain the following day. The likelihood that rain will occur on any given day through the year is illustrated at the top of Figure 29. The top of Figure 29 indicates the dates rainy phases have began and ended for each year. Figure 30 illustrates the probability that a given day will be followed by rainfall or not. An impression that should be made particularly clear here is that during the long dry season each day is more likely to be followed with a dry day than a rainy day. This continual uncertainty of when the next rain will come means each opportunity to capture rainfall should be taken advantage of.

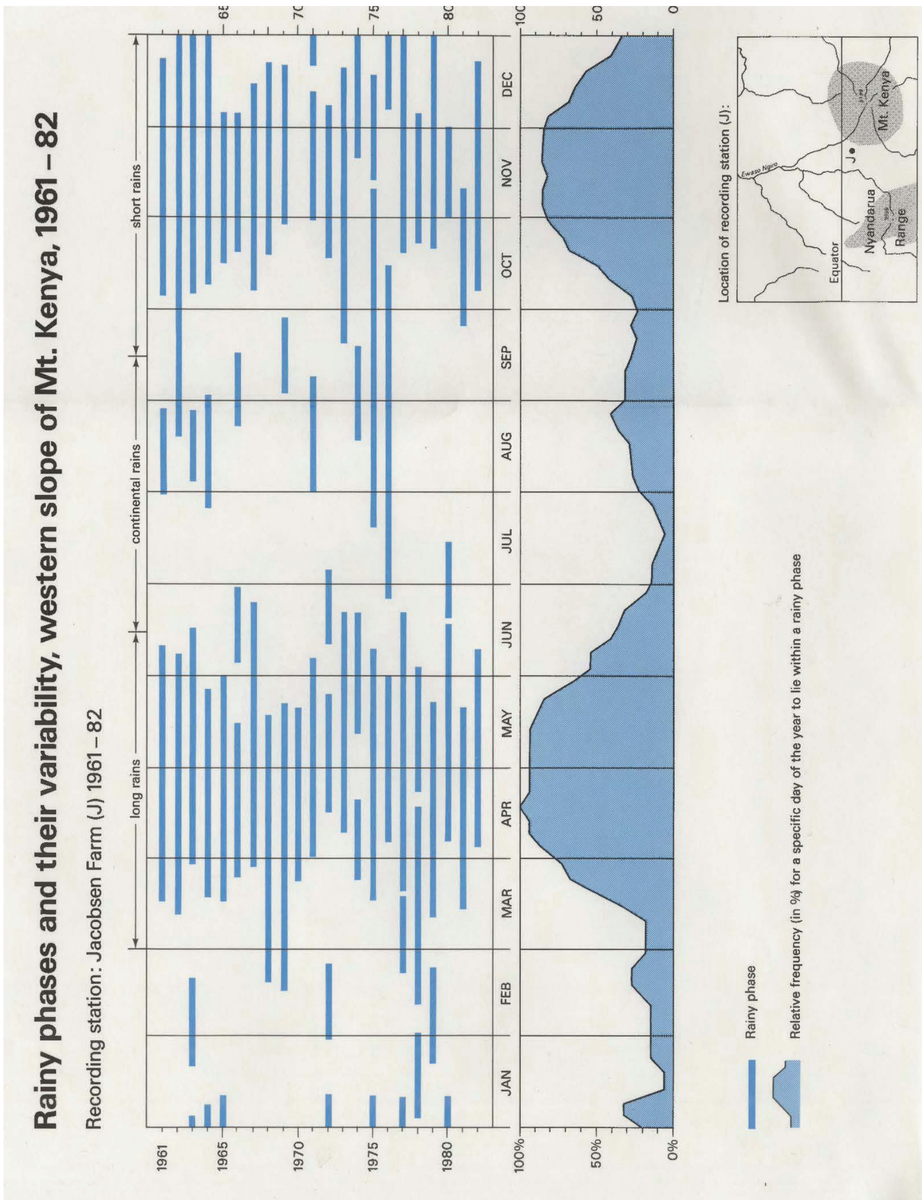


Figure 29: Rainy phases and their variability (Berger, 1989)

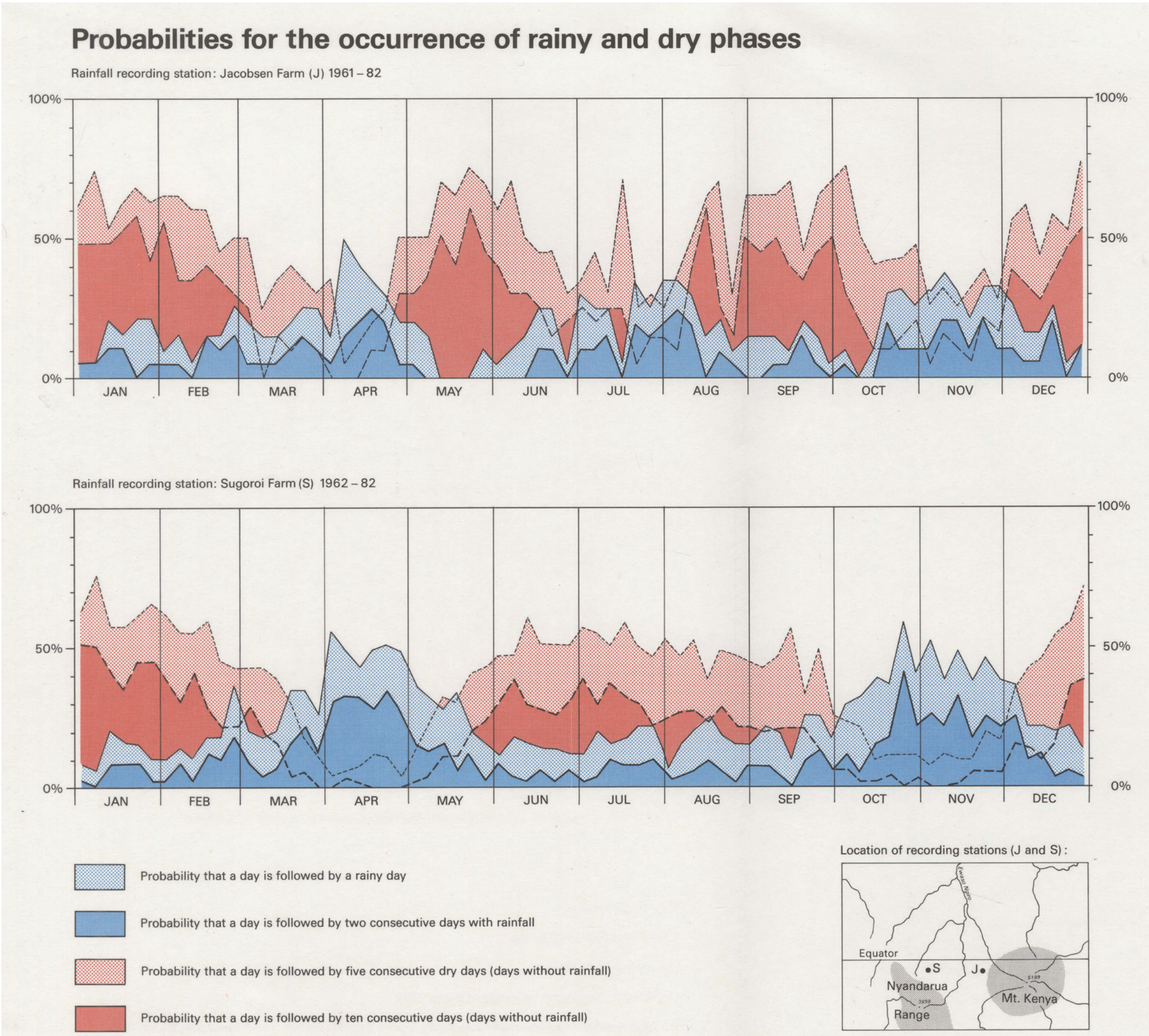


Figure 30: Probability that a specific day is followed by a rainy or dry day (Berger, 1989)

Potential for Rainwater Capture

A significant difference in the total annual amount of rainfall exists between MRC and the Ranch (p=0.00004). It is assumed for the purposes of this report that there is no spatial variation within MRC or the Ranch but only between them, i.e. all rooftops at each respective location receive equal rainfall (Table 36, Figure 31). Because rainfall amount fluctuates significantly year to year and no single observed value represents typical rainfall, we used mean monthly rainfall. Monthly aggregation of rainfall was used because analysis on a monthly time-scale yielded reasonable stabilization of natural variation, while also remaining a brief enough time period to produce valuable supply modeling results when combined with demand and water storage data.

Table 36: Annual Rainfall at MRC and Ranch

	Annual Rainfall (mm)	
	MRC	**Ranch**
1999	456	443
2000	343.9	186.9
2001	786.7	513
2002	532.3	420.2
2003	734.6	610.3
2004	839.2	571.6
2005	552.3	421.4
2006	644.8	540.6
2007	592.3	641
2008	645.5	510
2009	324.3	234.2
2010	822.2	849.9
2011	1016.4	845.8

Rooftop areas of MRC and Ranch buildings were measured from aerial imagery taken in 2009, which were then contrasted to those reported by Antokal et al. (2011) and Odhiambo (n.d.) where possible (Appendix 20). Estimates of rooftop areas in previous studies relied on building floor plans. When areas could be directly compared, the difference was usually less than 13%, but range between 3% and 63%. In most cases, areas measured from aerial imagery were larger than the areas reported using floor plans. Discrepancies between these two types of estimates are likely due to poor resolution of the aerial imagery, deviation from building plans during construction, or roof overhang allowance not indicated on the floor plans. The two buildings with large differences in reported areas, the McCormick Lab and the Administration building, have large covered porch areas that may not have been indicated on the floor plans and therefore were unaccounted for as potential rooftop capture area.

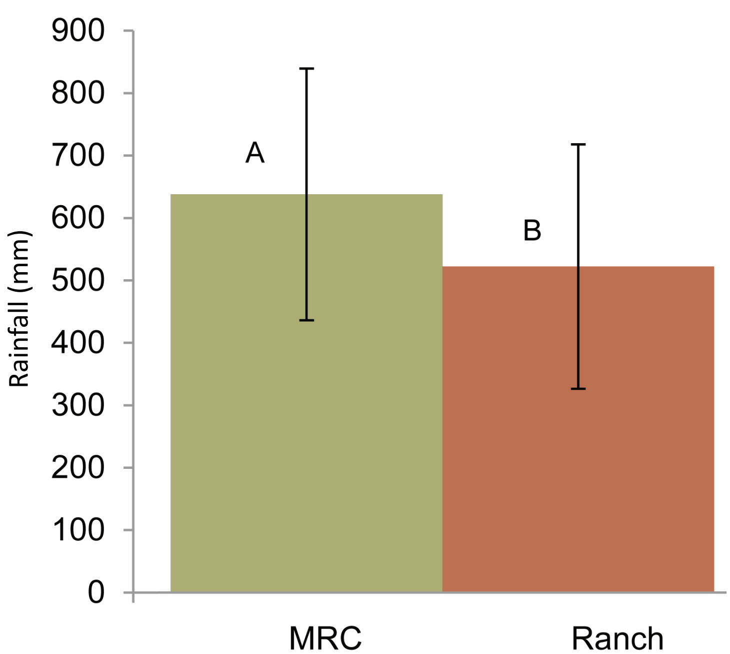


Figure 31: Annual rainfall at MRC and Ranch.

Potential rainfall can be calculated using the amount of rainfall, roof area, and a run off coefficient (Equation 2). The roof material determines the runoff coefficient. Materials that water will quickly and easily run off of, such as sheet metal, will have a coefficient close to 1 while materials that absorb or delay run off, such as a thatch roof, will have a coefficient close to zero. All calculations in this report assume a run off coefficient of 0.85 which is typical of sheet metal currently present on a number of MRC buildings (Aquasearch Ltd., 2010).

Equation 2:

potential rainfall capture (m^3)
= roof area (m^2) *x runoff coefficient x rainfall (m)*

In order to calculate the amount of rain currently captured, the percentage of the building that is guttered needs to be accounted for, as shown in Equation 3. In order to capture and store rainwater, both the guttering system and storage infrastructure (defined as either above ground or below ground storage tanks made from concrete, metal, or plastic) need to be intact and connected. For this analysis, we assumed that if gutters and storage tanks are both present on a building, then they are properly linked. 'Fully guttered' indicates that the entire roof is guttered and 'partially guttered' indicates that guttering is present on a portion of the roof but is not sufficient to collect all of the rainwater that falls on the roof. 'Full storage capacity' indicates that current storage capacity is large enough to store all potential rainfall without overflow. 'Partial storage capacity' indicates that a storage tank exists, but that it is not large enough to store all potential rainfall. Without both guttering and full storage capacity, the maximum potential rainfall capture cannot be met.

Equation 3:

Current rainfall capture (m^3)
= roof area (m^3) *x fraction of roof guttered*
x runoff coefficient
x rainfall (m)

Mpala Research Centre (MRC)

The workshop buildings and parking structure are not recommended for rainwater harvesting because these locations present greater than usual risk for contamination due to the use of oil and fuel at the garage area and extensive dust in both locations. Excluding these unacceptable structures, there is potential for 2,375 m^3 of rainfall to be collected at the MRC annually, assuming average annual rainfall and sufficient storage. This is just less than the design volume of Nanja weirs 2, 3, and 5 (designed to hold 2,500 m^3, 2,500 m^3, and 2,570 m^3 respectively) (T. Traexler, personal communication, 2012). The volume of potential water capture each year at MRC is approximately double their demand from September to November 2011.

The only fully guttered buildings at MRC are the two labs (McCormack and NSF), the library, Princeton Dorm, Smithsonian House, and the gym. Partially guttered buildings include the dining hall, kitchen/laundry, Grevy, Klee, Heathrow, Wild Dog, and Jenga House (Table 37). Several tanks are so small relative to their potential that they can be filled in a single month during any rainy season and would overflow most of the year if there were no withdrawals. All of the tanks except the tank at the kitchen/laundry building would fill and overflow before the end of the second month during the long rainy season, assuming no withdraws. The assumption that no water is withdrawn isn't realistic, but thinking about storage capacity in this way illustrates the importance of a management plan to prevent overflow and maximize system efficiency.

Table 37: Fraction of rooftop with rooftop infrastructure (i.e. gutters)

	Fraction of Building with Rooftop Infrastructure	Current Storage Capacity (m^3)
Dining Hall	0.75	13.4
Kitchen/Laundry	0.25	7.7
Grevy	0.5	12.1
Klee	0.5	11.8
Heathrow	0.25	7.3
Wild Dog	0.5	6.9
McCormack Lab	1	39.3
NSF Lab	1	12.2
Library	1	20.6
Princeton Dorm	1	10
Jenga House	0.5	6.9
Smithsonian	1	13.8
Gym	1	9.3

Mpala Ranch

The Ranch currently does not have rainwater harvesting infrastructure, but, adding it to acceptable buildings could increase rainwater collection to 327.7 m^3 annually (Table 38). This volume of water is enough to provide the Ranch Village with 2-3 months of water.

Nanja Weirs

The Nanja weirs provide Mpala with a previously unutilized source of water by capturing and storing runoff from the surrounding landscape (Figure 32). This report includes an examination of both the volume of water supply at any time, as well as a discussion about how the weirs fill in relation to rainfall runoff on a monthly basis. For the purposes of this report the weirs are numbered 1-5, with the bottom most weir (the most northeastern) called "weir 1" and the topmost weir designated "weir 5." Each of the Nanja weirs were designed to capture and hold a large volume of water, ranging from 1,866 m^3 to 5,225 m^3 (Table 39). The constructed capacities of the weirs are somewhat less than those in the design specifications (Table 39). Constructed weir volumes were calculated based on pre-construction surveys and are the best reflection of the actual volumes. Details of these calculations are discussed later in this section and will be used in this report for all further analyses and discussion.

Table 38: Volume of potential rainfall capture at the Ranch (m^3)

	Long Dry	Long Rains	Int. Rains	Short Dry	Short Rains	Annual
Staff Housing	3.48	14.75	11.12	7.93	2.24	41.23
Ranch Kitchen	2.62	11.07	8.35	5.96	1.68	30.95
Ranch Admin Building	7.33	31.03	23.4	16.69	4.7	86.76
Clinic	1.53	6.48	4.89	3.49	0.98	18.12
Garage	4.92	20.81	15.69	11.2	3.15	58.18
Ranch Guest House	9.56	40.48	30.53	21.78	6.14	113.18
Ranch Guest House	1.44	6.09	4.59	3.27	0.92	17.01
School	1.73	7.31	5.51	3.93	1.11	20.43
TOTAL	27.69	117.19	88.4	63.06	17.77	327.68

Rainfall runoff collection potential

Unlike rooftop rainwater harvesting, which is primarily dependent on rainfall and rooftop material, calculating the volume of water that the weirs will capture must include a survey of the natural landscape to take into account additional factors like infiltration and evaporation. Because landscapes are not as uniform as sheet metal used on rooftops, estimating an acceptable runoff coefficient is more difficult. To estimate a representative run-off coefficient, annual runoff coefficients were calculated for six catchments that have coinciding rainfall and flow records. These catchments were selected from a comprehensive Naro Moru study (Decurtins, 1992) because of their close proximity and similarity to the Nanja weir catchment. While the catchment of the Nanja weirs is

Table 39: Weir storage volumes (m³)

	Storage Volume	
	Designed	**Measured**
Weir 1	2575	1378
Weir 2	1866	1158
Weir 3	2500	1392
Weir 4	2500	2215
Weir 5	5225	4918

Figure 32: Drainage area and weir

notably smaller than the proxy catchments, the soil type, land cover, evaporation, temperature, and precipitation patterns are all comparable to the weir catchment. The mean (0.5), median (0.2), and minimum (0.04) of these coefficients were calculated (Equation 4) and used to estimate the volume of water collected into the weirs on a monthly basis. Other run-off coefficients reported in the literature for the region list values as high as 0.24 and as low as 0.09 (Ondieki, 1996). A conservative estimate of 0.1 was used as an annual runoff coefficient for planning purposes. It should be noted that this coefficient did not have a large effect on the analysis. This is because storage volume of the weirs is small compared to the potential amount of rainfall that could be collected, assuming even the lowest runoff coefficient.

Equation 4:

$$runoff\ coefficient = runoff\ volume\ (m^3) / [rainfall\ (m) \times area\ (m^2)]$$

In addition to a runoff coefficient, catchment area and rainfall estimates are needed to calculate the volume of water that the weirs can capture (Equation 5).

Equation 5:

$$volume\ of\ water\ flowing\ from\ the\ landscape\ into\ the\ weirs\ (m^3) = runoff\ coefficient \times catchment\ area\ (m^2) \times precipation\ (mm)$$

Delineation of the Nanja weir catchment is difficult because the landscape draining to the weirs is very flat over a large area, requiring very detailed elevation information. Neither the best digital elevation model (DEM) nor best contour map available could provide the level of detail desirable to calculate an exact drainage area. In light of planning and management goals, calculations in this report used the most conservative catchment estimate (1.8 km^2). This estimate was delineated using ArcGIS and ArcHydro, and a 90x90 meter resolution DEM of the Laikipia District as the base data. A notable challenge presented by digital delineation of drainage areas from DEMs is that their resolution is typically lower than desirable, and in some cases can present deceptive elevations. For example, over a body of water the DEM may be more representative of the water surface elevation then it is the surface of the earth, thereby making it necessary to manually modify the DEM to 'burn' in streamlines, etc.

The alternative method of delineating drainage areas relies on a contour map. Like digital delineation, the accuracy of hand-delineation is dependent on the resolution of the map. Even with the most detailed contour map, local knowledge is invaluable. Using the best available contour map (20 m contours), the catchment area was delineated to be approximately 3.4 km^2 (Traexler, personal communication, 2012).

On a monthly basis, the water that can be captured in the Nanja weirs exceeds Mpala's total water demand during nearly all months of the year (Table 40). Calculated monthly stored volumes accounted for the potential input, withdrawal (demand), and evaporation (Equation 6).

Assuming average rainfall, the weirs do not empty because during months when the input does not exceed the demand, there is enough water remaining in the weirs from the previous month to avoid water deficit (Figure 33).

In addition to the average rainfall scenario, two different drought conditions were also considered. Drought 1 was a replication of the 2009 low rainfall year (234 mm) and Drought 2 was a replication of the 2000 low rainfall year (187 mm). These two years mark the lowest annual rainfalls in the past 12 years. While a similar amount of rainfall was observed during both drought scenarios, the pattern of how that rain was distributed in time was very different. In 2009, rain fell in small volumes throughout the year, and a simulation of the 2009 drought year shows that the weirs would not empty assuming current demand (Figure 34). However, in 2000, Mpala experienced no rainfall for several months. The weirs would be depleted during the second

Table 40: Amount of runoff added to weirs each month assuming a year of average rainfall. Also shown, as a comparison, is Mpala's current total monthly demand.

	Rain Collected into Weirs (m^3)				
	Jan	**Feb**	**Mar**	**Apr**	**May**
Mpala's total demand	1,470	1,280	1,490	1,370	1,300
Average year	3,250	900	6,670	1,650	1,260

Equation 6:

Stored Volume = Previous months end volume + input - evaporation - demand

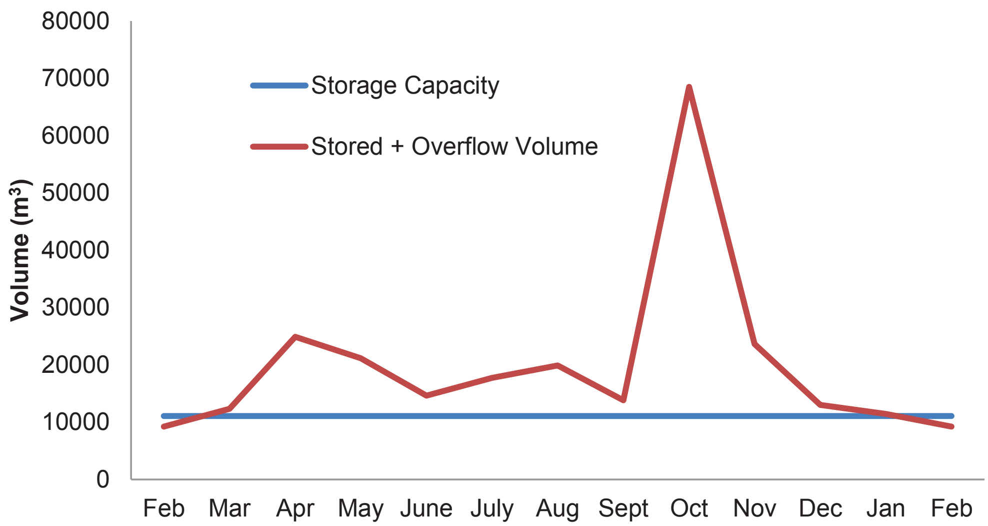


Figure 33: One year cumulative weir storage volume under average rainfall conditions.

consecutive year of 2000 pattern of drought (Figure 35). Because this scenario experiences no overflow after the start of the drought, an alternative water source would be required under these extreme conditions.

Evaporation is also an important factor in determining the volume of water stored in the weirs. The volume of water lost due to evaporation from the weirs is dependent on surface area, and therefore, distribution amongst the weirs needs to be managed. For all calculations previously presented, water was assumed to be equally distributed among the weirs to estimate a conservatively high amount of daily evaporation. To illustrate the importance of evaporation, an otherwise identical analysis was conducted using the 2000 drought scenario, this time excluding evaporation. In the previous analysis, which accounts for evaporation but not population growth (Figure 35), Mpala would empty the weirs during the 1st drought year. The analysis excluding evaporation shows that Mpala would not expect to empty the weirs until the 2nd consecutive drought year, even if they doubled bednights at MRC (simultaneously increasing the village population) (Figure 36). This clearly illustrates that ignoring evaporation grossly overestimates the availability of water. Failure to account for evaporation they could empty the weirs at least a year earlier than otherwise predicted.

In the same way that a daily or weekly analysis was inappropriate in the rainwater harvesting analysis, natural variation in rainfall also makes a daily or weekly scale analysis inappropriate

Rain Collected into Weirs (m^3)

Jun	Jul	Aug	Sep	Oct	Nov	Dec
1,460	1,520	1,510	1,190	1,300	1,160	1,110
6,080	9,300	1,150	5,420	7,530	14,940	4,290

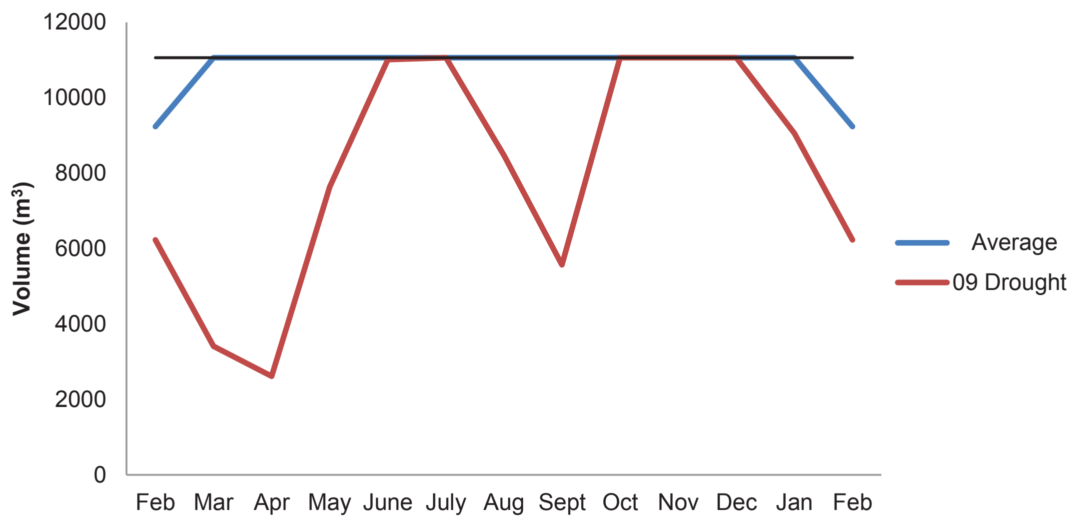


Figure 34: Comparison of water storage volume in the Nanja weirs under the 2009 drought scenario vs the average rainfall scenario. Black line indicates the weir capacity.

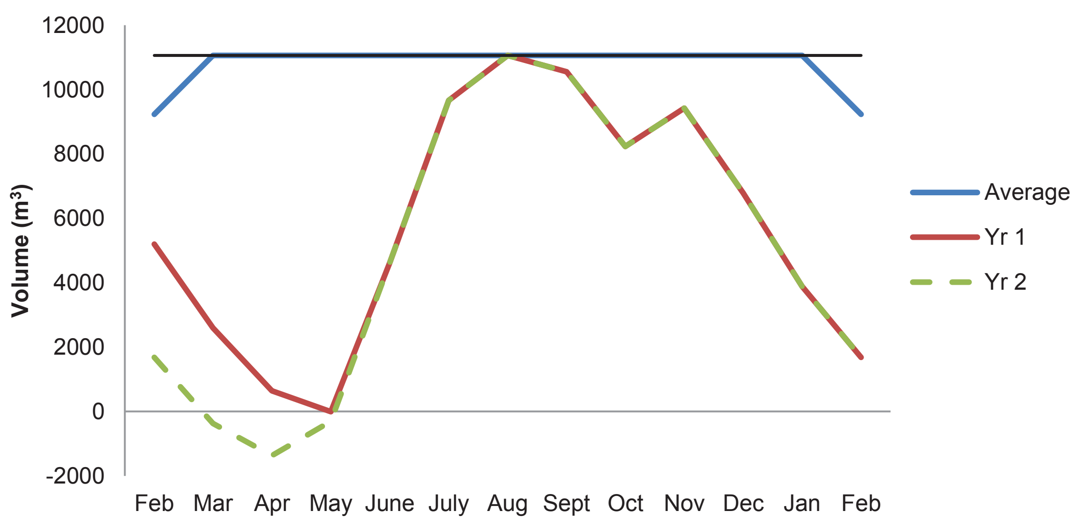


Figure 35: Quantity of water stored in the Nanja weirs after one and two consecutive years of the 2000 drought scenario. Black line indicates the weir capacity.

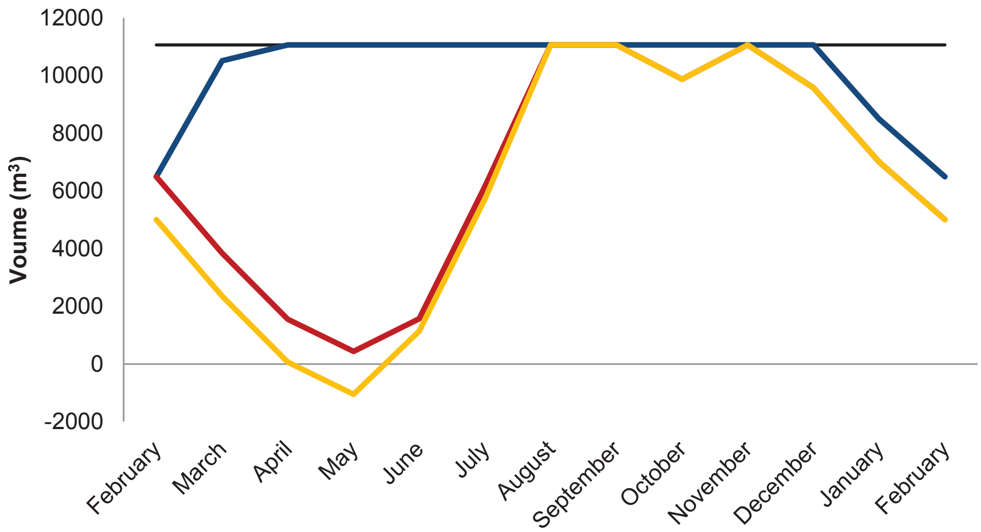


Figure 36: Total volume stored in weirs assuming no evaporation, 200% bednights, & 133% village population. Black line indicates the weir capacity, blue line indicates volume assuming average rainfall, red line indicates volume during 2000 replicated drought, and yellow line indicates volume and deficit during a 2nd consecutive 2000 replicated drought.

for the purpose of assessing water availability in the weirs. When managing a water resource, careful attention must be paid to note the variability. For example, even though April and May yielded a net positive volume during the first year of the 2000 replicated drought, the weirs were very close to being empty becuase this analysis was based on monthly rainfall rates. Depending on the daily and/or weekly pattern of rainfall in relationship to relatively constant demand, the weirs may not be able to provide sufficient water when needed.

On-site monitoring of water surface elevation, combined with a volume analysis tool will allow for more accurate monitoring of volume stored with time. Directly determining the volume of water in the weir is much more difficult than determining its relative surface water elevation. The relative surface elevation is the distance of the water surface from the crest of the weir, which can be easily measured by walking out to the middle of each weir wall and measuring the distance down to the water surface. For planning and management purposes, we developed a tool to estimate the volume stored in a weir at any given time using only the relative water surface elevation as an input. Figure 37 provides a graphical representation of the relationship between relative water surface elevation and volume, and helps to visualize how storage volume decreases with water surface elevation. Using the curve-fitted polynomial equations (Equation 7) which describe this relationship, the volume of water stored at a given time in each weir can be calculated if the water surface elevation is known. To generate these specific equations, the surface areas of each impoundment was measured at ½ m increments using a planimeter and a ½ m contour map. Using Equation 8, the sectional volume of water (the volume of water between two elevations), was calculated in ½ m increments). The sum of all sectional volumes below the water surface elevation yields the total volume of water stored in the weirs. The volume calculated was then plotted against the known associated relative water surface elevations (at every ½ m contour).

Currently, a gravity-fed pipeline draws water from weir 1 and delivers it to the Ranch. A second pipeline has been proposed that will take water from weir 4 to the MRC. If the demand at the MRC were to become greater than the storage volume of weirs 4 and 5, an alternative

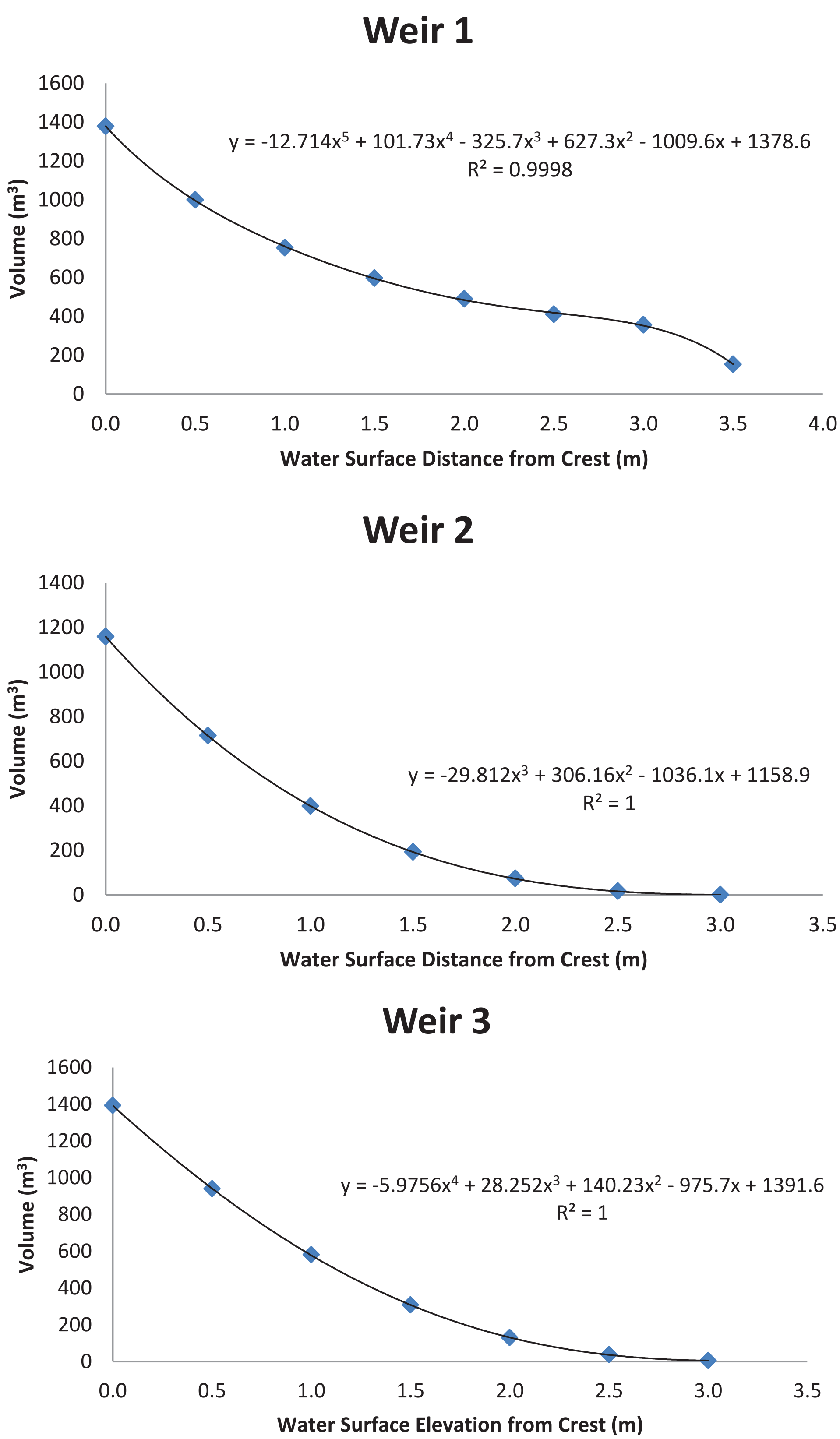
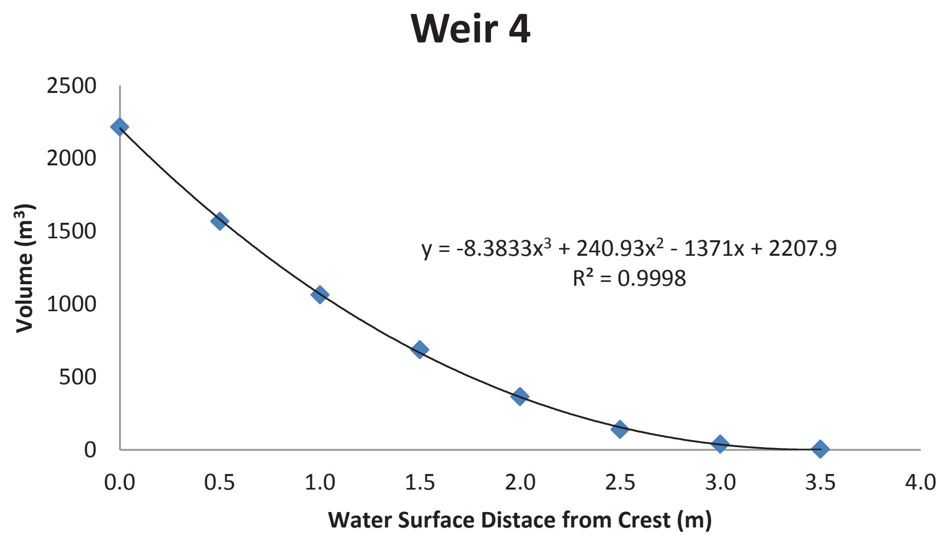


Figure 37: Graphical illustration of the relationship between water surface elevation and weir volume. The best fit line shown (in black) visually represents the curve-fitted polynomial equations which can be used as a management tool.



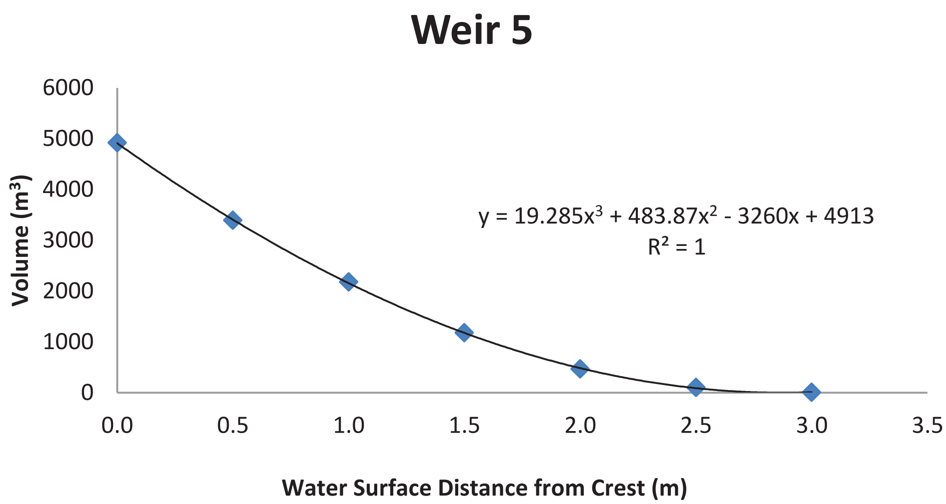


Figure 37 (continued): Graphical illustration of the relationship between water surface elevation and weir volume. The best fit line shown (in black) visually represents the curve-fitted polynomial equations which can be used as a management tool.

pipeline plan should be considered so that the need to truck water from the lower weirs to the MRC can be avoided. Since the MRC demand accounts for, on average, only 43% of the monthly average demand, whereas the storage of weirs 4 and 5 contribute 60% of the total weir storage. The larger proportion of weir 4 and 5 storage relative to the percent of total demand accounted for by the MRC suggests that the current and proposed infrastructure will be acceptable. A management plan should be developed to ensure distribution of water amongst the weirs in a way that minimizes water surface area (and therefore evaporation), ensuring that each weir has enough water to meet demand considering existing infrastructure.

Equation 7: Volume estimation equations. X represents the relative water surface elevation in meters while Y solves for the volume. Weir 5 remained under construction as of February 2012 and is therefore not included here.

Weir 1	$y = -12.714x^5 + 101.73x^4 - 325.7x^3 + 627.3x^2 - 1009.6x + 1378.6$
Weir 2	$y = -29.812x^3 + 306.16x^2 - 1036.1x + 1158.9$
Weir 3	$y = -5.9756x^4 + 28.252x^3 + 140.23x^2 - 975.7x + 1391.6$
Weir 4	$y = -8.3833x^3 + 240.93x^2 - 1371x + 2207.9$

Equation 8:

$$\text{Sectional volume} = \frac{1}{3}\Delta Z\left(A1 + A2 + \sqrt{A_1 A_2}\right)$$

Where ΔZ is the distance between contours and where Ax is the area at a contour x.

Borehole

The Mpala property sits on the Miocene aquifer system and while infrastructure is in place to provide both the MRC and the Ranch with groundwater pumped from the borehole, the water is currently used primarily at the MRC. Unfortunately the availability of water from this source is finite, and the aquifer is being depleted at a rate of 0.56m/month or 6.8m/year (Figure 38) (Aquasearch Ltd., 2010). The aquifer, containing 'fossil water' from 4,000-10,000 years ago during the African Humid Period, receives only small amounts of modern recharge (Aquasearch Ltd., 2010). Based on our analysis and communication with Mpala staff we conclude that Mpala's relianace on the borehole is no longer necessary or sustainable, except in extreme situations.

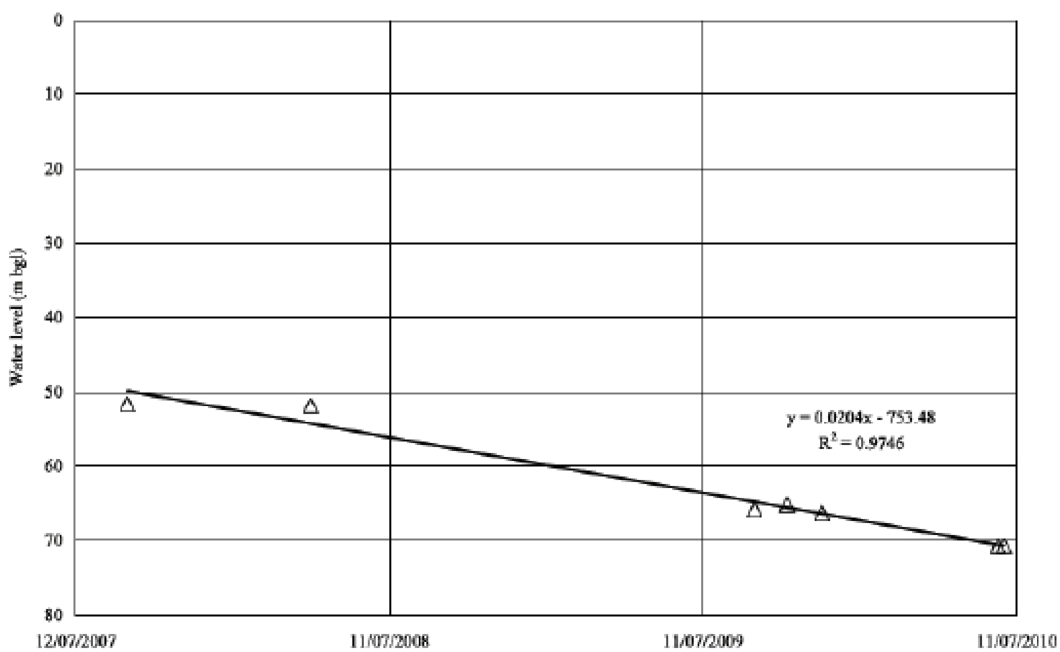


Figure 38: Water level decline in the Miocene aquifer which the Mpala borehole provides water from (Aquaseardch Ltd., 2010).

Water Quality

Introduction

Purpose

Antokal et al. (2011) and Aquasearch, Ltd. (2010) outline a number of concerns regarding water quality at Mpala. High fluoride levels in the borehole render it undrinkable without treatment, and undesirable for washing. The Nanja weirs and Ewaso Nyiro River are fed by surface runoff, which typically is contaminated with fecal matter. Antokal et al. also expressed concern that the Ewaso Nyiro River may be contaminated from fertilizer and pesticide use at upstream farming operations. They also raised concerns about debris and bird waste entering and contaminating the rainwater storage tanks that are used for drinking water.

Historical water quality testing at Mpala was limited to the borehole until June 2010, when further analyses were conducted by Aquasearch, Ltd. (2010) at the Nanja weirs and Ewaso Nyiro River. A more recent study was conducted in 2012 by Rural Focus, Ltd. on the Nanja weirs, and revealed elevated iron concentrations. Historical water quality sampling results are presented in Appendix 21.

The objective of our water quality analysis was threefold. First, we aimed to further identify and quantify contaminants in Mpala's primary water sources - Nanja weirs, the Ewaso Nyiro River, borehole, and rainwater harvesting tanks. Secondly, we sampled throughout Mpala to quantify and better understand any contamination that may be occurring throughout the distribution system. This included sampling at taps, storage tanks and other points of use. Finally, we evaluated different water treatment options that could be used at Mpala.

Water usage at Mpala

The drinking water that the Mpala Research Centre provides to its guests is obtained from various rainwater harvesting tanks near the kitchen. After water is collected from one of these tanks, it is brought to a boil in the kitchen and then set out to cool. We observed a pot of water sitting uncovered on the floor in the dish washing room (adjacent to the dining hall) while it was cooling. It is then poured into one of two household size water filters with ceramic candles, located in the dining area. Sometimes tap water from the dish washing room is fed through a filter next to the sink; according to Mpala management and staff, this is a reverse osmosis filter. During meal times, water is obtained from both types of filters, put into glass carafes, covered with plastic wrap, and put on the tables.

MRC cooking water is obtained from either the hot or cold water taps in the kitchen, or from nearby rainwater harvesting tanks. The cold tap feeding into the kitchen splits off of the main MRC distribution line, passes through a shed across the road from the carport, and then through a reverse osmosis filter (which was offline during the dry season sampling event), and into the kitchen. A separate hot water line feeding into the kitchen splits off the main line, is diverted to an elevated tank, fed through a kuni booster (wood burning heater), and into the kitchen. The pipeline schematic was presented in the Demand section as Figure 5.

Residents of the MRC Village obtain drinking water from the Black Tank, village tap, or personal rainwater harvesting tanks. The Black Tank contains water pumped from the river, and according to surveys conducted by Antokal et al. (2011), residents of the village prefer this water for washing clothes. The village tap is fed directly from Tank 5, which usually contains borehole water. If the borehole is offline or in high capacity situations when Tank 4 is unable to feed Tank 5 fast enough to keep up with demand, Tank 5 is filled with river water. Attempts to treat or disinfect water on an individual basis by MRC Village residents are currently unknown.

Residents of Grevy, Klee, Wild Dog, Heathrow, the Director's House, Jenga, and the newly built Smithsonian houses have their own rainwater harvesting tanks, and individual rainwater water usage varies. Some residents pass it through a ceramic candle filter and/or boil it for cooking and drinking while others obtain their drinking water from the dining hall area.

Bathing water provided to all locations at MRC, including the village, private residences, dorms, bandas, and bathrooms, is from Tank 5, and is not filtered or treated before use.

Sampling

Water samples were collected and analyzed during two sampling events. Sampling conducted from August 27th to September 2nd, 2011 is referred to as the rainy season sampling event. There were two significant rainfall events just prior to this sampling; one on August 12th and 13th, and another on August 26th and 27th. This rain visibly increased turbidity at the weir, which did not appear to decrease throughout the sampling event. This likely affected some of the water quality parameters analyzed during that time. The sampling event from February 25th to March 4th, 2012 is referred to as the dry season sampling event.

After mapping the locations of the pipelines at Mpala, 17 sites were chosen as representative of conditions for water quality sampling locations. These site locations are shown on Figure 39 and are summarized in Tables 41a and 41b. Selected sampling locations represent all four primary sources: river, weir, borehole, and rain. River water samples were collected from the Ewaso Nyiro at both the Ranch and MRC pumping locations. Weir water samples were collected from the outlet at the bottom of Nanja Weir#2. The rainwater storage tanks selected for testing were the underground tank at the gym, and two above ground tanks. The above ground tank at Grevy House is newer with a concrete roof, and the kitchen tank is older, with a metal roof (Figures 40 and 41). The following point of use locations were also tested: taps in both the MRC and Ranch villages, the Black Tank near the MRC Village, the Ranch Kitchen tap, the cold tap in the kitchen at MRC, and the River Camp tap. The hot and cold taps at the Banda numbers 7 and 8 shared bathroom were also sampled. More detailed information, including how and where samples were collected at these locations, can be found in Appendix 22.

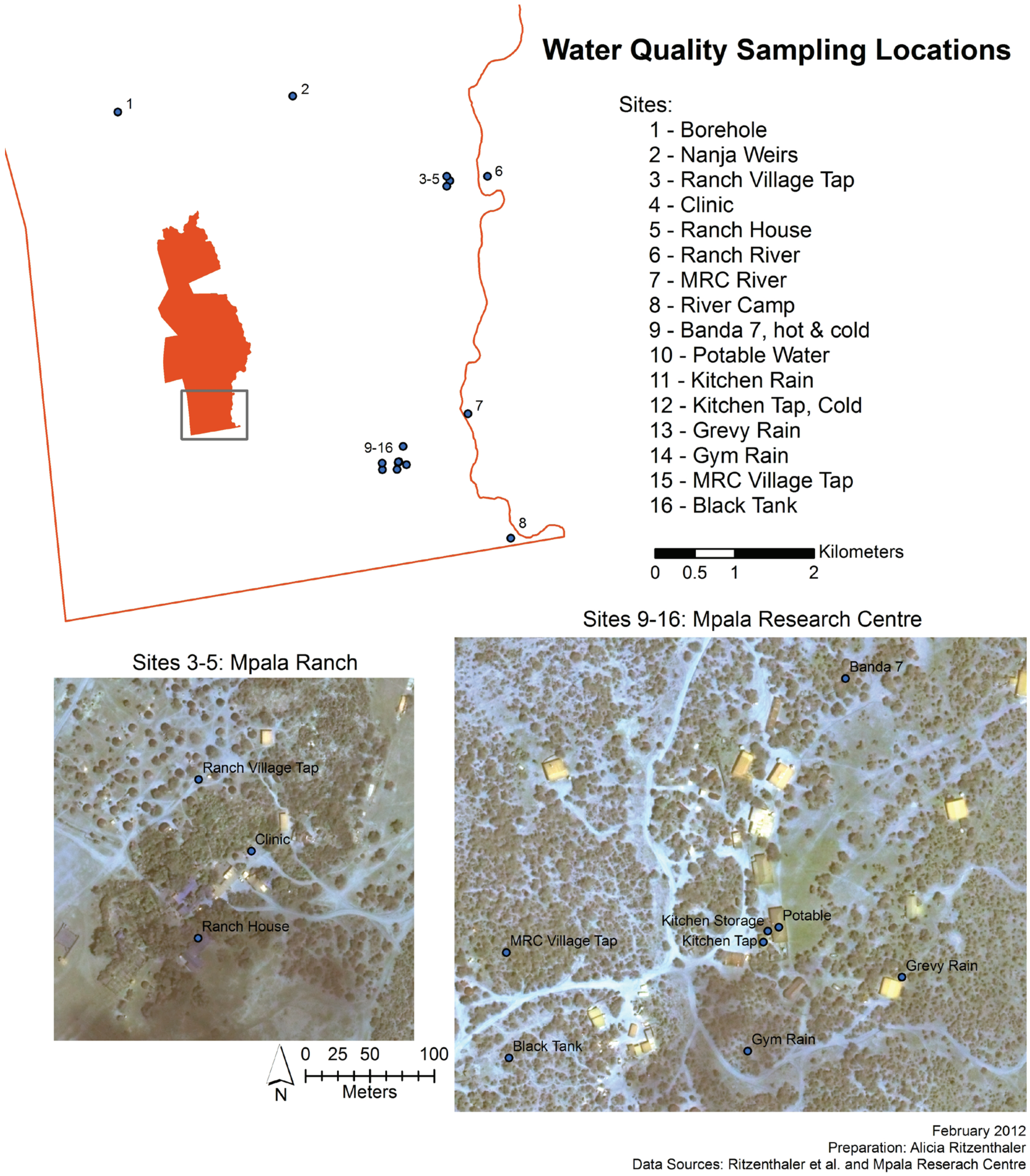


Figure 39: Water quality sampling locations

Table 41a: Primary water source sampling locations

Location Name	Water Type
Weir	Surface
MRC River	Surface
Ranch River	Surface
Borehole	Aquifer
Kitchen Rain	Rain - aboveground, metal roof
Grevy Rain	Rain - aboveground, concrete roof
Gym Rain	Rain - underground

Table 41b: Point of use sampling locations

Location Name	Rainy Season Sources	Dry Season Sources
Ranch Village	Weir, Ranch River	Weir
Ranch House	Weir, Ranch River	Weir
Clinic	Weir, Ranch River	Weir
MRC Village	MRC River	River, Borehole, or mix
Kitchen Cold	MRC River	River, Borehole, or mix
Banda 7 Hot	MRC River	River, Borehole, or mix
Banda 7 Cold	MRC River	River, Borehole, or mix
River Camp	MRC River	River, Borehole, or mix
Potable	Rain	Rain, River, Borehole, or mix
Black Tank	MRC River	River, Borehole, or mix

Figure 40: Grevy rainwater harvesting tank

Figure 41: Kitchen rainwater harvesting tank

Methods and Procedures

Total Coliform and E. coli

Coliform bacteria are a group of mostly harmless microorganisms that are present in humans, animals, water, and soil. They are characterized as "all aerobic and facultative anaerobic, gram-negative, non-spore forming rod-shaped bacteria that ferment lactose with gas and acid formation within 48 hours at 35°C" (APHA et al., 1992). They have been studied extensively and are typically used as an indicator of water quality. In the United States, presence of coliform in drinking water is an indication of problems within the treatment system or recontamination within the distribution system. The United States Environmental Protection Agency (EPA or USEPA) regulations state that if coliform tests are positive for drinking water, the sample must be further analyzed to determine whether a specific type of bacteria is present, such as fecal coliform or *Escherichia coli* (USEPA, 2011). Many different pathogenic coliforms exist, and while testing for all of them is the only way to ensure their absence, this is expensive and impractical. *E. coli* is found only in human and other warm-blooded animals' feces and therefore is the best indicator of health risks in bathing and recreational water.

Standard Methods for the Examination of Water and Wastewater provides three EPA-accepted methods for coliform testing: membrane filtration, multiple tube fermentation, and enzyme substrate coliform test (APHA et al., 1992). Hach's EPA-approved membrane filtration technique 10029 with m-ColiBlue24® media was used during both the rainy and dry sampling events due to its ability to selectively grow both total coliform and *E. coli*. For both sampling events, at least two rounds of sampling were performed for each location. In the first round, samples were collected from each site and three different concentrations were prepared with deionized (DI) water. Each dilution was independently poured through a membrane filter apparatus with a 0.45 μm filter, plated on media, and incubated for 24 hours at 35°C. After the CFU were counted, a second set of samples were obtained and diluted to yield the desired number of CFU (based on the preliminary dilutions recorded in the first round). Data from plates yielding less than 20, or greater than 200 total CFU per plate (including *E. coli*), were disregarded for statistical analysis with the exception that all data obtained when filtering a 100 mL sample without dilution were retained. To retain procedural consistency, all samples plated on this media were prepared, filtered, plated, counted, and recorded, and all equipment was rinsed by the same analyst except where otherwise noted in Appendix 22.

Hach's EPA-approved modified m-TEC Method 8367 is an *E. Coli* selective media and was used to obtain additional data during the dry season sampling event. Procedures for this method are similar to those used in the m-ColiBlue24® procedures above, except that the majority of locations did not need two rounds of sampling because they yielded less than the recommended minimum of 20 CFU without dilution. Samples were incubated at 35°C for 2 hours and at 44°C for 22 hours. It should be noted that 44°C is slightly outside of the ideal temperature range called for in the method (44.5 ± 0.2°C) but it was decided to be close enough to proceed. To retain procedural consistency, all samples plated on this media were prepared, filtered, plated, counted, and recorded, and all equipment was rinsed by the same analyst except where otherwise noted.

Three potential sources of error were identified in our procedures, the first of which was difficulty in equipment and lab sterilization. Keeping the lab sterile at Mpala posed a challenge due to a lack of clean washing water and access to sterilization equipment, such as an autoclave. The filter apparatus, graduated cylinders, mixing cups, and beakers were thoroughly washed with ethanol and rinsed with DI water between each use. Forceps were sterilized in ethanol and flamed between uses. Quality control for microbial testing was ensured by conducting positive and negative controls. Positive control slurries made from fresh fecal matter were plated to ensure the media had not spoiled. All positive controls came back with high presence of coliform bacteria, indicating that the media was still good. Due to the unsterile nature of the lab, 100 mL of DI water (negative control) was plated thrice daily to monitor washing and disinfecting techniques. Twenty five of 32 negative control samples for total coliform yielded 0 CFU and all 32 yielded less than 20 CFU. This indicates that sources of error in our analyses resulting from poor sterilization are low. All 13 control samples for *E. coli* were negative.

The second potential source of error identified in our procedures can be attributed to the lack of access to calibrated measuring equipment during the rainy season sampling event. During this sampling event, disposable sterile syringes were purchased in Nanyuki for measuring small amounts of sample and DI water. We were unable to verify the accuracy and sterility of these syringes purchased in Nanyuki. For samples requiring significant dilution, even a small discrepancy in liquid measurement could result in large errors. To eliminate this source of error, we secured an electronic pipette and an auto-micropipette with sterile tips for the dry season sampling event.

The final potential source of error identified in our procedure was the use of DI water in place of a buffered sterile solution. Hach methods for total coliform and E. coli analyses call for sterile buffered water to be used when preparing dilutions, but it was impractical to obtain the quantity required. The use of DI water, rather than a buffered saline solution, can osmotically stress organisms and result in falsely low coliform counts. Organism stress can also be caused by a difference in pH of the samples and the agar, which were regularly over 8 and near neutral, respectively. This rapid pH change can shock organisms and inhibit their growth.

Nitrate, Nitrite, and Phosphate

Nitrate (NO_3^-) was tested using Hach's Low Range Nitrate Cadmium Reduction Method 8192, which reduces nitrite (NO_2^-) to nitrate and reports both as nitrate-nitrogen (NO_3^--N). This is a low range test with an upper limit of 0.50 mg/L NO_3^--N. Samples that exceeded this limit were diluted to within range of the colorimeter. Nitrate/nitrite color test strips were used as an inexpensive and rapid way to confirm analytical results. In 30 and 60 seconds, the test strips can detect a maximum of 10 mg/L NO_3^--N and 3 mg/L NO_2^--N, respectively.

Phosphate (PO_4^{2-}) was analyzed using Hach's PhosVer 3 (Ascorbic Acid) Method 8048, a procedure equivalent to USEPA Method 365.2 and Standard Method 4500-PE for wastewater. The upper limit on this test is 2.50 mg/L as phosphate and samples with concentrations above this limit were diluted to within range of the colorimeter.

The DR 890 Colorimeter that was used for nitrate and phosphorus analysis had been pre-programmed with a calibration curve for each method, and daily calibrations were performed using nitrate and phosphate standard solutions. During the rainy season sampling event, all calibrations were successful, showing no indication of user or machine error. During the dry season sampling event, we were unable to calibrate the colorimeter using the nitrate standard solution. In order to identify the reason the colorimeter would not calibrate, the quality of the reagents, standards, and instrument were all investigated. To test for a reagent problem, a second, unopened lot of reagents was used. However, calibration results were the same as those obtained using the original lot of reagents, indicating the problem was being caused by something else. The nitrate solution, opened during the rainy season sampling, was unexpired and had been stored next to reagents and standard solutions with the same storage requirement and were still good. This indicated that it was unlikely that the nitrate standard was exposed to degrading conditions. It is also unlikely that internal error with the colorimeter itself prevented successful calibration, because the instrument functioned properly during other analyses, including phosphate. Given the age of the instrument and the high quality of care that it had received since it was purchased it is unlikely, but possible, that the wavelength was not being emitted properly. An absorbance standard was not available to confirm or disprove a wavelengh problem. Ultimately, the source of the calibration problem was never determined and the colorimeter was not used for nitrate analysis during the dry season sampling event. Instead, the limited number of remaining test strips were used in select locations to analyze for nitrate and nitrite.

Total Dissolved Solids, Hardness, and Alkalinity

During the rainy sampling event, a YSI instrument was used to determine electrical and specific conductivity, dissolved oxygen, and temperature. During the dry season, handheld HANNA Instruments (TDS/EC; pH) meters were used to collect conductivity, pH, and temperature. The YSI and HANNA instruments were calibrated in the United States and recalibrated on-site again at Mpala to ensure accurate analysis. TDS values were obtained by multiplying specific conductivity by a factor dependent upon water type; the freshwater factor of 0.7 was used for our analysis (Walton, 1989; Aquasearch Ltd., 2010).

Hardness was tested using Hach's dual range Total Hardness Test Kit Model HA-71A with a low range from 1-20 mg/L (1 mg/L increments) and a high range up to 340 mg/L as $CaCO_3^-$ (17 mg/L increments). Hach Total Hardness Color Test Strips with a range of 0-425 mg/L as $CaCO_3^-$ (various increments) were also used for confirming analytical hardness results.

Samples were collected during the dry season sampling event on March 4th for phenophthalein and methyl orange alkalinity analysis. The samples were transported back to the United States where a titration anaylsis was performed on March 7th using Hach Alkalinity Test Kit, Model AL-AP.

Total Suspended Solids and Turbidity

Total suspended solids (TSS) and turbidity are important physical indicators of water quality and suitability for use. TSS is a measurement of the concentration of suspended particles in solution and turbidity is a measurement of how those particles scatter light. These physical parameters are important in determining water quality for aesthetic, filterability, and disinfection reasons. While TSS and turbidity are related, there is no easy way to convert between the two measurements. We analyzed samples for TSS during both the rainy and dry season sampling events, and turbidity during the dry season.

TSS testing, calculation, and quality control procedures followed Standard Method 2540D (APHA et al., 1992) and USEPA Method 160.2. Filters were first washed with DI water, then dried in an oven to a constant weight, which is defined as a weight change less than 4% or 0.5 mg, whichever is less. Then 100 mL of sample was passed through the prepared filters and dried to a constant weight again. If the sample produced less than 1 mg of residue on the filter, as was the case for most samples, then the test was rerun using enough sample to yield at least 1 mg of residue. The concentration of TSS is reported in mg/L.

Deviations from Standard Method 2640D included reduced oven temperature and imprecision of the scale. *Standard Methods* calls for the filters to be dried at 103-105°C, but the oven at Mpala only reached a maximum of 67.5°C. To compensate for this difference, all filters were dried overnight, which was longer than the one hour suggested by *Standard Methods* (APHA et al., 1992). A 100 g weight was used to check the accuracy of the scale, which ranged between 99.9944 and 99.9970 g. Because this analysis did not require a high level of precision, the values were recorded as the scale reported and not adjusted for this discrepancy.

Turbidity was measured using a turbidimeter, which measures the amount of light passing through a sample and is reported in nephelometric turbidity unit (NTU).

Results and Discussion

Coliform Bacteria

As discussed above, coliform bacteria are used as an indicator of water quality. According to the World Health Organization, 1.5 million children die annually due to the lack of access to safe drinking water and sanitation (WHO, 2012). In addition to gastrointestinal illness, consumption of poor quality water can cause other health effects such as infection, pneumonia, meningitis, fever, and muscle pains among others. Inhalation of contaminated water can cause Legionnaire's disease, and contact with contaminated water can cause schistosomiasis, which can result in seizure and death (WHO, 2011). High numbers of total coliform and E. coli are good indicators of the presence of other, potentially more dangerous, biological contamination. As an indicator of fecal contamination, E. coli is considered a primary contaminant by the USEPA, which means that its limit is enforceable by law. The EPA, WHO, and the Kenya Environmental Bureau of Standards (KEBS) unanimously set the limit for total coliform and E. coli at 0 mg/100 mL for drinking water (USEPA, 2009; WASREB, n.d.; WHO, 2011). WHO recommends a more in-depth statistical analysis of total and fecal coliform counts to determine safety of water for bathing, which is beyond the scope of this analysis (Bartram & Rees, 2000).

Due to the serious concern that approximately 884 million people lack access to safe drinking water, in August 2010, the United Nations General Assembly passed Resolution 64/292, recognizing access to safe water and sanitation as essential human rights. The resolution "calls upon States and international organizations to provide financial resources, capacity-building and technology transfer, through international assistance and cooperation, in particular to developing countries, to order to scale up efforts to provide safe, clean, accessible and affordable drinking water and sanitation for all" (UN General Assembly, 2010).

While Mpala provides accessible and affordable drinking water to its employees, this resolution calls upon organizations like Mpala to strive to increase the quality of water supplied. This is an excellent opportunity for Mpala to become a leader in appropriate water treatment technology transfer and capacity building.

Total Coliform

As discussed previously, the membrane filtration method recommends that only samples yielding between 20-200 total CFU on the plate be retained for statistical analysis. All water quality results, both those retained and those disregarded for statistical analysis, are located in Appendix 22. Where possible, biological water quality was compared between the rainy and dry season sampling events. Thirteen sampling locations had total coliform data from both seasons: MRC River, MRC Village, borehole, Clinic, Grevy rain tank, Gym rain tank, kitchen cold tap, kitchen rain tank, potable, Ranch House, Ranch River, River Camp, and weir. Total coliform counts across Mpala using the sites listed above were statistically lower during the dry season than the rainy season ($p_{12,2}=0.002$).

MRC

WASREB sets forth guidelines for water treatment based on total coliform levels in the source water, which are shown in Table 42. Figure 42 shows the results of total coliform analysis at MRC during both the rainy and dry season sampling events. Note these values are on a logarithmic scale and 1 CFU was added to all samples so that samples showing no contamination would appear as 1 CFU/100 mL. Also plotted are the WASREB guidelines from Table 42. As Figure 42 shows, contamination at MRC during the rainy season is extremely high; three samples from the kitchen cold tap, one from MRC River, and two from MRC Village are categorized to be "unacceptable as a source of drinking water unless no other alternative exists" (WASREB, n.d.). WASREB also states that if no alternative source exists, "special treatment" is required; however they neglected to provide a more detailed explanation. Figure 42 also shows that the majority of samples collected during the rainy season are considered heavily polluted and would need to be extensively treated before use, however, “extensive treatment” is also not defined by WASREB. The majority of dry season samples collected show the need for “full treatment”, which WASREB defines as sedimentation, coagulation, filtration, and disinfection. Few samples tested for total coliform had less than 50 CFU/100 mL, requiring only disinfection before consumption (WASREB, n.d.). These include all of the samples from the borehole in both seasons, one sample from the Gym in the rainy season and one in the dry season, all Tank 5 and potable water samples for the dry season, and two of the five samples collected at the MRC Village during the dry season.

A comparison of the total coliform levels between the underground rainwater storage tanks at the gym and the above ground rainwater storage tanks at Grevy and the kitchen, shows that the underground storage tank has significantly cleaner water during both the rainy and dry seasons ($P_{rainy, 5, 2}$=0.005, $P_{dry, 8, 2}$=0.001). The Gym rain tank was a much newer tank when samples were collected which could result in an overall clearner environment and lower total coliform counts. The newness of the tank probably also contributed to the high pH (pH=9), which could further inhibit coliform growth both in the water and on the sampling plate.

Table 42: WASREB guidelines for water treatment (WASREB, n.d.)

Coliform organism (Number/ 100ml)	Recommended treatment
0-50	Bacterial quality requiring disinfection only
50-5000	Bacterial quality requiring full treatment (coagulation, sedimentation, filtration and disinfection only)
5000-50000	Heavy pollution requiring extensive treatment
Greater than 50000	Very heavy pollution unacceptable as a source unless no alternative exists. Special treatment needed.

Ranch

Results from total coliform sampling at the Ranch for both the rainy and dry season sampling events, along with WASREB guidelines, are displayed on a logarithmic scale in Figure 43. Although water samples collected at the Ranch were generally less contaminated with bacteria than those from MRC, there is still extensive biological contamination, and zero samples fell in the category requiring disinfection only. All of the rainy season samples were heavily polluted, and should the water be used for drinking, it would need extensive treatment. One sample collected from the Ranch House was considered “unacceptable as a source unless no alternative exists,” and all of the rainy season data is considered heavily polluted, needing extensive treatment.

Comparison by Primary Water Source

A statistical analysis of the rainy season total coliform data from the four primary sources (rain, river, borehole, and weir) allows categorization of the sites into two groups of two based on the level of contamination, shown in Figure 44. The first group contains the borehole and rainwater sources, which have considerably less biological contamination than the second group, which contains the weir and river sources.

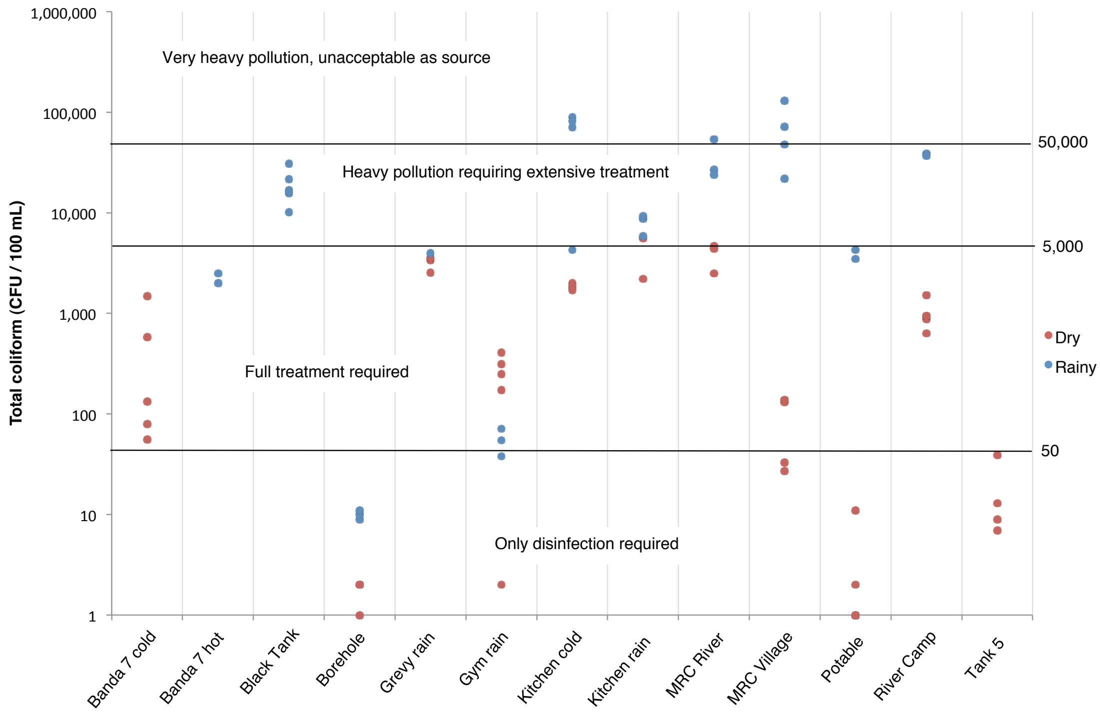


Figure 42: Total coliform results at the MRC

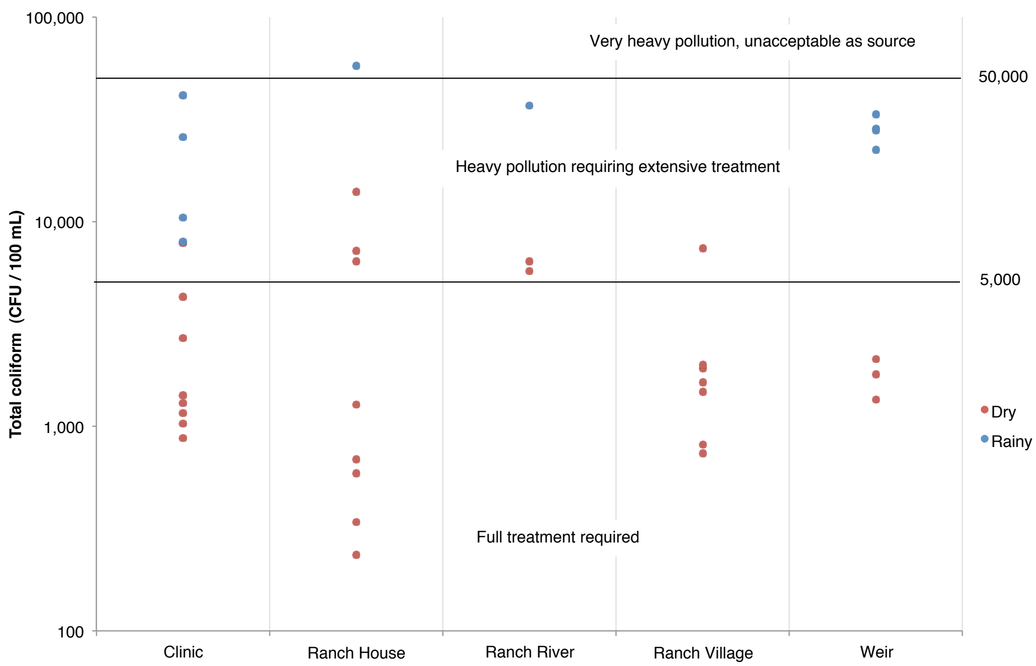


Figure 43: Total coliform results at the Ranch

This is expected, because the sources from surface runoff should have higher levels of contamination than rain and aquifer. During the rainy season, samples taken from the weir, rivers, and the kitchen rainwater storage tanks were "heavily polluted requiring extensive treatment" as characterized by WASREB (n.d.).

Dry season total coliform data, grouped by source, is shown in Figure 45. Between the rainy and dry season sampling events, the coliform counts of the river and weir decreased considerably, but the rainwater did not show as significant of a decrease. Due to these changes, the rainwater better resembled the coliform levels observed in the river and weir and could no longer be grouped with the borehole.

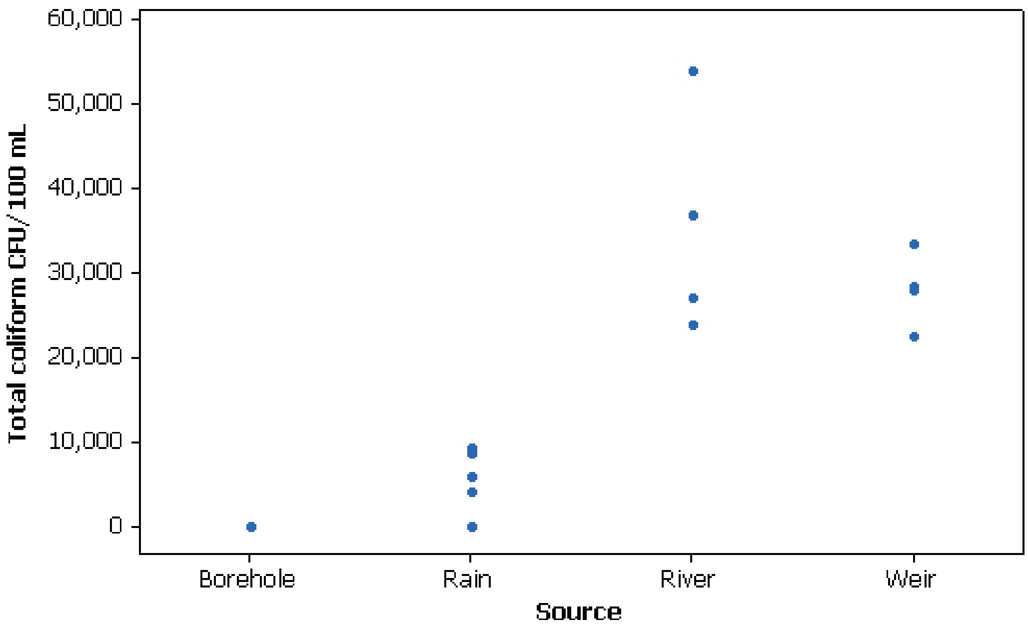


Figure 44: Rainy season total coliform by source

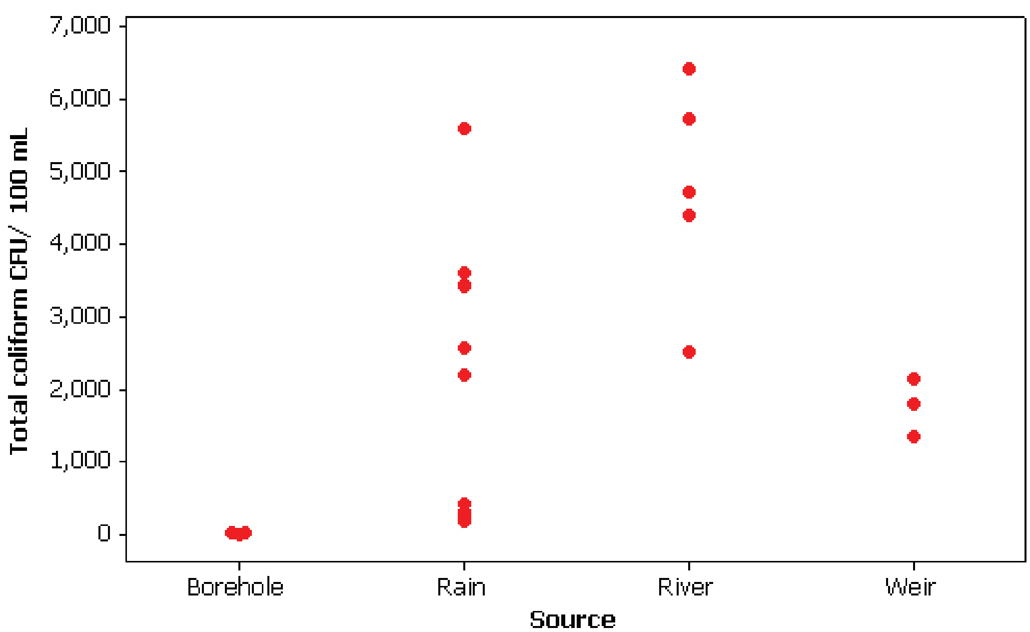


Figure 45: Dry season total coliform by source

E. coli

Rainy Season

Figure 46 illustrates *E. coli* sampling results from the rainy season sampling event. It should be noted that there is a strong possibility for false negatives in reporting *E. coli* when using the m-ColiBlue24® method. This is because the number of *E. coli* CFU can only be accurately enumerated if the number of total coliform CFU is between 20 and 200. The ideal number of *E. coli* CFU per plate is between 20 and 60 for this method. In many cases, due to high total coliform counts, samples were diluted to yield 20-200 CFU of total coliform. Diluted samples reporting 0 *E. coli* CFU/100 mL are not necessarily representative of the true values of *E. coli*, yet failing to dilute the sample would result in a total coliform count of more than 200 total CFU, which is inaccurate due to potential competition between microorganisms. *E. coli* results from samples yielding between 20-200 total coliform CFU per plate are shown in Figure 46. From this figure it is clear that, with the exception of potable water and the kitchen cold tap, every site had at least one sample that violated the standard of 0 *E. coli* CFU/100 mL.

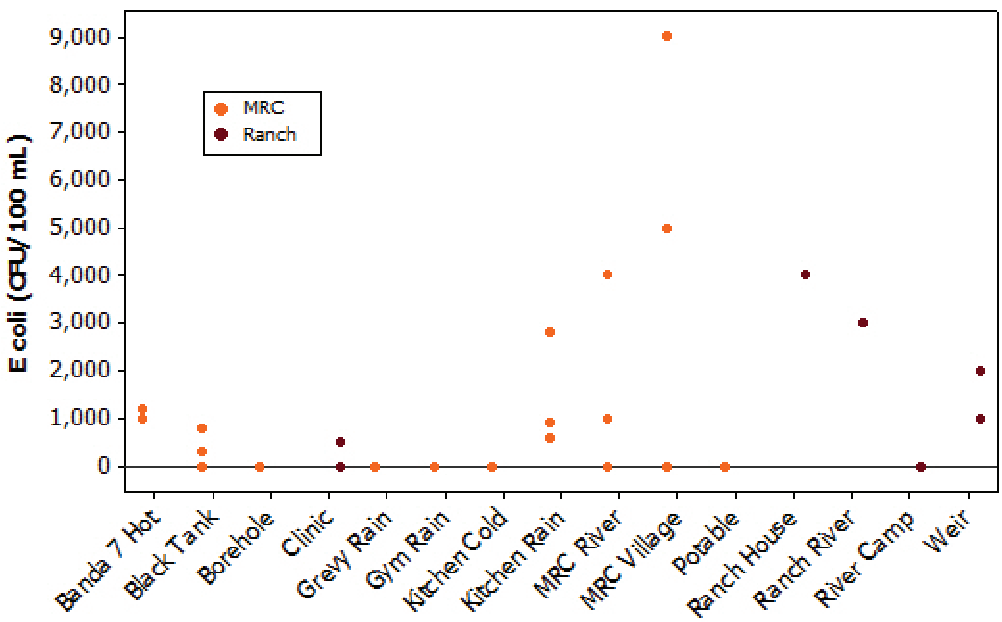


Figure 46: Rainy season E. coli *sampling results*

Dry Season

In an effort to collect more accurate *E. coli* data during the dry season, the modified m-TEC method was used in addition to the m-ColiBlue® method. *E. coli* results from the dry season sampling event are shown in Figure 47, which illustrates that water at Mpala is less contaminated from a biological standpoint during the dry season. It also shows that the river has the highest level of contamination and that the kitchen rainwater storage tank, where a majority of drinking water is obtained from, is also highly contaminated. Comparatively, the weir water is significantly less contaminated. Numerous sites tested negative for *E. coli* contamination in 100 mL of sample including the borehole, Clinic, Grevy rain, kitchen cold, potable, and Ranch Village locations.

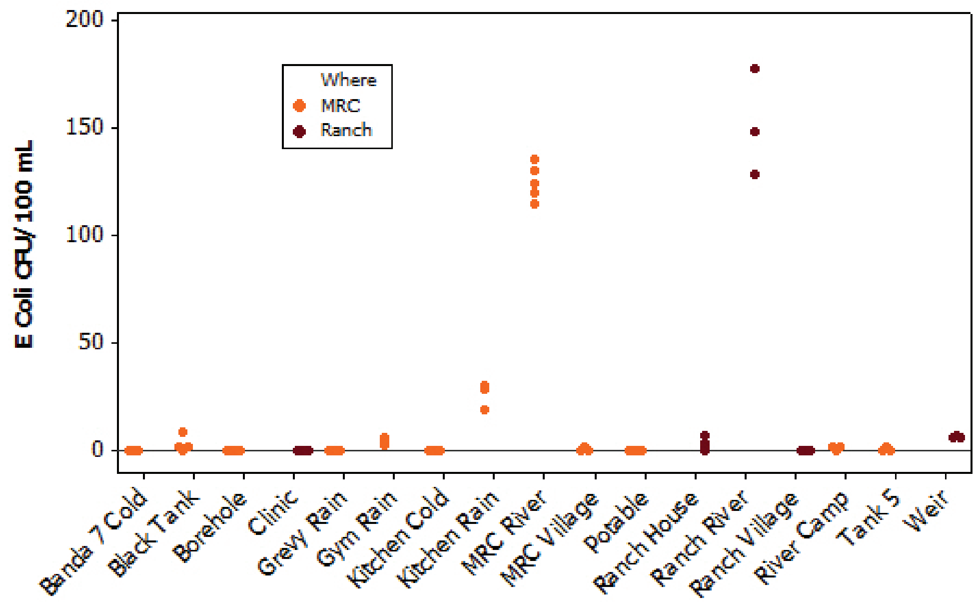


Figure 47: Dry season E. coli *sampling event*

Physical and Chemical Quality

Nitrate, Nitrite, and Phosphate

Fertilizers used in agricultural operations are often high in nitrogen and phosphorus, which can seep into the ground and contaminate shallow groundwater or run off and contaminate surface water. Antokal et al. (2011) expressed concern that agricultural activities upstream may be contaminating the Ewaso Nyiro River at Mpala. In an effort to determine whether or not agricultural runoff may be posing a risk to the water quality at Mpala, samples were collected and analyzed in both the rainy and dry season sampling events for nitrate and phosphate.

The Kenya Bureau of Standards' upper limit for nitrate is 11.3 mg/L NO_3^--N (50 mg/L as NO_3^-). and the EPA maximum contaminate level (MCL) for nitrate is 10 mg/L NO_3^--N (44 mg/L as NO_3^-). The EPA MCL for nitrite is 1 mg/L NO_2^--N; no KEBS limits were found for nitrite (USEPA, 2009; WASREB, n.d.). When nitrate is ingested, it is converted to nitrite in the body, which has serious health effects on infants including shortness of breath, blue baby syndrome, and death. The major sources of nitrate in drinking water are agricultural runoff, leakage from septic tanks, sewage, and erosion of natural deposits (USEPA, 2012b).

Reactive phosphate, also known as orthophosphate, or phosphate, is not regulated as a primary (legally enforceable) or secondary (non-enforceable guideline) contaminant by the EPA (USEPA, 2009). It is also not regulated by KEBS (WASREB, n.d.). In the United States, phosphates are commonly added to drinking water supplies to inhibit corrosion of water piping systems. The health effects of phosphate are currently unknown but consumption is generally considered to be safe and it is an additive to many foods in the United States (USEPA, 2010).

Figure 48 shows the nitrate test strip results for both sampling events and the

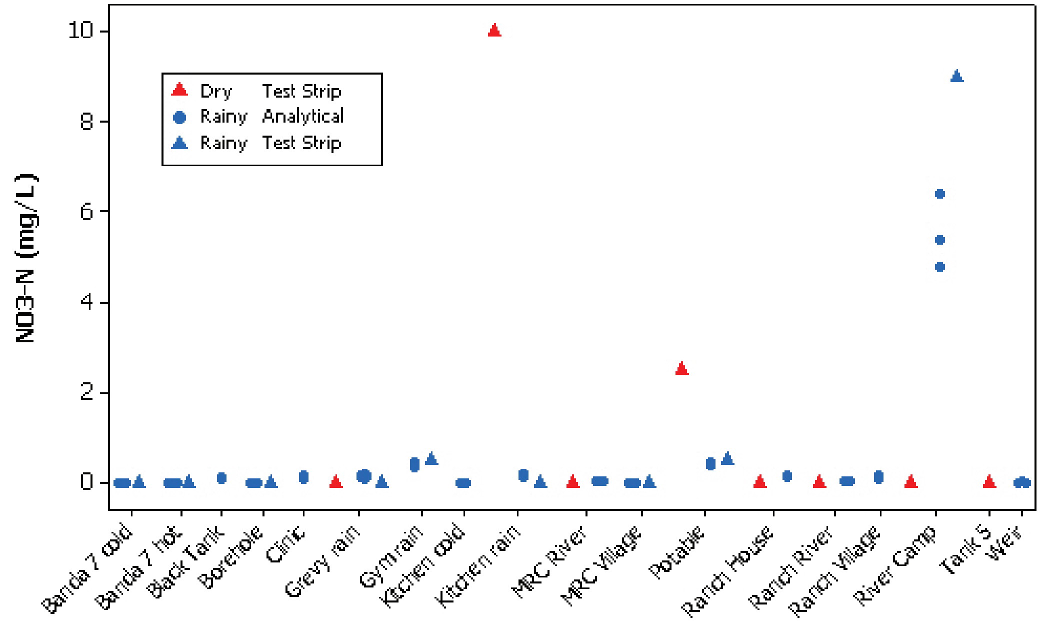


Figure 48: Nitrate results

analytical nitrate results for the rainy season event. This figure shows that none of the analytical results exceeded the EPA MCL or KEBS standards of 10 and 11 mg/L NO_3^--N, respectively, but the test strip from the kitchen rain tank indicated 10 mg/L NO_3^--N during the dry season sampling event. As presented in Appendix 22, during the rainy season sampling event, the test strip showed concentrations of 9 and 3 mg/L of NO_3^--N and NO_2^--N respectively, at the River Camp. Even though this nitrate result was below the standard, the level of nitrite is three times the MCL of 1 mg/L NO_2^--N. During the dry season, test strips were used at nine locations: both river locations, Tank 5, River Camp, kitchen rain, potable, Ranch House, and Grevy. All of these locations showed nitrate and nitrite levels of approximately zero with the exception of the kitchen rain tank, which showed the maximum levels of nitrate and nitrite measurable by the strip, 10 and 3 mg/L NO_3^--N and NO_3^--N, respectively.

The sample collected from River Camp during the rainy season was obtained from a large black tank filled with water from Tank 5, which was river-fed at that time. Since elevated nitrate levels were not found in the river, this contamination likely occurred within the distribution system or during storage. During the dry season sampling event, the River Camp water samples did not show elevated nitrate or nitrite, but the kitchen rain location did. None of the other rainwater harvesting tanks showed elevated levels of nitrate at this time, leading to the conclusion that nitrate and nitrite contamination is most likely a storage issue. The cause for this is unclear and further testing and analysis should be completed to determine the source of contamination.

Results from the phosphate analysis are shown in Figure 49. This figure illustrates that most of the results are low across Mpala; typically less than 1.0 mg/L as PO_4^{2}. This figure shows that, with the exception of the River Camp in the rainy season, and kitchen rain in the dry season, all samples were below this KEBS limit. The sites showing elevated levels of phosphate correspond with the elevated levels of nitrate and nitrite discussed above, and were not found at the MRC River, or other rainwater harvesting tanks. This further supports the hypothesis that this contamination happened either during distribution or storage. The cause for this is currently unknown and further testing and analysis should be completed to determine the source of contamination.

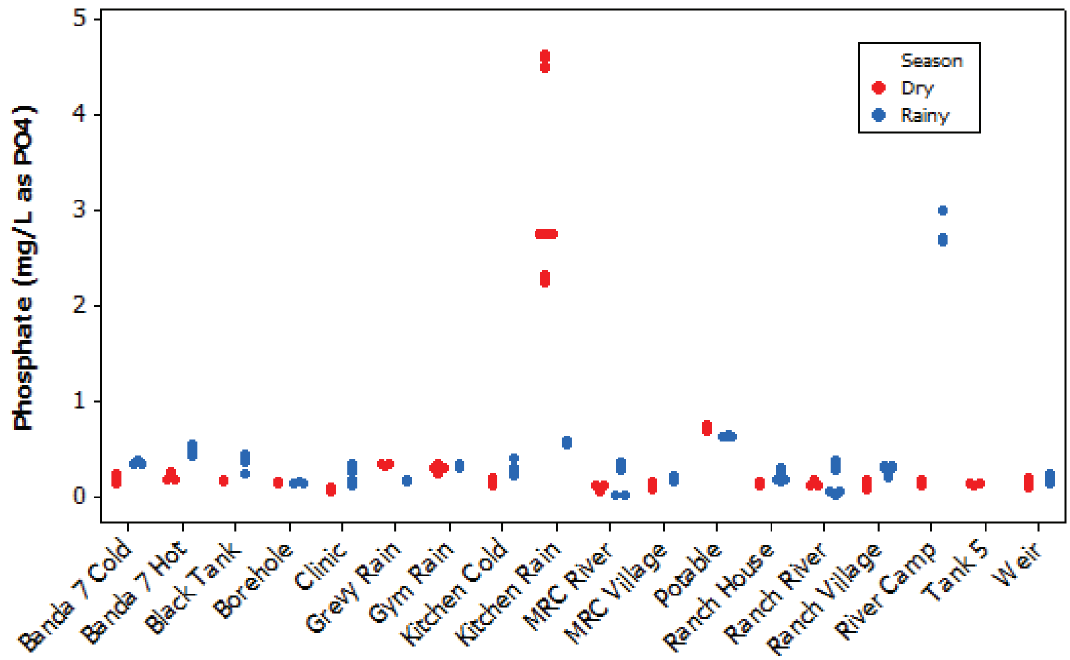


Figure 49: Phosphate results

Total Suspended Solids and Turbidity

As discussed above, turbidity and total suspended solids (TSS) are important physical indicators of water quality. These two parameters are highly correlated because turbid water usually has high levels of TSS and vice versa. High levels of TSS and turbidity are common in surface water bodies, especially during the rainy season, due to surface runoff washing particulates into the receiving water body. Highly turbid water is likely to have elevated levels of biological contamination. It can also have heavy metals and other organic compounds associated with it. Adverse aesthetic characteristics such as taste, odor, and color are generally associated with turbid water, and can render it undesirable for consumption. This is likely to cause consumers to find an alternative, and sometimes more contaminated, water source. WHO sets a guideline of no more than 5 NTU, and the USEPA and KEBS set regulatory limits of 5 NTU. KEBS sets a limit for suspended matter at 0 mg/L, and TSS is not directly regulated by the USEPA nor are guidelines presented by WHO (USEPA, 2009; WASREB, n.d.; WHO, 2011). Turbidity and TSS are also important parameters to consider when selecting water treatment methods, as discussed in the Conclusion section (Sawyer et al., 2003). We analyzed samples for TSS during both sampling events and for turbidity during the dry season sampling event.

Figure 50 shows that in general, TSS levels were higher during the rainy season than the dry season with the exception of Banda 7 hot and the Clinic. Samples taken from the Banda 7 hot tap during the dry season sampling event had unexpectedly high levels of TSS. Even after allowing the hot water to run from the tap for a few minutes, it was still turbid (Figure 51). There are a number of potential causes of the elevated

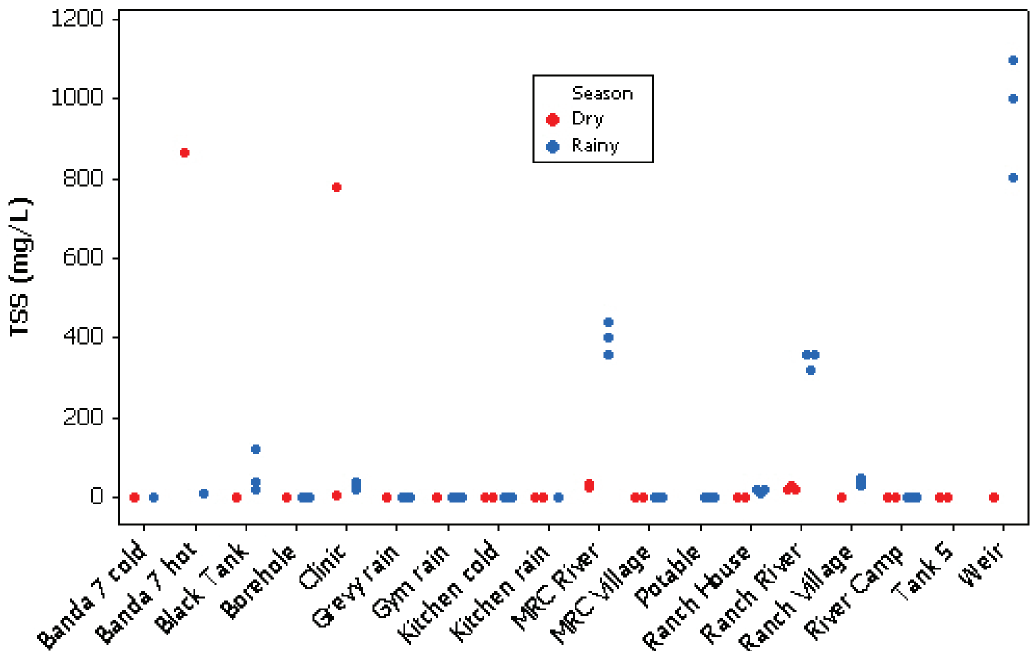


Figure 50: Total suspended solids results

levels of sediment coming from the tap. Sometime between the rainy and dry season sampling events, the old, aging metal tank was replaced with a new plastic one. Sediment could have been loosened and suspended in the pipes during this process. There could also be a break or leak in the pipe, which could allow mud to enter them. Elevated TSS levels were also found at the Ranch Clinic tap. For a couple of days during the dry season sampling event, the Ranch Village tank was empty. When it was refilled, the force from from the water kicked up sediment from the bottom of the tank, allowing it to enter the distribution system. Samples were collected after this event, which is likely the cause of elevated TSS. Turbidity results, excluding those from Banda 7 hot, which ranged from 1470-1530 NTU, and the MRC River, which ranged from 123-141 NTU, are show in Figure 52. This figure illustrates that, even during the dry season, when total suspended solids are lower across Mpala, turbidity at several locations exceeds regulatory limits.

Figure 51: Sample taken from the hot tap

Other Physical and Chemical Characteristics

Total dissolved solids (TDS) are comprised of inorganic salts and small bits of organic matter in water. TDS can be from natural sources, sewage, agricultural and urban runoff, and industrial wastewater. KEBS' standard for TDS is 1,500 mg/L and the EPA lists it as a secondary contaminant with an goal of less than 500 mg/L (USEPA, 2009; WASREB, n.d.).

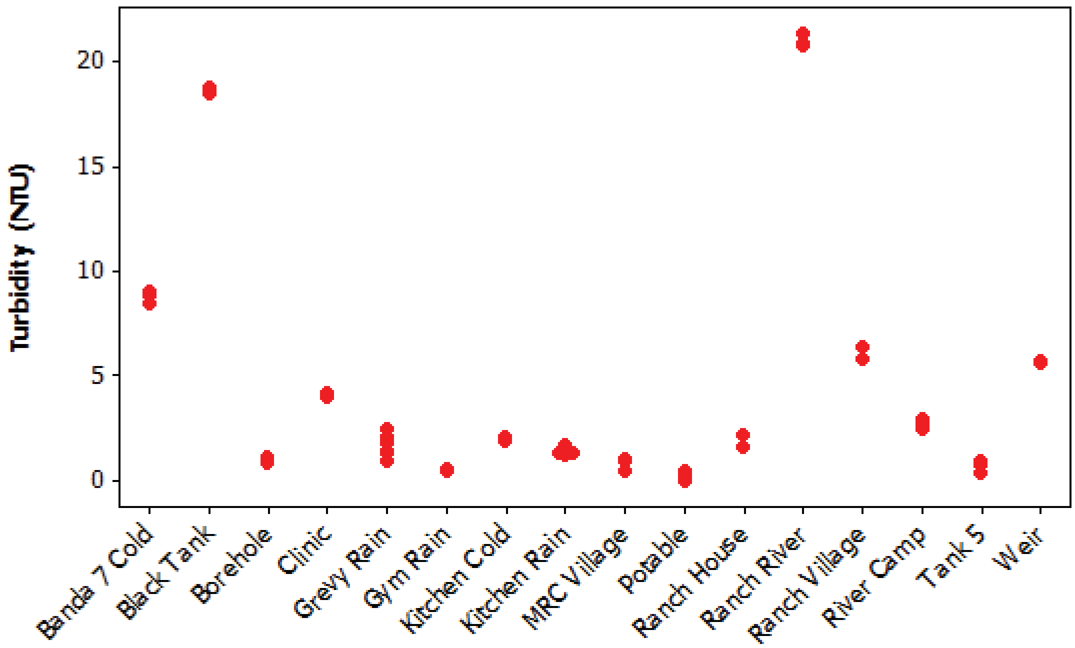


Figure 52: Dry season turbidity results

There are currently no reliable data on adverse health effects from high levels of TDS in drinking water. High TDS is associated with aesthetic problems such as taste and can cause excessive scaling in water pipes, reducing the lifetime of the piping systems. Extremely low TDS in water pipes can be corrosive to pipes and also result in poor tasting water (USEPA, 2012a; Atekwana et al., 2004).

Results for the calculated values of total dissolved solids for MRC and the Ranch are displayed in Figures 53 and 54, respectively. As seen if Figure 53, the KEBS TDS limit of 1,500 mg/L was not exceeded, but the EPA guideline was exceeded by Banda 7 cold and hot, the borehole, and the kitchen cold during both sampling events. Two additional locations exceeded the EPA guideline during the dry season: River Camp and Tank 5. None of the sites at the Ranch exceeded either the EPA or KEBS guidelines.

Hardness is a measure of dissolved multivalent cations such as calcium, magnesium, and iron. Elevated hardness in water isn't a direct health concern but it consumes soap, making it difficult to lather and increasing the amount of soap required for washing. Soft water doesn't consume soap but it makes things feel slippery or slimy after washing. Mpala's village residents noticed this effect, and they stated they prefer river water to borehole water for washing purposes (Antokal et al., 2011). Water is considered soft if the hardness is below 60 mg/L $CaCO_3^-$, and hard if it's greater than 130 mg/L $CaCO_3^-$. For aesthetic reasons, the ideal range for hardness in water is 75-120 mg/L as $CaCO_3^-$ (Davis & Cornwell, 1998).

Hardness results for MRC and the Ranch (Figures 55 and 56) show that water is generally softer during the dry season than during the rainy season, which is expected given the large amount of runoff in the rainy season. Borehole water is much softer than the river water throughout the year, which is unusual given its

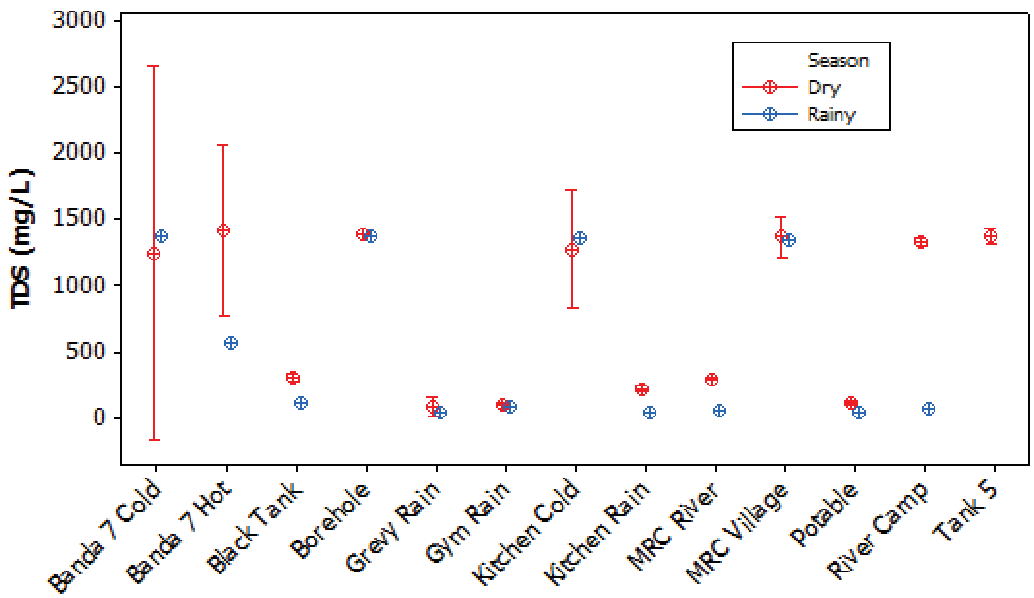


Figure 53: Total dissolved solids results at the MRC with 95% confidence intervals

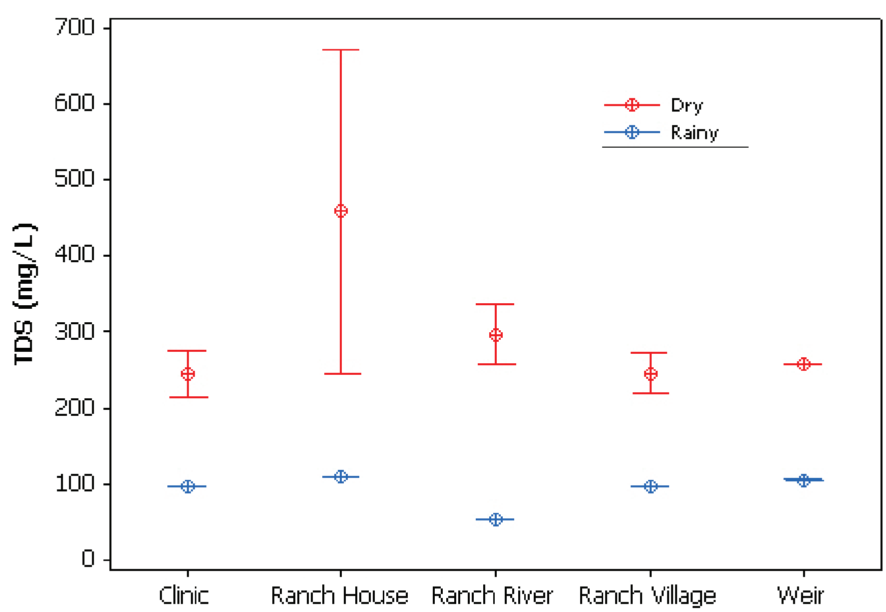


Figure 54: Total dissolved solids results at the Ranch with 95% confidence intervals

high level of TDS. This indicates that the elevated TDS levels at the borehle are due to ions other than divalent cations, and historical sampling shows high levels of monovalent anions fluoride and chloride, which may account for some of this difference (Aquasearch Ltd., 2010). Figure 55 also shows that the hot water at Banda 7 was harder than the cold water during the rainy season, which was likely because the hot water storage tank was made from metal that released divalent cations such as iron into the water. This tank was replaced with a plastic tank before the dry season sampling event. Figures 55 and 56 also show that the rain, weir, and river water are harder during the dry season than the rainy season. Elevated dry season hardness in rainwater storage tanks can most likely be attributed to less dilution and lower turnover of the water supply. As the water sits in a tank, some of the lime from the cement

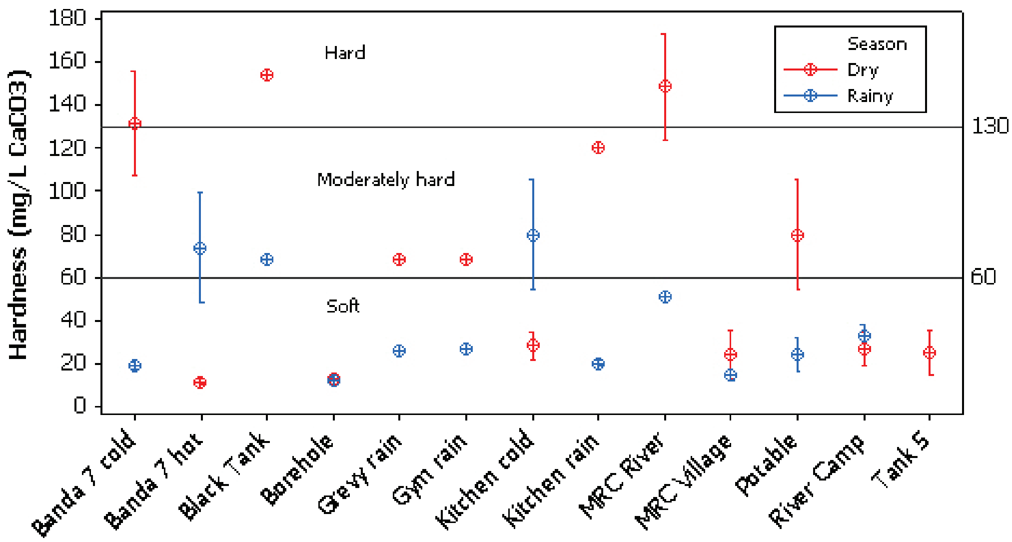


Figure 55: Hardness results at the MRC with 95% confidence intervals

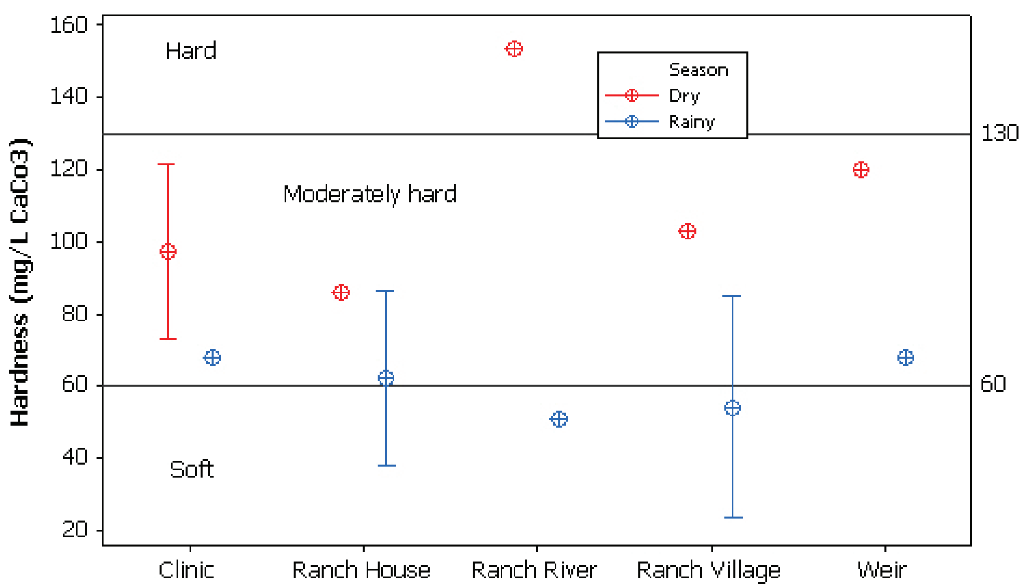


Figure 56: Hardness results at the Ranch with 95% confidence intervals

can leach into it, and without a fresh supply of rainwater coming in, the calcium concentration will increase over time. The kitchen rain tank had a greater increase in hardness than the Grevy and Gym rain tanks from rainy to dry season, likely caused by pieces of metal from the roof in the bottom of the tank, which could leach iron into the water and increase hardness.

During the rainy season, the weir water was harder than the other surface water sampled at the MRC and Ranch river sites. This is could be because construction was occurring at Weir 3. Cement contains lime, which probably increased the amount of calcium, and therefore hardness, in the water. During the dry season, however, the weir hardness was much less than the river, which could be due to a number of factors, the most notable of which is the difference in drainage basins. Figure 56 shows that water at the Ranch, which is mostly Nanja water, is overall closer to the ideal hardness range of 75-120 mg/L as $CaCO_3^-$. Evaporation, as well as shallow groundwater contribution, could be factors contributing to higher hardness at the weir during the dry season. Nanja water was in the in the ideal hardness range for both sampling events.

Conclusion

An in-depth statistical analysis of biological and chemical water quality data provides a picture of how complicated the distribution system throughout Mpala is. According to records by Mpala's plumber, Tank 5 contained only river water at the beginning of the dry season sampling event due to a broken pipe on the borehole line. On February 25th, the borehole line was repaired and pumping from the river to Tank 5 ceased. Inevitably, there was some mixing in the pipes as Tank 5 filled with borehole water and the river water in the pipes was replaced. Based on statistical analyses of water collected during this source switching event, we were able to get a rough idea of how quickly water moves within the system, and how mixing water sources in the pipes effects water quality.

A one way ANOVA was performed on total coliform sampling results from the dry season at the MRC to help determine if water at the point of use was biologically, statistically similar to the water from its source. This analysis showed that the samples obtained from the MRC Village and Banda 7 cold tap were not statistically similar to either the MRC River or the borehole. The kitchen cold and River Camp samples were also both found to be statistically different from the borehole, but statistically similar to the river.

A one way ANOVA was also performed on TDS data collected at MRC during the dry season. The results showed that, among others, Banda 7 cold, kitchen cold, MRC Village, River Camp, and Tank 5 were all similar to the borehole water.

Banda 7 cold TDS results were found to be similar to the borehole water on February 27th, two days after the borehole came back online. Just one day later, on February 28th, the water at Banda 7 cold was still more biologically contaminated than water from the borehole, but not as much as the MRC River. Also on February 28th, the Kitchen cold tap was statistically similar to the borehole water when TDS data were compared, but the biological activity was similar to the MRC River. On February 29th , when TDS results were compared, samples collected from Tank 5 and the MRC Village tap were similar to the borehole, and samples analyzed the following day for coliform bacteria, on March 1st, were also statistically similar to the borehole. TDS samples collected on March 1st from the River Camp were statistically similar to the borehole, but were biologically similar to the MRC River.

Due to the nature of total dissolved solids in water, it should be recognized that when TDS data from a specific location was statistically similar to the borehole data, the water source supplying that location was likely the borehole. With this understanding, there are three main conclusions that can be drawn from the statistical analyses described above. First, one can deduce the maximum amount of time it takes for water leaving the borehole pump to arrive at these sampling locations. It took (at most) two days to reach Banda 7, three days to the kitchen cold tap, and had arrived at River Camp in at most four days. The second conclusion that can be drawn from this analysis is that, although the water from the kitchen cold and River Camp locations originated from the borehole, these samples still had high biological contamination similar to the river. The final conclusion is that, given enough time, this elevated level of biological contamination will reduce to lower levels, approaching those of the borehole, as shown at the MRC Village and Tank 5 sampling locations. The implications of this analysis are twofold. First, this level of water quality variability could make it extremely difficult to design and implement a water treatment plan. Secondly, the high levels of bacteria still present in the pipes after borehole water had replaced river water, sometimes at least a day later, indicates that there is some bacterial colonization in the pipes.

Bacterial colonization of piping systems is sometimes the result of pipe corrosion. Pipe corrosion is a problem that can have serious adverse effects on a distribution system, including leaching of heavy metals (copper, cadmium, lead, chromium, and nickel), bacterial growth, plugging of pipes, increased turbidity, and water loss (Shams El Din, 2009; Lehtola et al., 2004; Zacheus et al., 2001; Moore, 1977). Corrosion can be caused or inhibited by a number of different factors including dissolved ions, hardness, alkalinity, pH, and dissolved oxygen. At Mpala, the borehole water has high chloride (250 mg/L) and fluoride (24 mg/L) concentrations, which can increase corrosion by preventing formation of protective layers (Aquasearch Ltd., 2010; Sander et al., 1996). Langelier and Aggressiveness Indices were calculated using data obtained from the dry season, and all water samples were determined to be nonaggressive, meaning it is unlikely to cause corrosion. Even though these samples are considered nonaggressive, it is clear from visual inspection of the pipe interior that some reactions are taking place and deteriorating the integrity of the piping system (Figure 57). This particular pipe had a slimy film on the inside, which was likely a biologically active layer.

Figure 57: Photograph of a pipe interior at Mpala

The aging nature of Mpala's distribution system increases the likelihood that the interior of pipes will become damaged and obstructed. Corroded, damaged, or obstructed pipes need to be taken into consideration when evaluating water treatment options, because if water is to be treated and disinfected prior to distribution, significant amounts of clean water can be lost from pipes. Furthermore, pipes can harbor bacteria, and these colonies can recontaminate the previously treated water.

Treatment and Disinfection

The level of biological contamination across Mpala is high, including *E. coli* levels above the EPA guidelines for bathing and recreational water use. Mpala should treat all water to be used for drinking, all bathing water obtained from the river, and bathing water obtained from the weir during the rainy season. To be safe, Mpala should treat bathing water obtained from the weir year round. Given the high levels of total coliform observed in both of these sources during the rainy and dry seasons, WASREB recommends that full treatment be implemented if they are to be sources for potable water. Full treatment consists of storage, pretreatment, slow sand filtration, and chlorination, as shown in Figure 58 (Davis & Lambert, 2002; WASREB, n.d.). Turbidity levels are often used in developing countries to assist in selection of a treatment process. Water with low turbidity and high fecal contamination can be treated with a settling tank followed by slow sand filtration. Water with high turbidity and fecal contamination needs to be treated using a preliminary settling tank, followed by pretreatment, which can be either coagulation, flocculation, and sedimentation, or roughing filtration. If roughing filtration is chosen for pretreatment, the water should then be treated using slow sand filtration. Irrespective of the process chosen, all water should go through a disinfection process such as chlorination if it is to be used for drinking (Davis & Lambert, 2002).

At Mpala, the turbidity and TSS at the weir were both low during the dry season, but due to the high correlation of TSS and turbidity, elevated TSS levels during the rainy season indicate that the weir can become very turbid after a rain event. With the increasing intensity of storms, this will likely pose a barrier to simpler water treatment technologies, such as slow sand filtration without pretreatment.

Storage Tanks for Settling and Equalization

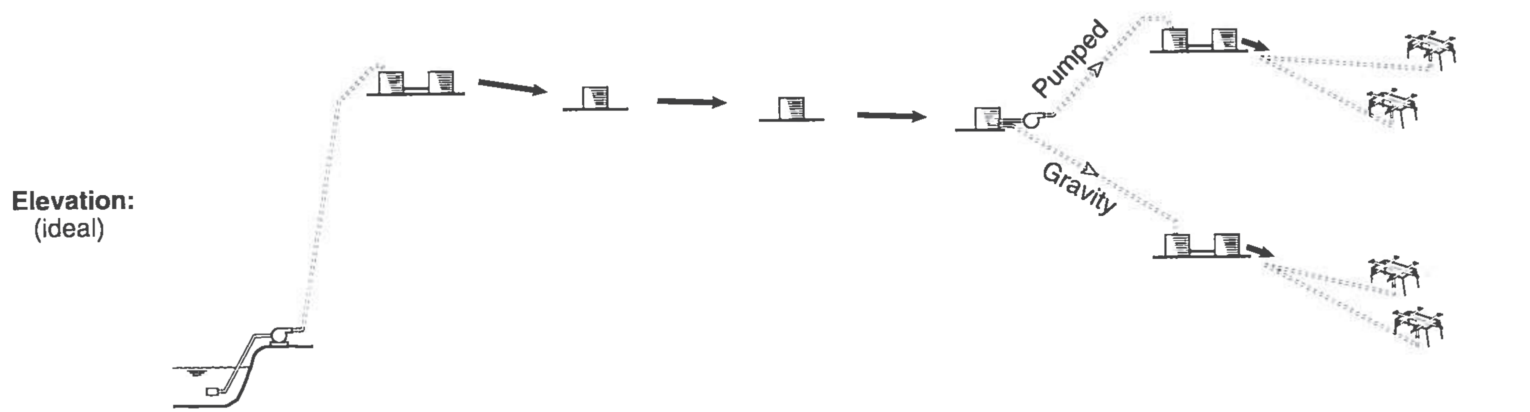
Water abstracted from a turbid source (>20 NTU) should first be sent to an equalization tank to allow for the removal of settleable solids and turbidity reduction. A simple storage tank, such as those already installed at numerous places throughout Mpala, will achieve solids reduction as well as flow equalization. Almost all treatment systems, even those without pretreatment, have an equalization tank in order to maintain a constant flow of water entering the treatment system. This is necessary in order to smooth rapid changes in water quality due to storm events; keeping influent turbidity levels relatively constant eases operation of the system. Furthermore, treatment systems such as slow sand filtration cannot operate effectively without a constant flow. These tanks will also provide a safety net of stored water in the event that the distribution system becomes compromised with a leaky or broken pipe. Davis and Lambert (2002) suggest storing at least one day's worth of water in the event of emergency. The only maintenance required of these tanks is to clean them out on a regular basis to ensure that settled solids don't rejoin the liquid stream entering the distribution system.

Coagulation, Flocculation, and Sedimentation

Surface water has colloidal particles such as clay that cannot easily settle out in a tank. The two most applicable methods to developing countries for removal of colloidal material prior to biological treatment are coagulation/flocculation and roughing filtration.

Coagulation and flocculation is the process of adding chemicals or natural coagulants to encourage colloidal particles to clump together and settle out in flocs (flocculation). Typical chemical coagulants used in developed countires are alum, ferric chloride, and ferric sulphate, but studies show that crushed seeds from Moringa trees, grown in Kenya, are an effective natural coagulant (Ali et al., 2010; Pritchard et al., 2010; Katayon et al., 2006). In order to determine the amount of coagulant required, jar testing needs to be carried out on a daily basis. The process of coagulation consumes naturally occurring alkalinity, so water with low alkalinity requires addition of lime, caustic soda, or soda ash.

To achieve adequate flocculation, the influent water needs to be rapidly mixed while the



	Water abstraction	Raw water storage	Pre-treatment	Slow sand filtration	Chlorination	Storage	Distribution
Stage:	**Water abstraction** Surface intake. Infiltration gallery or well(s). Spring(s). Large diameter well(s). Borehole(s).	**Raw water storage** Contingency reserve. May be combined with settlement and/or pH correction.	**Pre-treatment** Either: Settlement – plain or chemically assisted. Or: Roughing filtration.	**Slow sand filtration** Only include if filter can accept the turbidity of the influent.	**Chlorination** Final treatment stage. Safeguards downstream supplies.	**Storage** At strategic points on the distribution system. May be combined with chlorination contact tanks in simple systems.	**Distribution** To communal collection points – tapstands.
Design capacity:	Average flow rate over operating period.	Several tanks. Storage capacity will depend on reliability of the source (a few hours' to one day's supply).	Average flow rate over operating period.	Average flow rate over 24 hours.	Sufficient capacity to give the required contact time at the average flow rate.	Several tanks. A minimum of one day's storage.	Sized to meet peak demand flow rate.

Figure 58: Water storage, treatment and distribution (Davis & Lambert, 2002)

coagulant is being added; this can occur naturally if the water is under enough pressure when it enters the tank. It then needs to be stirred gently during flocculation and settling; this can be achieved using an upflow clarifier (Figure 59) or a mechanical mixer with an external energy input. Upflow clarifiers can be difficult to maintain because the floc blanket needs to stay intact for the process to work and external energy inputs can be expensive (Davis & Lambert, 2002).

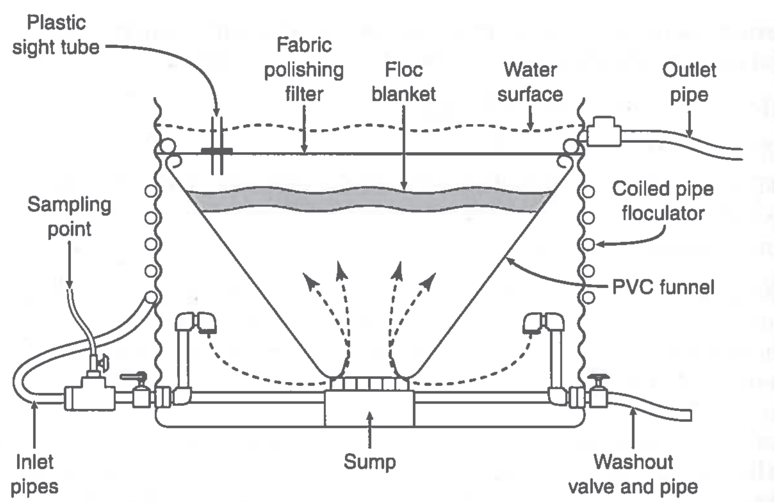


Figure 59: Upflow clarifier used during flocculation (Davis & Lambert, 2002)

After coagulation and flocculation, the water goes through a sedimentation tank to allow the flocs to settle out. The settled flocs, called sludge, needs to be dewatered and dried before disposal. The sludge and supernatant liquid from the dewatering process can be hazardous and needs to be disposed of properly. In the United States, dried sludge is typically incinerated or sent to a landfill, which is expensive. At Mpala, sludge incineration or disposal is likely to be expensive and logistically challenging. Coagulation, flocculation, and sedimentation is generally more costly than other pretreatment alternatives due to the purchase requirements of coagulants and alkalinity, as well as high sludge handling costs. The major benefit of coagulation, flocculation, and sedimentation is that no further treatment is necessary; the water can just be disinfected and distributed.

Roughing Filtration

Roughing filtration is a low cost and efficient pretreatment process, even for highly turbid waters (Destanaie et al., 2007; Nkwonta et al., 2010). It can achieve solids, color, and turbidity reductions without the addition of coagulants. Roughing filters are designed as horizontal or vertical (up- or down-) flow (Figure 60). Removal efficiency is dependent on both design and influent water quality. They are typically divided into three compartments where water flows through coarse, medium, and then fine media. Filter media can be made from gravel, bricks, plastic, charcoal, rocks, and/or sand (Davis & Lambert, 2002). In addition to turbidity and solids removal, coliform, iron, and manganese removal have been observed in these systems (Destanaie et al., 2007). Due to recent data revealing elevated levels of iron at the weir, roughing filtration should be considered by Mpala an inexpensive and effective iron removal method (Appendix 21). Maintenance on the filter includes periodic draining, at which time the sediment and sludge that accumulated at the bottom is flushed out. The sludge from a roughing filter isn't hazardous and can be easily disposed of (Davis & Lambert, 2002). Since roughing filtration is not likely to produce potable water, some type of further treatment would be required before consumption.

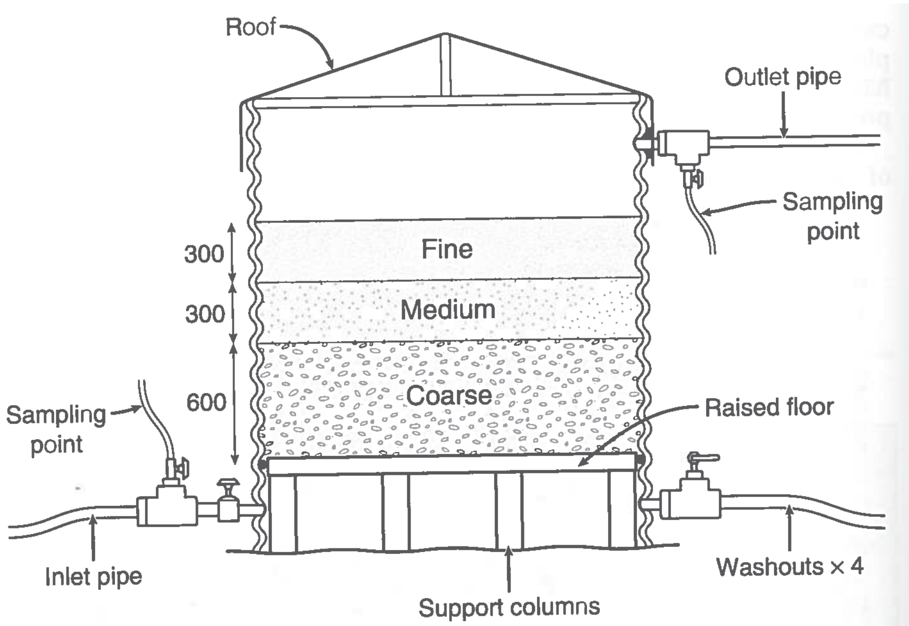


Figure 60: A vertical upflow roughing filter (Davis & Lambert, 2002)

Slow Sand Filtration

Slow sand filters use sand as a medium to achieve very high pathogen reduction from low turbidity water. Removal of biological contamination is due to the presence of a biologically active layer, called the Schmutzdecke, which lives in the top layer of the media. While a slow sand filter can produce water clean enough to drink, perhaps the biggest limitation on this type of filter is that it best treats water with turbidity around 5 NTU. If the turbidity of the influent water is regularly greater than 20 NTU, roughing filtration should be used as pretreatment prior to slow sand filtration (Davis & Lambert, 2002). Maintenance on the system can be difficult and requires a trained operator. Slow sand filters require a constant input of water to keep the Schmutzdecke layer alive. If the influent stops for more than a day, the filter needs to be drained completely to prevent anaerobic conditions from forming in the media, or the water will develop a bad taste. Synthetic fabric can be placed on top of the filter so that when head loss is noticed, the fabric is removed, washed, and replaced after a small layer of sand is scraped. Routine maintenance consists of this scraping, typically every two to 20 weeks, but can occur more frequently with more turbid water. The Schmutzdecke layer takes a few days to grow, during which time the water needs to be treated another way. Every three to four years, or if anaerobic conditions develop, the filter needs to be emptied and the sand replaced. Even though a slow sand filter will produce safe and potable water when operated properly, disinfection is strongly recomended as a safely precaution and to prevent recontamination in the distrubution system (Davis & Lambert, 2002).

Disinfection

Regardless of the water source, all drinking water should be disinfected to kill any bacteria remaining after treatment, and to protect water from becoming recontaminated before use. Disinfection can be achieved in a number of ways, including chlorination, iodine, boiling, and UV radiation.

The most common disinfection technique is chlorination. Chlorine comes in several forms and different concentrations. In order to be effective, both the appropriate dose and contact time need to be calculated based on the level of contamination so that all organic and inorganic matter is oxidized and pathogens are killed. The dose also needs to be high enough to leave a residual to prevent against further contamination, but this can leave an undesirable taste. Water should have turbidity less than 5 NTU for effective chlorination, although it can sometimes be effective up to 20 NTU. Chlorination is not effective in highly turbid water because pathogens hidden inside organic matter are unlikely to be killed by chlorine. When chlorine reacts with organic matter, it forms disinfection byproducts such as chloroform, chloramines, and trihalomethanes. The health risks due to consumption of these compounds is currently unknown (Sedlack & von Gunten 2011; Milhelcic et al., 2009). The major benefits of chlorination are that it provides protection from further contamination along the distribution line, and it is highly effective in killing a wide range of pathogens.

Iodine is also sometimes used for disinfection because it is simple and more effective than chlorine at penetrating suspended matter. Iodine is more expensive than chlorine and is not recommended for long-term use due to potential adverse health effects (Davis & Lambert, 2002; Backer & Hollowell, 2000).

Water can also be effectively disinfected by boiling it for 5-10 minutes. Unfortunately, the required boiling time is often not met, resulting in only partial disinfection. Boiled water requires significant time to cool before it can be consumed, leaving an opportunity for recontamination. This process is energy and time intensive, leaves the water with an unpleasant, flat taste, and provides no residual protection against recontamination. High total coliform results in September 2011 at the MRC potable water filter showed how previously boiled water was recontaminated after passing though a ceramic filter.

An increasingly popular way to disinfect water in developing countires is by use of UV radiation, or solar water disinfection (SODIS). SODIS is most effective in semiarid regions between the equator and 35°N/S latitude where Mpala falls (Milhelcic et al., 2009; Meierhofer, 2006). Water disinfected by solar radiation for six hours at a temperature of at least 40°C will experience polio virus inactivation and a 3-4 log (99.9-99.99%) reduction in bacteria, rotavirus, and giardia, in addition to a 2-3 log (99-99.9%) reduction in cryptosporidium (Meierhofer, 2006). SODIS can be achieved by filling a clear, unscratched plastic or glass bottle with water and placing it on the roof for a day, as shown in Figure 61 (Meierhofer, 2006).

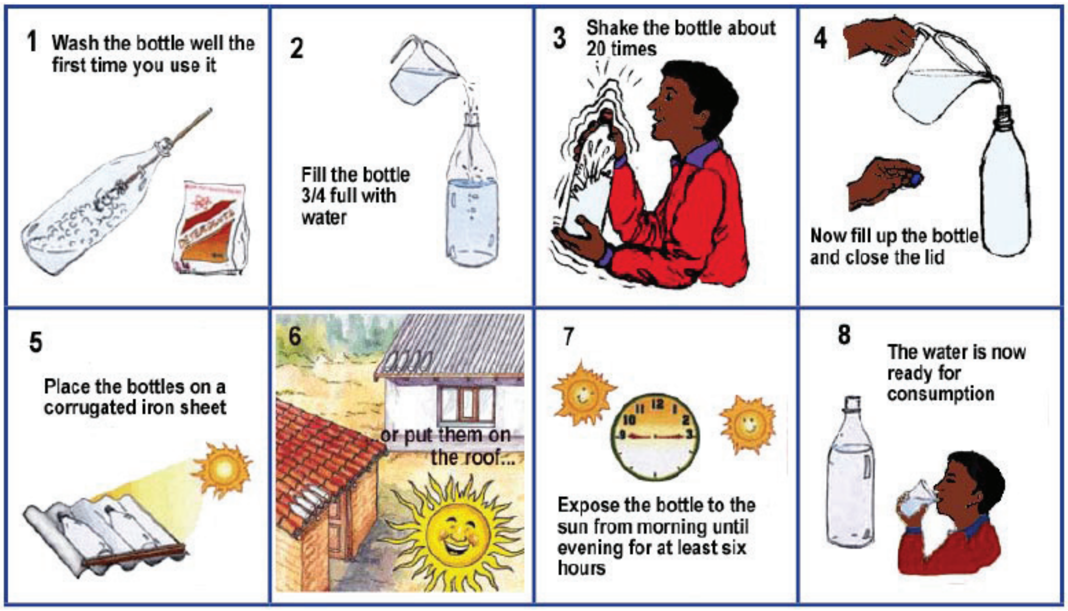


Figure 61: Disinfection using a clear, unscratched plastic or glass bottle (Meierhofer, 2006)

Recommendations

Given the seriousness of the water scarcity and quality issues facing Mpala, perhaps the most important recommendation is that Mpala hire a full-time water expert. This individual will need to have the knowledge and leadership skills necessary to oversee all aspects of water management across the property, as well as the technical expertise to implement the detailed recommendations provided in this report.

System Monitoring and Maintenance

Meters provide valuable information regarding water demand as well as inefficiencies in the system. Mpala already has an extensive network of meters in place, but a few additional meters would enhance their understanding of water use. As of March 1, 2012, there was not a meter measuring the amount of water pumped from the river to MRC. At that time, a meter for this line was being stored at the MRC garage and had yet to be installed. This meter should be installed near the river pump and readings should be taken both before and after water is pumped. Once all the weirs are completed and a pipeline is laid to MRC, a flow meter should be installed at the beginning of this line (by the weirs) to measure the amount of weir water used. It would also be useful to install a meter at the end of the pipeline where the water will be delivered to MRC in order to monitor losses along the line. Due to the uncertainties around river and weir water mixing in the pipes, it would be valuable to install a meter on the line up to the Top Spray Race above the junction. With meters at the beginnings and ends of these lines, a more accurate monthly water balance could be calculated and water loss could be monitored.

It is highly recommended that Mpala continue monitoring the water distribution system using meter readings from the installed flow meters. Based on the calculated water loss of the borehole distribution system (Table 20), it is not recommended that any major pipeline replacement projects be undertaken to locate leakages in the system. It is, however, recommended that a physical check of the borehole line be conducted every month, perhaps more frequently, during the dry season when elephants are more likely to tear up the pipes. This check would involve driving along the borehole line looking for any areas that are uncharacteristically wet or lush in comparison with surrounding land, indicating a potential leak. Continual monitoring of the system should be performed using monthly meter readings, as illustrated in Appendix 8, to identify when losses are abnormally high (above 20% of the total supply). Losses exceeding 20% of total supply are an indication that there was/is a substantial leak in the pipeline, or that there has been overflow from one or more storage tanks. If losses are this high, then the cause should be identified and the proper actions taken to stop the leak if it's ongoing, and reduce the chance of the event occurring in the future. As of March 1, 2012, one of the two previously mentioned leaks on the borehole pipeline had still not been repaired because much of the surrounding vegetation was dead, leading Mpala staff to conclude that the leak was small. However, at this location, the pipeline is approximately two meters underground, and it's unlikely that the roots of surrounding grasses penetrate to that depth. This means that most water from a leak, even a large one,would seep further underground or flow downhill at a depth great enough that it would not be taken up by vegetation in the immediate vicinity. Also, vehicles driving along the pipeline could be inhibiting the growth of vegetation at this location. Given that the pipeline is so deep and that water was visible at the surface (Figure 62), there is reason to believe that the leak may

Figure 62: Picture of borehole water coming to surface from an existing leak

be substantial. These two leaks were located on a section of pipeline made of PVC that may be under greater stress than other areas of the distribution system due to increased pressure at that location. If leaks continue, a portion of the PVC pipe carrying water down the hill, especially near the base, may need to be replaced with stronger GI pipe.

Predict and Monitor MRC Water Use

The two equations developed for predicting water use at the Centre/River Camp and at the MRC Village should be used to predict monthly water demand at MRC for as many months into the future as possible. This will provide Mpala staff with key insight into water use and will allow them to make anticipatory water management decisions based on expected use. Coupling this with the volume quantification tool for assessing current water storage at the weirs (discussed in the next section) will make this an even more powerful tool. In addition, predicted monthly water use quantities can be compared with actual water use to both identify irregularities and to enhance the accuracy of the prediction equations. The equations for predicting monthly water use are as follows:

Equation 9: Water Use (m^3) at Centre/River Camp = $0.415x + 38.425$

Equation 10: Water Use (m^3) at MRC Village = $0.011x + 28.999$

In these equations, x is the number of bednights per month. These equations are designed to predict monthly water use and should not be used to predict water use over any other increment of time. To monitor actual water use by the Centre/River Camp and the Village, the values obtained from the meters in Table 43 should be used (refer to Figure 5 for the location of these meters).

Table 43: Meters at MRC measuring guest and Village water use

	Meter(s)
MRC Guests Use	#4
MRC Village Use	#2 + #3

The Nanja Weirs

Our analysis suggests that the Nanja weirs will provide a plentiful source of water to Mpala and it is strongly recommended that Mpala rely on them as their primary source of water. In order to use the Nanja weirs most efficiently, Mpala will need to perform additional monitoring and select appropriate treatment measures to improve quality.

Assuming average rainfall, the Nanja weirs will collect a sufficient volume of water to meet and/or exceed current demand. The volume quantification tool, which uses the height from the top of the weir wall to the water surface level, was developed to quantify the amount of water in the weir at any given time, and should be used alongside demand prediction. If the volume of water stored at any given time (Equation 7) is not sufficient to meet demand until the next rainfall, Mpala should consider themselves to be water scarce, enact water conservation measures, and begin to supplement the supply from other sources. Although not sufficient to provide a large buffer, when drought conditions threaten to empty the weir, rainwater should be used to supplement the supply. If rainwater is unavailable then borehole water may be mixed in at a fraction 1:10 (one part borehole to nine parts water from another source). This level of mixing will allow Mpala to increase supply while ensuring fluoride concentrations are dilute enough to remain at a safe level for consumption.

Data inputs for the volume quantification tool were limited due to the very recent construction of the weirs, and Mpala should refine these inputs as more detailed information becomes available. Additional site-specific information regarding evaporation rates and surface runoff coefficients could substantially enhance the precision of prediction model. Every catchment is unique, and while those nearby Mpala can serve as a reasonable proxy, data specific to Nanaja should be collected and calculations should be revised accordingly. Evidence of maintained water levels during the drought despite significant evaporation, and the presence of nearby springs, suggests shallow subsurface groundwater interactions at the Nanja weirs. This interaction could either add or subtract from the amount of water stored in the weirs. A better understanding of the Nanja hydrology after weir construction is complete will allow for even further refinement of the volume quantification model. Mpala should monitor the water surface elevation in each weir, particularly during the dry season, to provide a framework for assessing these less quantified site-specific aspects. In the next several years, regularly collected monitoring data (relative water surface elevation in particular) should be collected, and can be used to better understand the water balance as a whole. Monitoring should continue at least long enough for Mpala to create a representative record though average, dry, and rainy years. Refinement and use of this volume quantification tool, combined with the demand prediction model, will allow Mpala to manage water distribution amongst the weirs and be alert in advance of a water crisis so that necessary precautions can be taken.

Water Storage and Treatment

We recommend that water storage/settlement tanks be installed on both weir outlet pipelines as close to the weirs as possible. These tanks would provide more storage along the pipeline, and protection against the loss of an entire weir's worth of water in the event of a pipeline breakage or undetected leak. The storage tank will also act as a preliminary settling tank, allowing some sediment to settle out before it can enter the distribution system, increasing water quality by lowering turbidity and suspended solids. Finally, tanks placed along the pipeline from the weirs to the MRC and Ranch will act as flow equalizers, which will keep flow constant throughout the water treatment process. All water tanks at Mpala, regardless of their designed purpose should be cleaned at least at the end of the rainy season and ideally more often.

Characteristic of water sources available to Mpala, weir water must be treated prior to use for bathing, cooking, or drinking. After the storage tanks on each pipeline, roughing filters should be installed to remove most of the remaining turbidity, iron, and reduce biological contamination. The roughing filters should be kept online during the rainy season due to the frequency and intensity of storm events. During the dry season, turbidity should be monitored in the storage tank effluent, and if it is consistently low, (~10 NTU) Mpala can consider allowing the flow to bypass the roughing filters.

Mpala should install a slow sand filter near the kitchen to filter all water from the taps and rainwater tanks to be consumed by guests for drinking and cooking. The drinking water should then be disinfected with chlorine prior to distribution so that there is enough residual to prevent recontamination when researchers go to the field, or if dishes or filters are contaminated. The kitchen rainwater harvesting tank roof should be repaired and the tank should be cleaned. In the meantime, it should not be used as a source for drinking or cooking water.

Slow sand filters should also be installed at both the MRC and Ranch Villages for treatment of drinking and cooking water. It is recommended that SODIS, rather than chlorination, be used as a disinfection technique in the villages. While the taste of chlorine is probably acceptable, and perhaps even comforting to many of Mpala's guests from developed countries and Nairobi, residents from rural areas are less likely to accept the taste, and may turn to other, more contaminated sources for drinking if the taste is undesirable to them. The importance of SODIS, as well as treatment procedures, should be taught to the community leaders in the villages and its use should be encouraged. Maintaining this practice will help ensure clean, safe water is provided even when the filter becomes ineffective for the three days following the scraping of the Schmutzdecke.

Water Quality Monitoring

After treatment and disinfection systems are in place, Mpala should continue to monitor their water quality by periodically testing for biological contamination such as *E. coli* to ensure the treatment system is functioning properly. They will also need to monitor any chlorine residuals if chlorine is to be used. Mpala should purchase nitrate/nitrite test strips and periodically sample at the various taps where drinking and cooking water is obtained, such as River Camp, the kitchen rain tank, MRC Village tap and from the filters at the dining hall. Our analysis was unable to determine the cause of elevated nitrate and nitrite levels discovered during our sampling, and until the source of contamination is discovered, Mpala should take the necessary precautions to protect their guests, staff and families.

Rainwater Harvesting

It is recommended that Mpala install rainwater harvesting systems at all remote locations such as the homes near the MRC river pump and security outposts. In remote locations where rainwater harvesting systems cannot be installed, such as the mobile bomas and some security outposts, rainwater should be delivered via bowser and household size water filtration systems should be provided.

At MRC, where existing rainwater storage capacity is just over 7% of total capture potential, expansion of rainwater storage could greatly increase the availability of this resource. Due to the high capital cost of increasing rainwater storage capacity, and because the Nanja weirs are expected to meet Mpala's demand, it is recommended that Mpala focus their effort on maintaining their current rainwater harvesting infrastructure rather than expanding it. For gutters to properly channel water into a storage tank they must be clear of debris. Partially or completely blocked gutters do not allow water to flow unimpeded, which can result in overflow and loss of water (Figure 63). Improper connections between rooftop and storage infrastructure also illustrate the need for improved maintenance practices (Figure 64). When rooftop and storage infrastructure are disconnected, water that is captured and could be stored is lost. Between September 2011 and February 2012, some of this infrastructure was improved significantly, most notably the infrastructure at the McCormack Lab, shown in Figure 65. To maximize efficiency of rainwater infrastructure, regular inspection and maintenance must be carried out.

Figure 63: Poorly maintained gutters at MRC, August 2011

Figure 64: Disconnected storage infrastructure at McCormack Lab, August 2011

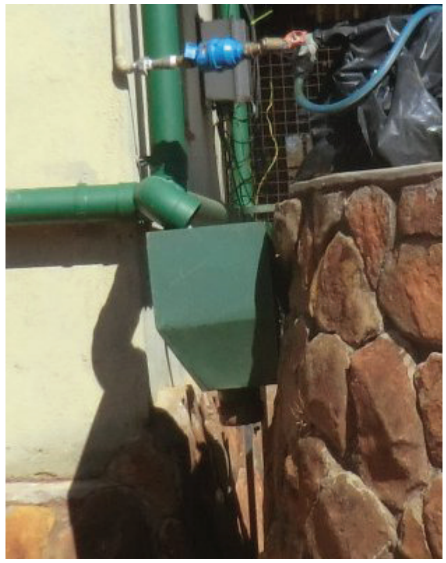


Figure 65: Repaired rainwater harvesting system at McCormack Lab, March 2012

To ensure better water quality of the rainwater as it enters the storage tanks, first flush devices should be installed on all rooftops where rainwater is harvested. It is also recommended that when replacing or building new rainwater storage tanks, they should be constructed with concrete roofs like the Grevy rainwater tank, as opposed to metal roofs like the kitchen rain tank, because metal roofs rust and allow debris to enter. Rainwater harvesting tanks should be cleaned out at least annually before the long rains begin.

Use of Other Water Sources

Ewaso Nyiro River

Challenges associated with relying on river water include significant water quality concerns, extreme fluctuation in flow, and the necessity to co-manage the resource with other users. For these reasons, Mpala should not use river water except for livestock operations such as at the Top Spray Race. Pumping of river water to the MRC should cease, and the Black Tank supplying the village should be repurposed to store rain or weir water.

Borehole

Due to the high fluoride content, dropping level of the aquifer, and the borehole's low recharge rate we recommend that Mpala stop pumping from the borehole entirely, but reserve the capacity to do so. As discussed previously, if Mpala can predict they will run out of water, they can supplement the weir water with borehole water.

Low-Flow Fixture Installation

Installing low-flow fixtures was discussed briefly in the Water Demand section of this report. A more detailed discussion regarding the costs and benefits of installing low-flow fixtures at Mpala can be found in the Antokal et al. (2011) report. In the past, Mpala lacked the expertise to maintain and repair the low flow fixtures, however, in August 2011, Mpala hired a new plumber experienced in working with low-flow fixtures who can conduct the maintenance and repairs needed to keep them functioning. In order to reduce water consumption, it is recommended that Mpala revisit installation of low-flow fixtures.

Behavioral Intervention

Mpala should design and implement a behavioral intervention plan that focuses on promoting water conservation behaviors. The behavioral approach should target guests and researchers, as opposed to villagers, because guests use much more water. This large difference in water use is evident when comparing guest water use at the Banda 7/8 Bathroom, approximately 80 liters/capita/day, with the total water use by villagers, approximately 15 liters/capita/day. Appealing characteristics of behavioral intervention strategies are that they are low-cost, and if done correctly, highly effective in decreasing water use. To be effective, Mpala must implement a multi-faceted plan that is integrated into its core operations. The overarching goal of this behavioral intervention strategy should be to create a culture of awareness and a strong sense of community, which leads to intrinsically motivated and voluntarily adopted behavior changes that reduce water consumption. To increase chances of successfully reducing demand, Mpala should implement most of, if not all the initiatives/actions suggested, rather than just choosing one or two. Also, as the guest population is constantly changing, continual outreach and consistent feedback will be absolutely necessary (McMakin et al., 2002). An effective behavioral intervention program could result in major water savings, but Mpala must be serious about implementing and sustaining the program. In the end, if people don't see that MRC is taking the program and water conservation seriously, neither will they.

Orientation

Guests should be informed about the importance of water conservation immediately upon arrival to Mpala. An ideal time to discuss this is during the orientation that all guests receive when they first arrive. It should be emphasized to the guest that they are now a part of the Mpala community; they should be told that as a member of the community, they have a responsibility to be mindful of their actions and behaviors, particularly in regards to their water use. Guests should also be provided information about water scarcity in the area and specific occurrences of water scarcity at Mpala (e.g. river drying up in 2009); pictures illustrating this can be used as excellent supplemental material. Additionally, it should be explained that when water demand at MRC is high, water from the borehole (or from the weirs once they are completed) must be supplemented with river water, which is extremely dirty and can have a negative impact on one's health (e.g. eye infections from bathing in it). Framing information in terms of how individual health could be impacted should promote the development of conservation behaviors, such as taking shorter showers (Pelletier & Sharp, 2008).

During the orientation, it is important to provide both declarative and procedural knowledge to the guest (Kaiser & Fuhrer, 2003). Declarative knowledge includes information about the water scarcity problem, facts, and data, such as how much water MRC uses each month and how much water could be saved if everyone reduced their shower time. Procedural knowledge is information that will help the guest accomplish what is being asked of them. For instance, they could be told that people use a lot of water while waiting for the shower to heat up, so if they are going to want warm showers they should shower between X time and Y time, since water is solar heated and is more readily available during those times. Another example would be to encourage individuals to bring their own water container to dinner to drink out of, since that would reduce the number of cups that would need to be washed, or to suggest taking showers no longer than 8 minutes. Even though these behavioral changes may only have a small impact on demand reduction, it's extremely important to cultivate this culture of awareness surrounding water scarcity at Mpala.

Voluntary Commitment

Simply providing the guest with information is not enough, however, as evidence shows that information alone is not an effective behavior change strategy (Abrahamse et al., 2005). To enhance effectiveness, it must be paired with other strategies that cultivate conservation behaviors. One such strategy is through the use of commitment. At the end of the orientation, a simple signage sheet could be presented to the guest that, in essence, says, "I agree to be mindful of my water consumption and to reduce the amount of water I use whenever I can." This form ought to be voluntary, but it should involve the person signing their name, as studies have shown that verbal commitments do not have the same lasting effect as written commitments (Schultz et al., 1995).

Goal Setting

Another motivational strategy that has shown to be successful, particularly when paired with other strategies such as those discussed above, is goal setting (Abrahamse et al., 2005). Goal setting is a great way to motivate people towards achievement, and the monthly prediction equations in this report are perfect for setting a water use goal. As Mpala is already using this tool to calculate expected monthly water use for guests, this number could also be posted on the bulletin board in the dining area as the target number to beat, with a title that conveys the message, "let's use less than this much water!"

A critical component of goal setting is to provide guests with consistent and regular feedback about their performance; the longer the delay in providing feedback, the less effective the strategy will be (Boerschig, 1993). On the first day of the month, the goal should be posted on the board, then every week the cumulative water use for the month to that point should be posted next to the goal (#4 Bush Meter measures all water use by guests), so people know how they are doing. Importantly, if there are any major leakages (or construction projects) that occur during the month that raise water use at MRC considerably, then attempts should be made to accurately remove this use/leakage from the feedback values posted on the board. An additional element to this goal/feedback component could be a "Water Savers Wall of Fame," highlighting perhaps the three months in which water reduction was highest at MRC (compared to expected water use). These records could also include the names of all the guests that stayed at MRC during that month.

Social Norms

In considering a behavioral intervention plan, particularly in a small, changing social environment such as Mpala, the concept of norms must be addressed. Norms are social cues that people observe and model on their own, and people tend to conform to the norms most prevalent in the setting they're in. The two types of norms are injunctive norms, involving perceptions of which behaviors are typically approved or disapproved (e.g. people should conserve water), and descriptive norms, involving observations of which behaviors are typically performed (i.e. people engaging in water conservation behaviors). Research indicates that both types of norms motivate human behaviors, and the effect that each has is enhanced when they are in line with, rather than in opposition to, one another (Cialdini, 2003). The focus on water in the orientation, the goals posted, and information displayed about water availability will tell new arrivals that conserving water is something that the community thinks is important (i.e. injunctive norms). Ensuring that the descriptive norms perceived by people are aligned with these injunctive norms can be more difficult. For this alignment to exist, all people living and working at the Centre and River Camp need to be conscientious about their water use. If a pipe breaks, it should be fixed as soon as possible so that water isn't lost. If guests see a pipe leaking water for an extended amount of time, they will perceive that it is acceptable to waste water, despite everyone saying that water conservation is important. The recommendation to install low-flow fixtures also has a role in aligning injunctive and descriptive norms. If people are being told they need to conserve water, but when they flush the toilet they see excessive amounts of water being flushed, it will likely result in the normatively muddled message that wasting water is socially disapproved of, but widespread. In this way, low-flow fixtures can either be a stimulus to the desired behavior changes or a barrier.

Mpala's long-term guests also will carry much weight in establishing water conservation norms. It is critical that they be supportive of the behavioral program and exhibit model water conservation behaviors that new guests can observe and replicate; these long-term guests will have a major influence on the success of this program, so getting their buy-in is essential (they should also receive the water conservation orientation discussed earlier).

Works Cited

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology, 25(3), 273-291.

Airy, M. W. B. (n.d.). Report on water supplies for Mpala Research Centre and Mpala Farm. Unpublished manuscript. Nairobi, Kenya.

Ali, E. N., Muyibi, S. A., Salleh, H. M., Alam, M. Z., & Salleh, M. R. M. (2010). Production of natural coagulant from Moringa oleifera seed for application in treatment of low turbidity water. Journal of Water Resource and Protection, 2, 259-266.

American Public Health Association (APHA), American Water Works Association (AWWA), & Water Environment Federation (WEF). (1992). Standard methods for the examination of water and wastewater. (18th ed.). Washington, DC: American Public Health Association.

American Water Works Association. (2012). IWA/AWWA water audit method. WaterWiser: The Water Efficiency Clearinghouse. Retrieved from http://www.awwa.org/Resources/WaterLossControl. cfm?ItemNumber=48055

Antokal, M., Ryan, C., Seeba, N., & Varadharajan, A. (2011). Building a sustainable community in Africa: Water sustainability at the Mpala Research Centre and Conservancy. University of Michigan, Ann Arbor.

Aquasearch Ltd. (2010). Draft hydrogeological assessment study report; Groundwater conditions in the southern part of Mpala Ranch, Laikipia North District. Nairobi, Kenya: Lane.

Atekwana, E. A., Atekwana, E. A., Rowe, R. S., Werkema Jr., D. D., & Legall, F. D. (2004). The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. Journal of Applied Geophysics, 56(4), 281-294.

Backer, H., & Hollowell, J. (2000). Use of iodine for water disinfection: Iodine toxicity and maximum recommended dose. Environmental Health Perspectives, 108(8), 679-684.

Bartram, J., & Rees, G. (2000). Monitoring bathing waters – A practical guide to the design and implementation of assessments and monitoring programmes. London: WHO.

Berger, P. (1989) Rainfall and agrocilmatology of the Laikipia Plateau, Kenya. In African Studies Series (Vol. A7). Berne, Switzerland: Geographica Bernensia and Geographical Society of Berne.

Boerschig, S. (1993). Feedback Research. Unpublished manuscript.

Cialdini, R. (2003). Crafting normative messages to protect the environment. Current Directions in Psychological Science, 12(4), 105-109.

Cole, M., Easley-Appleyard, C., Holdstein, B., Morris, J., & Opatowski, A. (2012). Evaluating and reducing water consumption at Mpala Research Centre and River Camp. Unpublished manuscript.

Davis, J., & Lambert, R. (2002). Engineering in emergencies: A practical guide for relief workers (2nd ed.). London: ITDG Publishing.

Davis, M. L., & Cornwell, D. A. (1998). Introduction to Environmental Engineering (3rd ed.). Boston, MA: McGraw-Hill.

Dastanaie, A. J., Bidhendi, G. R. N., Nasrabadi, T., Habibi, R., & Hoveidi, H. (2007). Use of horizontal flow roughing filtration in drinking water treatment. International Journal of Environmental Science and Technology, 4(3), 379-382.

Decurtins, S. (1992). Hydrogeographical investigations in the Mount Kenya subcatchment of the Ewaso Ng'iro River. In African Studies Series (Vol. A10). Berne, Switzerland: Geographica Bernensia and Geographical Society of Berne.

Department of Environment and Resource Management. (2011). Guidelines for the preparation of a system leakage management plan: For water service providers (Office of the Water Supply Regulator Publication No. 29384). Queensland, Australia: DERM.

Federation of Canadian Municipalities, & National Research Council (2003). Guide to Sustainable Municipal Infrastructure. Water use and loss in water distribution systems: A best practice by the national guide to sustainable municipal infrastructure. (Issue No.1.0) Canada: Federation of Canadian Municipalities and National Research Council.

Franz, T. E., Caylor, K. K., Nordbotten, J. M., Rodriguez-Iturbe, I., Celia, M. A. (2010). An ecohydrological approach to predicting regional woody species distribution patterns in dryland ecosystems. Advances in Water Resources, 33(2), 215-230.

Franz, T. (2007). Ecohydrology of the Upper Ewaso Ngiro River Basin, Kenya. (Unpublished master's thesis). Princeton University, Princeton, NJ.

International Organization for Standardization (ISO). (2005). ISO 4064-1: Measurement of water flow in fully charged closed conduits – Meters for cold potable water and hot water – Part 1: Specifications (3rd ed.). Switzerland: ISO.

Kaiser, F. & Fuhrer, U. (2003). Ecological behavior's dependence on different forms of knowledge. Applied Psychology, 52(4), 598-613.

Katayon, S., Ng, S. C., Johari, M. M. N. M., & Ghani, L. A. A. (2006). Preservation of coagulation efficiency of Moringa oleifera, a natural coagulant. Biotechnology and Bioprocess Engineering, 11(6), 489-495.

Kayaga, S. (n.d.). Water loss management in distribution systems: An overview [PowerPoint slides]. Retrieved from http://switch.cedare.int/cedare.int/files28/File2280.pdf

Kinnaird, M. (2010a). Social welfare background data V4: Background materials for social welfare contract subcommittee. Unpublished manuscript.

Kinnaird, M. (2010b). From Dr. Kinnaird: Some initial long-range thoughts from Margaret Kinnaird, the executive director. Unpublished manuscript

Meierhofer, R. (2006) Establishing solar water disinfection as a water treatment method at a household level. Madagascar Conservation & Development, 1(1), 25-30.

Ministry of Water and Irrigation. (2005). Practice manual for water supply services in Kenya. Nairobi, Kenya.

Lehtola, M. J., Nissinen, T. K., Miettinen, I. T., Martikainen, P. J., & Vartiainen, T. (2004). Removal of soft deposits from the distribution system improves the drinking water quality. Water Research, 38(3), 601-610.

Leibundgut, C. (1986). Hydrogeographical Map of Mount Kenya Area. In African Studies Series (Vol. A3). Berne, Switzerland: Geographica Bernensia and Geographical Society of Berne.

McMakin, A., Malone, E., & Lundgren, R. (2002). Motivating residents to conserve energy without financial incentives. Environment and Behavior, 34(6), 848-863.

Mihelcic, J. R., Fry, L. M., Myre, E. A., Phillips, L. D., & Barkdoll, B. D. (2009). Field guide to environmental engineering for development workers. Reston, VA: American Society of Civil Engineers.

Mogaka, H., Gichere, S., Davis, R. & Hirji, R. (2006). Climate Variability and Water Resources Degradation in Kenya: Improving Water Resources Development and Management. Washington, D.C.: The World Bank

Moore, M. (1977). Lead in drinking water in soft water areas-health hazards. Science of the Total Environment, 7(2), 109-115.

Mpala Wildlife Foundation & Mpala Research Trust. (2009). Mpala Memos: News from Mpala (July 2009). Retrieved from http://mpala.org/documents/Get_our_Newsletter_11_1265033371.pdf

Nkwonta, O., Olufayo, O., Ochieng, G., Adeyemo, J., & Otieno, F. (2010). Turbidity removal: Gravel and charcoal as roughing filtration media. South African Journal of Science, 106(11/12), 77-81.

Odhiambo, C., Petters, J., & Wreford, K. (n.d.). Water supply and consumption at the Mpala conservancy. Unpublished manuscript.

Ondieki, C. M. (1996). Potential of episodic flows in some four representative non-perennial river flow catchments in semi arid Laikipia district, Kenya. Environmental Monitoring and Assessment, 45(3), 285-299.

Pelletier, L. & Sharp, E. (2008). Persuasive Communication and Proenvironmental Behaviours: How Message Tailoring and Message Framing Can Improve the Integration of Behaviours Through Self-Determined Motivation. Canadian Psychology. 49(3), 210-217.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., & O'Neill, J. G. (2010). A comparison between Moringa oleifera and chemical coagulants in the purification of drinking water – an alternative sustainable solution for developing countries. Physics and Chemistry of the Earth, 35(13/14), 798-805.

Sander, A., Berghult, B., Broo, A. E., Johansson, E. L., & Hedberg, T. (1996). Iron corrosion in drinking water distribution systems—The effect of pH, calcium and hydrogen carbonate. Corrosion Science, 38(3), 443-455.

Sawyer, C. N., McCarty, P. L., & Parkin, G. F. (2003). Chemistry for environmental engineering and science (5th ed.). Boston, MA: McGraw-Hill.

Schultz, P.W., Oskamp, S., & Mainieri, T. (1995). Who recycles and when? A review of personal and situational factors. Journal of Environmental Psychology, 15(2), 105-121.

Sedlak, D.L., & von Gunten, U. (2011). The chlorine dilemma. Science, 331(6013), 42-43.

Shams El Din, A. M. (2009). Three strategies for combating the corrosion of steel pipes carrying desalinated potable water. Desalination, 238(1), 166-173.

Thomas, M. K. & Liniger, H. (1994). Rainfall Summary, Analysis and Trends: Additional Stations of Good Quality in the Upper Ewaso Ng'iro Basin and the Mount Kenya Area. In Laikipia-Mt. Kenya Papers (Vol. B-7). Berne, Switzerland: Institute of Geography at the University of Berne.

UN General Assembly, 64th session. (2010). Resolution 64/292. The human right to water and sanitation.

UN-WATER. (2006). Kenya water report 2005: Water for wealth creation & healthy environment for a working nation (Publication No. UN-WATER/WWAP/2006/12).

USEPA. (2009). National primary drinking water regulations. Retrieved from http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf

USEPA. (2010). Why do water systems add phosphate to drinking water? What are the health effects of drinking water containing phosphates. Retrieved from: http://safewater.supportportal.com/link/portal/23002/23015/Article/24942/Why-do-water-systems-add-phosphate-to-drinking-water-What-are-the-health-effects-of-drinking-water-containing-phosphates

USEPA. (2011). Drinking water pathogens and their indicators: A reference resource. Retrieved from www.epa.gov/enviro/html/icr/gloss_path.html

USEPA. (2012a). 5.8 total solids: What are total solids and why are they important? Retrieved from http://water.epa.gov/type/rsl/monitoring/vms58.cfm

USEPA. (2012b). Basic information about nitrate in drinking water. Retrieved from http://water.epa.gov/drink/contaminants/basicinformation/nitrate.cfm

Walton, N.R.G. (1989). Electrical conductivity and total dissolved solids—What is their precise relationship? Desalination, 72(3), 275-292.

Washington State Department of Health. (2011). Water use efficiency guidebook (3rd ed.). (DOH Publication No. 331-375). Olympia, WA: Office of Drinking Water.

Water Services Regulatory Board (WASREB). (n.d.). Drinking water quality and effluent monitoring guideline. Retrieved June 2012 from http://www.wasreb.go.ke/index.php?option=com_content&task=view&id=73&Itemid=148

World Health Organization. (2011). Guidelines for drinking-water quality (4th ed.). Geneva, Switzerland: WHO.

WHO. (2012). Facts and figures on water quality and health. Retrieved from http://www.who.int/water_sanitation_health/facts_figures/en/

Yaniv, S. (2009). Reduction of apparent losses using the UFR (unmeasured-flow reducer). Retrieved from http://www.arivalves.com/index.php?option=com_zoo&task=item&item_id=223&Itemid=29

Zacheus, O. M., Lehtola, M. J., Korhonen, L. K., & Martikainen, P. J. (2001). Soft deposits, the key site for microbial growth in drinking water distribution networks. Water Research, 35(7), 1757-1765.

Appendices

Appendix 1: Mpala water demand estimates from existing literature

Source	Demand Estimate	Notes
"Report on Water Supplies for Mpala Research Center and Mpala Farm" (Airy, n.d.)	200 l/person/d	Those with baths, flushing toilets, and who wash cars
	20 l/person/d	For labour lines with standpipes and people using communal showers/pit latrines
	28,480 l/d	Consumption of farm (Ranch)
"Water Supply and Consumption at the Mpala Conservancy" (Odhiambo et al., n.d.)	89 l/person/d	Demand for general cleaning (bathing, laundry, washing, etc.)
	8 l/person/d	Amount of clean water required for drinking, brushing teeth, and cooking
	16,910 l/d	Ranch - human consumption
	15,000 l/d	Research centre - human demand
	31,910 l/d	Total human water demand at Mpala
	11,572,150 l/y	River water used by people
	40 l/d	Amount of water consumed by one head of cattle
	140,000 l/d	Livestock water demand
	43,400,000 l	River water needed for livestock during a drought (100 days)
	54,972,150 l/y	Total river water requirement for people and livestock (excludes wildlife)
	400 l/d	Clean water (rainwater) consumption at MRC
	19,000 l/y	Clean water provided to management staff
	1,520 l/d	Rainwater consumption at MRC
	2,560 l/d	Rainwater consumption at Ranch
	4,080 l/d	Total rainwater consumption at Mpala
	1,489,200 l/y	Total rainwater consumption at Mpala
	44,557,200 l/y	Total required for human (e.g. laundry, toilets, washing) and livestock utilization
"Building a Sustainable Community in Africa: Water Sustainability at the Mpala Research Centre and Conservancy" (Anatokal et al., 2011)	30-35 m^3/d	Water drawn from the borehole
	~ 1,000 l/d	Essential water needs of current population at MRC (w/ village)
	8 l/person/d	Essential water needs: 2.5L for drinking; 2.5L for cooking; 3L for laundry/bathing
	50 l/d	Water demand of each head of cattle
	~ 125 m^3/d	Total demand by cattle
	189 l/person/d	Demand by visitors staying at MRC
	20 l/person/d	Demand by center employees
	80 l/person/d	Demand by visitors staying at River Camp
	75 l/person/d	Demand at the Centre village
"Hydrogeological Assessment Study Report: Groundwater Conditions in the Southern Part of Mpala Ranch, Laikipia North District" (Aquasearch Ltd, 2010)	30.3 m^3/d	Total ranch human domestic water demand
	15.35 m^3/d	Total centre human water demand
	~50 m^3/d	Maximum domestic water demand for both MRC & Ranch
	50 l/d	Cattle per capita water demand
	125 m^3/d	Maximum daily livestock water demand
	40 m^3/d	Water used for irrigation

Appendix 2: Mpala water meter information

Meter Number	Meter Name	Meter Size (in)	Water Source(s)
-	Borehole Pump	1 1/2"	Borehole
Mpala Research Center Meters			
1	Tank 4	1"	Borehole
2	Black Tank	1/2"	River
3	Village	3/4"	River/Borehole
4	Bush Meter	3"	River/Borehole
5	Margaret	3/4"	River/Borehole
6	Garage/Bandas	3/4"	River/Borehole
7	Kitchen Filter	3/4"	River/Borehole
8	Kitchen Hot	3/4"	River/Borehole
9	Princeton Dorm	3/4"	River/Borehole
10	River Camp	1"	River/Borehole
11	Klee/Heathrow	3/4"	River/Borehole
12	Bathroom Hot	3/4"	River/Borehole
13	Bathroom Cold	3/4"	River/Borehole
14	Lab	1"	River/Borehole/Rainwater
15	Guest Toilet	3/4"	River/Borehole
Mpala Ranch Meters			
1	Garden	2"	Weirs/River
2	Workshop/Clinic	1 1/2"	Weirs/River
3	Nanja into Village Tank	1 1/2"	Weirs/River
4	Gabriel	1"	Weirs/River
5	Village	3/4"	Weirs/River
6	Main House Tank	1"	Weirs/River
7	River into Village Tank	2"	Weirs/River
-	Field (Borehole)	1"	Borehole
-	Ranch (River)	3"	River
-	Nanja	1 1/2"	Weirs

Appendix 3: Major storage tanks at Mpala

Name/Number	Storage Capacity (m^3)
Tank 1: Borehole	$50m^3$
Tank 2: Borehole	$50m^3$
Tank 3: Break Pressure Tank	$10m^3$
Tank 4: MRC Tank	$25m^3$
Tank 5: MRC Tank	$12m^3$
MRC Village Black Tank	$12m^3$
Ranch Village Tank	$30m^3$
Ranch House Tank	$25m^3$
River Camp Tank	$10m^3$
Top Spray Race Tank	$100m^3$

Appendix 4: Example of bednight records (October 2011)

BANDAS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL
1	1	1	1	1	1	1	1		1	1	1	1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	27
2																						1	1	1	1	1	1	1	1			8
3	1	1	1	1	1	1	1	1	1																							9
3															1	1	1	1														4
3																										1	1	1		1		4
4			1																													1
4						5																										5
4																	1	1	1	1												4
4																															2	2
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											21
5																										1	1	1	1	1	1	6
5																																0
6			1	1																												2
6																											1	1				2
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
8										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			60
9	1	1	1	1	1	1											1	1	1	1	1											11
9																											1	1	1	1	1	5
10																											1	1	1	1	1	5
10	1	1	1	1	1	1											1	1	1	1												10
11	1	1	1	1	1	1											1	1	1	1	1											11
11																											1	1	1	1	1	5
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
12	1																															1
12	1																															1
12	1																															1
12	1																															1
12																						1	1						1	1	1	5
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1	1	1	1	1	1	1	1	1	1	1	1	26
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1	1	1	28
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
13	1											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					17
13																											1	1		1	1	4
13																														1	1	2
13																																0
13																																0
Princ. Dorm																																0
14	1	1	1	1	1	1											1	1	1	1	1											11
14																											1	1				2
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
16																											2	2	2	2	2	10
16	1	1	1	1	1	1											1	1	1	1												10
16	1	1	1	1	1	1											1	1	1	1												10
17																											2	2	2	2	2	10
17	1	1	1	1	1	1											1	1	1	1												10
17	1	1	1	1	1	1											1	1	1	1												10
18	1	1	1	1	1	1											1	1	1	1												10
18	1	1	1	1	1	1											1	1	1	1												10
19			1	1	1					1	1	1	1	1			1	1							1	1	1					13
JENGA	1	1	1	1	1	1																										6
JENGA	1	1	1	1	1	1																										6
JENGA															3	3	3	3														12
JENGA																										1	1	1	1	1	1	6
CAMPSITE	16	16	16	16	16	16				16	16	16	17	17	17	17	17	17														246
CAMPSITE																					18	18	18	18	18							90
DIRECTOR	2	2	2	2								1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	2	3	2	2	2	38
Grevy	2	2	2	2	2	2											2	2	2	2	1											21
Klee																											2	2		2	2	8
Klee	2	2	2	2	2	2											2	2	2	2	2											22
Wild Dog	2	2	2	2	2	2											2	2	2	2	1											21
Wild Dog																											2	2	2	2	2	10
Heathrow	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	89
	56	51	52	51	50	54	15	14	15	34	34	36	36	36	38	40	58	58	36	36	44	38	38	37	38	22	37	36	31	32	33	1186

Appendix 5: MRC meter readings (m^3)

Month	Week	Date	#1 Tank 4	#2 Black Tank	#3 Village	#4 Bush Meter	#5 Margaret	#6 Garage & Bandas	#7 Kitchen Filter	#8 Kitchen Hot	#9 Princeton Dorm	#10 River Camp	#11 Klee & Heathrow	#12 Bathroom Hot	#13 Bathroom Cold	#14 Lab	#15 Guest Toilet
8	35	8/27/11	-	-	-	-	0.005	0	0.0055	-	-	-	-	-	-	-	-
8	36	8/28/11	-	0.362	-	-	0.22	-	1.21	-	0	0.5497	-	-	-	-	0.0095
8	36	8/29/11	85.17	0.62	5.83	107.35	0.44	1.04	2.42	0.012	0.7	0.5597	0.0061	0.01	0.019	0.35	0.16
8	36	8/30/11	85.18	1.8255	11.4303	128.693	1.058	2.81	5.859	0.012	1.9431	0.6864	1.0561	0.01	0.0425	0.35	0.8203
8	36	8/31/11	106.197	2.0488	13.9855	135.2905	1.2791	3.4	7.3196	0.04	2.2294	0.7558	1.6695	0.01	0.452	0.35	1.1176
9	36	9/1/11	120.09	2.5	15.51	139.04	2.26	3.96	7.91	0.04	4.32	0.87	2.6	0.01	0.626	0.35	1.47
9	36	9/2/11	140.8	2.58	19.11	159.2	2.71	5.7	10.61	0.04	4.32	0.87	3.53	0.01	0.8	0.35	1.82
9	36	9/3/11	149.98	2.83	20.39	162.37	3.17	6.19	11.15	0.04	6.52	0.87	3.81	0.01	0.81	0.35	2
9	37	9/4/11	173	3.04	25.05	170.67	3.62	7.38	12.95	0.4	7.74	0.9	4.01	0.06	0.9	0.35	2.15
9	37	9/5/11	177.92	3.25	27.65	179.23	4.08	8.57	14.06	0.43	8.15	1.01	5.05	0.08	0.92	0.35	2.39
9	37	9/6/11	190.62	3.45	30.02	186.48	4.53	9.42	15.67	0.45	9.31	1.09	5.6	0.08	0.93	0.35	2.6
9	37	9/7/11	201.86	3.58	32.66	193.84	4.99	10.1	16.93	0.48	10.03	1.17	6.31	0.08	1.13	0.35	2.86
9	37	9/8/11	213.87	4.2	33.95	201	5.47	11.39	18.72	0.5	10.95	1.26	6.8	0.08	1.18	0.35	3.17
9	37	9/9/11	233.22	4.33	35.25	218.86	5.79	12.05	20.1	0.52	11.66	1.35	7.33	0.08	1.24	0.35	3.57
9	37	9/10/11	254.75	4.45	36.93	236.2	6.18	13	21.39	0.8	12.44	1.42	7.74	0.08	1.33	0.35	3.86
9	38	9/11/11	277.64	4.59	40.04	254	6.18	14.43	22.61	1.18	13.21	1.49	8.2	0.08	1.37	0.35	4.14
9	38	9/12/11	298.21	4.75	42.69	271.83	7.18	15.21	23.71	1.49	14.2	1.58	8.76	0.08	1.42	0.35	4.26
9	38	9/13/11	316.25	4.81	44.18	286.07	7.41	17.51	25.01	1.88	14.84	1.75	9.46	0.08	1.94	0.35	4.62
9	38	9/14/11	334.85	4.91	47.09	298.75	8.27	18.93	26.46	2.32	15.75	1.88	10.06	0.09	2	0.35	4.93
9	38	9/15/11	346.85	5.29	48.66	306.39	8.57	19.91	27.78	2.74	16.58	1.97	10.6	0.09	2.05	0.76	5.16
9	38	9/16/11	361.1	5.38	49.97	319.98	8.82	20.99	29.1	3.3	17.54	2.07	11.1	0.29	2.1	0.76	5.49
9	38	9/17/11	381.03	6.29	54.07	331	9.61	27.73	30.94	3.83	18.36	2.16	11.61	0.3	2.16	0.76	5.78
9	39	9/18/11	404.79	6.67	57.17	341.6	9.97	29.55	32.25	4.15	19.17	2.63	11.99	0.32	2.21	0.76	5.99
9	39	9/19/11	419.64	7.04	60.22	352.31	10.79	30.39	33.56	4.74	20.27	5.21	12.66	0.43	2.27	0.76	6.21
9	39	9/20/11	439.84	7.61	63.11	375.52	11.12	31.13	35.23	5.46	21.08	5.63	13.2	0.51	2.33	0.76	6.49
9	39	9/21/11	453.57	8.36	65.27	383.74	11.41	31.77	36.61	6.08	22.25	6.84	13.82	0.52	2.43	0.76	6.72
9	39	9/22/11	467.43	10.47	68.46	403.5	12.13	33.36	37.89	6.66	23.05	7.31	14.3	0.53	2.47	0.76	6.78
9	39	9/23/11	487.98	10.83	71.01	421.39	12.46	33.93	38.91	7.17	24	14.75	14.79	0.53	2.51	0.76	7.21
9	39	9/24/11	504.67	11.37	74.23	433.49	13.33	35.12	40.16	7.7	25.11	17.4	15.4	0.53	2.55	0.76	7.55
9	40	9/25/11	519.01	11.58	78.2	440.32	13.58	36.02	41.17	8.12	26.09	18.19	16.13	0.54	2.6	0.76	7.8
9	40	9/26/11	532.41	11.78	78.34	447.21	13.91	36.91	42.19	8.51	27.2	18.84	16.59	0.55	2.62	0.76	7.93
9	40	9/27/11	550.71	12.03	83.73	461.08	14.71	37.26	43.17	9.08	28.41	25.2	17.19	0.57	2.69	0.76	8.27
9	40	9/28/11	567.53	12.43	86.87	471.63	14.88	37.57	44.35	9.49	29.48	27.65	17.77	0.57	2.71	0.76	8.62
9	40	9/29/11	584.83	13.25	89.45	484.76	15.74	38.61	45.44	9.9	30.55	32.6	18.53	0.58	2.74	0.76	11
9	40	9/30/11	599.68	13.98	92.07	493.1	16.07	39.22	46.81	10.69	31.76	34.07	18.87	0.58	2.78	0.76	11.39
10	40	10/1/11	622.38	14.53	95.04	512.71	16.92	40.97	48.18	11.41	32.58	40.92	19.16	0.58	2.82	0.76	11.86
10	41	10/2/11	647.045	15.035	98.5	531.455	17.215	41.275	49.52	12.075	34.06	52.12	19.69	0.6	2.935	0.76	11.885
10	41	10/3/11	671.71	15.54	101.96	550.2	17.51	41.58	50.86	12.74	35.54	63.32	20.22	0.62	3.05	0.76	11.91
10	41	10/4/11	691.91	15.98	104.97	573.05	18.41	42.97	52.65	13.59	37.02	75.75	20.92	0.66	3.08	0.76	12.18
10	41	10/5/11	723.26	16.41	108	594.45	18.69	44.01	54.38	13.9	38.22	86.84	21.35	0.72	3.17	0.76	12.44
10	41	10/6/11	749.07	17.02	110.41	619.8	18.93	44.52	55.91	14.65	39.49	104.25	22.05	0.75	3.2	0.76	12.99
10	41	10/7/11	774.88	17.57	112.7	649.41	19.59	45.65	57.01	15.4	40.57	124.95	22.63	0.75	3.21	0.76	13.55
10	41	10/8/11	800.82	18.16	114.86	685.85	19.6	45.87	58.61	16.07	41.01	141.12	23.04	0.86	3.26	0.76	13.85
10	42	10/9/11	819.32	18.7	118.41	729.02	19.6	46.33	59.77	16.51	41.2	146.65	23.3	0.86	3.3	0.76	14.05
10	42	10/10/11	843.4	19.07	120.77	744.98	19.61	46.57	60.33	16.72	41.57	146.68	23.62	0.86	3.3	0.76	14.2
10	42	10/11/11	868.19	19.6	123.29	758.29	20	46.8	61.33	17.72	42.05	156.12	24.04	0.86	3.57	0.76	14.48
10	42	10/12/11	892.94	20.2	125.59	772.85	20	47.53	62.22	18.81	42.74	163.11	24.47	0.86	4.23	0.76	14.88
10	42	10/13/11	918.99	20.52	129.41	783.41	20.79	49.01	62.97	19.59	43.5	166.47	24.8	0.86	4.78	0.76	15.17
10	42	10/14/11	945.14	20.83	130.78	793.99	21.03	49.27	63.71	20.37	44.11	169.74	25.32	0.86	5.22	0.76	15.57
10	42	10/15/11	969.95	21.08	133.77	807.08	21.23	49.5	64.43	21.63	44.89	177.52	25.78	1.33	5.44	0.76	16.06
10	43	10/16/11	995.435	21.325	136.42	818.41	21.735	50.295	65.06	22.51	45.425	182.375	26.07	1.49	5.69	0.76	16.34
10	43	10/17/11	1020.92	21.57	139.07	829.74	22.24	51.09	65.69	23.39	45.96	187.23	26.36	1.65	5.94	0.76	16.62
10	43	10/18/11	1047.1	21.57	141.3	845.42	22.85	52.94	66.52	24.24	47.45	193.23	26.76	1.81	6.16	0.76	17.07
10	43	10/19/11	1071.86	21.57	143.68	859.88	23.35	53.89	67.37	25.34	48.47	202.49	27.25	1.97	6.27	0.76	17.63

Month	Week	Date	#1 Tank 4	#2 Black Tank	#3 Village	#4 Bush Meter	#5 Margaret	#6 Garage & Bandas	#7 Kitchen Filter	#8 Kitchen Hot	#9 Princeton Dorm	#10 River Camp	#11 Klee & Heathrow	#12 Bathroom Hot	#13 Bathroom Cold	#14 Lab	#15 Guest Toilet
10	43	10/20/11	1097.57	21.57	146.195	870.285	23.78	54.74	68.27	26.48	49.46	204.89	27.55	2.1	6.49	0.76	18.27
10	43	10/21/11	1123.28	21.57	148.71	880.69	24.21	55.59	69.17	27.62	50.45	207.29	27.85	2.23	6.71	0.76	18.91
10	43	10/22/11	1148.5	21.63	150.64	890.01	24.64	55.96	70.1	28.56	51.73	210.04	28.72	2.38	6.91	0.76	19.29
10	44	10/23/11	1173.01	21.82	154.34	900.11	24.83	56.8	71.03	29.525	52.425	213.545	29.1	2.52	7.085	0.76	19.85
10	44	10/24/11	1197.52	22.01	158.04	910.21	25.02	57.64	71.96	30.49	53.12	217.05	29.48	2.66	7.26	0.76	20.41
10	44	10/25/11	1220.28	22.14	160.49	921.82	25.97	58.62	72.61	31.48	53.88	220.18	30	2.82	7.43	0.76	20.87
10	44	10/26/11	1244.9	22.26	162.68	934.32	26.18	59.98	73.3	32.43	54.41	225.76	30.35	2.91	7.65	0.76	21.42
10	44	10/27/11	1267.13	22.5	165.55	944.56	26.96	60.86	73.82	33.39	55	228.19	30.74	2.95	7.81	0.76	21.96
10	44	10/28/11	1286.92	22.69	168.1	951.13	27.27	61.17	74.46	34.58	56.01	228.74	31.22	3.02	7.98	0.76	22.25
10	44	10/29/11	1306.66	23.06	169.88	956.39	27.6	61.42	75.19	35.47	57	228.74	31.65	3.13	8.1	0.76	22.56
10	45	10/30/11	1326.67	23.13	172.71	965.17	28.37	62.09	76.20	36.22	58.47	228.93	32.09	3.16	8.22	0.76	22.87
10	45	10/31/11	1347.1	23.19	175.55	973.95	29.14	62.75	77.22	36.98	59.95	229.13	32.54	3.18	8.34	0.76	23.19
11	45	11/1/11	1367.53	23.26	178.38	982.73	29.91	63.42	78.23	37.73	61.42	229.32	32.98	3.21	8.46	0.76	23.5
11	45	11/2/11	1386.08	23.27	180.4	987.28	30.34	63.87	79.32	38.49	62.45	229.4	33.59	3.21	8.46	0.76	23.9
11	45	11/3/11	1402.37	23.3	182.14	992.16	30.69	65.37	80.04	39.03	62.89	229.43	34.07	3.21	8.51	0.76	24.41
11	45	11/4/11	1421.55	23.31	184.29	1001.78	31.04	66.1	81.24	39.54	63.93	229.44	34.32	3.21	8.54	0.76	24.59
11	45	11/5/11	1440.01	23.33	187.26	1006.15	31.38	66.55	82.51	40	64.74	229.46	34.86	3.21	8.54	0.76	24.94
11	46	11/6/11	1449.82	23.46	189.59	1011.54	31.78	66.91	83.38	40.55	65.5	229.88	35.22	3.21	8.54	0.76	25.05
11	46	11/7/11	1455.63	23.59	191.92	1015.25	32.05	67.05	83.63	40.71	66.26	230.31	35.57	3.22	8.56	0.76	25.27
11	46	11/8/11	1464.51	23.67	194.96	1022.44	32.57	68.05	84.6	41.22	66.96	230.34	35.98	3.22	8.61	0.76	25.54
11	46	11/9/11	1471.08	23.84	197.24	1027.49	33.03	68.21	85.72	41.45	67.6	231.02	36.72	3.22	8.63	0.76	25.86
11	46	11/10/11	1486.94	24.24	199.67	1034.95	33.14	68.62	86.78	41.81	68.25	231.97	37.19	3.23	8.74	0.76	26.04
11	46	11/11/11	1494.12	24.49	201.74	1043.29	33.45	70.23	88.23	42.34	68.98	233.46	37.54	3.33	8.89	0.76	26.48
11	46	11/12/11	1506.49	24.99	204.79	1052.54	33.75	71.01	89.37	42.84	69.53	233.83	38.04	3.44	9.05	0.76	26.93
11	47	11/13/11	1523.74	25.36	206.8	1057.85	33.94	71.21	90.19	43.44	70.05	234.54	38.29	3.54	9.22	0.76	27.22
11	47	11/14/11	1542.95	26.03	210	1064.94	34.11	71.63	91.52	43.98	70.75	234.54	38.64	3.63	9.45	0.76	27.49
11	47	11/15/11	1561.85	26.17	212.44	1070.5	34.31	71.77	92.56	44.54	71.29	234.54	38.74	3.77	9.62	0.76	27.87
11	47	11/16/11	1577.23	26.91	215.84	1077.84	34.64	72.76	93.34	44.89	72.18	234.56	39.28	3.87	9.77	0.76	28.22
11	47	11/17/11	1590.01	27.43	218.24	1083.47	34.86	73.16	94.32	45.21	72.86	235.12	39.87	4.01	9.89	0.76	28.45
11	47	11/18/11	1602.76	27.83	220.29	1090	35.21	73.86	95.18	45.56	73.88	235.51	40.12	4.15	10.08	0.76	28.73
11	47	11/19/11	1614.46	28.45	223.38	1097.23	35.92	74.07	96.01	46.14	74.78	235.76	40.56	4.27	10.31	0.76	29.1
11	48	11/20/11	1632.85	29.14	227.4	1108.72	36.22	74.39	96.89	46.5	75.54	241.05	40.74	4.27	10.44	0.76	29.24
11	48	11/21/11	1645.13	29.6	231.03	1113.25	36.54	74.6	97.87	46.92	76.18	241.32	41.1	4.27	10.75	0.76	29.39
11	48	11/22/11	1663.59	30.48	234.64	1125.21	40.56	74.77	99.02	47.37	76.94	241.48	41.51	4.27	11.12	0.76	29.6
11	48	11/23/11	1682.07	31.06	237.6	1136.32	40.81	75	99.84	47.75	77.48	241.49	41.71	4.53	11.29	0.76	29.85
11	48	11/24/11	1699.28	31.45	240.47	1142.48	41.12	75.22	100.83	48.13	78.22	241.49	42.43	4.62	11.45	0.76	30.17
11	48	11/25/11	1715.81	31.81	241.82	1150.79	41.36	75.87	101.83	48.63	78.84	241.5	42.58	4.79	11.62	1.11	30.47
11	48	11/26/11	1729.63	32.27	245.11	1157.27	41.55	76.63	102.55	49.02	79.55	241.51	42.85	4.85	11.75	1.15	30.47
11	49	11/27/11	1739.45	32.27	246.4	1163.37	41.86	76.89	103.16	49.29	80.19	241.51	43.02	4.99	12.1	1.19	31.15
11	49	11/28/11	1752.45	32.59	249.65	1171.43	42.04	78.43	104.14	49.72	80.91	241.51	43.47	5.12	12.29	1.25	31.31
11	49	11/29/11	1759.36	33.12	250.83	1178.84	42.24	79.47	105.06	50.22	81.98	241.51	43.98	5.27	12.53	1.29	31.56
11	49	11/30/11	1773.73	33.59	252.63	1207.33	42.32	79.8	106.08	50.95	82.59	241.51	44.18	5.4	12.75	1.29	31.93
12	49	12/1/11	1791.48	33.67	254.21	1212.22	42.62	80.08	106.64	50.99	83.12	241.51	44.21	5.58	12.91	1.43	32.25
12	49	12/2/11	1811.75	33.93	256.12	1226.86	42.78	81.22	107.56	51.36	83.88	241.51	44.53	5.66	13.12	1.43	32.68
12	49	12/3/11	1819.4	34.31	257.69	1233.09	43.05	81.45	108.36	51.98	84.58	241.51	44.65	5.82	13.36	1.57	32.95
12	50	12/4/11	1827.69	34.54	259.44	1237.48	43.16	82.01	108.92	52.37	84.87	241.51	44.66	5.89	13.38	1.61	33.09
12	50	12/5/11	1836.72	34.82	261.79	1251.14	43.26	83.19	109.68	52.83	85.54	241.73	44.73	6.1	13.62	1.66	33.32
12	50	12/6/11	1838.96	35.51	263.93	1257.33	43.43	83.48	110.72	53.32	86.31	241.76	44.76	6.25	13.88	1.72	33.52
12	50	12/7/11	1853.23	35.98	266.06	1263.42	43.69	83.87	111.61	53.76	87.24	241.93	44.76	6.37	14.08	1.74	33.73
12	50	12/8/11	1864.38	36.26	267.86	1268.86	43.96	83.97	112.38	54.36	88.96	241.96	44.78	6.47	14.25	1.79	33.97

***Highlighted cells indicate an estimated value because no meter reading was recorded**

Month	Week	Date	#1 Tank 4	#2 Black Tank	#3 Village	#4 Bush Meter	#5 Margaret	#6 Garage & Bandas	#7 Kitchen Filter	#8 Kitchen Hot	#9 Princeton Dorm	#10 River Camp	#11 Klee & Heathrow	#12 Bathroom Hot	#13 Bathroom Cold	#14 Lab	#15 Guest Toilet
12	50	12/9/11	1874.58	36.57	270.75	1273.49	44.36	84.84	112.99	54.69	89.86	241.99	44.78	6.62	14.42	1.81	34.22
12	50	12/10/11	1884.78	36.82	273.49	1278.64	44.7	85.62	114.17	55.09	90.7	242.02	44.78	6.75	14.56	1.86	34.39
12	51	12/11/11	1895.61	37.68	276.91	1283.08	45.44	86.32	114.91	55.63	91.62	242.06	44.78	6.88	14.7	1.86	34.52
12	51	12/12/11	1902.73	38.04	279.73	1287.35	45.59	86.72	115.54	55.98	92.31	242.07	44.79	7.01	14.87	1.94	34.62
12	51	12/13/11	1914.83	38.43	281.05	1293.47	45.81	87.09	116.01	56.41	93.09	244.54	44.79	7.18	15.09	2.03	34.76
12	51	12/14/11	1927.73	38.92	285.21	1299.43	46.72	87.49	116.81	57	93.75	245.12	44.79	7.18	15.1	2.15	34.98
12	51	12/15/11	1939.13	39.28	287.93	1306.74	47.36	88.57	117.65	57.48	94.56	246.08	44.96	7.18	15.13	2.25	35.18
12	51	12/16/11	1951.81	39.97	291.09	1312.49	47.55	89.05	118.61	58.02	95.33	247.31	45.01	7.2	15.14	2.33	35.54
12	51	12/17/11	1964.68	40.86	293.87	1320.01	48.23	89.58	119.65	58.72	95.9	248.45	45.33	7.2	15.18	2.39	35.77
12	52	12/18/11	1978.15	41.55	296.16	1329.87	48.59	90.44	120.64	59.3	96.54	250.87	45.65	7.2	15.2	2.39	35.9
12	52	12/19/11	1988.42	42.3	299.24	1332.46	48.83	90.89	121.15	59.62	96.98	251.76	45.67	7.2	15.22	2.52	35.91
12	52	12/20/11	1997.96	43.04	301.24	1337.31	49.43	91.43	122.01	60.11	97.43	252.66	45.76	7.2	15.23	2.59	36.18
12	52	12/21/11	2010.08	43.91	304.39	1344.67	49.78	92.41	122.55	60.43	97.95	253.51	46.09	7.2	15.25	2.66	36.42
12	52	12/22/11	2026.54	44.72	308.78	1354.13	49.97	93.26	123.03	60.86	98.39	254.22	46.39	7.2	15.26	2.75	36.58
12	52	12/23/11	2043.11	44.87	313.52	1363.52	50.79	94.34	123.71	61.21	99.05	255.22	46.75	7.2	15.28	2.75	36.87
12	52	12/24/11	2053.49	44.87	320.02	1363.52	51.13	95.14	124.38	61.5	99.68	255.93	47.11	7.2	15.29	2.75	37.04
12	53	12/25/11	2079.8	44.87	330.07	1366.14	51.43	95.14	124.93	61.76	102.87	257.05	47.4	7.2	15.32	2.75	37.11
12	53	12/26/11	2086.14	44.87	339.17	1383.87	51.87	96.47	125.16	62.02	104.31	257.26	47.64	7.2	15.34	2.8	37.52
12	53	12/27/11	2104.36	44.87	354.38	1393.45	52.31	97.25	125.82	62.39	108.86	258.34	47.89	7.2	15.37	2.83	37.75
12	53	12/28/11	2121.47	44.87	358.55	1402.28	52.63	98.63	126.43	62.81	112.66	259.3	48.22	7.2	15.38	2.91	37.86
12	53	12/29/11	2138.52	44.87	361.26	1409.86	53.41	99.6	127.01	63.14	114.15	260.09	48.29	7.2	15.38	2.96	38
12	53	12/30/11	2155.55	44.87	363.78	1416.79	53.41	100.55	127.55	63.47	115.01	261.19	48.29	7.2	15.53	3.08	38.24
12	53	12/31/11	2172.37	44.87	367.72	1423.03	54.14	101.74	128.05	64.29	115.94	262.12	48.37	7.2	15.53	3.11	38.44
1	1	1/1/12	2189.1	44.87	370.71	1434.52	54.95	102.72	128.87	64.94	117.33	266.66	48.5	7.2	15.53	3.11	38.59
1	1	1/2/12	2204.76	45.85	373.02	1440.91	55.19	103.45	129.41	65.28	119.33	267.76	48.5	7.2	15.55	3.16	38.73
1	1	1/3/12	2221.45	47.08	377.35	1451.73	55.88	104.75	130.2	65.82	121.33	270.06	48.76	7.2	15.57	3.19	38.85
1	1	1/4/12	2238.61	-	381.34	1464.97	56.28	106.15	130.89	66.25	123.23	275.3	48.81	7.27	15.62	3.23	39.11
1	1	1/5/12	2255.6	-	383.8	1483.49	57.66	106.99	131.77	66.66	125.39	279.36	49.06	7.35	15.77	3.28	39.3
1	1	1/6/12	2272.48	-	387.17	1497.34	58	108.41	132.37	67.28	127.22	281.68	49.31	7.46	15.98	3.32	39.63
1	1	1/7/12	2289.43	-	391.25	1517.08	58.89	109.39	133.68	68.6	132.84	282.83	49.59	7.53	16.31	3.4	40.3
1	2	1/8/12	2306.64	-	392.87	1538.45	59.05	110.99	134.94	69.12	135.68	284.28	49.81	7.55	16.55	3.4	41.05
1	2	1/9/12	2323.32	-	395.03	1545	59.78	112.08	136.18	70.43	136.84	285.49	50.1	7.77	16.88	3.44	41.77
1	2	1/10/12	2340.15	-	396.55	1567.74	60.96	113.05	137.48	71.57	137.86	294.54	50.56	7.92	17.04	3.49	42.71
1	2	1/11/12	2356.91	-	399.91	1584.79	61.78	113.85	138.59	73.06	139.14	299.35	50.78	8.07	17.25	3.56	43.53
1	2	1/12/12	2373.81	-	404.03	1602.91	62.93	114.72	140.14	73.94	140.31	302.95	51.04	8.21	17.4	3.66	44.63
1	2	1/13/12	2390.51	-	404.72	1618.51	63.67	115.59	141.58	75.34	141.59	305.54	51.55	8.34	17.64	3.74	45.39
1	2	1/14/12	2407.23	-	406.98	1639.46	64.49	116.14	143.25	77.25	142.77	308.48	52.19	8.47	17.84	3.81	46.45
1	3	1/15/12	2423.68	-	409.18	1683.87	65.11	116.56	144.66	79.43	144.02	312.96	52.77	8.59	18.02	3.81	46.87
1	3	1/16/12	2440.13	-	411.38	1728.27	65.72	116.98	146.08	81.62	145.27	317.44	53.35	8.71	18.2	3.9	47.29
1	3	1/17/12	2458.38	-	414.36	1826.72	66.57	117.8	147.97	82.87	146.76	319.9	53.99	8.82	18.38	4.05	47.96
1	3	1/18/12	2476.92	-	416.12	1962.24	67.54	119.27	149.65	83.56	148.18	322.48	54.13	8.87	18.61	4.15	48.51
1	3	1/19/12	2495.51	-	419.02	2043.37	68.11	119.65	151.33	84.38	149.75	328.25	55.31	8.98	18.78	4.23	49.13
1	3	1/20/12	2514.11	-	421.7	2060.74	69.27	120.3	153.02	84.94	151.04	330.8	55.9	9.12	18.95	4.31	49.95
1	3	1/21/12	2532.73	-	424.19	2074.77	69.83	120.97	154.72	85.65	152.32	331.73	56.58	9.25	19.1	4.37	50.6
1	4	1/22/12	2551.95	-	427.76	2092.16	70.32	122.19	156.49	86.15	153.62	332.2	57.17	9.38	19.1	4.37	51.16
1	4	1/23/12	2570.02	-	430.62	2104.34	71.23	122.99	158.25	87.11	155.28	333.92	57.91	9.53	19.47	4.43	52.28
1	4	1/24/12	2588.51	-	433.25	2117.52	72.31	123.68	159.94	87.41	156.56	334.74	58.54	9.66	19.6	4.5	52.49
1	4	1/25/12	2606.92	-	436.49	2131.26	73.03	125.56	161.64	88.52	158.17	334.8	59.09	9.78	19.74	4.55	53.64
1	4	1/26/12	2625.59	-	438.88	2143.75	74.33	126.26	163.43	89.38	159.09	334.84	60.29	9.82	19.78	4.63	54.31
1	4	1/27/12	2644.46	-	442.62	2156.62	75.46	127.49	164.91	89.98	159.77	334.86	61.12	9.82	19.83	4.66	56.38
1	4	1/28/12	2668.42	-	445.17	2163.41	76.21	128.04	165.94	90.57	160.28	334.88	61.54	9.82	19.84	4.71	56.68
1	5	1/29/12	2686.1	-	448.66	2170.81	77.03	128.83	166.74	91.01	161.04	334.88	61.86	9.82	19.86	4.75	56.87
1	5	1/30/12	2703.79	-	452.16	2178.21	77.85	129.61	167.54	91.45	161.79	334.89	62.17	9.82	19.89	4.78	57.07
1	5	1/31/12	2718	-	455.3	2188.33	78.95	130.57	168.92	92.04	162.57	334.9	62.51	9.86	19.96	4.85	58.08
2	5	2/1/12	2735.11	-	458.55	2198.26	79.41	132.21	170.01	92.66	163.18	334.9	63.11	9.9	20.03	4.89	58.91
2	5	2/2/12	2755.9	-	461.91	2216.45	80.46	133.48	171.13	93.18	163.9	334.9	63.97	10.02	20.11	4.94	59.18
2	5	2/3/12	2772.84	-	464.61	2233.47	80.8	134.16	172.17	93.78	164.52	352.06	64.45	10.08	20.15	4.97	59.63

Month	Week	Date	#1 Tank 4	#2 Black Tank	#3 Village	#4 Bush Meter	#5 Margaret	#6 Garage & Bandas	#7 Kitchen Filter	#8 Kitchen Hot	#9 Princeton Dorm	#10 River Camp	#11 Klee & Heathrow	#12 Bathroom Hot	#13 Bathroom Cold	#14 Lab	#15 Guest Toilet
2	5	2/4/12	2792.06	-	467.65	2247.91	81.33	135.05	173.31	94.42	165.44	358.98	64.96	10.23	20.41	5	60.05
2	6	2/5/12	2806.39	-	471.1	2256.29	82.06	136.09	174.35	94.88	165.94	360.54	65.43	10.39	20.61	5.06	60.22
2	6	2/6/12	2820.72	-	474.54	2264.67	82.8	137.12	175.39	95.34	166.44	362.11	65.9	10.56	20.8	5.12	60.39
2	6	2/7/12	2834.3	-	476.64	2273.92	83.99	138.85	176.23	95.45	167.27	362.7	66.36	10.7	20.94	5.21	60.8
2	6	2/8/12	2849.52	-	479.93	2283.26	84.52	141.63	177.26	96.41	168.02	363.65	66.67	10.82	21.18	5.24	61.22
2	6	2/9/12	2866.37	-	482.5	2295.84	84.93	143.12	178.19	96.65	168.45	369.01	67	10.91	21.32	5.27	61.83
2	6	2/10/12	2880.88	-	484.63	2306.67	86.12	145.08	179.66	97.42	168.9	370.8	67.42	11.01	21.43	5.34	62.18
2	6	2/11/12	2896.31	-	487.88	2338.44	86.72	146.77	180.76	98.03	169.69	371.96	67.86	11.15	21.71	5.39	62.64
2	7	2/12/12	2911.52	-	491.7	2346.96	87.76	147.71	181.63	98.64	170.09	373.31	68.4	11.23	21.85	5.47	63.02
2	7	2/13/12	2926.73	-	495.52	2355.47	88.81	148.64	182.5	99.26	170.48	374.66	68.95	11.32	21.98	5.55	63.39
2	7	2/14/12	2940.02	-	498.16	2364	89.46	149.46	183.3	99.93	170.89	375.85	69.45	11.43	22.16	5.63	63.71
2	7	2/15/12	2954.4	-	500.75	2377.52	90.25	150.26	184.2	100.43	171.25	381.06	70.12	11.5	22.43	5.64	64.1
2	7	2/16/12	2969.44	-	503.15	2385.08	91.69	150.74	185.02	100.75	171.62	381.78	70.91	11.57	22.52	5.66	64.38
2	7	2/17/12	2984.97	-	506.6	2396.92	92.86	151.47	186.3	101.61	171.9	382.96	71.72	11.69	22.78	5.72	64.76
2	7	2/18/12	3000.36	-	509.76	2406.76	93	153.27	187.26	102.16	172.37	383.87	72.19	11.82	22.88	5.76	65.11
2	8	2/19/12	3011.06	-	514.01	2415.03	93.95	154.19	187.88	102.63	172.95	385.15	72.87	11.95	23.15	5.78	65.3
2	8	2/20/12	3029.53	-	518.27	2423.31	94.89	155.11	188.5	103.11	173.52	386.43	73.55	12.08	23.41	5.8	65.49
2	8	2/21/12	3029.53	-	521.1	2434.56	96.1	156.61	190.17	103.83	174.13	387.2	74.09	12.23	23.69	5.84	65.81
2	8	2/22/12	3032.19	-	524.17	2443.26	96.74	157.45	191.08	104.24	174.96	387.51	75.2	12.4	24.08	5.91	66.07
2	8	2/23/12	3034.85	-	527.09	2452.3	98.18	158.34	192.12	104.66	175.49	387.51	75.7	12.47	24.3	5.97	66.36
2	8	2/24/12	3044.45	-	529.05	2487.07	98.98	163.31	194.29	105.47	176.56	388.08	76.29	12.47	24.36	6.06	66.69
2	8	2/25/12	3054.05	-	530.93	2527.07	100.16	163.87	194.62	105.61	177.32	388.77	76.55	12.47	24.37	6.11	66.92
2	9	2/26/12	3088.46	0.88	535.22	2589.18	101.27	164.51	195.48	106.25	178.25	393.31	77.12	12.47	24.41	6.18	67.35
2	9	2/27/12	3108.62	1.8	537.91	2598.31	101.89	165.54	196.86	107.33	178.86	393.9	78.03	12.47	24.45	6.18	67.67
2	9	2/28/12	3123.38	2.61	540.18	2609.71	103.02	166.26	198.33	107.91	179.39	394.38	78.43	12.47	24.48	6.26	68.05
2	9	2/29/12	3139.87	3.5	542.32	2621.05	103.99	167.88	199.49	108.45	180.2	397.32	79.19	12.49	24.49	6.36	68.38
3	9	3/1/12	3157.67	4.55	545.2	2634.47	104.89	168.95	201.25	109.13	180.92	399.03	79.83	12.6	24.72	6.4	68.95

***Highlighted cells indicate an estimated value because no meter reading was recorded**

Appendix 6: Ranch meter readings (m^3)

Month	Week	Date	#1 Garden	#2 Workshop & Clinic	#3 Nanja into VT	#4 Gabriel	#5 Village	#6 Ranch House Tank	#7 River into VT	Field (BH)	Ranch (River)	Nanja	Borehole Pump	Hours Pumped
8	35	8/27/11	16.433	4.726	14.85	1.2898	8.832	1.3634	4.612	1103	7545	4196	8921	-
8	36	8/28/11	22.163	5.896	14.85	1.845	13.263	1.376	4.612	1103	7545	4220	8958	-
8	36	8/29/11	22.217	9.672	14.85	2.884	16.696	14.988	4.612	1103	7545	4255	8972	-
8	36	8/30/11	38.61	16.056	14.85	3.506	20.82	16.58	58.59	1103	7585	4255	8985	-
8	36	8/31/11	38.6195	18.12	14.85	3.95	24.3847	16.58	59.615	1103	7585	4255	9011	-
9	36	9/1/11	39.86475	23.525	14.85	4.59	28.49735	16.58	105.5925	1103	7585	4334.5	9029.5	-
9	36	9/2/11	41.11	28.93	14.85	5.23	32.61	16.58	151.57	1103	7585	4414	9048	2
9	36	9/3/11	41.11	30.33	14.85	5.61	34.48	16.58	151.57	1103	7585	4433	9048	2
9	37	9/4/11	41.11	32.18	14.85	6.12	37.31	16.58	151.57	1103	7585	4470	9073	4
9	37	9/5/11	41.11	34.85	14.85	6.95	43.62	16.58	241.66	1103	7585	4498	9095	4
9	37	9/6/11	41.11	36.81	14.85	7.4	46.14	16.58	241.66	1103	7585	4520	9107	2
9	37	9/7/11	41.11	39.17	14.85	8.05	49.94	16.58	265.91	1103	7585	4555	9125	2
9	37	9/8/11	41.11	41.32	14.85	8.58	53.14	16.58	265.91	1103	7585	4555	9142	2
9	37	9/9/11	41.11	44.07	14.85	8.66	56.93	16.58	328.11	1103	7655	4620	9160	2
9	37	9/10/11	41.11	47.05	14.85	9.05	59.79	54.84	349.52	1103	7655	4669	9181	3
9	38	9/11/11	58.46	52.21	14.85	9.11	62.86	54.85	423.18	1103	7655	4750	9205	3
9	38	9/12/11	58.46	54	14.85	9.47	66.16	54.85	423.18	1103	7655	4862	9230	3
9	38	9/13/11	60.72	56.3	14.85	11.28	69.88	54.85	531.7	1103	7655	4893	9244	2
9	38	9/14/11	66.12	59.42	14.85	11.81	72.92	54.85	531.7	1103	7655	4902	9274	3
9	38	9/15/11	71.49	64.84	14.85	12.13	75.45	57.21	546.99	1103	7655	4919	9292	2
9	38	9/16/11	71.49	67.89	14.85	12.74	78.55	57.21	546.99	1103	7706	4919	9310	3
9	38	9/17/11	75.51	75.38	14.85	13.5	81.1	57.21	578.77	1103	7706	4930	9328	2
9	39	9/18/11	75.63	78.89	14.85	14.44	86.51	57.21	578.77	1103	7706	4953	9352	2
9	39	9/19/11	82.22	82.58	14.85	15.34	91.38	57.21	603.82	1103	7706	4972	9375	2
9	39	9/20/11	92.5	85.18	14.85	16.15	94.68	57.21	661.58	1103	7706	5009	9401	3
9	39	9/21/11	106.13	91.54	14.85	16.74	98.34	57.21	690.33	1103	7706	5077	9424	3
9	39	9/22/11	108.95	94.13	14.85	17.25	103.85	57.21	707.17	1103	7706	5179	9448	3
9	39	9/23/11	116.05	98.9	14.85	17.85	111.53	57.21	788.96	1103	7707	5210	9466	3
9	39	9/24/11	119.32	101.28	14.85	18.17	113.82	57.21	815.57	1103	7707	5322	9490	3
9	40	9/25/11	119.41	105.93	14.85	18.55	118.45	57.21	815.57	1103	7707	5347	9509	2
9	40	9/26/11	120.96	107.61	14.85	19.22	122.27	57.21	815.57	1103	7707	5356	9529	2
9	40	9/27/11	128.56	110.33	14.85	19.87	126.62	57.21	827.23	1103	7707	5412	9547	2
9	40	9/28/11	142.28	117.97	14.85	20.42	127.78	57.21	845.28	1103	7707	5425	9565	2
9	40	9/29/11	148.76	124.2	14.85	20.83	130.98	57.21	879.1	1103	7707	5453	9584	3
9	40	9/30/11	148.76	131.14	14.85	21.28	134.64	83.15	974.17	1103	7707	5500	9596	2
10	40	10/1/11	148.76	133.33	15	21.9	137.31	84.09	974.28	1103	7726	5587	9630	3
10	41	10/2/11	162.17	137.46	15.25	22.33	142.28	84.09	1001.24	1103	7726	5631	9655	3
10	41	10/3/11	172.42	140.18	15.48	23.04	146.57	84.09	1086.48	1103	7726	5676	9682	2
10	41	10/4/11	172.42	143.77	15.48	23.7	150.34	84.09	1086.48	1103	7726	5721	9710	2
10	41	10/5/11	172.42	146.58	15.7	23.96	154.13	84.09	1087.58	1103	7726	5765	9740	4
10	41	10/6/11	174.94	153.68	15.7	24.35	157.85	84.09	1119.37	1103	7726	5810	9769	3

Month	Week	Date	#1 Garden	#2 Workshop & Clinic	#3 Nanja into VT	#4 Gabriel	#5 Village	#6 Ranch House Tank	#7 River into VT	Field (BH)	Ranch (River)	Nanja	Borehole Pump	Hours Pumped
10	41	10/7/11	174.98	162.45	15.7	24.76	161.26	84.09	1192.48	1103	7726	5855	9798	3
10	41	10/8/11	174.98	176.32	15.7	26.44	166.72	84.09	1192.48	1103	7726	5900	9827	3
10	42	10/9/11	174.98	176.58	15.7	26.99	168.18	84.09	1192.48	1103	7726	5944	9856	3
10	42	10/10/11	192.19	181.02	15.81	27.4	172.3	84.09	1320.86	1103	7726	5989	9888	2
10	42	10/11/11	193.82	184.27	15.84	27.89	175.01	85.35	1325.83	1103	7773	6034	9907	4
10	42	10/12/11	209.26	188.58	27.995	29.19	178.06	87.835	1325.83	1103	7812	6079	9936	3
10	42	10/13/11	224.7	192.88	40.15	30.48	181.11	90.32	1325.83	1103	7852	6088	9965	3
10	42	10/14/11	253.28	195.84	40.15	31.42	183.87	90.32	1325.83	1103	7885	6097	9993	3
10	42	10/15/11	253.28	197.33	40.15	32.17	185.48	90.32	1325.83	1103	7900	6106	10044	4
10	43	10/16/11	268.27	200.07	62.87	32.83	189.4	90.32	1325.83	1103	7900	6115	10052	-
10	43	10/17/11	268.27	202.34	63.78	33.57	192.16	90.32	1325.83	1103	7903	6124	10061	6
10	43	10/18/11	268.63	204.26	63.78	34.08	195.04	90.32	1325.83	1103	7903	6133	10134	3
10	43	10/19/11	293.11	206.22	63.78	34.54	197.53	90.32	1325.83	1103	7935	6144	10163	3
10	43	10/20/11	293.12	207.95	86.45	34.79	199.88	90.32	1325.83	1103	7935	6153	10163	3
10	43	10/21/11	293.12	210.49	86.45	34.89	204.23	90.32	1325.83	1103	7935	6162	10186	4
10	43	10/22/11	296.31	212.38	86.45	35.19	207.28	90.32	1325.83	1103	7935	6171	10215	3
10	44	10/23/11	301.75	215	86.45	35.57	211.65	90.32	1325.83	1103	7942	6180	10241	2
10	44	10/24/11	301.75	218.37	114.11	36.3	215.85	90.32	1325.83	1103	7942	6189	10265	5
10	44	10/25/11	325.12	220.78	114.11	36.67	218.17	90.32	1325.83	1103	7971	6198	10303	3
10	44	10/26/11	325.92	223.85	125.89	37.11	221.87	97.61	1325.83	1103	7971	6207	10326	3
10	44	10/27/11	326.81	226.32	125.89	37.65	224.57	101.45	1325.83	1103	7975	6216	10350	3
10	44	10/28/11	326.51	228.96	125.89	38.16	227.53	101.7	1325.83	1103	7975	6225	10373	2
10	44	10/29/11	327.97	231.22	152.71	38.59	229.23	101.71	1325.83	1103	7975	6234	10390	3
10	45	10/30/11	327.97	233.52	152.71	39.12	232.59	101.71	1325.83	1103	7975	6244	10419	2
10	45	10/31/11	329.17	235.55	152.71	39.55	236.65	101.71	1325.83	1103	7975	6268	10431	4
11	45	11/1/11	340.64	237.38	152.71	40.14	239.79	101.71	1325.83	1103	7975	6292	10458	3
11	45	11/2/11	340.67	239.29	152.71	40.56	242.12	135.48	1378.63	1103	8027	6348	10481	3
11	45	11/3/11	353.5	241.11	152.71	40.91	244.78	153.65	1402.77	1103	8027	6378	10501	3
11	45	11/4/11	353.6	242.89	152.71	41.61	247.55	153.69	1402.77	1103	8027	6399	10522	4
11	45	11/5/11	353.6	244.33	152.71	41.86	250.77	156.15	1402.77	1135	8027	6403	10547	4
11	46	11/6/11	353.6	246.6	152.71	42.72	253.96	156.46	1402.77	1135	8027	6418	10571	3
11	46	11/7/11	374.37	249.45	152.71	43.32	256.77	156.46	1402.77	1135	8027	6454	10605	4
11	46	11/8/11	374.37	251.32	152.71	43.94	259.25	156.46	1428.53	1135	8027	6496	10628	6
11	46	11/9/11	409.8	253.23	152.71	44.45	262.44	156.46	1475.92	1135	8044	6564	10669	3
11	46	11/10/11	409.93	254.9	152.71	44.85	265.46	156.46	1487.25	1135	8044	6564	10686	4
11	46	11/11/11	409.93	257.98	152.71	45.71	268.68	156.46	1487.31	1136	8044	6564	10714	2
11	46	11/12/11	409.93	260.07	152.71	46.43	272.68	156.46	1487.31	1136	8044	6627	10726	-

***Highlighted cells indicate an estimated value because no meter reading was recorded**

Month	Week	Date	#1 Garden	#2 Workshop & Clinic	#3 Nanja into VT	#4 Gabriel	#5 Village	#6 Ranch House Tank	#7 River into VT	Field (BH)	Ranch (River)	Nanja	Borehole Pump	Hours Pumped
11	47	11/13/11	409.93	263.49	152.71	47.52	277.09	156.46	1528.95	1136	8044	6661	10733	-
11	47	11/14/11	420.09	267.64	152.71	47.82	279.26	156.46	1538.07	1136	8049	6696	10765	-
11	47	11/15/11	430.25	271.79	152.71	48.13	281.43	156.46	1547.18	1136	8049	6731	10798	-
11	47	11/16/11	440.41	275.94	152.71	48.43	283.6	156.46	1556.3	1136	8049	6765	10830	-
11	47	11/17/11	454.06	284.45	152.71	49.35	290.05	156.46	1567.35	1136	8095	6765	10851	-
11	47	11/18/11	454.06	286.65	152.71	49.8	292.63	156.46	1568.54	1136	8095	6765	10869	-
11	47	11/19/11	461.44	288.16	152.71	50.49	295.12	156.46	1587.35	1136	8095	6765	10878	-
11	48	11/20/11	461.92	290.42	152.71	50.89	298.55	156.46	1591.11	1136	8095	6765	10901	-
11	48	11/21/11	475.37	292.72	152.71	51.89	304.35	156.46	1605.71	1136	8095	6765	10924	-
11	48	11/22/11	475.55	294.37	152.71	52.45	307.2	156.46	1605.82	1136	8145	6765	10935	-
11	48	11/23/11	477.58	298.11	152.71	53.13	312.01	156.46	1605.92	1136	8145	6765	10947	-
11	48	11/24/11	477.99	300.21	152.71	53.85	314.33	156.46	1605.92	1136	8145	6806	10976	-
11	48	11/25/11	485.62	302.82	152.71	54.21	318.48	156.46	1620.51	1136	8145	6824	10993	-
11	48	11/26/11	485.62	303.59	152.71	55.06	321.48	156.46	1620.51	1136	8145	6872	11016	-
11	49	11/27/11	485.62	304.24	152.71	55.6	324.35	156.46	1620.51	1136	8145	6901	11028	-
11	49	11/28/11	486.42	305.78	177.98	57.13	327.31	156.46	1625.15	1136	8145	6915	11039	-
11	49	11/29/11	487.18	307.64	177.98	58.08	332.36	156.46	1625.98	1136	8145	6932	11056	-
11	49	11/30/11	489.66	307.77	177.98	58.35	334.01	156.46	1689.64	1136	8145	6966	11066	-
12	49	12/1/11	489.66	308.43	177.98	59.03	337.04	156.46	1693.81	1136	8145	6999	11086	-
12	49	12/2/11	489.66	309.03	177.98	59.62	341.87	156.46	1693.81	1136	8145	7033	11109	-
12	49	12/3/11	489.66	309.11	177.98	60.15	345.09	156.46	1693.81	1136	8145	7066	11126	-
12	50	12/4/11	490.88	310.39	177.98	60.78	350.35	156.46	1693.81	1136	8145	7100	11141	-
12	50	12/5/11	490.88	310.68	177.98	61.62	354.62	156.46	1757.82	1136	8145	7133	11147	-
12	50	12/6/11	510.6	312.86	177.98	62.31	358.7	156.46	1757.82	1136	8145	7167	11159	-
12	50	12/7/11	511.6	314.23	177.98	63.43	363.55	156.46	1771.21	1136	8145	7200	11165	-
12	50	12/8/11	564.25	320.83	177.98	64.77	368.3	156.46	1791.1	1136	8145	7233	11188	-
12	50	12/9/11	589.13	322.43	177.98	66.22	372.98	156.46	1842.16	1136	8145	7266	11195	-
12	50	12/10/11	589.33	324.37	177.98	66.98	377.98	156.46	1843.43	1136	8145	7300	11205	-
12	51	12/11/11	610.22	324.86	177.98	67.47	380.22	156.46	1854.21	1136	8145	7333	11219	-
12	51	12/12/11	621.18	326.32	177.98	68.25	386.76	156.46	1894.12	1136	8145	7367	11231	-
12	51	12/13/11	621.65	327.86	177.98	68.9	391.71	156.46	1894.12	1136	8145	7402	11243	-
12	51	12/14/11	631.03	330.47	177.98	69.78	395.81	164.28	1909.41	1136	8145	7430	11265	-
12	51	12/15/11	631.04	333.51	177.98	70.53	400.29	164.28	1911.55	1136	8145	7458	11283	-
12	51	12/16/11	635.08	340.21	177.98	71.83	404.89	164.28	1940.16	1136	8145	7485	11294	-
12	51	12/17/11	635.67	342.58	178.14	72.54	409.42	188.07	1940.16	1136	8145	7513	11316	-
12	52	12/18/11	638.72	346.06	208.58	73.71	413.26	188.15	1947.42	1136	8145	7540	11328	-
12	52	12/19/11	638.72	349.13	208.58	74.92	418.33	188.15	1947.58	1136	8145	7568	11362	-
12	52	12/20/11	638.72	352.44	208.58	75.58	423.61	188.15	1947.58	1136	8145	7596	11373	-
12	52	12/21/11	652.19	360.23	248.13	76.4	428.21	188.15	1960.27	1136	8145	7625	11373	-
12	52	12/22/11	664.9	368.52	248.22	76.95	434.7	190.97	1960.27	1136	8145	7653	11389	-
12	52	12/23/11	664.9	372.02	248.22	78.04	440.2	190.97	1970.8	1136	8217	7683	11405	-
12	52	12/24/11	664.9	375.15	248.22	78.86	444.95	190.97	1970.94	1136	8217	7683	11429	-
12	53	12/25/11	690.89	377.22	292.91	79.27	452.46	201.88	1977.63	1136	8217	7731	11447	-

Month	Week	Date	#1 Garden	#2 Workshop & Clinic	#3 Nanja into VT	#4 Gabriel	#5 Village	#6 Ranch House Tank	#7 River into VT	Field (BH)	Ranch (River)	Nanja	Borehole Pump	Hours Pumped
12	53	12/26/11	694.33	382.02	314.39	79.47	457.51	205.18	1978.07	1136	8217	7780	11460	-
12	53	12/27/11	701.46	385.18	314.39	79.52	464.02	205.18	1994.19	1136	8217	7827	11486	-
12	53	12/28/11	722.71	389.42	314.39	79.58	467.66	205.18	2008.38	1136	8217	7875	11508	-
12	53	12/29/11	749.84	394.7	314.39	80.07	472.71	205.18	2036.29	1136	8217	7923	11527	-
12	53	12/30/11	762.14	399.44	314.39	81.62	479.04	205.18	2053.27	1136	8217	7971	11552	-
12	53	12/31/11	768.77	401.25	314.39	82.39	482.1	205.18	2081.22	1136	8218	8024	11575	1
1	1	1/1/12	769.16	404.96	314.39	83.55	488.73	205.18	2082.48	1136	8218	8024	11587	3
1	1	1/2/12	769.33	407.92	314.39	84.36	493.78	205.18	2082.55	1136	8218	8024	11611	2
1	1	1/3/12	788.39	414.65	332.55	85	498.27	205.18	2088.69	1136	8275	8024	11628	3
1	1	1/4/12	802.51	420.75	347.96	85.42	504.4	205.18	2100.98	1136	8275	8123	11651	2
1	1	1/5/12	804.17	423.72	348.15	86.13	508.48	205.18	2100.98	1136	8275	8123	11667	3
1	1	1/6/12	820.18	427.56	349.84	86.77	513.93	205.18	2110.18	1136	8323	8123	11688	3
1	1	1/7/12	832.56	430.73	349.84	87.43	517.78	205.18	2120.15	1136	8323	8123	11707	4
1	2	1/8/12	842.72	434.21	384.52	88.33	524.41	205.18	2126.33	1136	8323	8161	11735	3
1	2	1/9/12	853.08	436.82	384.52	89.14	527.46	205.18	2135.73	1136	8445	8161	11758	2
1	2	1/10/12	863.24	440.4	384.52	89.6	531.12	205.18	2143.51	1136	8445	8161	11776	3
1	2	1/11/12	863.24	443.31	384.52	90.36	535.37	205.18	2143.52	1136	8445	8161	11799	2
1	2	1/12/12	878.07	446.02	429.59	90.98	539.89	205.18	2151.39	1136	8468	8223	11816	2
1	2	1/13/12	901.28	450.03	430.05	91.51	543.56	205.18	2164.5	1136	8511	8223	11840	2
1	2	1/14/12	909.53	453.25	467.16	92.14	546.64	217.41	2176.3	1136	8575	8255	11863	1
1	3	1/15/12	909.53	456.31	471.08	93.31	551.62	217.86	2188.12	1136	8621	8255	11869	2
1	3	1/16/12	909.53	461.6	471.08	93.75	556.69	217.86	2200.31	1136	8660	8255	11881	3
1	3	1/17/12	909.53	466.07	497.6	94.6	560.7	217.86	2200.31	1136	8663	8266	11898	6
1	3	1/18/12	909.53	471.44	524.29	95.47	565	217.86	2210.41	1136	8663	8673	11931	3
1	3	1/19/12	909.53	476.33	524.32	96.1	568.32	217.86	2213.48	1136	8663	8673	11948	3
1	3	1/20/12	909.53	481.96	524.32	96.66	572.28	217.86	2213.48	1136	8663	8673	11965	4
1	3	1/21/12	909.53	483.71	556.65	97.06	579.69	217.86	2213.48	1136	8663	8673	11988	3
1	4	1/22/12	909.53	486.61	569.65	98.23	581	217.86	2213.48	1136	8663	8673	12007	3
1	4	1/23/12	909.53	489.52	569.65	98.96	585.46	217.86	2213.48	1136	8663	8673	12029	4
1	4	1/24/12	909.53	492.05	595.15	99.38	589.93	224.48	2216.1	1136	8665	8684	12051	5
1	4	1/25/12	910.54	494.58	620.72	99.81	594.39	231.11	2216.1	1136	8665	8684	12080	4
1	4	1/26/12	910.54	498.67	620.73	100.3	598.45	235.06	2235.07	1136	8665	8684	12102	2
1	4	1/27/12	910.54	502.13	620.73	100.94	602.74	237.78	2252.8	1136	8665	8684	12120	4
1	4	1/28/12	915.77	507.55	620.73	101.6	608.11	238.67	2273.47	1136	8665	8684	12148	4
1	5	1/29/12	915.77	508.51	620.73	102.32	612.37	238.67	2273.47	1136	8804	8684	12175	3

***Highlighted cells indicate an estimated value because no meter reading was recorded**

Month	Week	Date	#1 Garden	#2 Workshop & Clinic	#3 Nanja into VT	#4 Gabriel	#5 Village	#6 Ranch House Tank	#7 River into VT	Field (BH)	Ranch (River)	Nanja	Borehole Pump	Hours Pumped
1	5	1/30/12	918.85	510.32	620.73	102.98	616.75	238.67	2283.58	1136	8836	8694	12198	2
1	5	1/31/12	922.1	514.01	620.73	103.56	621.31	238.67	2291.06	1136	8841	8701	12210	2
2	5	2/1/12	928.41	518.02	620.73	104.24	624.98	239.56	2291.06	1136	8841	8701	12232	3
2	5	2/2/12	935.58	522.93	620.73	104.83	630.39	239.56	2291.06	1136	8847	8701	12260	4
2	5	2/3/12	940.28	525.42	620.73	105.46	634.9	239.56	2291.06	1136	8885	8701	12289	2
2	5	2/4/12	943.4	530.02	682.29	106.21	638.73	244.87	2291.06	1136	8885	8724	12306	4
2	6	2/5/12	943.4	533.86	690.93	106.74	641.74	248.17	2291.06	1136	8885	8744	12339	2
2	6	2/6/12	943.4	540.37	691.54	107.56	645.39	249.75	2291.06	1136	8886	8802	12351	2
2	6	2/7/12	943.4	544.74	751.12	108.13	649.54	253.34	2291.06	1136	8886	8832	12369	3
2	6	2/8/12	943.7	549.39	751.12	108.6	654.4	256.54	2291.06	1136	8886	8864	12392	4
2	6	2/9/12	943.7	553.81	770.68	109.19	658.56	256.58	2291.06	1136	8886	8941	12420	4
2	6	2/10/12	949.62	559.11	877.6	109.57	664.49	286.9	2291.06	1136	8886	8972	12443	2
2	6	2/11/12	949.62	565.05	899.26	110.07	668.07	287.54	2291.06	1136	8886	9037	12466	2
2	7	2/12/12	949.62	566.22	920.1	110.66	673.7	287.54	2291.06	1136	8886	9072	12510	3
2	7	2/13/12	949.62	569.65	940.94	111.12	677.83	287.54	2291.06	1136	8886	9107	12528	2
2	7	2/14/12	949.82	575.21	962.58	111.52	683.11	287.54	2291.06	1136	8886	9142	12540	4
2	7	2/15/12	949.82	579.79	982.91	112.2	687.22	287.54	2291.06	1136	8886	9177	12567	2
2	7	2/16/12	949.82	584.21	1037.46	112.78	689.79	296.46	2291.06	1136	8906	9212	12584	3
2	7	2/17/12	949.82	589.04	1074.63	113.46	696.86	296.46	2291.06	1136	8906	9245	12613	-
2	7	2/18/12	949.82	596.5	1095.43	114.24	703.62	296.46	2291.06	1136	8906	9278	12630	1
2	8	2/19/12	949.82	597.95	1107.19	114.65	706.65	296.46	2291.06	1136	8906	9311	12637	8
2	8	2/20/12	949.82	601.54	1128.12	115.33	712.46	296.46	2291.06	1136	8906	9345	12637	7
2	8	2/21/12	949.82	605.51	1155.55	115.99	716.06	296.46	2291.06	1136	8906	9378	12688	2
2	8	2/22/12	949.82	610.24	1162.19	116.2	720.4	296.46	2291.06	1136	8906	9411	12731	5
2	8	2/23/12	949.82	615.2	1162.19	116.65	725.22	296.47	2291.06	1136	8906	9444	12747	1
2	8	2/24/12	949.82	618.83	1162.2	117.12	728.82	296.51	2291.06	1136	8906	9478	12780	4
2	8	2/25/12	949.82	622.55	1162.2	117.7	732.36	296.58	2291.06	1136	8906	9511	12785	4
2	9	2/26/12	949.82	625.99	1191.41	118.04	738.07	296.59	2291.06	1136	8906	9544.61	12820	3
2	9	2/27/12	949.82	628.14	1197.41	118.35	742.22	296.6	2291.06	1136	8906	9544.61	12855	3
2	9	2/28/12	949.82	631.51	1209.9	118.94	746.01	296.6	2291.06	1136	8906	9572	12883	-
2	9	2/29/12	955.47	635.52	1210.68	119.54	749.9	296.62	2291.06	1136	8906	9600	12905	2
3	9	3/1/12	955.47	639.11	1210.68	120.73	753.46	296.64	2291.06	1136	8907	9629.1	12917	-

***Highlighted cells indicate an estimated value because no meter reading was recorded**

Appendix 7: Antokal et al. (2011) borehole data

Appendix W-1: Borehole meter Readings at Main (primary), Ranch & Centre borehole (secondary) (August – December 2010)

	Ranch House (m^3)	Ranch difference	MRC (m^3)	MRC difference	Borehole (m^3)	Borehole difference
10.08.2006			6031			
11.08.2007						
12.08.2007						
13.08.2008			6083			
14.08.2008	52		6107	23.75	25	
15.08.2009	55	3			44	19.38
16.08.2009						
17.08.2010			6196			
18.08.2010					217	
19.08.2010	110		6221		254	37
20.08.2010			6247	26	270	16
21.08.2010	113		6279	32	287	17
22.08.2010					341	54
23.08.2010					380	39
24.08.2010					401	21
25.08.2010					417	16
26.08.2010					447	30
27.08.2010					469	22
28.08.2010					487	18
29.08.2010					536	49
30.08.2010					593	57
31.08.2010					630	37
01.09.2010	177		6457		680	50
02.09.2010					695	15
03.09.2010					751	56
04.09.2010					786	35
05.09.2010					876	90
06.09.2010					912	36
07.09.2010					927	15
08.09.2010					1006	79
09.09.2010					1051	45
10.09.2010					1094	43
11.09.2010					1145	51
12.09.2010					1170	25
13.09.2010					1190	20
14.09.2010					1217	27

Building a Sustainable Community in Africa | 7/4/2011

61

15.09.2010					1232	15
16.09.2010					1286	54
17.09.2010					1340	54
18.09.2010					1372	32
19.09.2010					1396	24
20.09.2010					1423	27
21.09.2010					1456	33
22.09.2010					1462	6
23.09.2010					1480	18
24.09.2010					1515	35
25.09.2010					1545	30
26.09.2010					1581	36
27.09.2010					1624	43
19.10.2010	345		7431		2259	635
20.10.2010	345	0	7452	21	2285	26
21.10.2010	345	0	7469	17	2316	31
22.10.2010	345	0			2342	26
23.10.2010	346	1	7508		2374	32
24.10.2010	369	23	7524	16		
25.10.2010	369	0	7542	18	2396	
26.10.2010	369	0	7565	23	2441	45
27.10.2010	369	0	7572	7	2503	107
28.10.2010	369	0	19		2550	47
29.10.2010	369	0	35	16	2567	64
30.10.2010	370	1	52	17		
31.10.2010						
1.11.2010	370		93	41	2650	
2.11.2010	370	0	112	19	2677	27
3.11.2010	370	0	129	17	2703	26
4.11.2010	382	12	145	16	2750	47
5.11.2010	382	0	160	15	2786	36
6.11.2010	421	39	188	28	2835	49
7.11.2010	424	3	210	22	2867	32
8.11.2010	430	6	210	0	2884	17
9.11.2010	430	0	240	30	2910	26
10.11.2010	430	0	259	19	2931	21
11.11.2010	460	30	261	2	2952	21
12.11.2010	460	0	268	7	2968	16
13.11.2010	479	19	297	29	3014	46
14.11.2010	479	0	319	22	3041	27
15.11.2010	479	0	337	18	3058	17

16.11.2010	479	0	337	0	3080	22
17.11.2010	481	2	369	32	3108	28
18.11.2010	481	0	390	21	3145	37
19.11.2010	481	0	417	27	3186	41
20.11.2010	481	0	435	18	3214	28
21.11.2010	481	0	456	21	3251	37
22.11.2010	481	0	468	12	3262	11
23.11.2010	481	0	480	12	3284	22
24.11.2010	481	0	511	31	3305	21
25.11.2010	481	0	530	19	3326	21
26.11.2010	481	0	531	1	3344	18
27.11.2010	481	0	562	31	3376	32
28.11.2010	481	0	585	23	3390	14
29.11.2010	481	0	602	17	3406	16
30.11.2010	481	0	602	0	3425	19
1.12.2010	481	0	635	33	3452	27
2.12.2010	481	0	658	23	3478	26
3.12.2010	481	0	678	20	3524	46
4.12.2010	565	84	697	19	3555	31
5.12.2010	565	0	697	0	3561	6
6.12.2010	565	0	714	17	3587	26
7.12.2010	565	0	747	33	3618	31
8.12.2010	565	0	770	23	3639	21
9.12.2010	565	0	789	19	3650	11
10.12.2010	663	98	800	11	3661	11
11.12.2010	663	0	807	7	3683	22
12.12.2010	663	0	880	73	3725	42
13.12.2010	663	0	880	0	3754	29
14.12.2010	663	0	825	-55	3797	43
15.12.2010	663	0	841	16	3834	37
16.12.2010	663	0	881	40	3870	36
17.12.2010	663	0	914	33	3901	31
18.12.2010	663	0	948	34	3940	39
19.12.2010	663	0	971	23	3967	27
20.12.2010	708	45	990	19	3998	31
21.12.2010	708	0	1010	20	4034	36
22.12.2010	708	0	1028	18	4051	17
23.12.2010	708	0	1044	16	4073	22
24.12.2010	726	18	1056	12	4095	22
25.12.2010	726	0	1089	33	4123	28
26.12.2010	726	0	1110	21	4160	37

27.12.2010	726	0	1126	16	4193	33
28.12.2010	726	0			4241	48
29.12.2010	772	46				
AVERAGE DAILY		6.14		18.98		37.67
PERCENT OF TOTAL		24%		76%		

SHARE OF TOTAL BOREHOLE IF NO LOSSES	9.21	28.46

MISSING/ DISCREPANCY	**3.07**	**9.48**

Appendix 8: Sample Balance Worksheet for Borehole System

Meter Reading Date	MRC Reading	*MRC Use (Current - Previous)	Ranch Reading	*Ranch Use (Current - Previous)	*Total Use (MRC Use + Ranch Use)	Borehole Pump Reading	*Amount Pumped (Current - Previous)	*Unaccounted For (Amount Pumped – Total Use)	*% Supply Missing (Unaccounted / Amount Pumped) x 100
1-Oct-11	622.38		1103			9630			
1-Nov-11	1368.31	745.93	1103	0	745.93	10458	828	82.07	9.9%
1-Dec-11	1791.48	423.17	1136	33	456.17	11086	628	171.83	27.4%
1-Jan-12	2190.74	399.26	1136	0	399.26	11587	501	101.74	20.3%
1-Feb-12	2735.11	544.37	1136	0	544.37	12232	645	100.63	15.6%
1-Mar-12	3157.67	422.56	1136	0	422.56	12917	685	262.44	38.3%
1-Apr-12									
1-May-12									
1-Jun-12									
1-Jul-12									
1-Aug-12									
1-Sep-12									
1-Oct-12									
1-Nov-12									
1-Dec-12									
1-Jan-13									
1-Feb-13									
1-Mar-13									
1-Apr-13									
1-May-13									
1-Jun-13									
1-Jul-13									
1-Aug-13									
1-Sep-13									
1-Oct-13									
1-Nov-13									
1-Dec-13									

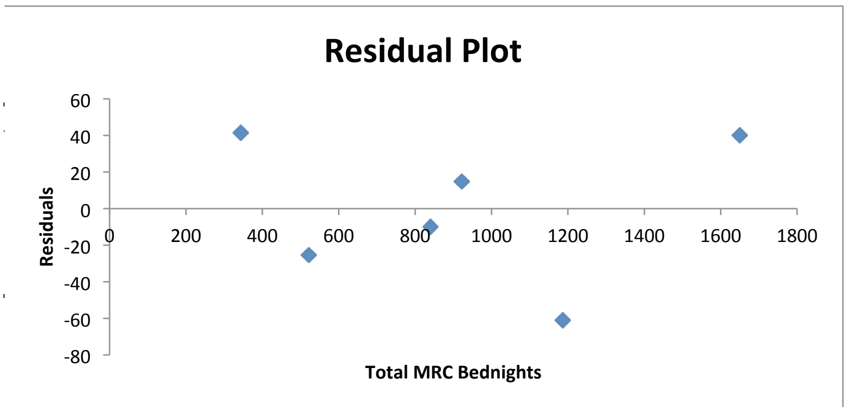
Appendix 9: Regression analysis results, total monthly bednights & monthly MRC water consumption (m^3)

Regression Statistics	
Multiple R	0.97960505
R Square	0.95962606
Adjusted R Square	0.94953258
Standard Error	44.7094553
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	190046.4107	190046.4107	95.0738	0.000619689
Residual	4	7995.741568	1998.935392		
Total	5	198042.1523			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	38.4248164	42.85867634	0.89654697	0.42064	-80.56994573	157.419579
Total MRC Bednights	0.41534797	0.042597257	9.750580164	0.00062	0.297079023	0.53361691



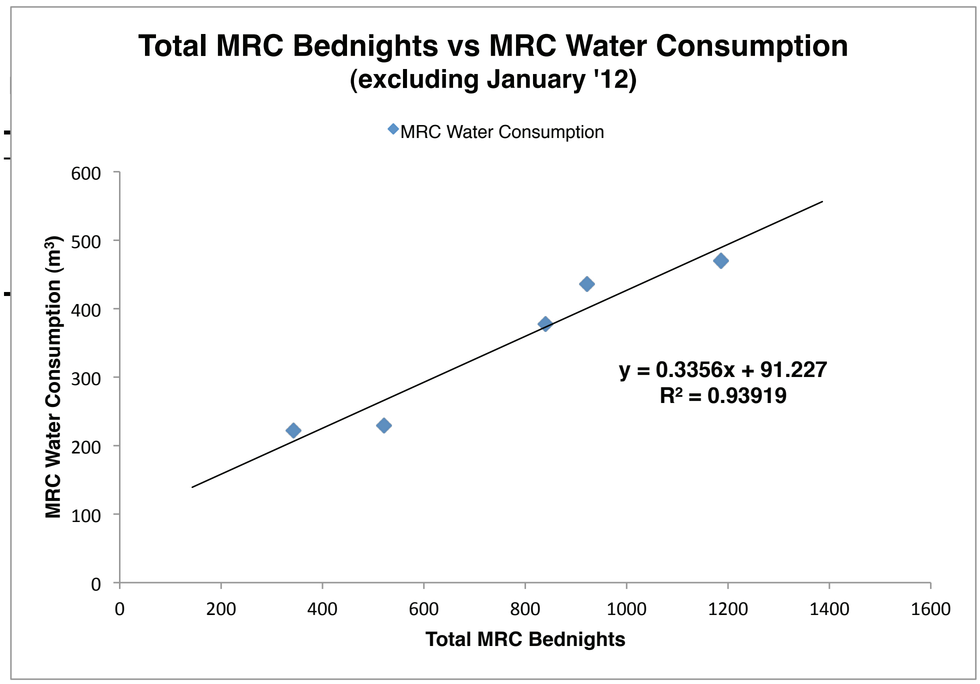
Appendix 10: Regression analysis results, total monthly bednights & monthly MRC water consumption (m^3) excluding January '12

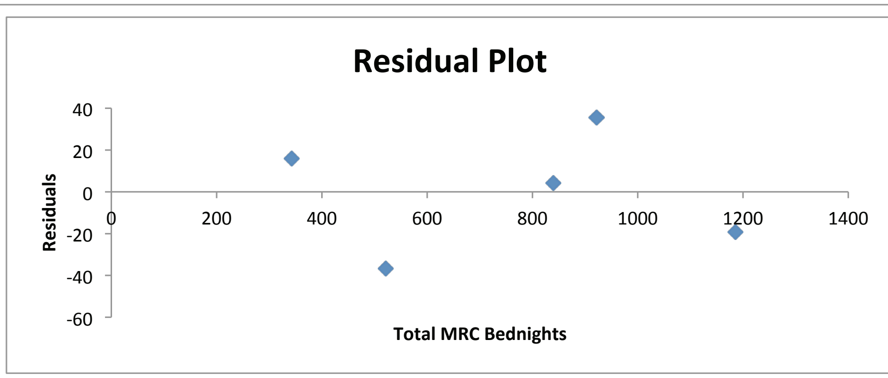
Regression Statistics	
Multiple R	0.96911778
R Square	0.93918927
Adjusted R Square	0.91891902
Standard Error	32.8930309
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	50130.4875	50130.4875	46.3334	0.006484472
Residual	3	3245.854451	1081.951484		
Total	4	53376.34195			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	91.2266784	40.36460412	2.260066224	0.10892	-37.23150683	219.684864
Total MRC Bednights	0.33559971	0.049303132	6.806863954	0.00648	0.178695143	0.49250428





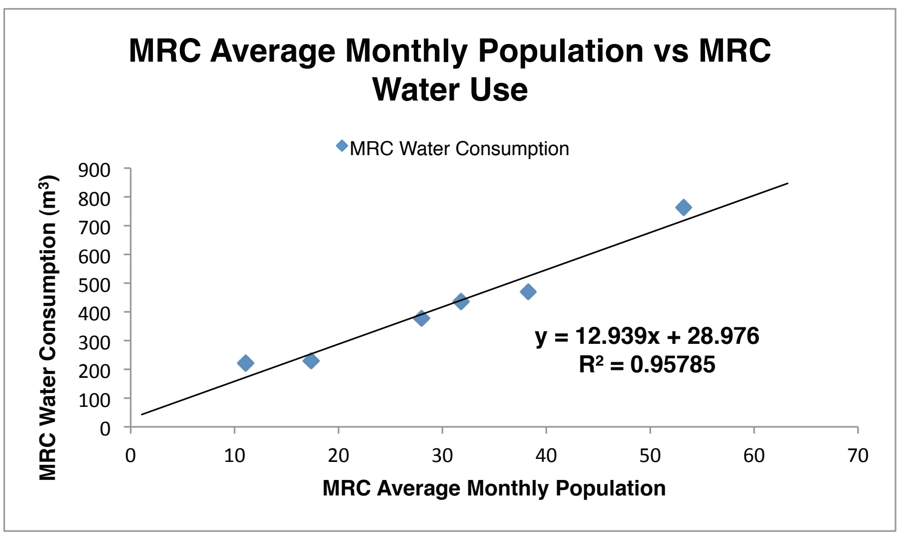
Appendix 11: Regression analysis results, MRC average monthly population vs MRC water consumption

Regression Statistics	
Multiple R	0.978700073
R Square	0.957853834
Adjusted R Square	0.947317292
Standard Error	45.68018587
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	189695.4348	189695.4	90.9078	0.000675699
Residual	4	8346.717525	2086.679		
Total	5	198042.1523			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	28.97589463	44.7211656	0.647924	0.552348	-95.18996669	153.14176
MRC Average Month	12.93944676	1.35711025	9.534558	0.000676	9.171504647	16.707389



Appendix 12: Monthly bednights & predicted water use at MRC

Monthly Bednights	Predicted Water Use (m^3)
50	59
100	80
200	121
300	163
400	205
500	246
750	350
1000	454
1250	558
1500	661
1750	765
2000	869
2250	973
2500	1077
3000	1284

***y = 0.415347968070325x + 38.4248163999807**

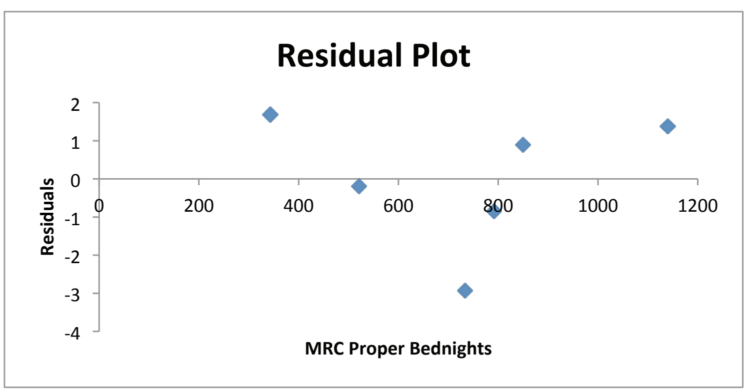
Appendix 13: Regression analysis results, monthly Centre bednights vs monthly water use at MRC Kitchen

Regression Statistics	
Multiple R	0.988772971
R Square	0.977671989
Adjusted R Square	0.972089986
Standard Error	1.927172218
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	650.4953098	650.49531	175.14717	0.000188362
Residual	4	14.85597102	3.7139928		
Total	5	665.3512808			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	20.29901242	2.414064944	8.4086439	0.0010949	13.59649362	27.0015312
MRC Proper Bednights	0.041385002	0.003127098	13.234318	0.0001884	0.032702788	0.05006722



Appendix 14: Predicted water use at Centre kitchen using average bednight data (2009-2012)

	Predicted Total MRC Water Use (m^3)	Average Centre Bednights	Predicted Kitchen Water Use (m^3)	Kitchen Use / Total MRC Use
January	557	808	54	10%
February	375	642	47	13%
March	597	827	55	9%
April	481	854	56	12%
May	421	638	47	11%
June	544	1028	63	12%
July	610	1186	69	11%
August	597	930	59	10%
September	303	599	45	15%
October	414	640	47	11%
November	271	534	42	16%
December	198	384	36	18%
Total (year)	5368	9069	619	12%
Average	447	756	52	12%

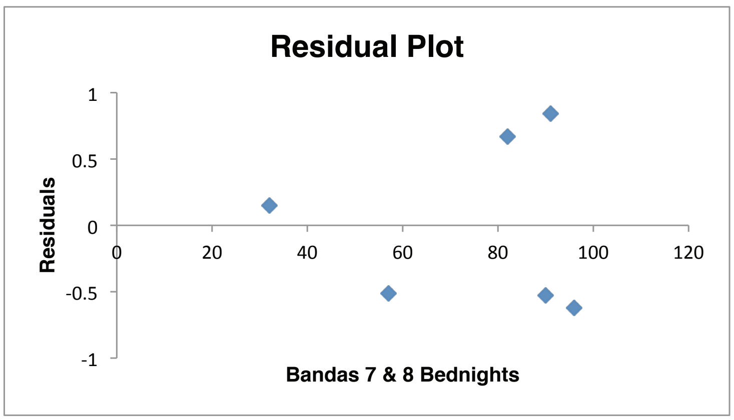
Appendix 15: Regression analysis results, monthly banda 7 & 8 bednights vs monthly Banda 7/8 Bathroom water use

Regression Statistics	
Multiple R	0.949874608
R Square	0.902261771
Adjusted R Square	0.877827214
Standard Error	0.726134819
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	19.4698501	19.46985	36.92564	0.003705861
Residual	4	2.1090871	0.527272		
Total	5	21.5789372			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.265779724	1.011466165	0.262767	0.805709	-2.542500559	3.07406
Bandas 7 & 8 Bednights	0.078702057	0.012951559	6.076647	0.003706	0.042742765	0.1146613



Appendix 16: Cold water & hot water use at Banda 7/8 Bathroom, Sept '11 through Feb '12

Month	Total Water Use (m^3)	Hot Water (m^3)	Cold Water (m^3)	Percent Hot	Percent Cold
September	2.93	0.57	2.37	19.3%	80.7%
October	8.27	2.63	5.64	31.8%	68.2%
November	6.82	2.37	4.45	34.8%	65.2%
December	4.24	1.62	2.62	38.2%	61.8%
January	7.20	2.70	4.50	37.5%	62.5%
February	7.39	2.70	4.69	36.5%	63.5%
				33.0%	**67.0%**

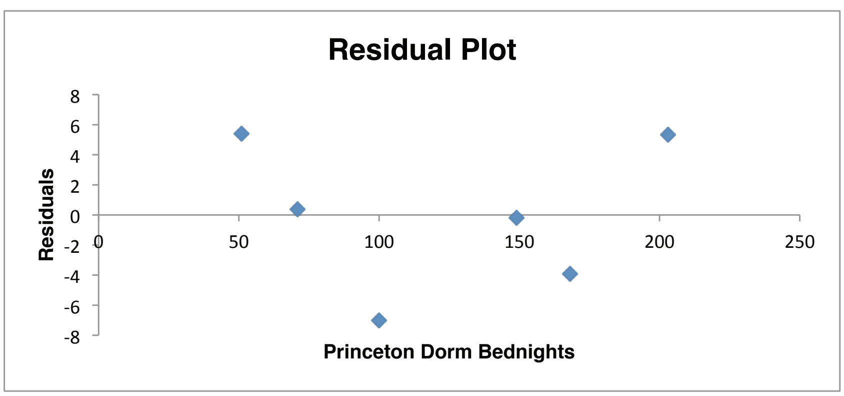
Appendix 17: Regression analysis results, monthly Princeton Dorm bednights vs monthly [adjusted] Princeton Dorm water use

Regression Statistics	
Multiple R	0.815267021
R Square	0.664660316
Adjusted R Square	0.580825395
Standard Error	5.535140303
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	242.9025409	242.9025	7.928204	0.048037286
Residual	4	122.5511127	30.63778		
Total	5	365.4536536			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	12.97847725	5.644249457	2.299416	0.082992	-2.692471531	28.649426
Princeton Dorm Bednights	0.117762448	0.041823409	2.815707	0.048037	0.001642049	0.2338828



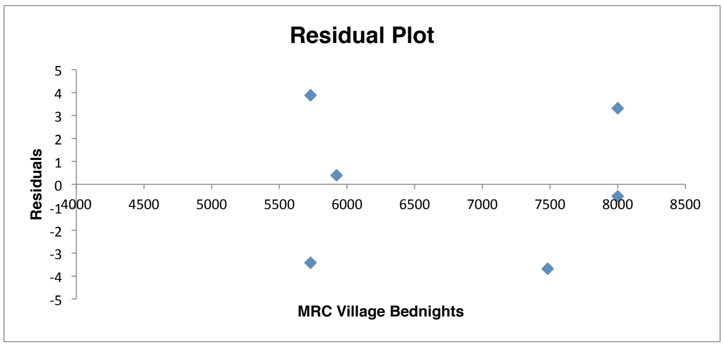
Appendix 18: Regression analysis results, monthly MRC Village bednights vs monthly MRC Village water use

Regression Statistics	
Multiple R	0.965759028
R Square	0.932690501
Adjusted R Square	0.915863126
Standard Error	3.596106328
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	716.7805841	716.7805841	55.42697592	0.001738593
Residual	4	51.72792289	12.93198072		
Total	5	768.5085069			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	28.99890436	9.792726814	2.961269615	0.041502099	1.809935929	56.18787279
MRC Village Bednights	0.010585018	0.001421775	7.444929544	0.001738593	0.006637537	0.0145325



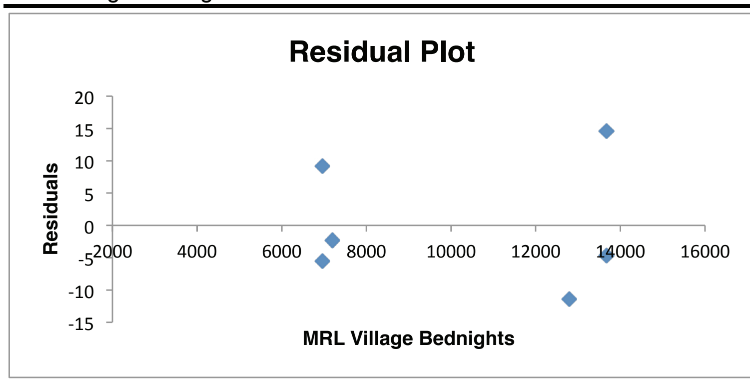
Appendix 19: Regression analysis results, monthly ranch village bednights vs monthly ranch village water use

Regression Statistics	
Multiple R	0.903441929
R Square	0.816207318
Adjusted R Square	0.770259148
Standard Error	11.01667645
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2155.92402	2155.924	17.76365	0.013535064
Residual	4	485.4686402	121.36716		
Total	5	2641.39266			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	80.21532367	15.10163272	5.3116988	0.006039	38.28646943	122.1441779
MRL Village Bednights	0.005952735	0.001412376	4.2146948	0.013535	0.00203135	0.00987412



Appendix 20: Comparison of rooftop areas reported at MRC and the Ranch

	Roof Area (m^2)		
	Ransom et al. (2012)	Antokal et al. (2011)	Lane (2010)
Administration Bathroom	68		
Administration Block	300	112*	112
Banda 1		39	
Banda 2		39	
Banda 3		39	
Banda 4		39	
Banda 5	46	39	
Banda 6		39	
Banda 7	19	39	
Banda 8	43	39	
Banda 9	54	39	
Banda 10	19	39	
Banda 11	29	39	
Banda 2/3/4 Bathroom	47		
Banda 7/8 Bathroom	9		
Banda 9/10 Bathroom	8		
Dining Hall	307	286*	286
Director's House	170	130*	130
Director's Shed	101		
Grevy House	177	155*	155
Gym		80	
Heathrow House	216	226	
Heathrow Shed	22		
Jenga House	190	175*	175
Julius's House		35	
Keller's ("Old") Dorm	158		
Kitchen/Laundry	63	66	
Klee House	198	155	
Library	191	199*	199
McCormack's Lab	349	175	
NSF Lab	170	175*	175
Parking	156		
Petrol Bunk	45	41	
Princeton Dorm		200	
Store 15		65*	65
Village house (1 bedroom)		19	
Village house (1 bedroom, plus)		30	
Village house (2 bedroom)		26	
Village house (Triplex)		12	
Wild Dog House	136	90	
Workshop (total of all buildings)	296		
Workshop (unknown building(s))		145	

* indicates that area was sited from Lane (2010) and is not an independently measured area

Appendix 21: Historical Water Quality Data Collected at Mpala

Water Analysis

Basic Drinking Water Analysis

Crop Nutrition Laboratory Services
Healthy, Profitable Farming

Customer:	Rural Focus Ltd	**Water Use:**	Drinking (W.H.O.)	**Date Received:**	12-Mar-12
Farm Name:	Impala Ranch	**Crop Stage:**		**Report Date:**	20-Mar-12
Contact Person:		**Comments:**		**Sample ID:**	CR027WA0070

Water Source: Nanja Dam

To maintain the correct history ensure that the next sample sent from this Water Source is labelled: Nanja Dam

History (Last 4 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Normal	High	Symbol	Current
pH		**8.05**	6.50	8.50				pH	8.05
Electrical Conductivity	mS cm -1	**0.35**		< 1.50				EC	0.35
Ammonium	ppm	**0.68**		< 1.50				NH4	0.68
Calcium	ppm	**19.42**		< 250.00				Ca	19.42
Magnesium	ppm	**5.55**		< 50.00				Mg	5.55
Potassium	ppm	**9.91**		< 12.00				K	9.91
Sodium	ppm	**43.13**		< 200.00				Na	43.13
Nitrate N	ppm	**0.46**		< 11.00				NO3N	0.46
Phosphorus	ppm	**< 0.01**		< 0.20				P	< 0.01
Sulphur	ppm	**0.74**		< 84.00				S	0.74
Iron	ppm	**0.70**		< 0.30				Fe	0.70
Manganese	ppm	**0.10**		< 0.50				Mn	0.10
Zinc	ppm	**< 0.01**		< 3.00				Zn	< 0.01
Copper	ppm	**< 0.01**		< 2.00				Cu	< 0.01
Boron	ppm	**0.02**		< 0.30				B	0.02
Chlorides	ppm	**33.78**		< 250.00				Cl	33.78
Bicarbonate	ppm	**132**		< 250				HCO3	132
Fluorides	ppm	**0.63**	0.00	1.50				Fl	0.63
Molybdenum	ppm	**< 0.01**		< 0.07				Mo	< 0.01
Sulphates	ppm	**2.22**		< 252.00				SO4	2.22
Silicon	ppm	**11.77**	0.00	50.00				Si	11.77

COMMENTS

Excess iron has no health effect, but causes color change which lead to offensive water. It stains laundry

Tel: +254 (0) 20 3561192 / 2044735 Fax: + 254 (0) 20 2044735
Mobile: +254 (0) 736 839933 / (0) 720 639933 Email: healthy_soils@cropnuts.com

www.cropnuts.com

Water Analysis

Basic Drinking Water Analysis

Crop Nutrition Laboratory Services
Healthy, Profitable Farming

Customer:	Rural Focus Ltd	Water Use:	Drinking (W.H.O.)	Date Received:	12-Mar-12
Farm Name:	Impala Ranch	Crop Stage:		Report Date:	20-Mar-12
Contact Person:		Comments:		Sample ID:	CR027WA0071

Water Source: Ranch House Tap

To maintain the correct history ensure that the next sample sent from this Water Source is labelled: Ranch House Tap

History (Last 4 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Normal	High	Symbol	Current
pH		**8.03**	6.50	8.50				pH	8.03
Electrical Conductivity	mS cm -1	**0.34**		< 1.50				EC	0.34
Ammonium	ppm	**0.13**		< 1.50				NH4	0.13
Calcium	ppm	**19.31**		< 250.00				Ca	19.31
Magnesium	ppm	**5.47**		< 50.00				Mg	5.47
Potassium	ppm	**8.61**		< 12.00				K	8.61
Sodium	ppm	**41.48**		< 200.00				Na	41.48
Nitrate N	ppm	**0.55**		< 11.00				NO3N	0.55
Phosphorus	ppm	**< 0.01**		< 0.20				P	< 0.01
Sulphur	ppm	**0.65**		< 84.00				S	0.65
Iron	ppm	**0.42**		< 0.30				Fe	0.42
Manganese	ppm	**0.07**		< 0.50				Mn	0.07
Zinc	ppm	**0.15**		< 3.00				Zn	0.15
Copper	ppm	**< 0.01**		< 2.00				Cu	< 0.01
Boron	ppm	**0.02**		< 0.30				B	0.02
Chlorides	ppm	**32.19**		< 250.00				Cl	32.19
Bicarbonate	ppm	**136**		< 250				HCO3	136
Fluorides	ppm	**0.55**	0.00	1.50				Fl	0.55
Molybdenum	ppm	**< 0.01**		< 0.07				Mo	< 0.01
Sulphates	ppm	**1.96**		< 252.00				SO4	1.96
Silicon	ppm	**9.88**	0.00	50.00				Si	9.88

COMMENTS

Excess iron has no health effect, but causes color change which lead to offensive water. It stains laundry

Tel: +254 (0) 20 3561192 / 2044735 Fax: + 254 (0) 20 2044735
Mobile: +254 (0) 736 839933 / (0) 720 639933 Email: healthy_soils@cropnuts.com

www.cropnuts.com

3. WATER QUALITY DATA

In the tables that follow we present the water chemistry data that were obtained during field work and from past programmes and studies. For discussion, see main text (Section 4).

Table A4.8 Historic Mpala Ranch analyses (1)

Parameter:	Units	mg/l	meq/l	% meq/l	mg/l	meq/l	% meq/l	mg/l	meq/l	% meq/l
Source Name:		Mpala GW/978			Mpala GW/978			Mpala GW/978		
Easting (UTM)	E	262421			262421			262421		
Northing (UTM)	N	36999			36999			36999		
Elevation:	m amsl	1819			1819			1819		
Sample by:		Insta Pumps Ltd			Rural Focus Ltd			Rural Focus Ltd		
Sample date:		11/09/2007			17/09/2007			11/04/2008		
Analysis by:		CWTL, MoWI			NCWSC			CDN		
Analysis date:		N/K			25/09/2007			14/04/2008		
Lab EC_{25}:	µS/cm:	1631			1250			1510		
pH:	- Log H^+	8.76			8.82			8.4		
Lab TDS:	mg l^{-1}	1011			1002.0			1120		
Colour:	Hazen	< 5			0			6		
Turbidity:	NTU	1			0.55			5		
CO_2 (aq):	mg/l	0						3.3		
Sodium, Na^+:	mg/l	334	14.53	89.0	13.69	0.60	58.3	220	9.57	92.4
Potassium, K^+:	mg/l	7.2	0.18	1.1	2.80	0.07	7.0		0.00	0.0
Calcium, Ca^{2+}:	mg/l	0.8	0.04	0.2	6.4	0.32	31.3	2	0.10	1.0
Magnesium, Mg^{2+}:	mg/l	19	1.56	9.6	0	0.00	0.0	8	0.66	6.4
Manganese, Mn^{2+}:	mg/l	0.01	0.00	0.0	0	0.00	0.0	0.1	0.00	0.0
Total Iron, Fe:	mg/l	0.01	0.00	0.00	0.64	0.03	3.36	0.4	0.02	0.21
Total cations:		**361.02**	**16.32**	**100.0**	**23.52**	**1.02**	**100.0**	**230.5**	**10.35**	**100.0**
Bicarbonate, HCO_3^-:	mg/l	267.3	4.38	28.7	381	6.24	42.3	492	8.06	44.2
Chloride, Cl^-:	mg/l	290	8.18	53.5	276.9	7.81	53.0	222	6.26	34.3
Fluoride, F^-:	mg/l	27.0	1.42	9.3	1.08	0.06	0.4	29.1	1.53	8.4
Nitrate, NO_3^-:	mg/l	2.6	0.04	0.3	0	0.00	0.0	0.7	0.01	0.1
Nitrite, NO_2^-:	mg/l	0.01	0.00	0.0	0	0.00	0.0		0.00	0.0
Carbonate, CO_3^{2-}:	mg/l	14.5	0.48	3.2	19	0.63	4.3	5.6	0.19	1.0
Sulphate, SO_4^{2-}:	mg/l	37.2	0.77	5.1	0	0.00	0.0	106	2.21	12.1
Total anions:		**638.6**	**15.28**	**100.0**	**678.0**	**14.74**	**100.0**	**855.4**	**18.26**	**100.0**
Other parameters:										
Silica, SiO_2:	mg/l				0			52		
Hardness as $CaCO_3$:	mg/l	80			17			37		
SAR (calc):		16.2			1.5			15.5		
Analysis:										
Calculated EC, µS/cm		1580			788			1431		
Calculated TDS, mg/l		1000			702			1086		
TDS/EC ratio (calculated)		0.63			0.89			0.76		
Reaction error (%)		3.3			-87.1			-27.6		
Calculated hardnesses										
Carbonate (as mg/l $CaCO_3$)		0			0			0		
Non-carbonate (as mg/l $CaCO_3$)		80.2			16.0			37.9		

Table A4.9 Historic Mpala Ranch (2) and Jessel analyses

Parameter:	**Units:**	**mg/l**	**meq/l**	**% meq/l**	**mg/l**	**meq/l**	**% meq/l**
Source Name:		Mpala GW/978			Jessel Suguroi BH		
Easting (UTM)	E:	262421			260500		
Northing (UTM)	N:	36999			26900		
Elevation:	m amsl:	1819			1720		
Sample by:		Rural Focus Ltd			Insta Pumps Ltd		
Sample date:		03/05/2010			28/07/2009		
Analysis by:		CDN			CWTL, MoWI		
Analysis date:		07/05/2010					
Lab EC_{25}:	µS/cm	1710			1432		
pH:	- Log H^+	8.6			8.50		
Lab TDS:	mg/l	1242			887.8		
Colour:	Hazen	4			< 5		
Turbidity:	NTU	1			1		
CO_2 (aq):	mg/l	2.0			0		
Sodium, Na^+:	mg/l	266	11.57	96.8	324	14.09	98.7
Potassium, K^+:	mg/l		0.00	0.0	1.2	0.03	0.2
Calcium, Ca^{2+}:	mg/l	4	0.20	1.7	0.8	0.04	0.3
Magnesium, Mg^{2+}:	mg/l	2	0.16	1.4	1.46	0.12	0.8
Manganese, Mn^{2+}:	mg/l	0.1	0.00	0.0	0.01	0.00	0.0
Total Iron, Fe:	mg/l	0.2	0.01	0.09	0.01	0.00	0.00
Total cations:		**272.30**	**11.95**	**100.0**	**327.48**	**14.28**	**100.0**
Bicarbonate, HCO_3^-:	mg/l	431	7.06	36.6	180.5	2.96	21.8
Chloride, Cl^-:	mg/l	292	8.24	42.6	235	6.63	48.9
Fluoride, F^-:	mg/l	25.1	1.32	6.8	18	0.95	7.0
Nitrate, NO_3^-:	mg/l	1.2	0.02	0.1	2.5	0.04	0.3
Nitrite, NO_2^-:	mg/l		0.00	0.0	0.01	0.00	0.0
Carbonate, CO_3^{2-}:	mg/l	7.1	0.24	1.2	5.4	0.18	1.3
Sulphate, SO_4^{2-}:	mg/l	117	2.44	12.6	134.2	2.79	20.6
Total anions:		**873.4**	**19.31**	**100.0**	**575.6**	**13.55**	**100.0**
Other parameters:							
Silica, SiO_2:	mg/l	52					
Hardness as $CaCO_3$:	mg/l	17					
SAR (calc):		27.1			49.8		
Analysis:							
Calculated EC, µS/cm		1563			1392		
Calculated TDS, mg/l		1146			903		
TDS/EC ratio (calculated)		0.73			0.65		
Reaction error (%)		-23.6			2.6		
Calculated hardnesses							
Carbonate (as mg/l $CaCO_3$		0			0		
Non-carbonate (as mg/l $CaCO_3$)		18.2			8.0		

Table A4.17 June 2010 analyses

Parameter:	Units:	mg/l	meq/l	% meq/l	mg/l	meq/l	% meq/l	mg/l	meq/l	% meq/l
Source Name:		Mpala GW/978			Nyanja source			Esawo Ngiro Road Bridge		
Easting (UTM)	E:	262421			264610			267056		
Northing (UTM)	N:	36999			37187			33688		
Elevation:	m amsl:	1819			1753			1664		
Sample by:		Aquasearch Ltd			Aquasearch Ltd			Aquasearch Ltd		
Sample date:		24/06/2010			24/06/2010			24/06/2010		
Analysis by:		Crop Nutrition			Crop Nutrition			Crop Nutrition		
Analysis date:		15/07/2010			15/07/2010			15/07/2010		
Lab EC_{25}:	µS/cm	1950			110			170		
pH:	- Log H^+	8.47			8.54			7.74		
Lab TDS:	mg/l	876			48			72		
Colour:	mg/l	10			40			20		
Sodium, Na^+:	mg/l	426.6	18.56	98.6	16.04	0.70	37.7	17.1	0.74	39.6
Potassium, K^+:	mg/l	2.33	0.06	0.3	5.80	0.15	8.0	3.98	0.10	5.4
Calcium, Ca^{2+}:	mg/l	2.45	0.12	0.6	5.07	0.25	13.7	12.02	0.60	31.9
Magnesium, Mg^{2+}:	mg/l	0.88	0.07	0.4	2.44	0.20	10.8	4.31	0.35	18.9
Manganese, Mn^{2+}:	mg/l	0.01	0.00	0.0	0.08	0.00	0.2	0.03	0.00	0.1
Total Iron, Fe:	mg/l	0.01	0.00	0.00	10.22	0.55	29.65	1.44	0.08	4.12
Total cations:		**432.28**	**18.81**	**100.0**	**39.65**	**1.85**	**100.0**	**38.88**	**1.88**	**100.0**
Bicarbonate, HCO_3^-:	mg/l	392	6.42	37.0	54	0.88	80.4	79	1.29	83.2
Chloride, Cl^-:	mg/l	258.44	7.29	41.9	5.21	0.15	13.3	6.30	0.18	11.4
Fluoride, F^-:	mg/l	24.66	1.30	7.5	0.11	0.01	0.5	0.34	0.02	1.2
Nitrate, NO_3^-:	mg/l	0.04	0.00	0.0	0.04	0.00	0.1	0.13	0.00	0.1
Nitrite, NO_2^-:	mg/l	0.01	0.00	0.0	0.01	0.00	0.0	0.03	0.00	0.0
Carbonate, CO_3^{2-}:	mg/l	7.5	0.25	1.4	0.01	0.00	0.0	0.01	0.00	0.0
Sulphate, SO_4^{2-}:	mg/l	101.7	2.12	12.2	2.99	0.06	5.7	2.99	0.06	4.0
Total anions:		**784.4**	**17.38**	**100.0**	**62.4**	**1.10**	**100.0**	**88.8**	**1.56**	**100.0**
Other parameters:										
Hardness as $CaCO_3$:	mg l^{-1}:	34.24			34.24			51.36		
Analysis:										
Calculated EC, µS/cm		1810			148			172		
Calculated TDS, mg/l		1217			102			128		
TDS/EC ratio (calculated)		0.67			0.69			0.74		
Reaction error (%)		4.0			25.4			9.4		
Calculated hardnesses										
Carbonate (mg/l $CaCO_3$)		0			0			0		
Non-carbonate (mg/l $CaCO_3$)		9.7			22.7			47.7		

Appendix 22: Water Quality Sampling Data

Compiled into this appendix are the water quality data we collected at Mpala during the 2011 rainy season and 2012 dry season sampling events. The following notes should help guide the reader through the information:

Coliform data

All samples were collected and analyzed on the same day.

- m-ColiBlue24® media was used during both sampling events to enumerate the quantity of total coliform and *E. coli* present
- modified m-TEC media was used during the dry season sampling event to more accurately enumerate the quantity of *E. coli* present
- cells highlighted in green represent all results from 100 mL of undiluted sample, and plates reporting the ideal number of colony forming units (CFU) per plate (20-200)

All other water quality data

All samples were collected and analyzed on the same day except alkalinity samples, which were all analyzed at the University of Michigan on March 7th, 2012.

- average and standard deviation: reported for all quantities measured by the YSI (dissolved oxygen, specific conductivity, and temperature during the rainy season), due to the large number of results reported by the machine.
- filtered: when samples were too turbid to yield results for phosphate and nitrate when using the colorimeter, they were filtered first, and then analyzed. This is noted for samples during the rainy season, but records were not obtained for those filtered during the dry season event.
- high/low range: the hardness and alkalinity test kits had two ranges, this represents the range used in each analysis.
- test strip: indicates the data was obtained from a rapid result test strip as opposed to an analytical method
- pH/TDS meter: this indicates which instrument (pH or TDS) the temperature data was obtained from
- _ mL filtered: this indicates the quantity of sample that was passed through the filter to obtain the reported result

There are a number of sites listed at the end of the appendix that were sampled with the extra media and reagents left over. These sites were not included in any statistical analysis, and were for illustration purposes only.

Abbreviations

- $CaCO_3^-$ - calcium carbonate
- CFU - colony forming unit
- mg/L - milligrams per liter
- NO_2^--N - nitrite nitrogen
- NO_3^--N - nitrate nitrogen
- NTU - nephelometric turbidity unit
- PO_4^{2-} - phosphate
- PtCo - platinum cobalt color unit
- TNTC - too numerous to count
- µS/cm - microsiemen per centimeter

Banda 7 cold tap

- Where and how was water collected?
Collected from the shared Banda 7/8 bathroom faucet in the shower

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean area; people bathe here; toilet located nearby.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	***E. coli* (CFU/100 mL)**	Other CFU on plate	Total CFU on plate	**Total coliform (CFU/100mL)**
29-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	500	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	1,000	1	**1,000**	2	3	**3,000**
31-Aug	m-ColiBlue24®	500	1	**500**	9	10	**5,000**
31-Aug	m-ColiBlue24®	500	1	**500**	16	17	**8,500**
31-Aug	m-ColiBlue24®	500	1	**500**	8	9	**4,500**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	***E. coli* (CFU/100 mL)**	Other CFU on plate	Total CFU on plate	**Total coliform (CFU/100mL)**
27-Feb	m-ColiBlue24®	250	0	**0**	1	1	**250**
27-Feb	m-ColiBlue24®	333	0	**0**	0	0	**0**
27-Feb	m-ColiBlue24®	500	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	none	2	**2**	132	134	**134**
28-Feb	m-ColiBlue24®	2.00	0	**0**	39	39	**78**
28-Feb	m-ColiBlue24®	100	0	**0**	0	0	**0**
28-Feb	modified m-TEC	1.25	0	**0**	--	--	**--**
28-Feb	modified m-TEC	2.00	0	**0**	--	--	**--**
28-Feb	modified m-TEC	2.00	0	**0**	--	--	**--**
1-Mar	m-ColiBlue24®	2.50	0	**0**	4	4	**10**
1-Mar	m-ColiBlue24®	5.00	0	**0**	1	1	**5**
1-Mar	m-ColiBlue24®	10.0	0	**0**	6	6	**60**
2-Mar	m-ColiBlue24®	2.50	0	**0**	TNTC	TNTC	**TNTC**
2-Mar	m-ColiBlue24®	4.00	0	**0**	TNTC	TNTC	**TNTC**
2-Mar	m-ColiBlue24®	10.0	1	**10**	148	149	**1,490**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
3-Mar	m-ColiBlue24®	1.54	0	**0**	9	9	**14**
3-Mar	m-ColiBlue24®	2.00	0	**0**	4	4	**8**
3-Mar	m-ColiBlue24®	2.50	0	**0**	22	22	**55**
3-Mar	m-ColiBlue24®	4.00	0	**0**	17	17	**68**
3-Mar	m-ColiBlue24®	10.0	0	**0**	11	11	**110**
3-Mar	m-ColiBlue24®	20.0	0	**0**	29	29	**580**

Banda 7 cold tap

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	6.76	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0197	mg/L	standard deviation
Hardness	8/29/11	rainy	19	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	19	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	20	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	50	mg/L as $CaCO_3$	test strip
Hardness	2/27/12	dry	137	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	137	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	257	mg/L as $CaCO_3$	test strip
Nitrate	8/29/11	rainy	0.01	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0	mg/L NO_3-N	test strip
Nitrite	8/29/11	rainy	0	mg/L NO_2-N	test strip
pH	2/27/12	dry	8.4	pH units	
pH	2/27/12	dry	9	pH units	test strip
pH	2/28/12	dry	8.7	pH units	
Phosphate	8/29/11	rainy	0.33	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.37	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.33	mg/L as PO_4	
Phosphate	2/27/12	dry	0.23	mg/L as PO_4	
Phosphate	2/27/12	dry	0.13	mg/L as PO_4	
Phosphate	2/27/12	dry	0.14	mg/L as PO_4	
Phosphate	2/27/12	dry	0.22	mg/L as PO_4	
Phosphate	2/27/12	dry	0.15	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	1948	µS/cm	average
Specific conductivity	8/31/11	rainy	1.302	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	1613	µS/cm	
Specific conductivity	2/28/12	dry	1932	µS/cm	
Temperature	8/31/11	rainy	24.26	°C	average
Temperature	8/31/11	rainy	0.02678	°C	standard deviation
Temperature	2/27/12	dry	20.7	°C	pH meter
Temperature	2/27/12	dry	20.7	°C	TDS meter
Temperature	2/28/12	dry	24.2	°C	pH meter
Temperature	2/28/12	dry	25.5	°C	TDS meter
Total suspended solids	9/1/11	rainy	4	mg/L	500 mL filtered
Total suspended solids	9/1/11	rainy	3	mg/L	750 mL filtered
Total suspended solids	9/1/11	rainy	2	mg/L	750 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	1,000 mL filtered
Turbidity	2/27/12	dry	9.01	NTU	
Turbidity	2/27/12	dry	8.49	NTU	
Turbidity	2/27/12	dry	8.87	NTU	

Banda 7 hot tap

- Where and how was water collected?
Collected from the sink in Banda 7/8 shared bathroom. Hot water was not flowing from shower when tap turned on.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Toilet and shower nearby. People brush their teeth and wash hands in the sink.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
2/28: Clear; 2/29: Very dirty; black

- Other notes
2/28: Temperature would drop rapidly after sample was taken, which made measuring TDS difficult.
2/29: TDS wouldn't go above 60 degrees Celsius; it just flashed "60°C"

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	***E. coli* (CFU/100 mL)**	Other CFU on plate	Total CFU on plate	**Total coliform (CFU/100mL)**
29-Aug	m-ColiBlue24®	100	0	**0**	2	2	**200**
29-Aug	m-ColiBlue24®	500	0	**0**	0	0	**0**
29-Aug	m-ColiBlue24®	1,000	0	**0**	0	0	**0**
31-Aug	m-ColiBlue24®	100	12	**1,200**	8	20	**2,000**
31-Aug	m-ColiBlue24®	100	5	**500**	3	8	**800**
31-Aug	m-ColiBlue24®	100	10	**1,000**	15	25	**2,500**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	***E. coli* (CFU/100 mL)**	Other CFU on plate	Total CFU on plate	**Total coliform (CFU/100mL)**
28-Feb	m-ColiBlue24®	2.00	0	**0**	1	1	**2**
28-Feb	m-ColiBlue24®	100	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	200	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	500	0	**0**	2	2	**1,000**
29-Feb	m-ColiBlue24®	1,000	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	1,000	0	**0**	1	1	**1,000**
29-Feb	modified m-TEC	200	0	**0**	--	--	**--**
29-Feb	modified m-TEC	500	0	**0**	--	--	**--**
29-Feb	modified m-TEC	1,000	0	**0**	--	--	**--**
3-Mar	modified m-TEC	20.0	1	**20**	--	--	**--**
3-Mar	modified m-TEC	25.0	0	**0**	--	--	**--**
3-Mar	modified m-TEC	33.3	0	**0**	--	--	**--**

*On March 3rd, the water was turbid and clogged the filter.

Banda 7 hot tap

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	400	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	3.23	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0821	mg/L	standard deviation
Hardness	8/29/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	86	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	120	mg/L as $CaCO_3$	test strip
Hardness	2/28/12	dry	12	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	11	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	12	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	26	mg/L as $CaCO_3$	test strip
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0	mg/L NO_3-N	test strip
Nitrite	8/29/11	rainy	0	mg/L NO_2-N	test strip
pH	2/28/12	dry	8.5	pH units	
pH	2/28/12	dry	9	pH units	test strip
pH	2/29/12	dry	8.4	pH units	
pH	2/29/12	dry	9	pH units	test strip
Phosphate	8/29/11	rainy	0.54	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.42	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.47	mg/L as PO_4	
Phosphate	2/28/12	dry	0.18	mg/L as PO_4	
Phosphate	2/28/12	dry	0.21	mg/L as PO_4	
Phosphate	2/28/12	dry	0.26	mg/L as PO_4	
Phosphate	2/28/12	dry	0.18	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	802	µS/cm	average
Specific conductivity	8/31/11	rainy	0.724	µS/cm	standard deviation
Specific conductivity	2/28/12	dry	1947	µS/cm	
Specific conductivity	2/29/12	dry	2091	µS/cm	
Temperature	8/31/11	rainy	36.52	°C	average
Temperature	8/31/11	rainy	0.1333	°C	standard deviation
Temperature	2/28/12	dry	46.5	°C	pH meter
Temperature	2/28/12	dry	44.8	°C	TDS meter
Temperature	2/29/12	dry	65.5	°C	pH meter
Temperature	2/29/12	dry	60+	°C	TDS meter
Total suspended solids	9/1/11	rainy	10	mg/L	300 mL filtered
Total suspended solids	9/1/11	rainy	13	mg/L	300 mL filtered
Total suspended solids	9/1/11	rainy	14	mg/L	300 mL filtered
Total suspended solids	3/3/12	dry	865	mg/L	20 mL filtered
True color	2/29/12	dry	538	PtCo	
True color	2/29/12	dry	518	PtCo	
Turbidity	2/29/12	dry	1468	NTU	
Turbidity	2/29/12	dry	1506	NTU	
Turbidity	2/29/12	dry	1527	NTU	

Black Tank

- Where and how was water collected?
Taken from spigot at bottom of black storage tank used by MRC villagers.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Kids are known to defecate in the surrounding area. Lots of water taken at this spigot by villagers.

- Does the water have an odor? If so, please describe.
Yes

- Does the water have color or cloudiness? If so, please describe.
Yes, yellowish; river water at this time.

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
29-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	500	0	**0**	43	43	**21,500**
29-Aug	m-ColiBlue24®	1,000	0	**0**	31	31	**31,000**
30-Aug	m-ColiBlue24®	200	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	400	2	**800**	37	39	**15,600**
30-Aug	m-ColiBlue24®	600	0	**0**	12	12	**7,200**
31-Aug	m-ColiBlue24®	300	0	**0**	56	56	**16,800**
31-Aug	m-ColiBlue24®	300	0	**0**	55	55	**16,500**
31-Aug	m-ColiBlue24®	300	1	**300**	33	34	**10,200**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)	Notes
29-Feb	m-ColiBlue24®	2.00	3	**6**	confluent growth with colonies			
29-Feb	m-ColiBlue24®	100	0	**0**	1	1	**100**	
29-Feb	m-ColiBlue24®	500	0	**0**	1	1	**500**	
29-Feb	modified m-TEC	none	8	**8**	--	--	**--**	b
29-Feb	modified m-TEC	2.00	4	**8**	--	--	**--**	b
29-Feb	modified m-TEC	2.00	6	**12**	--	--	**--**	b
1-Mar	m-ColiBlue24®	2.22	0	**0**	confluent growth with colonies			a
1-Mar	m-ColiBlue24®	3.33	0	**0**	confluent growth with colonies			a
1-Mar	m-ColiBlue24®	6.67	0	**0**	TNTC	TNTC	**TNTC**	
2-Mar	m-ColiBlue24®	5.00	0	**0**	TNTC	TNTC	**TNTC**	
2-Mar	m-ColiBlue24®	5.56	0	**0**	TNTC	TNTC	**TNTC**	
2-Mar	m-ColiBlue24®	6.67	0	**0**	TNTC	TNTC	**TNTC**	
3-Mar	m-ColiBlue24®	10.0	0	**0**	TNTC	TNTC	**TNTC**	a
3-Mar	m-ColiBlue24®	12.5	0	**0**	TNTC	TNTC	**TNTC**	a
3-Mar	m-ColiBlue24®	20.0	0	**0**	TNTC	TNTC	**TNTC**	a
3-Mar	m-ColiBlue24®	50.0	0	**0**	TNTC	TNTC	**TNTC**	a
3-Mar	m-ColiBlue24®	100	1	**100**	TNTC	TNTC	**TNTC**	a
3-Mar	m-ColiBlue24®	200	0	**0**	TNTC	TNTC	**TNTC**	a
3-Mar	modified m-TEC	none	1	**1**	--	--	**--**	
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**	
3-Mar	modified m-TEC	none	1	**1**	--	--	**--**	

a) Performed by different analyst
b) Sample was turbid and difficult to filter 100 mL through, so it was diluted for the 2nd and 3rd duplicates.

Black Tank

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	200	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	4.88	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.119	mg/L	standard deviation
Hardness	8/29/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	test strip
Hardness	2/29/12	dry	154	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	154	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	154	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	205	mg/L as $CaCO_3$	test strip
Nitrate	9/1/11	rainy	0.12	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.11	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.08	mg/L NO_3-N	filtered
pH	2/29/12	dry	8.3	pH units	
pH	2/29/12	dry	8	pH units	test strip
pH	3/1/12	dry	8.2	pH units	
pH	3/1/12	dry	8	pH units	test strip
Phosphate	8/29/11	rainy	0.35	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.24	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.38	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.40	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.44	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.39	mg/L as PO_4	filtered
Phosphate	2/29/12	dry	0.17	mg/L as PO_4	
Phosphate	2/29/12	dry	0.18	mg/L as PO_4	
Phosphate	2/29/12	dry	0.16	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	143	µS/cm	average
Specific conductivity	8/31/11	rainy	0.426	µS/cm	standard deviation
Specific conductivity	2/29/12	dry	422	µS/cm	
Specific conductivity	3/1/12	dry	416	µS/cm	
Temperature	8/31/11	rainy	19.42	°C	average
Temperature	8/31/11	rainy	0.02061	°C	standard deviation
Temperature	2/29/12	dry	20.9	°C	pH meter
Temperature	2/29/12	dry	20.9	°C	TDS meter
Temperature	3/1/12	dry	23.5	°C	pH meter
Temperature	3/1/12	dry	23.6	°C	TDS meter
Total suspended solids	9/1/11	rainy	40	mg/L	25 mL filtered
Total suspended solids	9/1/11	rainy	120	mg/L	25 mL filtered
Total suspended solids	9/1/11	rainy	20	mg/L	50 mL filtered
Total suspended solids	3/1/12	dry	3	mg/L	500 mL filtered
Total suspended solids	3/1/12	dry	4	mg/L	500 mL filtered
True color	2/29/12	dry	86	PtCo	
True color	2/29/12	dry	87	PtCo	
True color	2/29/12	dry	87.46	PtCo	
Turbidity	2/29/12	dry	18.8	NTU	
Turbidity	2/29/12	dry	18.6	NTU	
Turbidity	2/29/12	dry	18.5	NTU	

Borehole

- Where and how was water collected?
Collected from Tank 1 inlet pipe since they were pumping when sample was taken.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
30-Aug	m-ColiBlue24®	none	0	**0**	TNTC	**TNTC**	**TNTC**
30-Aug	m-ColiBlue24®	none	0	**0**	8	**8**	**8**
30-Aug	m-ColiBlue24®	none	0	**0**	9	**9**	**9**
31-Aug	m-ColiBlue24®	none	0	**0**	10	**10**	**10**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)	Notes
2-Mar	m-ColiBlue24®	none	0	**0**	1	**1**	**1**	a
2-Mar	m-ColiBlue24®	none	0	**0**	1	**1**	**1**	a
2-Mar	m-ColiBlue24®	none	0	**0**	0	**0**	**0**	a

a) Performed by different analyst

Borehole

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	420	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	400	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	3.59	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0676	mg/L	standard deviation
Hardness	8/30/11	rainy	12	mg/L as $CaCO_3$	low range
Hardness	8/30/11	rainy	12	mg/L as $CaCO_3$	low range
Hardness	8/30/11	rainy	13	mg/L as $CaCO_3$	low range
Hardness	8/30/11	rainy	17	mg/L as $CaCO_3$	test strip
Hardness	3/2/12	dry	14	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	13	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	13	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	26	mg/L as $CaCO_3$	test strip
Nitrate	8/30/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0.01	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0.01	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0	mg/L NO_3-N	test strip
Nitrite	8/30/11	rainy	0	mg/L NO_2-N	test strip
pH		dry	8.7	pH units	
pH		dry	8.5	pH units	test strip
Phosphate	8/30/11	rainy	0.13	mg/L as PO_4	
Phosphate	8/30/11	rainy	0.13	mg/L as PO_4	
Phosphate	8/30/11	rainy	0.15	mg/L as PO_4	
Phosphate	3/2/12	dry	0.15	mg/L as PO_4	
Phosphate	3/2/12	dry	0.13	mg/L as PO_4	
Phosphate	3/2/12	dry	0.16	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	1946	µS/cm	average
Specific conductivity	8/31/11	rainy	1.187	µS/cm	standard deviation
Specific conductivity		dry	1968	µS/cm	
Temperature	8/31/11	rainy	24.76	°C	average
Temperature	8/31/11	rainy	0.005071	°C	standard deviation
Temperature		dry	26.5	°C	pH meter
Temperature		dry	26.3	°C	TDS meter
Total suspended solids	8/31/11	rainy	1	mg/L	750 mL filtered
Total suspended solids	8/31/11	rainy	3	mg/L	750 mL filtered
Total suspended solids	8/31/11	rainy	3	mg/L	750 mL filtered
Total suspended solids	3/2/12	dry	1	mg/L	1,000 mL filtered
Total suspended solids	3/2/12	dry	0	mg/L	1,000 mL filtered
True color	3/2/12	dry	2	PtCo	
True color	3/2/12	dry	4	PtCo	
True color	3/2/12	dry	15	PtCo	
Turbidity	3/2/12	dry	1.15	NTU	
Turbidity	3/2/12	dry	1.14	NTU	
Turbidity	3/2/12	dry	0.84	NTU	

Clinic

- Where and how was water collected?
Water was collected from the sink faucet in the clinic located to the right when walking in through the doorway.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean; sink is the only thing against the wall

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
2/27: No; 2/29: A little yellow

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	200	0	**0**	9	9	**1,800**
28-Aug	m-ColiBlue24®	600	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
28-Aug	m-ColiBlue24®	1,000	0	**0**	3	3	**3,000**
30-Aug	m-ColiBlue24®	400	0	**0**	20	20	**8,000**
30-Aug	m-ColiBlue24®	600	1	**600**	14	15	**9,000**
30-Aug	m-ColiBlue24®	800	0	**0**	10	10	**8,000**
31-Aug	m-ColiBlue24®	500	0	**0**	52	52	**26,000**
31-Aug	m-ColiBlue24®	500	1	**500**	82	83	**41,500**
31-Aug	m-ColiBlue24®	500	0	**0**	21	21	**10,500**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	250	0	**0**	11	11	**2,750**
27-Feb	m-ColiBlue24®	333	0	**0**	18	18	**6,000**
27-Feb	m-ColiBlue24®	500	0	**0**	9	9	**4,500**
29-Feb	m-ColiBlue24®	200	2	**400**	1	3	**600**
29-Feb	m-ColiBlue24®	200	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	200	0	**0**	2	2	**400**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
29-Feb	modified m-TEC	2.00	0	**0**	--	--	**--**
29-Feb	modified m-TEC	2.00	0	**0**	--	--	**--**
2-Mar	m-ColiBlue24®	50.0	0	**0**	157	157	**7,850**
2-Mar	m-ColiBlue24®	100	0	**0**	43	43	**4,300**
2-Mar	m-ColiBlue24®	200	0	**0**	TNTC	TNTC	**TNTC**
3-Mar	m-ColiBlue24®	8.33	1	**8**	104	105	**875**
3-Mar	m-ColiBlue24®	10.0	0	**0**	142	142	**1,420**
3-Mar	m-ColiBlue24®	14.3	0	**0**	72	72	**1,030**
3-Mar	m-ColiBlue24®	20.0	0	**0**	58	58	**1,160**
3-Mar	m-ColiBlue24®	33.3	0	**0**	39	39	**1,300**
3-Mar	m-ColiBlue24®	100	0	**0**	27	27	**2,700**
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**

Clinic

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/3/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/3/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/3/12	dry	160	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/28/11	rainy	3.52	mg/L	average
Dissolved oxygen	8/28/11	rainy	0.0139	mg/L	standard deviation
Hardness	8/28/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/28/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/28/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	test strip
Nitrate	9/1/11	rainy	0.07	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.10	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.16	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.06	mg/L NO_3-N	filtered
pH	2/27/12	dry	7.7	pH units	
pH	2/27/12	dry	7.5	pH units	test strip
pH	2/29/12	dry	7.7	pH units	
pH	2/29/12	dry	7.5	pH units	test strip
Phosphate	8/28/11	rainy	0.11	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.18	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.15	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.33	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.26	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.27	mg/L as PO_4	filtered
Phosphate	2/27/12	dry	0.07	mg/L as PO_4	
Phosphate	2/27/12	dry	0.09	mg/L as PO_4	
Phosphate	2/27/12	dry	0.05	mg/L as PO_4	
Specific conductivity	8/28/11	rainy	140	µS/cm	average
Specific conductivity	8/28/11	rainy	0.00	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	348	µS/cm	
Specific conductivity	2/29/12	dry	355	µS/cm	
Temperature	8/28/11	rainy	27.39	°C	average
Temperature	8/28/11	rainy	0.008338	°C	standard deviation
Temperature	2/27/12	dry	26.9	°C	pH meter
Temperature	2/27/12	dry	26.9	°C	TDS meter
Temperature	2/29/12	dry	26.6	°C	pH meter
Temperature	2/29/12	dry	26.7	°C	TDS meter
Total suspended solids	8/31/11	rainy	20	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	40	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	30	mg/L	100 mL filtered
Total suspended solids	3/2/12	dry	776	mg/L	50 mL filtered
Total suspended solids	3/3/12	dry	5	mg/L	375 mL filtered
True color	2/27/12	dry	70	PtCo	
True color	2/27/12	dry	69	PtCo	
True color	2/27/12	dry	63	PtCo	
Turbidity	2/27/12	dry	4.02	NTU	
Turbidity	2/27/12	dry	4.2	NTU	
Turbidity	2/27/12	dry	3.98	NTU	
Turbidity	2/27/12	dry	3.99	NTU	

Deionized Water

- Where and how was water collected?
DI water was purchased from a variety of locations in Nanyuki

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
30-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
30-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
30-Aug	m-ColiBlue24®	none	0	**0**	2	2	**2**
31-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
31-Aug	m-ColiBlue24®	none	0	**0**	15	15	**15**
31-Aug	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Sep	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Sep	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Sep	m-ColiBlue24®	none	0	**0**	2	2	**2**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
26-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
26-Feb	modified m-TEC	none	0	**0**	--	--	**--**
27-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
27-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
27-Feb	m-ColiBlue24®	none	0	**0**	19	19	**19**
28-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	none	0	**0**	1	1	**1**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**
29-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
3-Mar	m-ColiBlue24®	none	0	**0**	7	7	**7**
3-Mar	m-ColiBlue24®	none	0	**0**	2	2	**2**
3-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**
3-Mar	modified m-TEC	none	0	**0**	--	--	**--**

Deionized Water

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/7/12	dry	10	mg/L as $CaCO_3$	low range
Alkalinity	3/7/12	dry	10	mg/L as $CaCO_3$	low range
Alkalinity	3/7/12	dry	10	mg/L as $CaCO_3$	low range
Alkalinity	3/7/12	dry	40	mg/L as $CaCO_3$	high range
Dissolved oxygen	9/1/11	rainy	7.32	mg/L	average
Dissolved oxygen	9/1/11	rainy	0.00686	mg/L	standard deviation
Hardness	8/30/11	rainy	0	mg/L as $CaCO_3$	low range
Hardness	8/30/11	rainy	0	mg/L as $CaCO_3$	test strip
Hardness	2/28/12	dry	0	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	0	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	0	mg/L as $CaCO_3$	low range
Hardness	2/28/12	dry	9	mg/L as $CaCO_3$	test strip
Nitrate	9/1/11	rainy	0.01	mg/L NO_3-N	
Nitrate	9/1/11	rainy	0.01	mg/L NO_3-N	
Nitrate	9/1/11	rainy	0.01	mg/L NO_3-N	
Phosphate	8/27/11	rainy	0.00	mg/L PO_4	
Phosphate	8/30/11	rainy	0.02	mg/L PO_4	
Phosphate	8/30/11	rainy	0.01	mg/L PO_4	
Phosphate	8/30/11	rainy	0.02	mg/L PO_4	
Phosphate	9/1/11	rainy	0.07	mg/L PO_4	
Phosphate	9/1/11	rainy	0.08	mg/L PO_4	
Phosphate	9/1/11	rainy	0.07	mg/L PO_4	
Phosphate	2/27/12	dry	0.02	mg/L PO_4	
Phosphate	2/28/12	dry	0.02	mg/L PO_4	
Phosphate	2/29/12	dry	0.07	mg/L PO_4	
Phosphate	3/1/12	dry	0.03	mg/L PO_4	
Phosphate	3/2/12	dry	0.07	mg/L PO_4	
Phosphate	3/2/12	dry	0.05	mg/L PO_4	
Phosphate	3/2/12	dry	0.05	mg/L PO_4	
Specific conductivity	9/1/11	rainy	2	µS/cm	average
Specific conductivity	9/1/11	rainy	0	µS/cm	standard deviation
Temperature	9/1/11	rainy	20.58	°C	average
Temperature	9/1/11	rainy	0.007906	°C	standard deviation
Total suspended solids	9/1/11	rainy	-1	mg/L	1,000 mL plated
Total suspended solids	9/1/11	rainy	1	mg/L	1,000 mL plated
Total suspended solids	9/1/11	rainy	0	mg/L	1,000 mL plated
Total suspended solids	2/27/12	dry	0	mg/L	100 mL plated
Total suspended solids	3/2/12	dry	0	mg/L	250 mL plated

Grevy rainwater harvesting tank

- Where and how was water collected?
Collected from spigot located at bottom of rainwater tank. Tank is on NE side of house and spigot is covered by brick enclosure.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean; vegetation around. Spigot covered by brick enclosure

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
31-Aug	m-ColiBlue24®	none	0	**0**	TNTC	TNTC	**TNTC**
31-Aug	m-ColiBlue24®	100	0	**0**	40	40	**4,000**
31-Aug	m-ColiBlue24®	500	0	**0**	14	14	**7,000**
1-Sep	m-ColiBlue24®	100	1	**100**	5	6	**600**
1-Sep	m-ColiBlue24®	100	3	**300**	5	8	**800**
1-Sep	m-ColiBlue24®	100	2	**200**	1	3	**300**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	none	0	**0**	TNTC	TNTC	**TNTC**
27-Feb	m-ColiBlue24®	2.00	0	**0**	TNTC	TNTC	**TNTC**
27-Feb	m-ColiBlue24®	100	0	**0**	19	19	**1,900**
28-Feb	m-ColiBlue24®	50.0	0	**0**	51	51	**2,550**
28-Feb	m-ColiBlue24®	50.0	0	**0**	69	69	**3,450**
28-Feb	m-ColiBlue24®	50.0	0	**0**	72	72	**3,600**
28-Feb	m-ColiBlue24®	100	0	**0**	34	34	**3,400**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**
28-Feb	modified m-TEC	none	0	**0**	--	--	**--**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	80	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	55	mg/L as $CaCO_3$	low range
Alkalinity	3/4/12	dry	80	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	80	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	2.08	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.157	mg/L	standard deviation

Grevy rainwater harvesting tank

Constituent	Date Sampled	Season	Result	Units	Notes
Hardness	8/31/11	rainy	26	mg/L as $CaCO_3$	low range
Hardness	8/31/11	rainy	26	mg/L as $CaCO_3$	low range
Hardness	8/31/11	rainy	26	mg/L as $CaCO_3$	low range
Hardness	8/31/11	rainy	34	mg/L as $CaCO_3$	test strip
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	75	mg/L as $CaCO_3$	test strip
Nitrate	8/31/11	rainy	0.18	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.18	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.10	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.06	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.10	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.12	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0.19	mg/L NO_3-N	
Nitrate	8/31/11	rainy	0	mg/L NO_3-N	test strip
Nitrate	3/4/12	dry	0	mg/L NO_3-N	test strip
Nitrite	8/31/11	rainy	0	mg/L NO_2-N	test strip
Nitrite	3/4/12	dry	0	mg/L NO_2-N	test strip
pH	2/27/12	dry	9	pH units	
pH	2/27/12	dry	8.5	pH units	test strip
pH	2/28/12	dry	9	pH units	
pH	2/28/12	dry	8.5	pH units	test strip
Phosphate	8/31/11	rainy	0.18	mg/L as PO_4	
Phosphate	8/31/11	rainy	0.16	mg/L as PO_4	
Phosphate	8/31/11	rainy	0.17	mg/L as PO_4	
Phosphate	2/28/12	dry	0.33	mg/L as PO_4	
Phosphate	2/28/12	dry	0.33	mg/L as PO_4	
Phosphate	2/28/12	dry	0.31	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	54	µS/cm	average
Specific conductivity	8/31/11	rainy	0.46	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	115	µS/cm	
Specific conductivity	2/28/12	dry	99	µS/cm	
Temperature	8/31/11	rainy	21.23	°C	average
Temperature	8/31/11	rainy	0.1572	°C	standard deviation
Temperature	2/27/12	dry	23.7	°C	pH meter
Temperature	2/27/12	dry	24.2	°C	TDS meter
Temperature	2/28/12	dry	23.6	°C	pH meter
Temperature	2/28/12	dry	24	°C	TDS meter
Total suspended solids	9/2/11	rainy	0	mg/L	420 mL filtered
Total suspended solids	9/2/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/2/11	rainy	0	mg/L	500 mL filtered
Total suspended solids	3/2/12	dry	1	mg/L	1,000 mL filtered
True color	2/27/12	dry	11	PtCo	
True color	2/27/12	dry	25	PtCo	
True color	2/27/12	dry	15	PtCo	
Turbidity	2/27/12	dry	0.88	NTU	
Turbidity	2/27/12	dry	1.29	NTU	
Turbidity	2/27/12	dry	1.44	NTU	
Turbidity	2/27/12	dry	2.4	NTU	
Turbidity	2/27/12	dry	2.02	NTU	
Turbidity	2/27/12	dry	1.78	NTU	

Gym rainwater harvesting tank

- Where and how was water collected?
Lid of underground tank was removed and bottle dipped into water (submerged about 8 inches under)

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean, surrounded by concrete.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
Clear

- Other notes (ie comments from people on source, etc.)
Debris floating on top of water (e.g. insects)

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	100	1	**100**	0	1	**100**
28-Aug	m-ColiBlue24®	500	0	**0**	1	1	**500**
28-Aug	m-ColiBlue24®	1,000	0	**0**	0	0	**0**
31-Aug	m-ColiBlue24®	none	1	**1**	36	37	**37**
31-Aug	m-ColiBlue24®	none	3	**3**	67	70	**70**
31-Aug	m-ColiBlue24®	none	2	**2**	52	54	**54**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	none	0	**0**	1	1	**1**
27-Feb	m-ColiBlue24®	2.00	0	**0**	86	86	**172**
27-Feb	m-ColiBlue24®	100	0	**0**	TNTC	TNTC	**TNTC**
28-Feb	m-ColiBlue24®	4.00	0	**0**	62	62	**248**
28-Feb	m-ColiBlue24®	4.00	1	**4**	77	78	**312**
28-Feb	m-ColiBlue24®	4.00	1	**4**	101	102	**408**
28-Feb	modified m-TEC	none	2	**2**	--	--	**--**
28-Feb	modified m-TEC	none	4	**4**	--	--	**--**
28-Feb	modified m-TEC	none	6	**6**	--	--	**--**

Gym rainwater harvesting tank

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	100	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	70	mg/L as $CaCO_3$	low range
Alkalinity	3/4/12	dry	90	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	90	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	4.76	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.164	mg/L	standard deviation
Hardness	8/28/11	rainy	27	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	27	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	27	mg/L as $CaCO_3$	low range
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	86	mg/L as $CaCO_3$	test strip
Nitrate	8/30/11	rainy	0.48	mg/L NO_3-N	2x dilution
Nitrate	8/30/11	rainy	0.32	mg/L NO_3-N	2x dilution
Nitrate	8/30/11	rainy	0.46	mg/L NO_3-N	2x dilution
Nitrate	8/30/11	rainy	0.5	mg/L NO_3-N	test strip
Nitrite	8/30/11	rainy	0	mg/L NO_2-N	test strip
pH	2/27/12	dry	9.4	pH units	
pH	2/27/12	dry	8.5-9	pH units	test strip
pH	2/28/12	dry	9.4	pH units	
pH	2/28/12	dry	9	pH units	test strip
Phosphate	8/28/11	rainy	0.30	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.31	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.33	mg/L as PO_4	
Phosphate	2/28/12	dry	0.23	mg/L as PO_4	
Phosphate	2/28/12	dry	0.30	mg/L as PO_4	
Phosphate	2/28/12	dry	0.34	mg/L as PO_4	
Phosphate	2/28/12	dry	0.30	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	104	µS/cm	average
Specific conductivity	8/31/11	rainy	0.403	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	126	µS/cm	
Specific conductivity	2/28/12	dry	131	µS/cm	
Temperature	8/31/11	rainy	20.93	°C	average
Temperature	8/31/11	rainy	0.02167	°C	standard deviation
Temperature	2/27/12	dry	23.3	°C	pH meter
Temperature	2/27/12	dry	23.5	°C	TDS meter
Temperature	2/28/12	dry	23.6	°C	pH meter
Temperature	2/28/12	dry	23.9	°C	TDS meter
Total suspended solids	9/2/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/2/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/2/11	rainy	0	mg/L	500 mL filtered
Total suspended solids	3/2/12	dry	0	mg/L	1,000 mL filtered
True color	2/27/12	dry	12	PtCo	
True color	2/27/12	dry	25	PtCo	
True color	2/27/12	dry	20	PtCo	
Turbidity	2/27/12	dry	0.41	NTU	
Turbidity	2/27/12	dry	0.53	NTU	
Turbidity	2/27/12	dry	0.47	NTU	

MRC Kitchen cold tap

- Where and how was water collected?
Two faucets located at the sink. Taken from right hand faucet in sink.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Pretty clean, cooking area.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	100	0	**0**	43	43	**4,300**
28-Aug	m-ColiBlue24®	500	1	**500**	14	15	**7,500**
28-Aug	m-ColiBlue24®	1,000	0	**0**	2	2	**2,000**
31-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
31-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
31-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
1-Sep	m-ColiBlue24®	1,000	0	**0**	71	71	**71,000**
1-Sep	m-ColiBlue24®	1,000	0	**0**	90	90	**90,000**
1-Sep	m-ColiBlue24®	1,000	0	**0**	82	82	**82,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Feb	m-ColiBlue24®	2.00	0	**0**	TNTC	TNTC	**TNTC**
28-Feb	m-ColiBlue24®	4.00	0	**0**	TNTC	TNTC	**TNTC**
28-Feb	m-ColiBlue24®	100	0	**0**	20	20	**2,000**
29-Feb	m-ColiBlue24®	50.0	0	**0**	36	36	**1,800**
29-Feb	m-ColiBlue24®	50.0	0	**0**	38	38	**1,900**
29-Feb	m-ColiBlue24®	50.0	0	**0**	34	34	**1,700**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	6.41	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0112	mg/L	standard deviation

MRC Kitchen cold tap

Constituent	Date Sampled	Season	Result	Units	Notes
Hardness	8/28/11	rainy	86	mg/L as $CaCO_3$	high range
Hardness	8/28/11	rainy	86	mg/L as $CaCO_3$	high range
Hardness	8/28/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	2/28/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/28/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/28/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/28/12	dry	34	mg/L as $CaCO_3$	test strip
Hardness	3/4/12	dry	23	mg/L as $CaCO_3$	low range
Hardness	3/4/12	dry	23	mg/L as $CaCO_3$	low range
Hardness	3/4/12	dry	23	mg/L as $CaCO_3$	low range
Nitrate	9/1/11	rainy	0.00	mg/L NO_3-N	
Nitrate	9/1/11	rainy	0.00	mg/L NO_3-N	
Nitrate	9/1/11	rainy	0.01	mg/L NO_3-N	
pH	2/28/12	dry	8.7	pH units	
pH	2/28/12	dry	9	pH units	test strip
pH	2/29/12	dry	8.7	pH units	
pH	2/29/12	dry	9	pH units	test strip
Phosphate	8/28/11	rainy	0.22	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.25	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.30	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.26	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.39	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.24	mg/L as PO_4	
Phosphate	2/28/12	dry	0.11	mg/L as PO_4	
Phosphate	2/28/12	dry	0.15	mg/L as PO_4	
Phosphate	2/28/12	dry	0.19	mg/L as PO_4	
Phosphate	2/28/12	dry	0.18	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	1930	µS/cm	average
Specific conductivity	8/31/11	rainy	3.022	µS/cm	standard deviation
Specific conductivity	2/28/12	dry	1766	µS/cm	
Specific conductivity	2/29/12	dry	1866	µS/cm	
Temperature	8/31/11	rainy	25.12	°C	average
Temperature	8/31/11	rainy	0.05215	°C	standard deviation
Temperature	2/28/12	dry	26.8	°C	pH meter
Temperature	2/28/12	dry	26.6	°C	TDS meter
Temperature	2/29/12	dry	26.6	°C	pH meter
Temperature	2/29/12	dry	26.5	°C	TDS meter
Total suspended solids	9/1/11	rainy	1	mg/L	750 mL filtered
Total suspended solids	9/1/11	rainy	0	mg/L	750 mL filtered
Total suspended solids	9/1/11	rainy	1	mg/L	750 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	696 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	1,000 mL filtered
True color	2/29/12	dry	25	PtCo	
True color	2/29/12	dry	19	PtCo	
True color	2/29/12	dry	2	PtCo	
True color	2/29/12	dry	3	PtCo	
True color	2/29/12	dry	18	PtCo	
Turbidity	2/29/12	dry	1.93	NTU	
Turbidity	2/29/12	dry	1.9	NTU	
Turbidity	2/29/12	dry	2.02	NTU	

MRC Kitchen rainwater harvesting tank

- Where and how was water collected?
Taken from faucet of rainwater storage tank located on NW corner of dining hall building (the one people wash their hands at).

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean; people wash their hands at this faucet. New rainwater pipes have been installed leading into this tank.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	100	28	**2,800**	59	87	**8,700**
28-Aug	m-ColiBlue24®	500	2	**1,000**	5	7	**3,500**
28-Aug	m-ColiBlue24®	1,000	0	**0**	2	2	**2,000**
30-Aug	m-ColiBlue24®	100	6	**600**	53	59	**5,900**
30-Aug	m-ColiBlue24®	100	9	**900**	84	93	**9,300**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	100	0	**0**	56	56	**5,600**
27-Feb	m-ColiBlue24®	100	0	**0**	22	22	**2,200**
27-Feb	m-ColiBlue24®	100	1	**100**	13	14	**1,400**
28-Feb	m-ColiBlue24®	100	0	**0**	11	11	**1,100**
28-Feb	m-ColiBlue24®	1,000	0	**0**	0	0	**0**
28-Feb	modified m-TEC	none	28	**28**	--	--	**--**
28-Feb	modified m-TEC	none	19	**19**	--	--	**--**
28-Feb	modified m-TEC	none	30	**30**	--	--	**--**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	1.47	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.358	mg/L	standard deviation
Hardness	8/28/11	rainy	20	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	20	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	21	mg/L as $CaCO_3$	low range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	257	mg/L as $CaCO_3$	test strip

MRC Kitchen rainwater harvesting tank

Constituent	Date Sampled	Season	Result	Units	Notes
Nitrate	8/30/11	rainy	0.19	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0.15	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0.14	mg/L NO_3-N	
Nitrate	8/30/11	rainy	0	mg/L NO_3-N	test strip
Nitrate	3/4/12	dry	10	mg/L NO_3-N	test strip
Nitrite	8/30/11	rainy	0	mg/L NO_2-N	test strip
Nitrite	3/4/12	dry	3	mg/L NO_2-N	test strip
pH	2/27/12	dry	8	pH units	
pH	2/27/12	dry	8	pH units	test strip
pH	2/28/12	dry	8	pH units	
pH	2/28/12	dry	8.5	pH units	test strip
Phosphate	8/28/11	rainy	0.55	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.54	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.58	mg/L as PO_4	
Phosphate	2/27/12	dry	4.50	mg/L as PO_4	2x dilution
Phosphate	2/27/12	dry	4.62	mg/L as PO_4	2x dilution
Phosphate	2/27/12	dry	4.48	mg/L as PO_4	2x dilution
Phosphate	2/27/12	dry	4.58	mg/L as PO_4	2x dilution
Specific conductivity	8/31/11	rainy	56	µS/cm	average
Specific conductivity	8/31/11	rainy	0.45	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	312	µS/cm	
Specific conductivity	2/28/12	dry	306	µS/cm	
Temperature	8/31/11	rainy	20.85	°C	average
Temperature	8/31/11	rainy	0.06491	°C	standard deviation
Temperature	2/27/12	dry	20.4	°C	pH meter
Temperature	2/27/12	dry	20.2	°C	TDS meter
Temperature	2/28/12	dry	22.1	°C	pH meter
Temperature	2/28/12	dry	22.1	°C	TDS meter
Total suspended solids	9/1/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/1/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/1/11	rainy	0	mg/L	500 mL filtered
Total suspended solids	3/2/12	dry	1	mg/L	1,000 mL filtered
Total suspended solids	3/2/12	dry	1	mg/L	750 mL filtered
True color	2/27/12	dry	80	PtCo	
True color	2/27/12	dry	56	PtCo	
True color	2/27/12	dry	47	PtCo	
Turbidity	2/27/12	dry	1.29	NTU	
Turbidity	2/27/12	dry	1.64	NTU	
Turbidity	2/27/12	dry	1.29	NTU	
Turbidity	2/27/12	dry	1.22	NTU	

MRC River

- Where and how was water collected?
From the river behind the pump house that pumps to MRC. Sample taken from the middle of the river

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
No other activity, just the river.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
Light yellow/brown

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
29-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	500	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	1,000	1	**1,000**	26	27	**27,000**
31-Aug	m-ColiBlue24®	1,000	0	**0**	54	54	**54,000**
31-Aug	m-ColiBlue24®	1,000	4	**4,000**	20	24	**24,000**
31-Aug	m-ColiBlue24®	1,000	0	**0**	7	7	**7,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
1-Mar	m-ColiBlue24®	100	0	**0**	25	25	**2,500**
1-Mar	m-ColiBlue24®	100	2	**200**	45	47	**4,700**
1-Mar	m-ColiBlue24®	100	3	**300**	41	44	**4,400**
1-Mar	modified m-TEC	2.00	65	**130**	--	--	**--**
1-Mar	modified m-TEC	5.00	24	**120**	--	--	**--**
1-Mar	modified m-TEC	100	2	**200**	--	--	**--**
2-Mar	modified m-TEC	2.50	54	**135**	--	--	**--**
2-Mar	modified m-TEC	2.86	40	**114**	--	--	**--**
2-Mar	modified m-TEC	2.00	62	**124**	--	--	**--**

MRC River

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	200	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	7.85	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0211	mg/L	standard deviation
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	test strip
Hardness	3/1/12	dry	137	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	154	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	154	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	171	mg/L as $CaCO_3$	test strip
Nitrate	8/31/11	rainy	0.02	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.04	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.04	mg/L NO_3-N	filtered
Nitrate		dry	0	mg/L NO_3-N	test strip
Nitrite		dry	0	mg/L NO_2-N	test strip
pH	3/1/12	dry	8.5	pH units	
pH	3/1/12	dry	8.5	pH units	test strip
pH	3/2/12	dry	8.5	pH units	
Phosphate	8/29/11	rainy	0.00	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.00	mg/L as PO_4	
Phosphate	8/31/11	rainy	0.36	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.28	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.30	mg/L as PO_4	filtered
Phosphate	3/1/12	dry	0.04	mg/L as PO_4	
Phosphate	3/1/12	dry	0.12	mg/L as PO_4	
Phosphate	3/1/12	dry	0.12	mg/L as PO_4	
Phosphate	3/1/12	dry	0.10	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	75	μS/cm	average
Specific conductivity	8/31/11	rainy	0.0	μS/cm	standard deviation
Specific conductivity	3/1/12	dry	413	μS/cm	
Specific conductivity	3/2/12	dry	415	μS/cm	
Temperature	8/31/11	rainy	17.73	°C	average
Temperature	8/31/11	rainy	0.003162	°C	standard deviation
Temperature	3/1/12	dry	21	°C	pH meter
Temperature	3/1/12	dry	21.3	°C	TDS meter
Temperature	3/2/12	dry	19.6	°C	pH meter
Temperature	3/2/12	dry	19.6	°C	TDS meter
Total suspended solids	8/31/11	rainy	360	mg/L	25 mL filtered
Total suspended solids	8/31/11	rainy	440	mg/L	25 mL filtered
Total suspended solids	8/31/11	rainy	400	mg/L	25 mL filtered
Total suspended solids	3/1/12	dry	34	mg/L	200 mL filtered
Total suspended solids	3/1/12	dry	28	mg/L	200 mL filtered
Total suspended solids	3/1/12	dry	33	mg/L	200 mL filtered
True color	3/4/12	dry	127	PtCo	
True color	3/4/12	dry	123	PtCo	
True color	3/4/12	dry	141	PtCo	
Turbidity	3/1/12	dry	127	NTU	
Turbidity	3/1/12	dry	123	NTU	
Turbidity	3/1/12	dry	141	NTU	

MRC Village tap

- Where and how was water collected?
Taken from the tap in the MRC Village. The tap has a meter on it and is surrounded by a concrete platform.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
People do laundry here and collect water in jugs. Houses surround the area and children play nearby.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
29-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	500	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	1,000	9	**9,000**	122	131	**131,000**
30-Aug	m-ColiBlue24®	1,000	0	**0**	22	22	**22,000**
30-Aug	m-ColiBlue24®	1,000	0	**0**	48	48	**48,000**
30-Aug	m-ColiBlue24®	1,000	5	**5,000**	67	72	**72,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
29-Feb	m-ColiBlue24®	2.00	0	**0**	15	15	**30**
29-Feb	m-ColiBlue24®	100	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	500	0	**0**	1	1	**500**
29-Feb	modified m-TEC	none	1	**1**	--	--	**--**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
29-Feb	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	m-ColiBlue24®	none	0	**0**	130	130	**130**
1-Mar	m-ColiBlue24®	1.11	0	**0**	TNTC	TNTC	**TNTC**
1-Mar	m-ColiBlue24®	1.25	0	**0**	109	109	**136**
1-Mar	m-ColiBlue24®	1.25	0	**0**	17	17	**21**
2-Mar	m-ColiBlue24®	none	0	**0**	137	137	**137**
2-Mar	m-ColiBlue24®	none	0	**0**	32	32	**32**
2-Mar	m-ColiBlue24®	none	0	**0**	36	26	**26**

MRC Village tap

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	6.91	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.0128	mg/L	standard deviation
Hardness	8/29/11	rainy	16	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	15	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	14	mg/L as $CaCO_3$	low range
Hardness	8/29/11	rainy	26	mg/L as $CaCO_3$	test strip
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	test strip
Hardness	3/2/12	dry	15	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	15	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	15	mg/L as $CaCO_3$	low range
Nitrate	8/29/11	rainy	0.01	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.00	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0	mg/L NO_3-N	test strip
Nitrite	8/29/11	rainy	0	mg/L NO_2-N	test strip
pH	2/29/12	dry	8.8	pH units	
pH	2/29/12	dry	9	pH units	test strip
pH	3/1/12	dry	8.8	pH units	
pH	3/1/12	dry	8.9	pH units	test strip
Phosphate	8/29/11	rainy	0.18	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.21	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.16	mg/L as PO_4	
Phosphate	2/29/12	dry	0.08	mg/L as PO_4	
Phosphate	2/29/12	dry	0.16	mg/L as PO_4	
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.13	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	1920	µS/cm	average
Specific conductivity	8/31/11	rainy	5.434	µS/cm	standard deviation
Specific conductivity	2/29/12	dry	1934	µS/cm	
Specific conductivity	3/1/12	dry	1968	µS/cm	
Temperature	8/31/11	rainy	22.72	°C	average
Temperature	8/31/11	rainy	0.01552	°C	standard deviation
Temperature	2/29/12	dry	22.7	°C	pH meter
Temperature	2/29/12	dry	22.4	°C	TDS meter
Temperature	3/1/12	dry	26.6	°C	pH meter
Temperature	3/1/12	dry	26.5	°C	TDS meter
Total suspended solids	9/1/11	rainy	1	mg/L	750 mL filtered
Total suspended solids	9/1/11	rainy	1	mg/L	750 mL filtered
Total suspended solids	9/1/11	rainy	0	mg/L	1,000 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	1,000 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	750 mL filtered
True color	3/4/12	dry	0	PtCo	
True color	3/4/12	dry	0	PtCo	
True color	3/4/12	dry	0	PtCo	
Turbidity	2/29/12	dry	0.97	NTU	
Turbidity	2/29/12	dry	0.42	NTU	
Turbidity	2/29/12	dry	0.87	NTU	

Potable

- Where and how exactly was water collected?
Taken from the larger filter tank on the table at the dining hall patio. Water taken from faucet at bottom of tank.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Clean around filter tanks. People eat in this area and lots of people use the faucet to get water.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
Clear

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	none	10	**10**	TNTC	TNTC	**TNTC**
28-Aug	m-ColiBlue24®	none	7	**7**	TNTC	TNTC	**TNTC**
28-Aug	m-ColiBlue24®	none	8	**8**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	none	12	**12**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	none	11	**11**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	none	21	**21**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	100	0	**0**	19	19	**1,900**
30-Aug	m-ColiBlue24®	100	0	**0**	35	35	**3,500**
30-Aug	m-ColiBlue24®	100	0	**0**	43	43	**4,300**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
26-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
26-Feb	m-ColiBlue24®	2.00	0	**0**	0	0	**0**
26-Feb	m-ColiBlue24®	100	0	**0**	0	0	**0**
26-Feb	modified m-TEC	none	0	**0**	--	--	**--**
26-Feb	modified m-TEC	none	0	**0**	--	--	**--**
26-Feb	modified m-TEC	none	0	**0**	--	--	**--**
28-Feb	m-ColiBlue24®	none	0	**0**	0	0	**0**
28-Feb	m-ColiBlue24®	none	0	**0**	10	10	**10**
28-Feb	m-ColiBlue24®	none	0	**0**	1	1	**1**

Potable

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Dissolved oxygen	8/31/11	rainy	6.24	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.00602	mg/L	standard deviation
Hardness	8/27/11	rainy	27	mg/L as $CaCO_3$	low range
Hardness	8/27/11	rainy	34	mg/L as $CaCO_3$	high range
Hardness	8/27/11	rainy	50	mg/L as $CaCO_3$	test strip
Hardness	8/28/11	rainy	24	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	19	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	18	mg/L as $CaCO_3$	low range
Hardness	2/26/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/26/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	2/26/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/26/12	dry	120	mg/L as $CaCO_3$	test strip
Nitrate	8/27/11	rainy	0.47	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.36	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.39	mg/L NO_3-N	
Nitrate	8/29/11	rainy	0.44	mg/L NO_3-N	2x dilution
Nitrate	8/29/11	rainy	0.5	mg/L NO_3-N	test strip
Nitrate	8/29/11	dry	2.5	mg/L NO_3-N	test strip
Nitrite	8/29/11	rainy	0	mg/L NO_2-N	test strip
Nitrite	8/29/11	dry	0	mg/L NO_2-N	test strip
pH	2/26/12	dry	7.6	pH units	
pH	2/26/12	dry	7.5	pH units	test strip
pH	2/29/12	dry	7.9	pH units	
pH	2/29/12	dry	7.5	pH units	test strip
Phosphate	8/27/11	rainy	0.62	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.65	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.63	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.63	mg/L as PO_4	
Phosphate	2/26/12	dry	0.69	mg/L as PO_4	
Phosphate	2/26/12	dry	0.74	mg/L as PO_4	
Phosphate	2/26/12	dry	0.75	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	52	µS/cm	average
Specific conductivity	8/31/11	rainy	0.0	µS/cm	standard deviation
Specific conductivity	2/26/12	dry	151	µS/cm	
Specific conductivity	2/29/12	dry	154	µS/cm	
Temperature	8/31/11	rainy	22.72	°C	average
Temperature	8/31/11	rainy	0.007188	°C	standard deviation
Temperature	2/26/12	dry	25.1	°C	pH meter
Temperature	2/26/12	dry	25.4	°C	TDS meter
Temperature	2/29/12	dry	25.2	°C	pH meter
Temperature	2/29/12	dry	25.5	°C	TDS meter
Total suspended solids	9/1/11	rainy	1	mg/L	1,000 mL filtered
Total suspended solids	9/1/11	rainy	1	mg/L	1,000 mL filtered
Total suspended solids	9/1/11	rainy	1	mg/L	1,000 mL filtered
True color	2/29/12	dry	0	PtCo	
True color	2/29/12	dry	13	PtCo	
True color	2/29/12	dry	13	PtCo	
True color	2/29/12	dry	22	PtCo	
Turbidity	2/29/12	dry	0.41	NTU	
Turbidity	2/29/12	dry	0	NTU	
Turbidity	2/29/12	dry	0.24	NTU	

Ranch House

- Where and how exactly was water collected?

Taken from the Ranch House kitchen sink faucet. Located on the right side as you walk in, opened left handle on tap.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)

Area is clean; cooking area.

- Does the water have an odor? If so, please describe.

No

- Does the water have color or cloudiness? If so, please describe.

No

- Other notes

2/27: They were cooking in the kitchen when sample was taken and had been using water from the sink

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
30-Aug	m-ColiBlue24®	500	0	**0**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	1,000	4	**4,000**	54	58	**58,000**
1-Sep	m-ColiBlue24®	500	0	**0**	19	19	**9,500**
1-Sep	m-ColiBlue24®	500	2	**1,000**	11	13	**6,500**
1-Sep	m-ColiBlue24®	500	2	**1,000**	12	14	**7,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	250	0	**0**	11	11	**2,800**
27-Feb	m-ColiBlue24®	333	0	**0**	17	17	**5,700**
27-Feb	m-ColiBlue24®	500	0	**0**	28	28	**14,000**
29-Feb	m-ColiBlue24®	200	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	200	0	**0**	0	0	**0**
29-Feb	m-ColiBlue24®	200	0	**0**	2	2	**400**
2-Mar	m-ColiBlue24®	10.0	0	**0**	14	14	**140**
2-Mar	m-ColiBlue24®	20.0	0	**0**	7	7	**140**
2-Mar	m-ColiBlue24®	100	0	**0**	2	2	**200**
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	modified m-TEC	2.00	0	**0**	--	--	**--**
2-Mar	modified m-TEC	3.33	0	**0**	--	--	**--**
3-Mar	m-ColiBlue24®	4.00	1	**4**	146	147	**588**
3-Mar	m-ColiBlue24®	5.00	2	**10**	66	68	**340**
3-Mar	m-ColiBlue24®	5.00	0	**0**	47	47	**240**
3-Mar	m-ColiBlue24®	10.0	0	**0**	69	69	**690**
3-Mar	m-ColiBlue24®	20.0	0	**0**	64	64	**1,300**
3-Mar	m-ColiBlue24®	33.3	0	**0**	11	11	**370**
3-Mar	m-ColiBlue24®	100	0	**0**	72	72	**7,200**
3-Mar	m-ColiBlue24®	200	0	**0**	32	32	**6,400**
3-Mar	modified m-TEC	none	2	**2**	--	--	**--**
3-Mar	modified m-TEC	none	7	**7**	--	--	**--**
3-Mar	modified m-TEC	none	3	**3**	--	--	**--**

Ranch House

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	200	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/28/11	rainy	4.86	mg/L	average
Dissolved oxygen	8/28/11	rainy	0.0718	mg/L	standard deviation
Hardness	8/30/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	test strip
Hardness	2/27/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	86	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	test strip
Nitrate	9/1/11	rainy	0.15	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.16	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.18	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.11	mg/L NO_3-N	filtered
Nitrate	3/4/12	dry	0	mg/L NO_3-N	test strip
Nitrite	3/4/12	dry	0	mg/L NO_2-N	test strip
pH	2/27/12	dry	8.6	pH units	
pH	2/27/12	dry	8.5-9	pH units	test strip
pH	2/29/12	dry	8.7	pH units	
pH	2/29/12	dry	8.5	pH units	test strip
Phosphate	8/30/11	rainy	0.16	mg/L as PO_4	
Phosphate	8/30/11	rainy	0.18	mg/L as PO_4	
Phosphate	8/30/11	rainy	0.18	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.25	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.26	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.29	mg/L as PO_4	filtered
Phosphate	2/29/12	dry	0.15	mg/L as PO_4	
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.14	mg/L as PO_4	
Specific conductivity	8/28/11	rainy	156	µS/cm	average
Specific conductivity	8/28/11	rainy	0.00	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	632	µS/cm	
Specific conductivity	2/29/12	dry	680	µS/cm	
Temperature	8/28/11	rainy	21.26	°C	average
Temperature	8/28/11	rainy	0.002582	°C	standard deviation
Temperature	2/27/12	dry	25	°C	pH meter
Temperature	2/27/12	dry	25.5	°C	TDS meter
Temperature	2/29/12	dry	23.8	°C	pH meter
Temperature	2/29/12	dry	24.4	°C	TDS meter
Total suspended solids	8/31/11	rainy	20	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	10	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	20	mg/L	100 mL filtered
Total suspended solids	3/1/12	dry	3	mg/L	200 mL filtered
Total suspended solids	3/1/12	dry	3	mg/L	200 mL filtered
True color	2/27/12	dry	30	PtCo	
True color	2/27/12	dry	28	PtCo	
True color	2/27/12	dry	39	PtCo	
Turbidity	2/27/12	dry	2.15	NTU	
Turbidity	2/27/12	dry	2.19	NTU	
Turbidity	2/27/12	dry	1.57	NTU	
Turbidity	2/27/12	dry	2.2	NTU	

Ranch River

- Where and how exactly was water collected?

Collected from river near hydro dam. River was low, rocks exposed just past pump house. Sample collected from middle of river standing on exposed rocks.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)

No activity, river low.

- Does the water have an odor? If so, please describe.

No

- Does the water have color or cloudiness? If so, please describe.

Cloudy (slightly) and yellowish

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
29-Aug	m-ColiBlue24®	200	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
29-Aug	m-ColiBlue24®	600	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
31-Aug	m-ColiBlue24®	1,000	0	**0**	11	11	**11,000**
31-Aug	m-ColiBlue24®	1,000	2	**2,000**	9	11	**11,000**
31-Aug	m-ColiBlue24®	1,000	3	**3,000**	34	37	**37,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
27-Feb	m-ColiBlue24®	1,000	2	**2,000**	4	6	**6,000**
27-Feb	m-ColiBlue24®	1,000	0	**0**	3	3	**3,000**
27-Feb	m-ColiBlue24®	1,000	0	**0**	3	3	**3,000**
29-Feb	m-ColiBlue24®	66.7	1	**70**	85	86	**5,700**
29-Feb	m-ColiBlue24®	100	1	**100**	63	64	**6,400**
29-Feb	m-ColiBlue24®	200	0	**0**	19	19	**3,800**
2-Mar	modified m-TEC	2.00	74	**148**	--	--	**--**
2-Mar	modified m-TEC	2.00	89	**178**	--	--	**--**
2-Mar	modified m-TEC	2.50	51	**128**	--	--	**--**

Ranch River

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	200	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	220	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	200	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	7.71	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.00515	mg/L	standard deviation
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/29/11	rainy	51	mg/L as $CaCO_3$	test strip
Hardness		dry	154	mg/L as $CaCO_3$	high range
Hardness		dry	154	mg/L as $CaCO_3$	high range
Hardness		dry	154	mg/L as $CaCO_3$	high range
Hardness		dry	257	mg/L as $CaCO_3$	test strip
Nitrate	8/31/11	rainy	0.05	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.03	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.03	mg/L NO_3-N	filtered
Nitrate	2/29/12	dry	0	mg/L NO_3-N	test strip
Nitrite	2/29/12	dry	0	mg/L NO_2-N	test strip
pH	2/27/12	dry	8.5	pH units	
pH	2/27/12	dry	8.5-9	pH units	test strip
pH	2/29/12	dry	8.5	pH units	
pH	2/29/12	dry	9	pH units	test strip
Phosphate	8/29/11	rainy	0.04	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.04	mg/L as PO_4	
Phosphate	8/29/11	rainy	0.37	mg/L as PO_4	
Phosphate	8/31/11	rainy	0.28	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.33	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.34	mg/L as PO_4	filtered
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.17	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	77	µS/cm	average
Specific conductivity	8/31/11	rainy	0.0	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	429	µS/cm	
Specific conductivity	2/29/12	dry	420	µS/cm	
Temperature	8/31/11	rainy	17.4	°C	average
Temperature	8/31/11	rainy	0.004523	°C	standard deviation
Temperature	2/27/12	dry	24.2	°C	pH meter
Temperature	2/27/12	dry	24.7	°C	TDS meter
Temperature	2/29/12	dry	25.2	°C	pH meter
Temperature	2/29/12	dry	25.5	°C	TDS meter
Total suspended solids	8/31/11	rainy	320	mg/L	25 mL filtered
Total suspended solids	8/31/11	rainy	360	mg/L	25 mL filtered
Total suspended solids	8/31/11	rainy	360	mg/L	25 mL filtered
Total suspended solids	2/27/12	dry	20	mg/L	100 mL filtered
Total suspended solids	2/27/12	dry	20	mg/L	100 mL filtered
Total suspended solids	2/27/12	dry	30	mg/L	100 mL filtered
True color	2/27/12	dry	118	PtCo	
True color	2/27/12	dry	107	PtCo	
True color	2/27/12	dry	107	PtCo	
Turbidity	2/27/12	dry	20.9	NTU	
Turbidity	2/27/12	dry	21.3	NTU	
Turbidity	2/27/12	dry	20.8	NTU	

Ranch Village tap

- Where and how exactly was water collected?

Taken from the spigot on a stone structure located about in the middle of the village. If coming from the Ranch House between the two storage tanks, it's northeast into the village. There is an elevated drain below the spigot.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)

Houses close by; in the middle of the village; seemed relatively clean but it gets a lot of use by villagers.

- Does the water have an odor? If so, please describe.

No

- Does the water have color or cloudiness? If so, please describe.

2/27: No; 2/29: Very light yellow tint

- Other notes

Sample was taken for analysis on 3/2, which was right after the village tank had been emptied and then filled, so lots of sediment from the tank was in the water.

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Aug	m-ColiBlue24®	200	0	**0**	14	14	**2,800**
28-Aug	m-ColiBlue24®	600	0	**0**	2	2	**1,200**
28-Aug	m-ColiBlue24®	1,000	0	**0**	1	1	**1,000**
30-Aug	m-ColiBlue24®	400	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	600	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	800	0	**0**	15	15	**12,000**
1-Sep	m-ColiBlue24®	500	4	**2,000**	2	6	**3,000**
1-Sep	m-ColiBlue24®	500	3	**1,500**	4	7	**3,500**
1-Sep	m-ColiBlue24®	500	6	**3,000**	11	17	**8,500**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)	Notes
27-Feb	m-ColiBlue24®	100	0	**0**	6	6	**600**	
27-Feb	m-ColiBlue24®	500	0	**0**	17	17	**8,500**	
27-Feb	m-ColiBlue24®	1,000	0	**0**	0	0	**0**	
29-Feb	m-ColiBlue24®	25.0	0	**0**	3	3	**80**	
29-Feb	m-ColiBlue24®	33.3	0	**0**	2	2	**70**	
29-Feb	m-ColiBlue24®	50.0	0	**0**	2	2	**100**	
2-Mar	m-ColiBlue24®	2.00	0	**0**	TNTC	TNTC	**TNTC**	
2-Mar	m-ColiBlue24®	3.33	0	**0**	TNTC	TNTC	**TNTC**	
2-Mar	m-ColiBlue24®	20.0	0	**0**	21	21	**420**	
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**	
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**	
2-Mar	modified m-TEC	none	0	**0**	--	--	**--**	
3-Mar	m-ColiBlue24®	10.0	0	**0**	200	200	**2,000**	a
3-Mar	m-ColiBlue24®	10.0	0	**0**	74	74	**740**	
3-Mar	m-ColiBlue24®	12.5	0	**0**	118	118	**1,480**	a
3-Mar	m-ColiBlue24®	14.3	1	**14**	56	57	**810**	
3-Mar	m-ColiBlue24®	20.0	0	**0**	82	82	**1,600**	
3-Mar	m-ColiBlue24®	20.0	0	**0**	96	96	**1,900**	

a) Performed by different analyst

Ranch Village tap

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/28/11	rainy	4.20	mg/L	average
Dissolved oxygen	8/28/11	rainy	0.0450	mg/L	standard deviation
Hardness	8/28/11	rainy	44	mg/L as $CaCO_3$	low range
Hardness	8/28/11	rainy	51	mg/L as $CaCO_3$	high range
Hardness	8/28/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	103	mg/L as $CaCO_3$	high range
Hardness	2/27/12	dry	120	mg/L as $CaCO_3$	test strip
Nitrate	9/1/11	rainy	0.06	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.07	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.18	mg/L NO_3-N	filtered
Nitrate	9/1/11	rainy	0.12	mg/L NO_3-N	filtered
pH	2/27/12	dry	7.9	pH units	
pH	2/27/12	dry	7.5	pH units	test strip
pH	2/29/12	dry	7.7	pH units	
pH	2/29/12	dry	7	pH units	test strip
Phosphate	8/28/11	rainy	0.19	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.26	mg/L as PO_4	
Phosphate	8/28/11	rainy	0.29	mg/L as PO_4	
Phosphate	9/1/11	rainy	0.29	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.32	mg/L as PO_4	filtered
Phosphate	9/1/11	rainy	0.32	mg/L as PO_4	filtered
Phosphate	2/27/12	dry	0.06	mg/L as PO_4	
Phosphate	2/27/12	dry	0.11	mg/L as PO_4	
Phosphate	2/27/12	dry	0.16	mg/L as PO_4	
Phosphate	2/29/12	dry	0.13	mg/L as PO_4	
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.17	mg/L as PO_4	
Specific conductivity	8/28/11	rainy	140	µS/cm	average
Specific conductivity	8/28/11	rainy	0.258	µS/cm	standard deviation
Specific conductivity	2/27/12	dry	349	µS/cm	
Specific conductivity	2/29/12	dry	355	µS/cm	
Temperature	8/28/11	rainy	22.93	°C	average
Temperature	8/28/11	rainy	0.04590	°C	standard deviation
Temperature	2/27/12	dry	25.9	°C	pH meter
Temperature	2/27/12	dry	26.5	°C	TDS meter
Temperature	2/29/12	dry	28.6	°C	pH meter
Temperature	2/29/12	dry	28	°C	TDS meter
Total suspended solids	8/31/11	rainy	50	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	40	mg/L	100 mL filtered
Total suspended solids	8/31/11	rainy	30	mg/L	100 mL filtered
Total suspended solids	3/3/12	dry	2	mg/L	500 mL filtered
True color	2/27/12	dry	61	PtCo	
True color	2/27/12	dry	60	PtCo	
True color	2/27/12	dry	87	PtCo	
Turbidity	2/27/12	dry	5.79	NTU	
Turbidity	2/27/12	dry	5.81	NTU	
Turbidity	2/27/12	dry	6.35	NTU	
Turbidity	2/27/12	dry	5.75	NTU	

River Camp

- Where and how exactly was water collected?
Taken from the black storage tank in the river camp village. Filled using spigot at the bottom of tank. If looking at tanks with sink at your back, it was the second black tank from the left.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
People living nearby; fire pit nearby (~3 m away) and fire going when sample taken. Top of tank not entirely sealed but it does have a lid.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
No

- Other notes
This is where the samples were taken during the rainy season sampling event as well.

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
30-Aug	m-ColiBlue24®	none	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	500	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
1-Sep	m-ColiBlue24®	800	6	**4,800**	TNTC	TNTC	**TNTC**
1-Sep	m-ColiBlue24®	800	4	**3,200**	TNTC	TNTC	**TNTC**
1-Sep	m-ColiBlue24®	800	7	**5,600**	TNTC	TNTC	**TNTC**
1-Sep	m-ColiBlue24®	1,000	6	**6,000**	10	16	**16,000**
1-Sep	m-ColiBlue24®	1,000	0	**0**	39	39	**39,000**
1-Sep	m-ColiBlue24®	1,000	0	**0**	37	37	**37,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
1-Mar	m-ColiBlue24®	none	1	**1**	TNTC	TNTC	**TNTC**
1-Mar	m-ColiBlue24®	2.00	0	**0**	TNTC	TNTC	**TNTC**
1-Mar	m-ColiBlue24®	4.00	2	**8**	156	158	**632**
1-Mar	modified m-TEC	none	1	**1**	--	--	**--**
1-Mar	modified m-TEC	none	1	**1**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
2-Mar	m-ColiBlue24®	10.0	0	**0**	TNTC	TNTC	**TNTC**
2-Mar	m-ColiBlue24®	12.5	0	**0**	TNTC	TNTC	**TNTC**
2-Mar	m-ColiBlue24®	20.0	0	**0**	44	44	**880**
3-Mar	m-ColiBlue24®	20.0	0	**0**	47	47	**940**
3-Mar	m-ColiBlue24®	20.0	0	**0**	76	76	**1,520**
3-Mar	m-ColiBlue24®	20.0	0	**0**	47	47	**940**

River Camp

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	340	mg/L as $CaCO_3$	high range
Dissolved oxygen	9/1/11	rainy	5.50	mg/L	average
Dissolved oxygen	9/1/11	rainy	0.121	mg/L	standard deviation
Hardness	8/30/11	rainy	34	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	30	mg/L as $CaCO_3$	low range
Hardness	8/30/11	rainy	34	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	51	mg/L as $CaCO_3$	test strip
Hardness	3/1/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	26	mg/L as $CaCO_3$	test strip
Hardness	3/2/12	dry	20	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	20	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	20	mg/L as $CaCO_3$	low range
Nitrate	8/30/11	rainy	4.8	mg/L NO_3-N	10x dilution
Nitrate	8/30/11	rainy	6.4	mg/L NO_3-N	20x dilution
Nitrate	8/30/11	rainy	5.4	mg/L NO_3-N	20x dilution
Nitrate	8/30/11	rainy	9	mg/L NO_3-N	test strip
Nitrate		dry	0	mg/L NO_3-N	test strip
Nitrite	8/30/11	rainy	3	mg/L NO_2-N	test strip
Nitrite		dry	0	mg/L NO_2-N	test strip
pH	3/1/12	dry	9	pH units	
pH	3/1/12	dry	9	pH units	test strip
pH	3/2/12	dry	9	pH units	
pH	3/2/12	dry	9	pH units	test strip
Phosphate	8/30/11	rainy	2.70	mg/L as PO_4	over limit (2.5 mg/L)
Phosphate	8/30/11	rainy	2.66	mg/L as PO_4	2x dilution
Phosphate	8/30/11	rainy	2.98	mg/L as PO_4	2x dilution
Phosphate	8/30/11	rainy	2.68	mg/L as PO_4	2x dilution
Phosphate	3/1/12	dry	0.17	mg/L as PO_4	
Phosphate	3/1/12	dry	0.14	mg/L as PO_4	
Phosphate	3/1/12	dry	0.12	mg/L as PO_4	
Specific conductivity	9/1/11	rainy	95	µS/cm	average
Specific conductivity	9/1/11	rainy	0.0	µS/cm	standard deviation
Specific conductivity	3/1/12	dry	1901	µS/cm	
Specific conductivity	3/2/12	dry	1895	µS/cm	
Temperature	9/1/11	rainy	19.40	°C	average
Temperature	9/1/11	rainy	0.1208	°C	standard deviation
Temperature	3/1/12	dry	18.5	°C	pH meter
Temperature	3/1/12	dry	18.3	°C	TDS meter
Temperature	3/2/12	dry	19.2	°C	pH meter
Temperature	3/2/12	dry	18.9	°C	TDS meter
Total suspended solids	9/1/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/1/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	9/1/11	rainy	2	mg/L	500 mL filtered
Total suspended solids	3/1/12	dry	1	mg/L	900 mL filtered
Total suspended solids	3/1/12	dry	1	mg/L	400 mL filtered
True color	3/1/12	dry	18	PtCo	
True color	3/1/12	dry	27	PtCo	
True color	3/1/12	dry	26	PtCo	
Turbidity	3/1/12	dry	2.94	NTU	
Turbidity	3/1/12	dry	2.45	NTU	
Turbidity	3/1/12	dry	2.63	NTU	

Tank 5

- Where and how exactly was water collected?
Collected from the opening at the top of Tank 5.

- Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Vegetation around it, and it sits recessed in a large divot). People are known to go to the bathroom nearby. Lid appears to remain open all of the time.

- Does the water have an odor? If so, please describe.
No

- Does the water have color or cloudiness? If so, please describe.
Clear

- Other notes
Borehole water being pumped in when samples taken. River water is occasionally pumped into this tank.

Coliform data

2011 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)	Notes
29-Feb	m-ColiBlue24®	2.00	0	**0**	11	11	**22**	
29-Feb	m-ColiBlue24®	100	0	**0**	4	4	**400**	
29-Feb	m-ColiBlue24®	500	0	**0**	0	0	**0**	
29-Feb	modified m-TEC	none	0	**0**	--	--	--	
29-Feb	modified m-TEC	none	0	**0**	--	--	--	
29-Feb	modified m-TEC	none	1	**1**	--	--	--	
1-Mar	m-ColiBlue24®	none	0	**0**	8	8	**8**	
1-Mar	m-ColiBlue24®	1.11	0	**0**	6	6	**7**	a
1-Mar	m-ColiBlue24®	1.25	0	**0**	18	18	**23**	a
2-Mar	m-ColiBlue24®	none	0	**0**	38	38	**38**	
2-Mar	m-ColiBlue24®	none	0	**0**	12	12	**12**	
2-Mar	m-ColiBlue24®	none	0	**0**	6	6	**6**	

a) Performed by different analyst

Tank 5

All other water quality data

Constituent	Date sampled	Season	Results	Units	Notes
Alkalinity	3/4/12	dry	380	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	360	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	34	mg/L as $CaCO_3$	high range
Hardness	2/29/12	dry	26	mg/L as $CaCO_3$	test strip
Hardness	3/2/12	dry	16	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	16	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	16	mg/L as $CaCO_3$	low range
Hardness	3/2/12	dry	26	mg/L as $CaCO_3$	test strip
Nitrate	3/4/12	dry	0	mg/L NO_3-N	test strip
Nitrite	3/4/12	dry	0	mg/L NO_2-N	test strip
pH	2/29/12	dry	8.8	pH units	
pH	2/29/12	dry	9	pH units	test strip
pH	3/1/12	dry	8.8	pH units	
pH	3/1/12	dry	9	pH units	test strip
Phosphate	2/29/12	dry	0.12	mg/L as PO_4	
Phosphate	2/29/12	dry	0.13	mg/L as PO_4	
Phosphate	2/29/12	dry	0.13	mg/L as PO_4	
Specific conductivity	2/29/12	dry	1947	µS/cm	
Specific conductivity	3/1/12	dry	1960	µS/cm	
Temperature	2/29/12	dry	23.4	°C	pH meter
Temperature	2/29/12	dry	22.7	°C	TDS meter
Temperature	3/1/12	dry	26.7	°C	pH meter
Temperature	3/1/12	dry	26.8	°C	TDS meter
Total suspended solids	3/1/12	dry	0	mg/L	1,000 mL filtered
Total suspended solids	3/1/12	dry	0	mg/L	1,000 mL filtered
True color	2/29/12	dry	4	PtCo	
True color	2/29/12	dry	0	PtCo	
True color	2/29/12	dry	0	PtCo	
Turbidity	2/29/12	dry	0.76	NTU	
Turbidity	2/29/12	dry	0.94	NTU	
Turbidity	2/29/12	dry	0.32	NTU	

Weir

- Where and how exactly was water collected?

Collected from outlet of weir 2 to weir 1 (i.e. bottom of weir 2)

Coliform data

2011 RAINY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
30-Aug	m-ColiBlue24®	none	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	100	TNTC	**TNTC**	TNTC	TNTC	**TNTC**
30-Aug	m-ColiBlue24®	500	2	**1,000**	65	67	**33,500**
31-Aug	m-ColiBlue24®	500	4	**2,000**	41	45	**22,500**
31-Aug	m-ColiBlue24®	500	4	**2,000**	53	57	**28,500**
31-Aug	m-ColiBlue24®	500	4	**2,000**	52	56	**28,000**

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
1-Mar	m-ColiBlue24®	25.0	0	**0**	72	72	**1,800**
1-Mar	m-ColiBlue24®	33.3	0	**0**	64	64	**2,100**
1-Mar	m-ColiBlue24®	50.0	0	**0**	27	27	**1,400**
1-Mar	modified m-TEC	10.0	0	**0**	--	--	**--**
1-Mar	modified m-TEC	20.0	0	**0**	--	--	**--**
1-Mar	modified m-TEC	100	0	**0**	--	--	**--**
2-Mar	modified m-TEC	none	7	**7**	--	--	**--**
2-Mar	modified m-TEC	none	6	**6**	--	--	**--**
2-Mar	modified m-TEC	none	6	**6**	--	--	**--**

Weir

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	180	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Alkalinity	3/4/12	dry	160	mg/L as $CaCO_3$	high range
Dissolved oxygen	8/31/11	rainy	4.82	mg/L	average
Dissolved oxygen	8/31/11	rainy	0.164	mg/L	standard deviation
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	68	mg/L as $CaCO_3$	high range
Hardness	8/30/11	rainy	100	mg/L as $CaCO_3$	test strip
Hardness	3/1/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	120	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	137	mg/L as $CaCO_3$	test strip
Nitrate	8/31/11	rainy	0.02	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.00	mg/L NO_3-N	filtered
Nitrate	8/31/11	rainy	0.00	mg/L NO_3-N	filtered
pH	3/1/12	dry	7.9	pH units	
pH	3/1/12	dry	8	pH units	test strip
Phosphate	8/30/11	rainy	0.14	mg/L as PO_4	
Phosphate	8/31/11	rainy	0.24	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.22	mg/L as PO_4	filtered
Phosphate	8/31/11	rainy	0.18	mg/L as PO_4	filtered
Phosphate	3/1/12	dry	0.09	mg/L as PO_4	
Phosphate	3/1/12	dry	0.20	mg/L as PO_4	
Phosphate	3/1/12	dry	0.10	mg/L as PO_4	
Phosphate	3/1/12	dry	0.14	mg/L as PO_4	
Specific conductivity	8/31/11	rainy	152	µS/cm	average
Specific conductivity	8/31/11	rainy	0.414	µS/cm	standard deviation
Specific conductivity	3/1/12	dry	369	µS/cm	
Temperature	8/31/11	rainy	22.21	°C	average
Temperature	8/31/11	rainy	0.3670	°C	standard deviation
Temperature	3/1/12	dry	24.3	°C	pH meter
Temperature	3/1/12	dry	24.8	°C	TDS meter
Total suspended solids	8/31/11	rainy	1,100	mg/L	25 mL filtered
Total suspended solids	8/31/11	rainy	1,000	mg/L	10 mL filtered
Total suspended solids	8/31/11	rainy	800	mg/L	10 mL filtered
Total suspended solids	3/3/12	dry	2	mg/L	500 mL filtered
True color	3/1/12	dry	35	PtCo	
True color	3/1/12	dry	85	PtCo	
True color	3/1/12	dry	83	PtCo	
True color	3/1/12	dry	85	PtCo	
Turbidity	3/1/12	dry	5.71	NTU	
Turbidity	3/1/12	dry	5.58	NTU	
Turbidity	3/1/12	dry	5.67	NTU	

Other sites

MRC Kitchen filter

Where and how was water collected?
Sample was collected from the filter next to the sink in the dish washing kitchen adjacent to the dining hall at MRC. Staff told us this is a reverse osmosis filter.

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Area is clean, dishes are washed in this room.

Does the water have an odor? If so, please describe.
No

Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
2-Mar	m-ColiBlue24®	none	0	**0**	11	11	**11**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Hardness		dry	1	mg/L as $CaCO_3$	low range
Hardness		dry	1	mg/L as $CaCO_3$	low range
Hardness		dry	1	mg/L as $CaCO_3$	low range
Hardness		dry	26	mg/L as $CaCO_3$	test strip
Nitrate	2/29/12	dry	0	mg/L NO_3-N	test strip
Nitrite	2/29/12	dry	0	mg/L NO_2-N	test strip
pH	2/29/12	dry	8.7	pH units	
pH	2/29/12	dry	7-7.5	pH units	test strip
Phosphate	2/29/12	dry	0.04	mg/L PO_4	
Phosphate	2/29/12	dry	0.02	mg/L PO_4	
Phosphate	2/29/12	dry	0.02	mg/L PO_4	
Specific conductivity	2/29/12	dry	206	µS/cm	
Temperature	2/29/12	dry	25.5	°C	pH meter
Temperature	2/29/12	dry	25.7	°C	TDS meter
Turbidity	2/29/12	dry	0.08	NTU	
Turbidity	2/29/12	dry	0.63	NTU	
Turbidity	2/29/12	dry	0.03	NTU	

Other sites

Clinic Potable

Where and how was water collected?
Sample was collected from the water filter in the Clinic.

Coliform data
2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)	Notes
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**	a
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**	a
2-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**	a

a) Performed by different analyst

Small MRC dining hall potable

Where and how was water collected?
Sample was collected from smaller of the two water filters at the MRC dining hall.

Coliform data
2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
3-Mar	m-ColiBlue24®	none	0	**0**	28	28	**28**
3-Mar	m-ColiBlue24®	none	0	**0**	10	10	**10**
3-Mar	m-ColiBlue24®	none	0	**0**	15	15	**15**

Other sites

River Camp potable

Where and how was water collected?
Sample was collected from the metal water filters in the dining area at River Camp

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
The area surrounding the source is clean. People eat here.

Does the water have an odor? If so, please describe.
No

Does the water have color or cloudiness? If so, please describe.
No

Coliform data

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
1-Mar	m-ColiBlue24®	none	0	**0**	1	1	**1**
1-Mar	m-ColiBlue24®	none	0	**0**	10	10	**10**
1-Mar	m-ColiBlue24®	none	0	**0**	0	0	**0**
1-Mar	m-ColiBlue24®	none	0	**0**	2	2	**2**
1-Mar	m-ColiBlue24®	none	0	**0**	16	16	**16**
1-Mar	m-ColiBlue24®	none	0	**0**	17	17	**17**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**
1-Mar	modified m-TEC	none	0	**0**	--	--	**--**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Hardness	3/1/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	68	mg/L as $CaCO_3$	high range
Hardness	3/1/12	dry	68	mg/L as $CaCO_3$	test strip
pH	3/1/12	dry	8.7	pH units	
pH	3/1/12	dry	7.5	pH units	test strip
Phosphate	3/1/12	dry	0.43	mg/L PO_4	
Phosphate	3/1/12	dry	0.46	mg/L PO_4	
Phosphate	3/1/12	dry	0.43	mg/L PO_4	
Specific conductivity	3/1/12	dry	272	µS/cm	
Temperature	3/1/12	dry	16.2	°C	pH meter
Temperature	3/1/12	dry	16.3	°C	TDS meter
Total suspended solids	3/1/12	dry	-4	mg/L	200 mL filtered
Total suspended solids	3/1/12	dry	-3	mg/L	250 mL filtered
Turbidity	3/1/12	dry	0.96	NTU	
Turbidity	3/1/12	dry	0.84	NTU	
Turbidity	3/1/12	dry	0.65	NTU	

Other sites

Nanyuki

Where and how was water collected?
Taken from a spigot at the petrol station across from Nakumatt

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
About 10 meters away from gas pumps and six meters from a road. The spigot comes from the ground, is approximately one meter high and is surrounded by grass.

Does the water have an odor? If so, please describe.
No

Does the water have color or cloudiness? If so, please describe.
No

Other Notes.
Verified with manager that this tap has municipal water and is the same water people use in their homes.

Coliform data

2012 DRY SEASON

Plate date	Media	Dilution	*E. coli* CFU on plate	*E. coli* (CFU/100 mL)	Other CFU on plate	Total CFU on plate	Total coliform (CFU/100mL)
28-Feb	modified m-TEC	none	42	**42**	--	--	**--**
28-Feb	modified m-TEC	none	34	**34**	--	--	**--**
28-Feb	modified m-TEC	none	41	**41**	--	--	**--**
28-Feb	m-ColiBlue24®	none	27	**27**	TNTC	TNTC	**TNTC**
28-Feb	m-ColiBlue24®	none	22	**22**	TNTC	TNTC	**TNTC**
28-Feb	m-ColiBlue24®	none	31	**31**	TNTC	TNTC	**TNTC**

All other water quality data

Constituent	Date sampled	Season	Result	Units	Notes
Nitrate	2/28/12	dry	0	mg/L NO_3-N	test strip
Nitrite	2/28/12	dry	0	mg/L NO_2-N	test strip
pH	2/28/12	dry	8.1	pH units	
pH	2/28/12	dry	7.5	pH units	test strip
Phosphate	2/28/12	dry	0.12	mg/L PO_4	
Phosphate	2/28/12	dry	0.16	mg/L PO_4	
Phosphate	2/28/12	dry	0.13	mg/L PO_4	
Specific conductivity	2/28/12	dry	58	µS/cm	
Temperature	2/28/12	dry	27	°C	pH meter
Temperature	2/28/12	dry	26.9	°C	TDS meter
Total suspended solids	2/29/12	dry	0	mg/L	850 mL filtered
Turbidity	2/29/12	dry	0.79	NTU	
Turbidity	2/29/12	dry	0.82	NTU	
Turbidity	2/29/12	dry	0.72	NTU	

Other sites

Top of Weir 1

Where and how was water collected?
Sample was collected by dipping sampling bottle into the weir water at the top of Weir 1.

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Weir is full of stagnant water and there is a significant amount of pond scum on top. There are also feces and dirt floating on top.

Does the water have an odor? If so, please describe.
The water has an earthy odor.

Constituent	Date sampled	Season	Result	Units	Notes
pH	3/1/12	dry	8.7	pH units	
Specific conductivity	3/1/12	dry	361	µS/cm	
Temperature	3/1/12	dry	28	°C	pH meter
Temperature	3/1/12	dry	28.5	°C	TDS meter

Top of Weir 2

Where and how was water collected?
Sample was collected by dipping sampling bottle into the weir water at the top of Weir 2.

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Weir is full of stagnant water and there is algal growth on top.

Does the water have an odor? If so, please describe.
The water has a musky/earthy odor.

Does the water have color or cloudiness? If so, please describe.
Water is somewhat yellow in the cup.

Constituent	Date sampled	Season	Result	Units	Notes
pH	3/1/12	dry	8.7	pH units	
pH	3/1/12	dry	9	pH units	test strip
pH		dry	8.2	pH units	
Phosphate	3/1/12	dry	0.12	mg/L PO_4	
Phosphate	3/1/12	dry	0.07	mg/L PO_4	
Phosphate	3/1/12	dry	0.16	mg/L PO_4	
Phosphate	3/1/12	dry	0.12	mg/L PO_4	
Specific conductivity	3/1/12	dry	347	µS/cm	
Specific conductivity		dry	366	µS/cm	
Temperature	3/1/12	dry	26.8	°C	pH meter
Temperature	3/1/12	dry	27.3	°C	TDS meter
Temperature		dry	24.1	°C	pH meter
Temperature		dry	25.1	°C	TDS meter
Total suspended solids	3/2/12	dry	3	mg/L	500 mL filtered
Total suspended solids	3/2/12	dry	2	mg/L	500 mL filtered
Turbidity	3/1/12	dry	3.9	NTU	
Turbidity	3/1/12	dry	3.49	NTU	
Turbidity	3/1/12	dry	3.59	NTU	

Other sites

Top of Weir 3

Where and how was water collected?
Sample was collected by dipping sampling bottle into the weir water at the top of Weir 3.

Describe the area surrounding the water source. Is it dirty? What types of activities are nearby? Do people wash clothes there, etc.)
Weir is full of stagnant water and there are feces floating on top of the water.

Does the water have an odor? If so, please describe.
No

Does the water have color or cloudiness? If so, please describe.
Water is an olive green color in the weir but no color in sampling cup.

Constituent	Date sampled	Season	Result	Units	Notes
pH	3/1/12	dry	8	pH units	
pH	3/1/12	dry	8.5	pH units	test strip
pH		dry	8	pH units	
Phosphate	3/1/12	dry	0.16	mg/L PO_4	
Phosphate	3/1/12	dry	0.08	mg/L PO_4	
Phosphate	3/1/12	dry	0.09	mg/L PO_4	
Phosphate	3/1/12	dry	0.09	mg/L PO_4	
Specific conductivity	3/1/12	dry	244	µS/cm	
Specific conductivity		dry	364	µS/cm	
Temperature	3/1/12	dry	25	°C	pH meter
Temperature	3/1/12	dry	24.8	°C	TDS meter
Temperature		dry	23.9	°C	pH meter
Temperature		dry	24.4	°C	TDS meter
Total suspended solids	3/2/12	dry	4	mg/L	500 mL filtered
Total suspended solids	3/2/12	dry	5	mg/L	420 mL filtered
Turbidity	3/1/12	dry	3.41	NTU	
Turbidity	3/1/12	dry	3.56	NTU	
Turbidity	3/1/12	dry	3.16	NTU	