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# A Practical Approach to Constant Head Drip Chlorination Using an Outlet Controlled System

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# A PRACTICAL APPROACH TO CONSTANT HEAD DRIP CHLORINATION USING AN OUTLET CONTROLLED SYSTEM

## CASE STUDY IN SAN PEDRO DE CASTA, PERU

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**Spring 2017**
**ENE 799H: Senior Honors Thesis**
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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# MOTIVATION FOR RESEARCH

## Background

In 2010, the United Nations General Assembly recognized the human right to clean water and sanitation as being integral in the realization of all other human rights. According to the United Nations, about 783 million people around the world lack access to affordable clean drinking water, and up to 8 million die each year from waterborne disease (UN, 2013). Through creative engineering solutions, however, this is a problem that can be significantly alleviated. There is a need for innovative, practical solutions in water disinfection that can be implemented worldwide in rural, remote, and developing communities.

One of the simplest and cheapest ways to achieve disinfection and reduce waterborne illness is to chlorinate drinking water supplies. Chlorine dosed at appropriate residual concentrations (usually around 0.5-1 mg/L (WHO, 2002)) is successful at reducing or eliminating bacteria in water. Chlorine is a chemical that is found commonly in all regions of the world, is inexpensive, and has a relatively low safety risk when handled by informed personnel. Chlorination is a process that can be used at both a large and small scale to achieve adequate disinfection in drinking water supplies.

## Methods of Chlorination

The methods for delivering chlorine to a drinking water supply range from complex to simple. In more urban areas with larger populations and the resources to do so, metering pumps dose precisely based on flow rates. These pumps require electricity, maintenance, and repair, but are extremely effective in dosing appropriate amounts of chlorine to drinking water supplies.

In more remote areas that lack access to resources such as supplies, trained maintenance personnel, and electricity, much simpler options must be explored. Methodologies include shock chlorination, tablet chlorination, and drip chlorination. Table 1 below shows different chemical options for chlorination including a typical concentration that can be found.

*Table 1: Common forms of chlorine for disinfection and their concentrations*

| Common Name | Chlorine Form | Concentration |
|---|---|---|
| Bleach | Sodium hypochlorite (HOCl-) | 8.25% |
| Tablet | Calcium hypochlorite (HOCl-) | 85% |
| Chlorine Gas | $Cl2$ (g) | 100% |

Shock chlorination is a method of disinfection that should only be used in sources of water that are found to be contaminated in occasional circumstances, but are otherwise usually found to be free of pathogens. This methodology involves dosing a well or storage tank with chlorine up to concentrations of 10 – 50 mg/L, and then allowing a reaction time such that residuals are below standard chlorine concentrations (around 2 – 4 mg/L). While shock chlorination is effective at killing contaminants, it should be used only in emergencies and not as a substitute to water supply protection or other methods of disinfection (Skipton, 2007).

Chlorine may be purchased in solid form as calcium hypochlorite ($Ca(OCl)_2$), which can be compressed into a soluble tablet. Chlorine is dosed to a water supply by varying the flow that the tablet is exposed to, and therefore how fast the tablet will dissolve. Exposing the tablet to a higher flow rate will deliver a higher dose of chlorine to the system. This method somewhat accounts for variation in water supply flow and provides accuracy in dosing provided the system has moderate to large flows. Drawbacks of tablet chlorination are the necessity to store the tablets in a cool, dry climate and the ability to purchase the tablets.

Briefly, drip chlorination is a method of delivering chlorine to a water supply by delivering a constant, small stream of liquid chlorine (usually bleach, NaOCl) to a feed system. Drip chlorination is appropriate when the water supply is fairly constant, and is advantageous because chlorine bleach is readily available in most parts of the world.

## Method of Drip Chlorination

According to the World Health Organization, there are two primary ways that a chlorine dose can be controlled to a water supply system when using the method of drip chlorination. The first is to manipulate the concentration of chlorine in the dosing solution that is being fed to the water supply. However, the concentration of hypochlorite in solution varies with the source of chlorine. While it is possible to manipulate the concentration of hypochlorite through dilutions, iterations of the solution may have to be made as time goes on and different residuals are measured throughout a piping network. There is also a risk involved in miscalculating a dosing mixture which could lead to over- or under-chlorinating, both of which pose health risks.

The second option to control chlorine dose is to monitor chlorine levels at the point of use (tap) and make appropriate adjustments in chlorine flow into the system (WHO, 2002). This method of controlling dose is more intuitive and has a more immediate response time than dosing based on chlorine concentration. If a residual in the system is measured as too high or too low, the flow will be throttled lower or higher, respectively, and the change will take place immediately. This paper therefore explores drip chlorination systems whose chlorine dose can easily be adjusted, but that can maintain a constant drip rate once set.

Typical drip chlorination systems rely on a constant head over an orifice in order to maintain a constant flow into the system. The dose of chlorine can therefore be maintained by changing the size of the orifice or the amount of head over the orifice.

### *Fluid Mechanics of an Orifice with Constant Head*

The flow rate of a fluid exiting from an orifice can be expressed with the following equation:

$$Q_{jet} = V_{jet} * A_{orifice} = A_{orifice}\sqrt{2g(z_{surface} - z_{outlet})}$$

Therefore, if the distance between the water surface level in the dosing container and the outlet remain constant, the flow out of the orifice will also remain constant (eFunda, 2017).

Chlorinating by simply installing a throttle to slowly drain a storage tank of chlorine solution therefore does not necessarily dose at a constant rate; as the storage tank emptied, the distance between the solution surface and the outlet decreases, and so the flow rate decreases as well. A system that effectively achieves a constant flow rate using an outlet controlled dispensing system needs to maintain a constant head between the solution surface and the outlet.

### *Past Research Involving Drip Chlorination Methods*

Previous years of research at the University of New Hampshire have investigated alternative methods of drip chlorination. Diagrams of the described systems can be found in Appendix A.

The first method utilized a mariotte bottle, which uses a siphon to maintain a constant pressure and therefore a constant drip rate out of the system. Research showed, however, that maintaining a constant drip rate was problematic, with issues in pressure build-up and unnecessarily complicated valve requirements (Burke et al, 2015).

The second method utilized a floating apparatus that operated with an inlet controlled system. The apparatus was made buoyant using two toilet ball floats which could be adjusted up and down. The apparatus was made to fit the inside of a dosing reservoir which would contain a chlorine solution. A vertical pipe was drilled with a small orifice that served as the inlet to the system. The pipe connected to a hose which connected to the outlet of the dosing reservoir. Chlorine solution is allowed in through the orifice, and as the system drains, the apparatus lowers with the solution level in the bucket. In this way, the driving head (solution level over the orifice) always remains constant.

Research (Cote et al, 2016) showed, however, that this method has several practical problems with implementation. First, the drip rate declined as the solution level in the bucket emptied. Further research concluded that this was due to crimping in the outlet tubing. A smaller orifice was found to remedy this problem and produce a steadier flow rate as the reservoir empties. However, the system is somewhat complex, with many adjustable parts, and can be unstable in the reservoir. While a viable option, the floating apparatus is not idealized for simple operation and maintenance.

## CASE STUDY: SAN PEDRO DE CASTA, PERU

San Pedro de Casta is a community of about 1,200 residents and is located at 10,300 feet elevation in the Peruvian Andes. The community is remote, about a three hour bus ride from the nearest city, and lacks access to both modern-day conveniences and basic living requirements, including clean drinking water.

The Students Without Borders chapter at the University of New Hampshire has been involved with the community since 2013 when several students and mentors traveled to assess the needs of the town. The most pressing issue that was found was the presence of contamination, namely

*E. coli*, in the drinking water supply. Community members had complained that the water was making them ill and asked for help in implementing a solution.

## Resources Available

### *Electricity*

The community has access to electricity via connection to a grid that obtains energy from hydroelectric generation, but the electricity is unreliable, often shutting off for hours and days at a time. This makes it necessary for a disinfection system to operate effectively without being on-the-grid. Solar panels to generate small quantities of electricity needed to run a dosing pump are not considered to be an option due to concerns of theft and the fact that the rainy season in San Pedro de Casta (approximately November through April) lacks sufficient sunlight during the majority of the afternoons to generate electricity. Trained maintenance personnel for solar panels is also unlikely available or affordable to the community.

### *Chlorine*

The community has access to a bus that runs twice a day to a nearby city, Chosica. The Students Without Borders Chapter at the University of New Hampshire has sought out available materials in the stores and markets of Chosica and has found that while chlorine bleach at 8.25% is readily available in large quantities, there are no chlorine tablets available. Tablets are available for purchase in Lima (Peru’s capital city), but that requires another hour’s taxi ride from Chosica, which is expensive and time-consuming for San Pedro de Casta’s residents.

### *Other Materials*

The community of San Pedro de Casta receives shipments via truck of basic supplies and materials from cities in the valley. Typical materials available would include shovels, buckets, a limited selection of pipe fittings and couplings, and basic hand tools. In order to purchase more specific supplies, the bus must be taken to the Chosica. Chosica has several hardware shops and markets that sell most of the same supplies as a local hardware store in the United States.

### *Personnel*

San Pedro de Casta has established a water and sanitation committee called the JASS (Junta Administradora de Servicios de Agua y Saneamiento)a which is run by a president and has appointed a water superintendent whose job it is to operate and maintain a safe drinking water supply for the community. The current water superintendent is Nilton Rojas, who also has obligations to another job. An implemented disinfection system must therefore accommodate his busy schedule. Mr. Rojas also lacks formal education in disinfection. While he has an understanding that chlorine bleach may be used to treat drinking water, the method that was taught to him was to shock the system periodically with bleach. San Pedro de Casta’s drinking water supply is therefore either overdosed with chlorine or not being treated at all.

## Overview of Water Supply System

The town of San Pedro de Casta obtains its drinking water supply from two springs that are located approximately 3,000 in elevation above the community at a distance of approximately 12 kilometers away. It is delivers approximately 50,000 gallons per day from these springs via a pipeline that runs down the mountainsides. A flow meter was installed in 2015 by UNH Students Without Borders in order to monitor the flow.

The pipeline from the springs to San Pedro de Casta is an approximately 2” diameter, PVC pipe, buried in some places but exposed or suspended in others. It is difficult to follow from the source to the community. It is very likely that there may be significant water losses and potential for contamination due to breaks in this pipeline. However, to replace the pipeline would be next to impossible given its location and length.

Approximately 0.5 kilometers from the edge of the community, there is a large storage tank, named Atagaca (see Appendix B). Its dimensions are 23.5 feet wide, 24.2 feet in length, and 10.4 feet high, with a maximum water depth at 7.83 feet. The total storage volume of Atagaca is 4,453 cubic feet. The pipeline exiting from this storage tank is buried and extends to an underground piping network that delivers water to community and individual taps. There are three small “stop-tanks” along this pipeline which contain a ball float valve that shuts off the flow in the pipeline when the tank fills. The idea behind this is to conserve water, although it has been observed by the UNH Students Without Borders travel teams that these stop tanks are never filled.

Currently, this pipeline bypasses another storage tank located along the edge of the community, called Urno. There is an open overflow opening. It has been recommended that this storage tank be put back online.

Given this system and network layout (See Appendix C for overall plan view), it is recommended that a chlorine disinfection system be placed at Atagaca in order for the chlorine to have enough contact time and proper mixing before reaching community taps. The inlet and outlet pipes to Atagaca are located at the base of the tank, giving a potential system approximately 10 feet of available head to operate.

**System Requirements**

Given San Pedro de Casta’s system layout, lack of access to reliable electricity, consistent materials, and other forms of chlorine besides bleach, a disinfection system to treat the town’s drinking water must meet the following criteria:

- Operate without electricity
- Dose at a rate of about 1 – 3 mL/min (see Appendix D for chlorine demand calculations)
    - Note that the dose rate depends on the flow rate in the system and the desired chlorine residual. See Appendix D for dosing rates at different chlorine residuals and system flows
- Ability to easily adjust the dose rate based on point-of-use residuals testing
- Operate with 10 feet of head or less
- Have an operational run length of 1 week
    - Accommodates the water superintendent’s busy schedule

  - Simplifies remembering to perform maintenance (can refill every *Tuesday*)
- Be built with materials available in Chosica
- Be built with materials that are resistance to chlorine
- Operate in a simple way to reduce the difficulty of operation and maintenance

# SYSTEM SET-UP

Outlet-controlled systems were investigated in order to maintain a consistent drip rate out of the system. The most hydraulically restrictive point in a conduit determines the location of control for the system. In outlet-controlled systems, the most restrictive point is at the end of the conduit (see Figure 1 below), and therefore the conduit always flows full and under pressure. The head that determines the flow that leaves the outlet is the difference in height of the water level in the reservoir and the point of outlet.

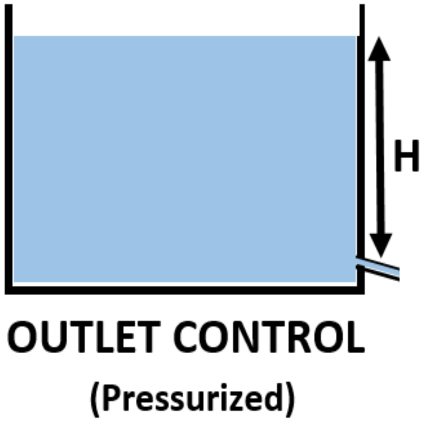

*Figure 1: Schematic of an outlet controlled reservoir*

In order to be able to control both of these factors, a two-reservoir design was created (see Figure 2 below). The upper reservoir would be filled with chlorine solution and allowed to drain over the maintenance period of the system. The lower (dosing) reservoir's water level needs to remain consistent at all times in order to preserve the driving head to the outlet of that reservoir. A valve must be installed between the reservoirs to allow water to pass from the upper to dosing reservoir when the water level in the dosing reservoir drops. A restrictor valve must also be placed on the outlet of the system in order to achieve the low chlorine dosing rates (1-3 mL/min) required by the system.

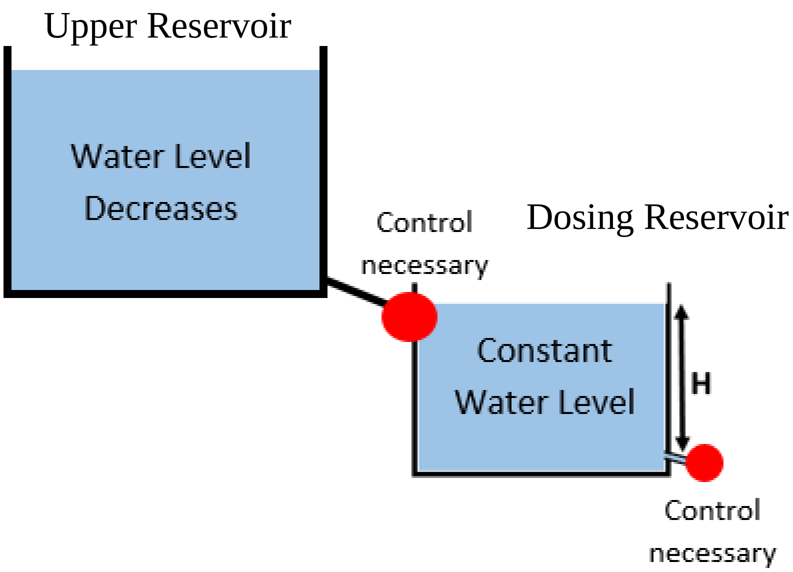

*Figure 2: Schematic of a two-reservoir outlet control system; red dots indicate where flow control is necessary*

Two controls were therefore necessary in order to create an effective outlet controlled system. A control for the most hydraulically restrictive point (the outlet) was necessary to throttle the flow out of the system to a desired drip rate, and a device to maintain a consistent water level in the dosing bucket was necessary to maintain a constant driving head to the outlet.

### Water Surface Level Controls

Floating valves were proposed as desirable as a way to control flow from the upper reservoir to the dosing reservoir based on the water level drop in the dosing reservoir. As a float was allowed to lower due to drainage out of the dosing reservoir, a valve to the upper reservoir was opened to allow the dosing reservoir to refill. Flow would be allowed to continue until the float was raised, and the valve was shut to an off position.

A toilet valve and bobber valve were selected as viable options to control the water surface level in the dosing reservoir. Both utilize floats to open and close valves and are described below.

#### *Toilet Valve*

A toilet valve was purchased from Gordy. This particular valve contains a square float encased in a box which has a slit approximately one inch from the bottom of the box. As water drains from the dosing reservoir, the float is buoyed by the water remaining in the box, even as the water level in the bucket drains. However, once the water level is below the bottom of the box, the float falls and the valve is opened, allowing water to flow through the spout and fill the dosing reservoir until the float is lifted again and the valve is shut.

The toilet valve was connected through the base of the 5-gallon dosing reservoir using a bulkhead fitting. The bulkhead fitting was connected to hosing which ran to the upper reservoir. Figure 3 below shows the dosing reservoir with the toilet valve.

### *Bobber (Float) Valve*

A ½” float valve (termed “bobber valve” in this paper) was connected to a stainless steel arm and a toilet float. The float valve was PVC and rated to 100 psi and 60 gallons per minute flow. The toilet float ball was polyethylene and four inches in diameter by five inches long. The stainless steel rod was bent into an “S” shape in order to fit inside the 5- gallon dosing reservoir and allow the valve to shut all the way.

The bobber valve was installed inside the dosing reservoir and was connected to its side using a bulkhead fitting. The outside of the bulkhead fitting was connected to a hose barb, which connected to hosing that ran to the upper reservoir. Figure 4 below shows the dosing reservoir with the bobber valve.

## Dose Rate Controls

A needle valve and IV restrictor were proposed as options in order to throttle the flow out of the outlet of the dosing reservoir to a rate that is acceptable for chlorine dosing (1-3 mL/min). These two valves allow the restriction to be adjusted as either flows change or point-of-use residual testing shows that the chlorine doses must be changed.

### *Needle Valve*

A plastic, ¼” needle valve was purchased from Spears. The needle valve acts as its own bulkhead fitting and was attached to the side of the dosing reservoir at its base. The barb at the end of the needle valve was allowed to drip freely in the lab setting. The needle valve is shown installed in Figure 4.

### *IV Restrictor*

The IV restrictor used was ordered from Qosina Corporation, product number 21294. This IV restrictor was chosen because it does not contain a filter within the unit, which will lessen the chance of clogging, and its connections made fitting tubing possible without the use of pliers. A bulkhead fitting was installed to the side of the dosing reservoir at its base. Tubing was attached to the barb of the bulkhead, which connected to the IV restrictor. A small section of tubing was placed on the outlet of the IV restrictor in order to more accurately direct the flow out of the unit. IV restrictors are shown installed in both Figure 3 and Figure 4.

## System Configurations

The following system configurations were made in order to test all four control devices:

1) A 5-gallon bucket was plumbed with the toilet valve and a hose barb that was connected to a small length of tubing and an IV restrictor (shown in Figure 3)
2) A 5-gallon bucket was plumbed with a bobber valve, attached to the float with a float rod that was bent in order to fit into the bucket. Two outlets were installed: a needle valve and a hose barb that was connected to a small length of tubing and an IV restrictor (shown in Figure 4).

Both buckets were connected by hose to an upper reservoir (7-gallon bucket) that was placed on an upper mezzanine approximately 10 feet above the level of the dosing reservoirs. This entire system setup is shown in Figure 5.

Photos of these system configurations are shown below.

*Figure 3: Photo of dosing reservoir with a toilet valve for water level control and IV restrictor for outlet flow control.*

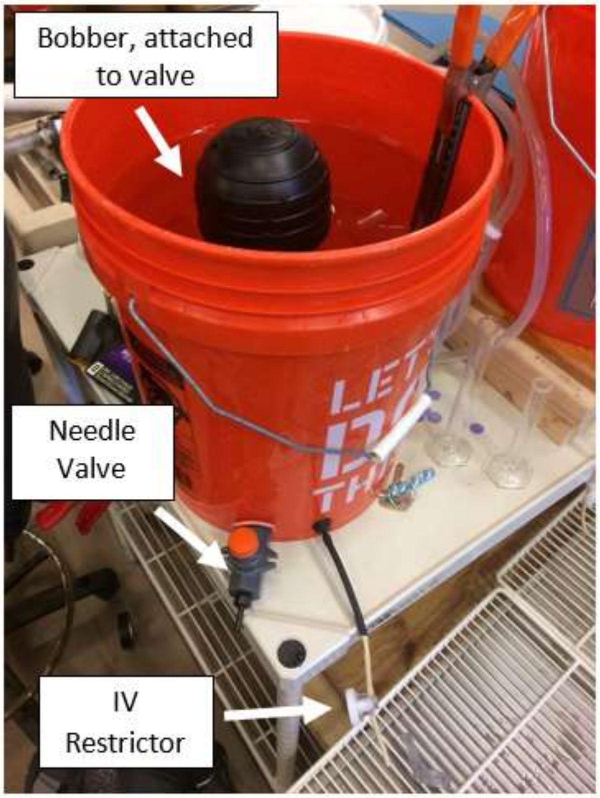

*Figure 4: Photo of dosing reservoir with a bobber valve for water level control and IV restrictor and needle valve for outlet flow control.*

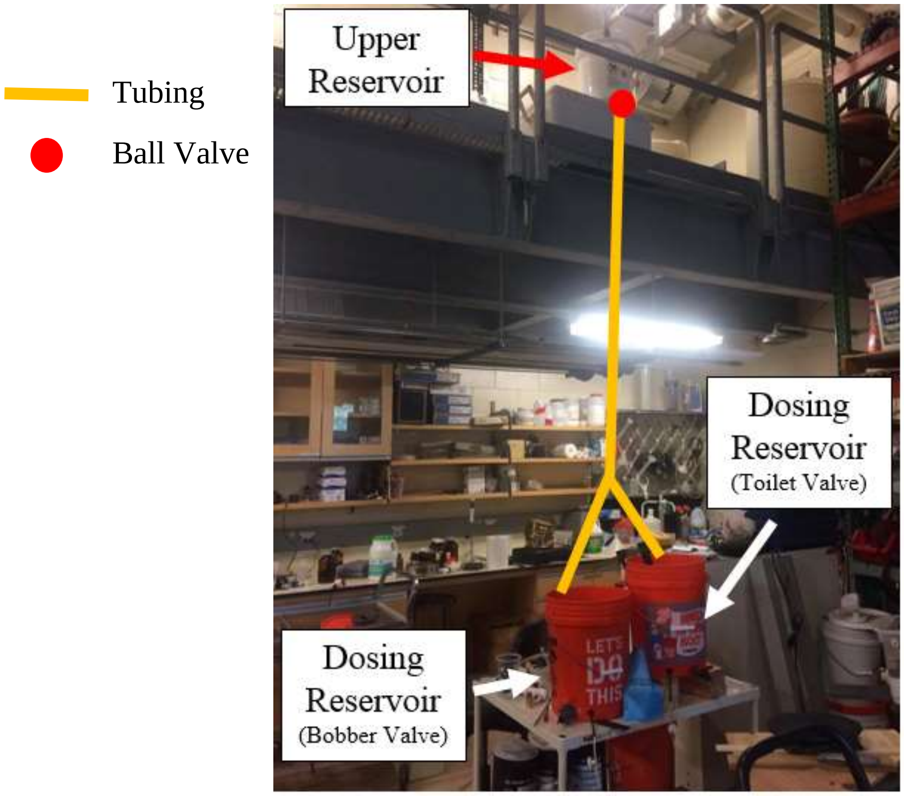

*Figure 5: Schematic of system setup with two dosing reservoirs connected to an upper reservoir.*

# EXPERIMENT AND RESULTS

A series of experiments were devised in order to test the practicality of each system component and its effectiveness at dosing low flow rates of chlorine. Throughout these tests, water (instead of a chlorine solution) was utilized for convenience. Implications of this simplification are discussed in Recommendations.

## Head Requirements

In order for these systems to be considered feasible for implementation, it is necessary that they operate under less than ten feet of head (the height of the water storage tank, Atagaca, and therefore the most convenient and readily available head). In order to test this, both the toilet valve and bobber valve dosing reservoirs were drained below the water surface level at which the floats were lowered enough to open the valves that allow water to pass through them. Water was then poured into the tubing connected to the inlet to the reservoirs. The water level in the tubing above the water level in the dosing reservoir was noted at the time water began flowing through the valves into the bucket and the water level in the bucket began to rise. This level is the required head to drive water into the dosing reservoir.

It was found that the toilet valve required approximately 3.5 inches (0.29 feet) of head in order to fill. It was found that the bobber valve required approximately 2 inches (0.17 feet) of head in order to fill. Such low head requirements make both of these water level controls feasible for implementation in many different settings, including San Pedro de Casta, so both were carried forward for more experiments.

## Water Level

The water level in the dosing reservoir was recorded at different time intervals for study periods of approximately five days for both the toilet valve and bobber valve systems in order to test their effectiveness at maintaining a constant water level in the dosing reservoir. Data taken included the day and time the reading was taken, and the water surface level as denoted on a ruler clamped to the side of the dosing reservoir. The water surface level reading was normalized to the “full” water height, or the highest water surface level reading present in the data. Any notable observations were also recorded. The raw data set can be seen in Appendix E and is plotted in Figure 6 below.

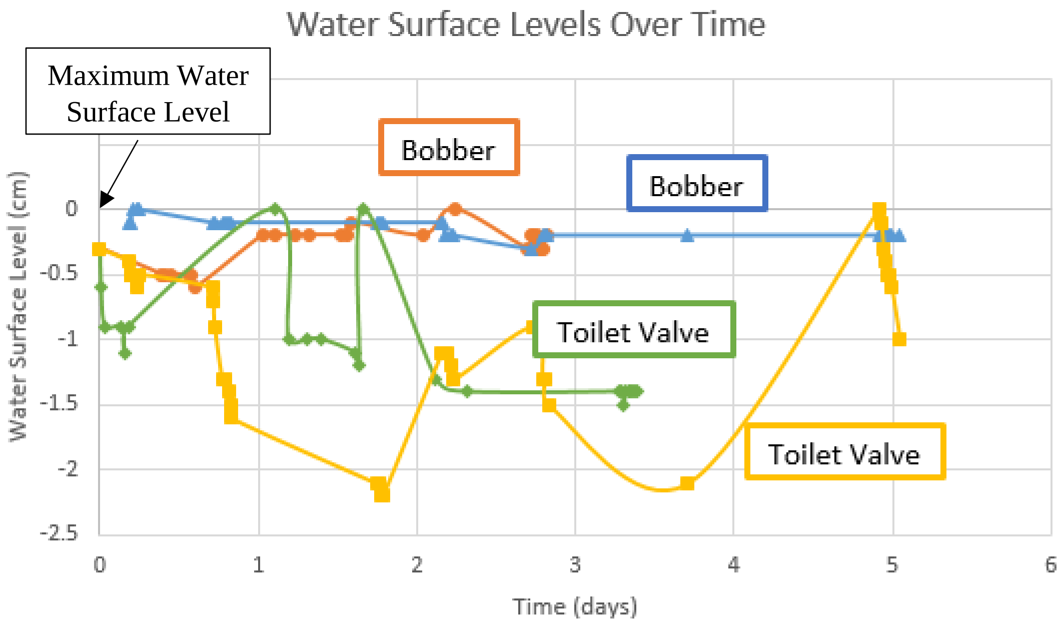

*Figure 6: Water Surface Level in the Dosing Reservoir Controlled by Bobber and Toilet Valves*

In Figure 6 above, the orange and blue lines represent trials performed with the bobber valve. As shown, the water level in the dosing reservoir remained consistent to within 0.5 centimeters of the "full" water level.

The green and yellow lines represent trials performed with the toilet valve. The water level in the dosing reservoir remained consistent to within 2.5 centimeters of the "full" water level. The refilling pattern can be seen in several time intervals, shown where there are steep increases in the water surface level over a short time interval.

**Dose Rate**

The drip rate was recorded at different time intervals for study periods of approximately five days for both the needle valve and the IV restrictors using both the bobber valve and toilet valves in order to test their effectiveness at maintaining a constant drip rate. Data taken included the day and time the reading was taken, the drip rate the IV restrictor was set to, adjustments made to the needle valve opening, and the drip rate from each valve. A graduated cylinder was placed at the outlet of each restrictor, and it was allowed to drip for three minutes. The drip rate in mL/min was calculated by dividing the volume in the graduated cylinder (mL) by three minutes. Any notable observations were also recorded. The raw data set can be seen in Appendix F and is plotted in Figure 7 below.

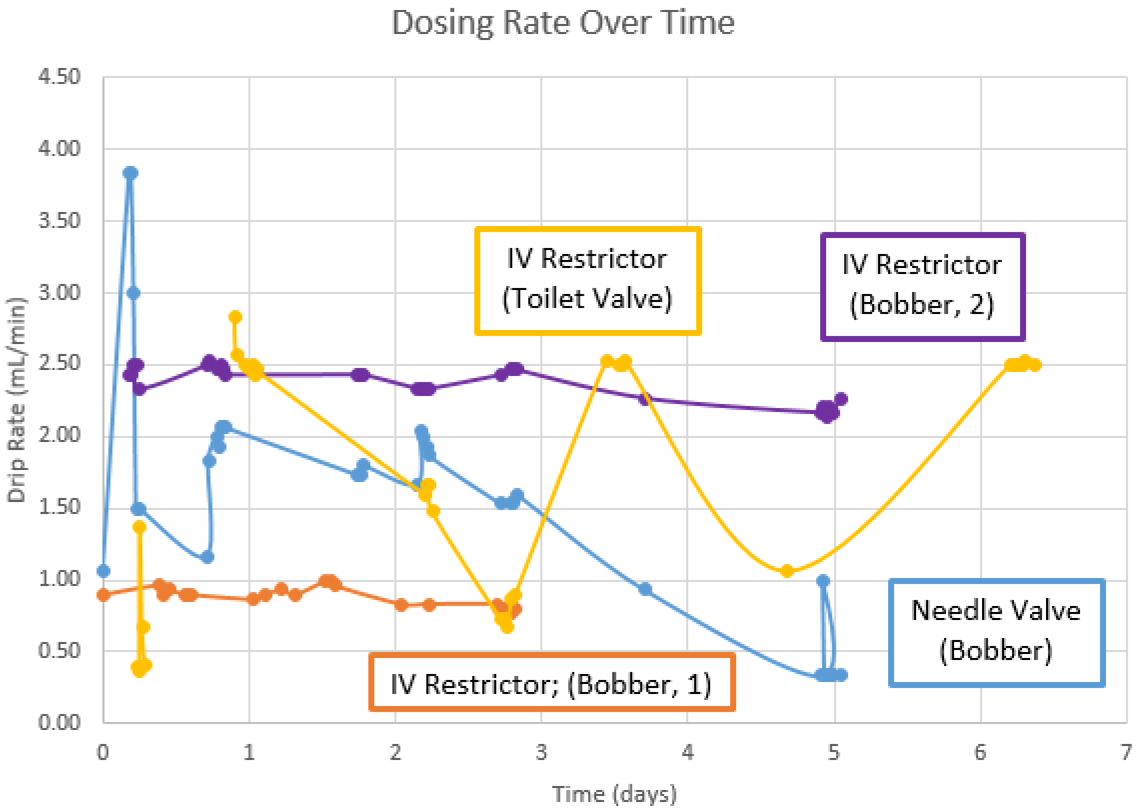

*Figure 7: Drip Rate from the Dosing Reservoir Controlled by IV Restrictor and Needle Valve*

In Figure 7 above, the orange and gray lines represent trials that combined the IV restrictor and the bobber valve. This combination was able to restrict variances in drip rate to less than 0.5 mL/min and was able to achieve a desired drip rate between 1 and 3 mL/min.

The blue line represents a trial that combined the needle valve and the bobber valve. The first several readings were used to establish an acceptable opening level for the needle valve to achieve an appropriate dosing rate (see raw data in Appendix F for notes on valve opening and closing). This combination was able to maintain the desired drip rate to within 1 mL/min for the majority of the run, but performance dropped in the last hours of the experiment; the reason for this is unknown.

The yellow line represents a trial that combined the IV restrictor and the toilet valve. Drip rates with this system were fairly sporadic, but a dose rate between 1 and 3 mL/min was achieved throughout the majority of the run.

### Water Level vs. Dose Rate

Figure 8 below shows the relationship between the dosing rate and the water surface level in the dosing reservoir for the different combinations of water level controls and outlet dose rate controls. Drip rates that are sensitive to the water surface level will have a flat slope; drip rates that remain constant despite variances in the water surface level will have a vertical slope.

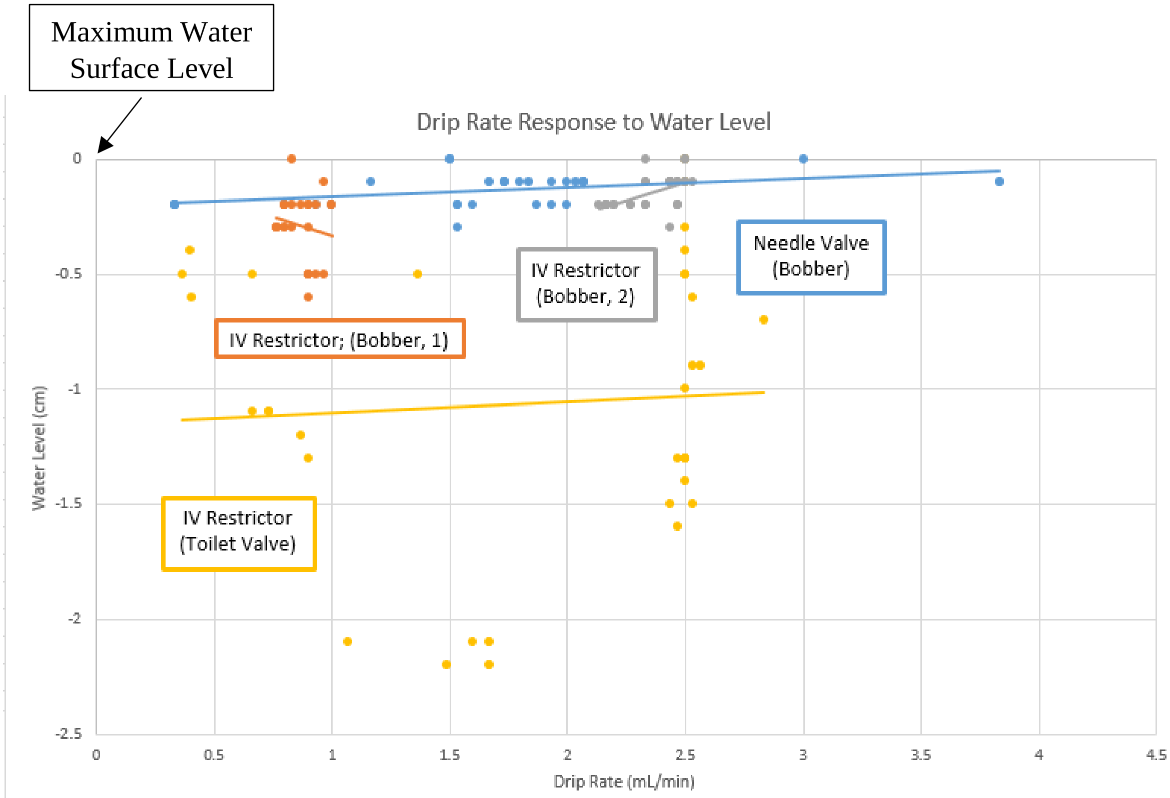

*Figure 8 Drip Rate out of the Dosing Reservoir as a Function of Water Level in Dosing Reservoir*

In Figure 8 above, the orange and gray lines represent trials that combined the IV restrictor and the bobber valve. These trials show data that fit with a steep trend line, meaning that the dosing rate out of the reservoir varies little with changes in water surface level. The data is also clustered close together, meaning that both the drip rate and the water surface level changed little throughout the experiment.

The blue line represents a trial that combined the needle valve and the bobber valve. This trial shows data that fits with a flatter slope, meaning that the dosing rate out of the reservoir varies depending on the water surface level.

The yellow line represents a trial that combined the IV restrictor and the toilet valve. This trial shows data that fits with a flatter slope, meaning that the dosing rate out of the reservoir varies depending on the water surface level.

Figure 8b, below, shows the same data as Figure 8, however the x- and y-axis are reversed. Water surface level (the independent variable) is on the x-axis and drip rate (the dependent variable) is on the y-axis.

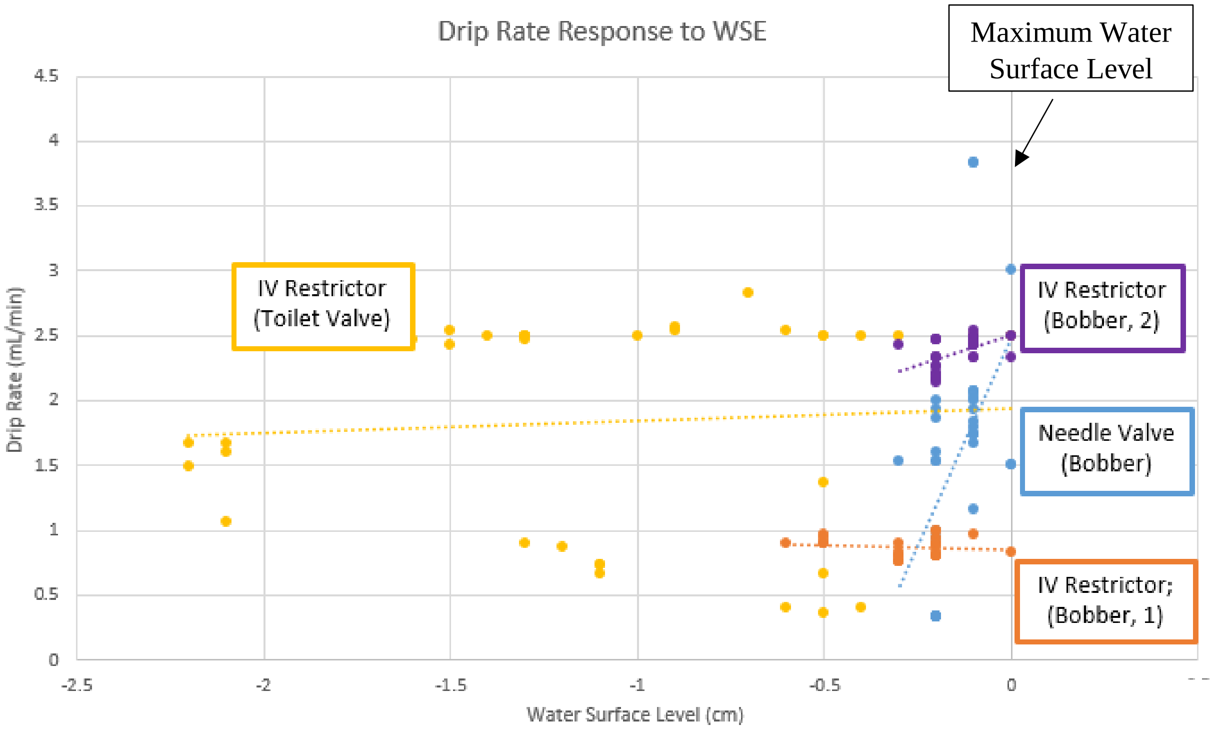

*Figure 8b Drip Rate out of the Dosing Reservoir as a Function of Water Level in Dosing Reservoir*

## Observations

This section notes observations made during the experimental process that could impact the practicality of implementing these systems in rural or remote communities.

### *Toilet Valve*

The toilet valve was difficult to install because it needed special connections designed specifically for toilets. While these connections would be available in Peru and other countries, they would have to be sought out during the installation or repair of a drip chlorination system. Communities would not be able to use just any available connections found in the community, which would delay any maintenance or cause the system to not work properly if the wrong connections were used.

This specific toilet valve could be prohibiting the water surface level from maintaining a tighter range by using the box to encase the float. It was noted in System Setup that the box maintained a higher water level in the box and only allowed the float to drop once the water level had dropped below the box (about 2.5 cm); if the box was not there, the float may have been allowed to drop faster, and therefore the dosing reservoir refill faster.

### *Bobber Valve*

The steel rod used to connect the valve to the float had to be bent to accommodate the dosing reservoir and allow the valve to be closed at an appropriate water level. The rod was bent using special tools, which may not be available in rural communities. It is noted, however, that people living in these places tend to be very industrious and could probably find a way to manipulate the materials to suit the system.

*IV Restrictor*

The drip rates measured from the IV restrictor were lower than indicated on the dial of the IV. This could cause under-dosing if an operator were to set the drip rate by following the IV restrictor dial without confirming with a drip test.

*Needle Valve*

The needle valve did not come with any indication of how “open” the dial was, which would make it difficult to keep on a consistent setting if it needed to be closed or opened for maintenance.

## SUMMARY OF FINDINGS

It was found through these experiments that both the toilet valve and bobber valve are both viable options for controlling the water surface elevation in the dosing reservoir. Both valves can operate under minimal head requirements (3 inches or less). The bobber valve was able to maintain the water level at a consistent level, varying only 0.5 cm, and the toilet valve was able to maintain the water level consistently to within 2.5 cm. A 2.5 cm difference in water level equates to a change in pressure at the outlet of only 0.19 psi.

It was found that the most effective combination of water level and outlet controls at maintaining a constant drip rate out of the system was the bobber valve and IV restrictor. This system was able to maintain a drip rate that varied less than 0.5 mL/min and could easily dose in the desired range of 1 – 3 mL/min.

## MATERIALS SOURCING

All materials used in these experiments may be sourced in Peru at locations accessible to the residents of San Pedro de Casta in Lima, a four hour bus ride from the community. Many of these materials could likely also be purchased in the markets of a more-nearby city, Chosica. The materials used in the systems tested are listed in Table 2 below, along with where they may be sourced in Peru and their cost. It is assumed that tools necessary to assemble the systems would be available in the community.

*Table 2 Materials sourced from Lima, Peru*

| Material | Product Name | Store | Product Number | Cost (S) | Cost ($) |
|---|---|---|---|---|---|
| Toilet Valve | Válvula de ingreso | Sodimac | SKU 173826-7 | 34.90 | $ 10.77 |
| Float (Bobber) Valve | VALV FLOT BRCE 1/2 S/BOYA | Sodimac | SKU 250091-4 | 19.90 | $ 6.14 |
| 5-gallon bucket | Balde de plástico 20 L | Sodimac | SKU 170064-2 | 9.50 | $ 2.93 |
| IV restrictor | Filtro de infusión | Braun (Peru) | N/A | N/A | N/A |
| Needle Valve | Valvula Control | Sodimac | SKU 165903-0 | 32.90 | $ 10.15 |
| Tubing | Tubería de PP 1/4" x 10 m Blanco | Sodimac | SKU 185990-0 | 45.90 | $ 14.17 |
| Bulkhead Fittings | Unión universal con rosca | Sodimac | SKU 30993-1 | 3.90 | $ 1.20 |
| Hose Barbs | Punta Manguera 1/4 NPT x 1/4" | Sodimac | SKU 35946-7 | 5.90 | $ 1.82 |

# RECOMMENDATIONS

This research identified several possible system configurations to build an effective drip chlorination system, but further testing and design refinements need to be made before a system could be ready for installation in San Pedro de Casta or other community.

These experiments were all conducted using water; in an implemented system, the reservoirs would be filled with a hypochlorite solution (bleach), which as a different density and viscosity than water. The solution has the potential to precipitate out calcium, which could clog tubing and orifices, especially the IV restrictor and needle valves. These experiments therefore need to be repeated using a chlorine solution to test the effects, and construct maintenance protocol should clogging occur.

The rod used to connect the bobber valve to the float in these experiments was stainless steel, which is resistant to the effects of chlorine. However, should stainless steel be unavailable in a remote community, other materials should be tested for their effectiveness. One option is PVC.

Finally, odor control is necessary for these systems for the safety of the operator. Chlorine fumes would be irritating to anyone performing maintenance on the system. To alleviate some odor, it is suggested that the lid of the 5 gallon bucket be placed on the system, with several air vents to ensure that the water level is at atmospheric pressure. In order to further control for odor, the possibility of attaching a container filled with granular activated carbon (GAC) to the lid of the 5 gallon bucket should be investigated. A product similar to those used in fish tanks would be an appropriate place from which to start.

# ACKNOWLEDGEMENTS

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- Dr. M. Robin Collins
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- Peter Dwyer
- Paige Taber
- University of New Hampshire Students Without Borders

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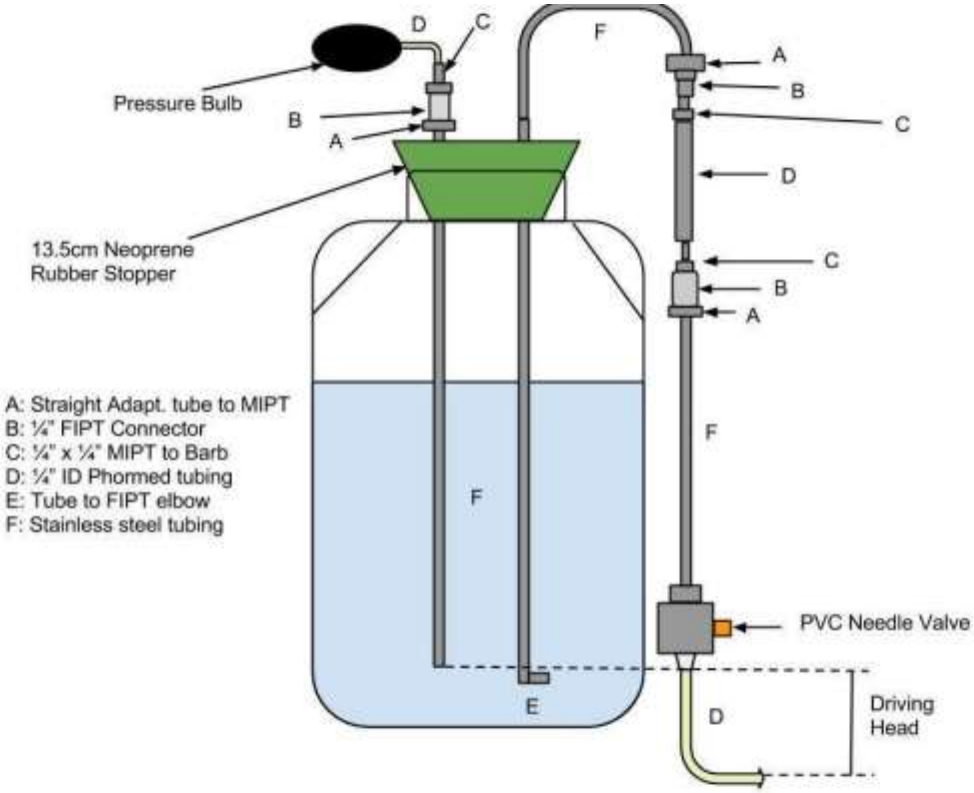
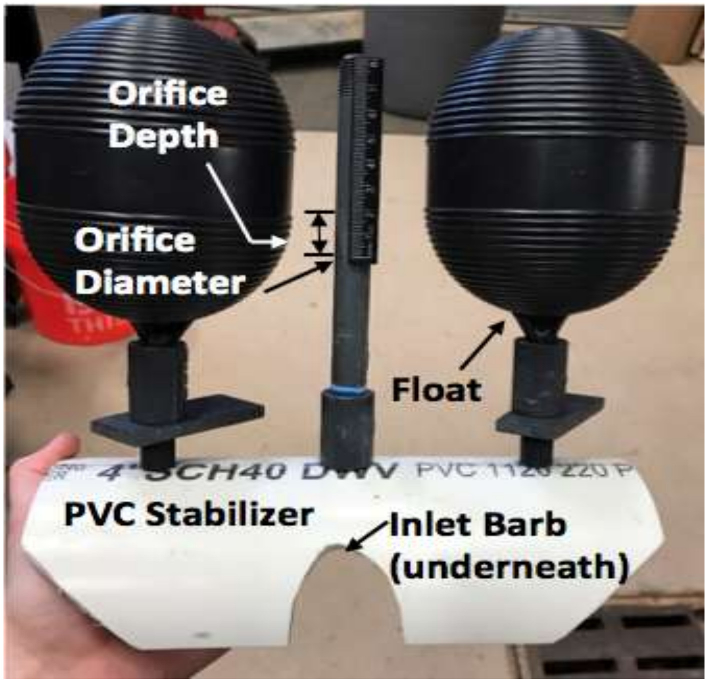
# APPENDICES

# APPENDIX A: Previous Drip Chlorinator Systems

## Marioette Bottle

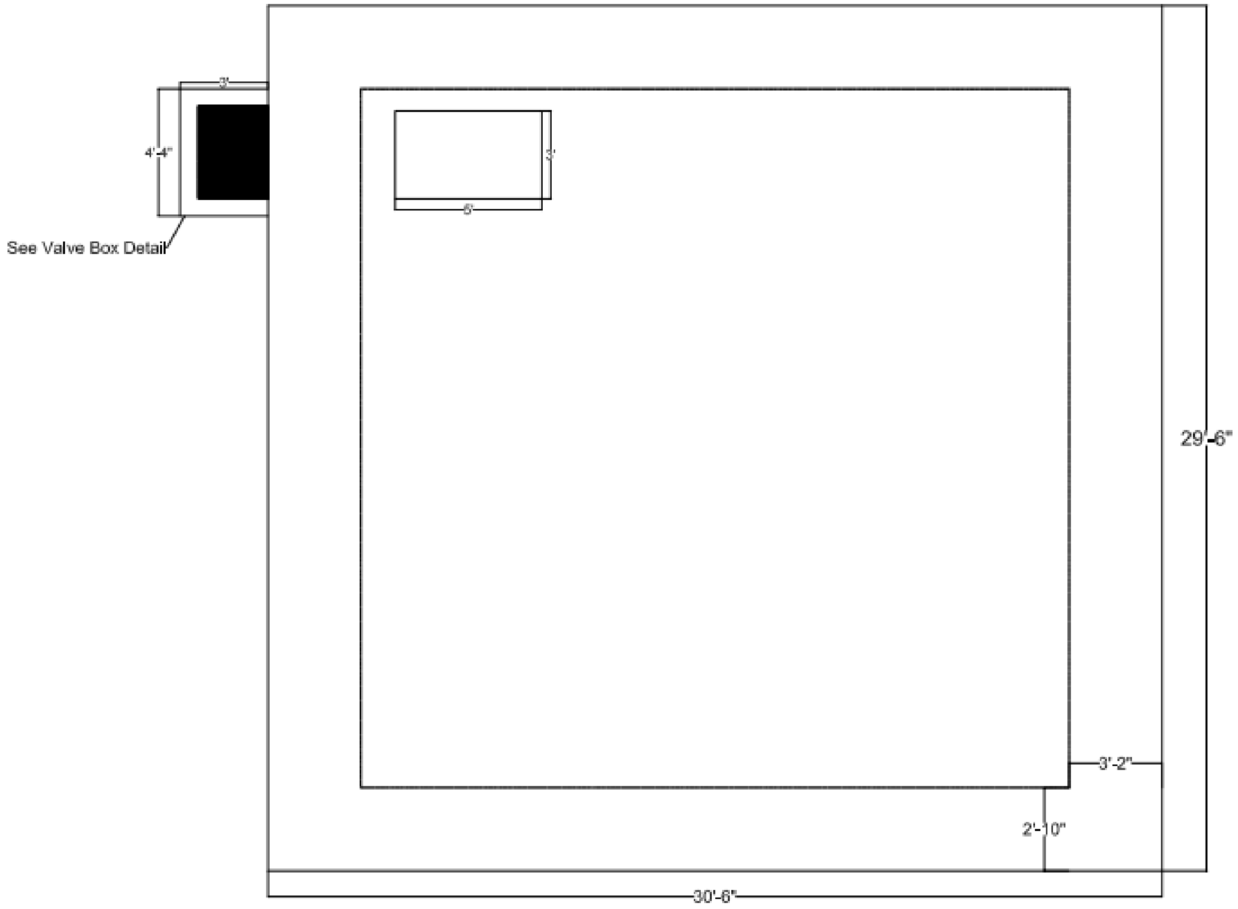


## Floating Apparatus

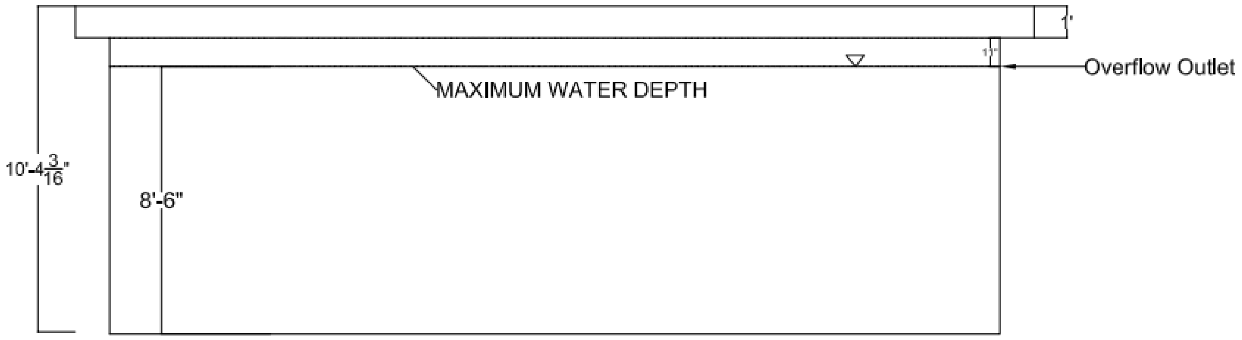


# APPENDIX B: Atagaca Water Tank Dimensions

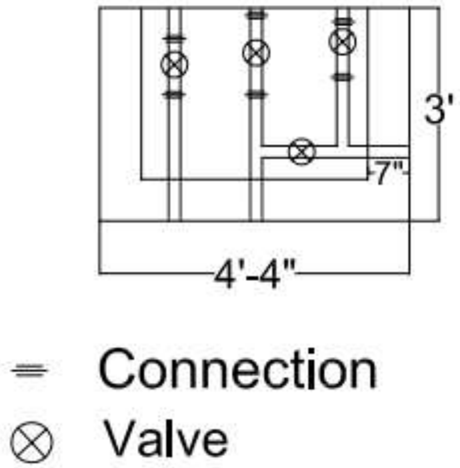
## Plan View



## Profile View



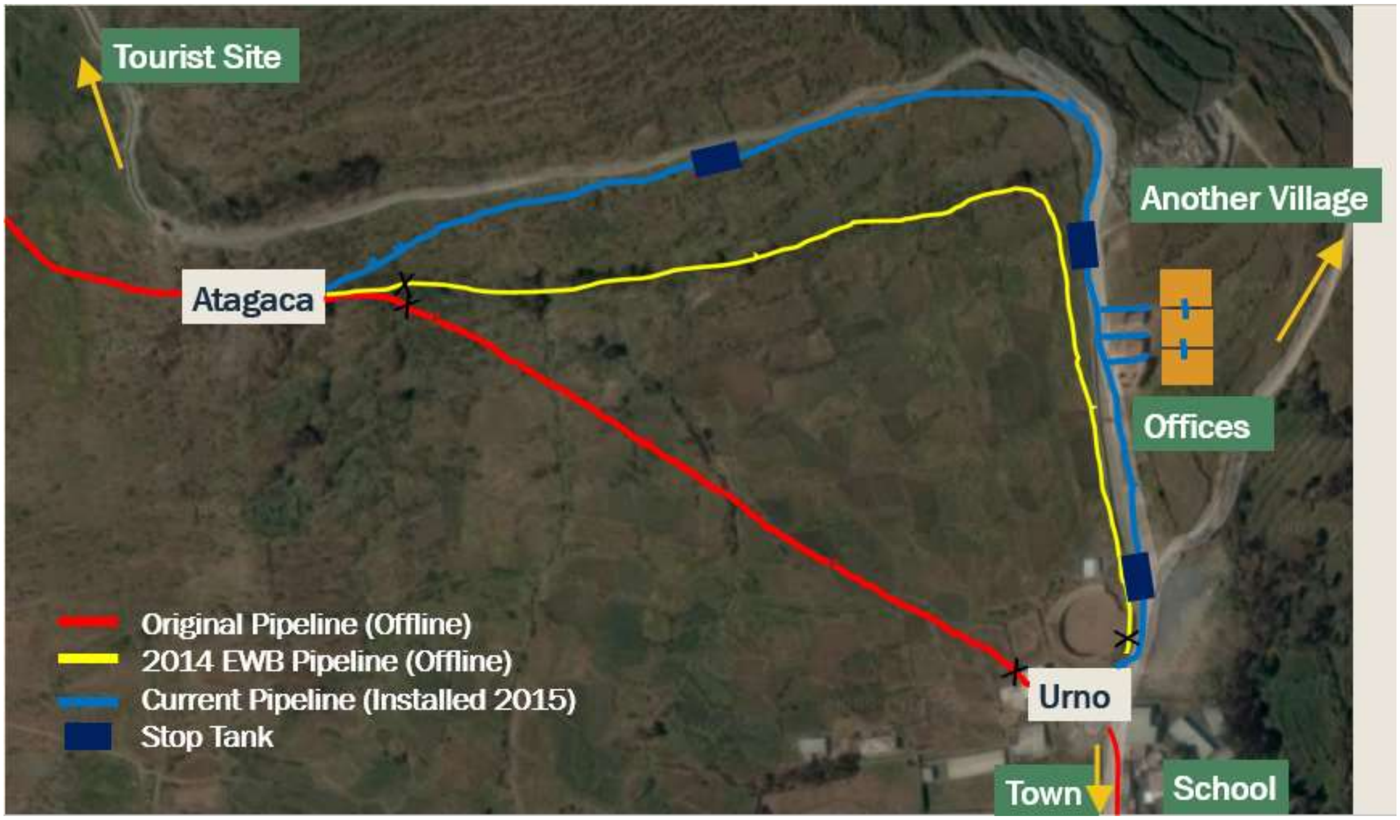
**Valve Box Detail**



Notes:

- Pipe is 2” diameter, PVC
- Left-most pipe is the outlet, which connects to a larger HDPE pipeline installed in 2015
- Right-most pipe is inlet

# APPENDIX C: Piping System Layout



# APPENDIX D: Chlorine Demand Calculation

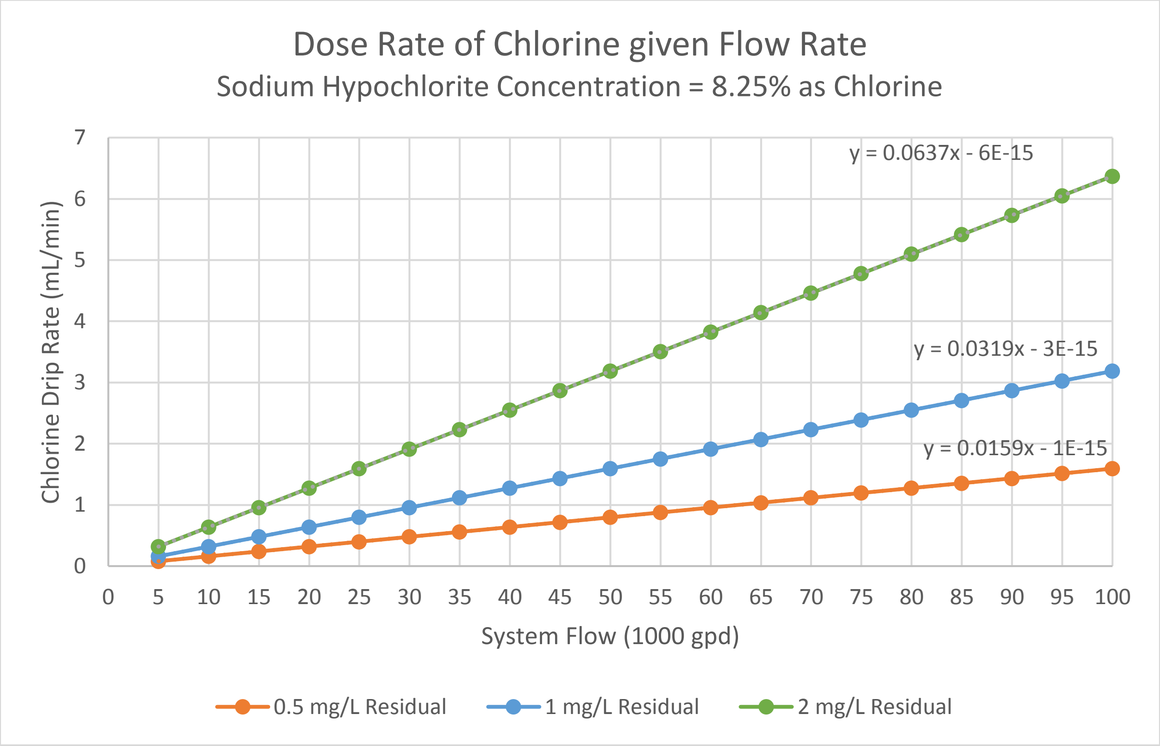
$$Drip\ Rate = \frac{Desired\ Residual\ * Flow\ Rate}{Hypochlorite\ Concentration}$$

- Desired chlorine residual of 1 mg/L
    - Recommend by the World Health Organization
- Flow rate in community = 50,000 gal/day = 131.4 L/min
    - Read from the flow meter installed in San Pedro de Casta
- Chlorine can be sourced at 8.25% hypochlorite = 82.5 mg/mL
    - Chlorine available Chosica

$$Drip\ Rate = \frac{1\frac{mg}{L} * 131.4\frac{L}{min}}{82.5\ \frac{mg}{mL}} = 1.6\ mL/min$$

An acceptable drip rate from the implemented system would be between 1 mL/min – 3 mL/min.

Note that the dosing/drip rate depends on the desired chlorine residual and the system flow rate. Below is a graph which allows operators to quickly estimate the required dose rate with changes in the desired residual and system flow rate. All rates are based on a chlorine solution at 8.25% concentration of hypochlorite.



# APPENDIX E: Water Level Raw Data

| Toilet Valve Trial 1 | | | |
|---|---|---|---|
| Time | Time (min) | Water Level (cm) | Normalized WSE (cm) |
| 7:00:00 AM | 0 | | |
| 7:09:00 PM | 9 | -9.5 | -0.3 |
| 7:44:00 PM | 44 | -9.8 | -0.6 |
| 10:20:00 PM | 200 | -10.1 | -0.9 |
| 10:42:00 PM | 222 | -10.1 | -0.9 |
| 11:19:00 PM | 259 | -10.3 | -1.1 |
| 9:33:00 AM | 1593 | -10.1 | -0.9 |
| 11:31:00 AM | 1711 | -9.2 | 0 |
| 2:20:00 PM | 1880 | -10.2 | -1 |
| 4:32:00 PM | 2012 | -10.2 | -1 |
| 9:31:00 PM | 2311 | -10.2 | -1 |
| 10:15:00 PM | 2355 | -10.3 | -1.1 |
| 10:55:00 PM | 2395 | -10.4 | -1.2 |
| 9:52:00 AM | 3052 | -9.2 | 0 |
| 2:35:00 PM | 3335 | -10.5 | -1.3 |
| 1:35:00 PM | 4715 | -10.6 | -1.4 |
| 2:05:00 PM | 4745 | -10.6 | -1.4 |
| 2:20:00 PM | 4760 | -10.6 | -1.4 |
| 2:35:00 PM | 4775 | -10.7 | -1.5 |
| 3:00:00 PM | 4800 | -10.6 | -1.4 |
| 3:15:00 PM | 4815 | -10.6 | -1.4 |
| 3:30:00 PM | 4830 | -10.6 | -1.4 |
| 3:50:00 PM | 4850 | -10.6 | -1.4 |
| 4:05:00 PM | 4865 | -10.6 | -1.4 |
| 4:30:00 PM | 4890 | -10.6 | -1.4 |

| Toilet Valve Trial 2 | | | | |
|---|---|---|---|---|
| Date | Time | Time (min) | Water Level (cm) | Normalized WSE (cm) |
| 4/3/2017 | 4:05:00 PM | 0 | -10.3 | -0.3 |
| 4/3/2017 | 8:30:00 PM | 265 | -10.4 | -0.4 |
| 4/3/2017 | 8:50:00 PM | 285 | -10.5 | -0.5 |
| 4/3/2017 | 8:55:00 PM | 290 | -10.5 | -0.5 |
| 4/3/2017 | 9:12:00 PM | 307 | -10.5 | -0.5 |
| 4/3/2017 | 9:34:00 PM | 329 | -10.6 | -0.6 |
| 4/3/2017 | 10:05:00 PM | 360 | -10.5 | -0.5 |
| 4/4/2017 | 9:05:00 AM | 1020 | -10.6 | -0.6 |
| 4/4/2017 | 9:15:00 AM | 1030 | -10.7 | -0.7 |
| 4/4/2017 | 9:27:00 AM | 1042 | -10.9 | -0.9 |
| 4/4/2017 | 10:36:00 AM | 1111 | -11.3 | -1.3 |
| 4/4/2017 | 11:10:00 AM | 1145 | -11.3 | -1.3 |
| 4/4/2017 | 11:30:00 AM | 1165 | -11.4 | -1.4 |
| 4/4/2017 | 11:49:00 AM | 1184 | -11.5 | -1.5 |
| 4/4/2017 | 12:03:00 PM | 1198 | -11.6 | -1.6 |
| 4/5/2017 | 10:01:00 AM | 2516 | -12.1 | -2.1 |
| 4/5/2017 | 10:17:00 AM | 2532 | -12.1 | -2.1 |
| 4/5/2017 | 10:34:00 AM | 2549 | -12.2 | -2.2 |
| 4/5/2017 | 10:52:00 AM | 2567 | -12.2 | -2.2 |
| 4/5/2017 | 7:48:00 PM | 3103 | -11.1 | -1.1 |
| 4/5/2017 | 8:14:00 PM | 3129 | -11.1 | -1.1 |
| 4/5/2017 | 8:35:00 PM | 3150 | -11.1 | -1.1 |
| 4/5/2017 | 9:15:00 PM | 3190 | -11.2 | -1.2 |
| 4/5/2017 | 9:43:00 PM | 3218 | -11.3 | -1.3 |
| 4/6/2017 | 9:33:00 AM | 3928 | -10.9 | -0.9 |
| 4/6/2017 | 11:05:00 AM | 4020 | -11.3 | -1.3 |
| 4/6/2017 | 11:33:00 AM | 4048 | -11.3 | -1.3 |
| 4/6/2017 | 12:00:00 PM | 4075 | -11.5 | -1.5 |
| 4/7/2017 | 9:01:00 AM | 5336 | -12.1 | -2.1 |
| 4/8/2017 | 2:00:00 PM | 7075 | -10 | 0 |
| 4/8/2017 | 2:20:00 PM | 7095 | -10.1 | -0.1 |
| 4/8/2017 | 2:40:00 PM | 7115 | -10.3 | -0.3 |
| 4/8/2017 | 3:00:00 PM | 7135 | -10.4 | -0.4 |
| 4/8/2017 | 3:20:00 PM | 7155 | -10.5 | -0.5 |
| 4/8/2017 | 3:35:00 PM | 7170 | -10.5 | -0.5 |
| 4/8/2017 | 3:55:00 PM | 7190 | -10.6 | -0.6 |
| 4/8/2017 | 5:10:00 PM | 7265 | -11 | -1 |

| Bobber Valve Trial 1 | | | | |
|---|---|---|---|---|
| Date | Time | Time (min) | Water Level (cm) | Normalized WSE (cm) |
| 3/29/2017 | 8:55:00 AM | 0 | -6.6 | -0.3 |
| 3/29/2017 | 6:19:00 PM | 564 | -6.8 | -0.5 |
| 3/29/2017 | 6:48:00 PM | 593 | -6.8 | -0.5 |
| 3/29/2017 | 7:44:00 PM | 649 | -6.8 | -0.5 |
| 3/29/2017 | 10:20:00 PM | 805 | -6.8 | -0.5 |
| 3/29/2017 | 10:42:00 PM | 827 | -6.8 | -0.5 |
| 3/29/2017 | 11:19:00 PM | 864 | -6.9 | -0.6 |
| 3/30/2017 | 9:33:00 AM | 1478 | -6.5 | -0.2 |
| 3/30/2017 | 11:28:00 AM | 1593 | -6.5 | -0.2 |
| 3/30/2017 | 2:20:00 PM | 1765 | -6.5 | -0.2 |
| 3/30/2017 | 4:32:00 PM | 1897 | -6.5 | -0.2 |
| 3/30/2017 | 9:31:00 PM | 2196 | -6.5 | -0.2 |
| 3/30/2017 | 10:15:00 PM | 2240 | -6.5 | -0.2 |
| 3/30/2017 | 10:55:00 PM | 2280 | -6.4 | -0.1 |
| 3/31/2017 | 9:52:00 AM | 2937 | -6.5 | -0.2 |
| 3/31/2017 | 2:35:00 PM | 3220 | -6.3 | 0 |
| 4/2/2017 | 1:35:00 PM | 3880 | -6.6 | -0.3 |
| 4/2/2017 | 2:05:00 PM | 3910 | -6.5 | -0.2 |
| 4/2/2017 | 2:20:00 PM | 3925 | -6.6 | -0.3 |
| 4/2/2017 | 2:35:00 PM | 3940 | -6.5 | -0.2 |
| 4/2/2017 | 3:00:00 PM | 3965 | -6.6 | -0.3 |
| 4/2/2017 | 3:15:00 PM | 3980 | -6.5 | -0.2 |
| 4/2/2017 | 3:30:00 PM | 3995 | -6.6 | -0.3 |
| 4/2/2017 | 3:50:00 PM | 4015 | -6.6 | -0.3 |
| 4/2/2017 | 4:05:00 PM | 4030 | -6.6 | -0.3 |
| 4/2/2017 | 4:30:00 PM | 4055 | -6.5 | -0.2 |

| Bobber Valve Trial 2 | | | | |
|---|---|---|---|---|
| Date | Time | Time (min) | Water Level (cm) | Normalized WSE (cm) |
| 4/3/2017 | 4:05:00 PM | 0 | -6.6 | -0.3 |
| 4/3/2017 | 8:25:00 PM | 260 | -6.8 | -0.5 |
| 4/3/2017 | 8:45:00 PM | 280 | -6.8 | -0.5 |
| 4/3/2017 | 9:10:00 PM | 305 | -6.8 | -0.5 |
| 4/3/2017 | 9:34:00 PM | 329 | -6.8 | -0.5 |
| 4/3/2017 | 10:05:00 PM | 360 | -6.8 | -0.5 |
| 4/4/2017 | 9:05:00 AM | 1020 | -6.9 | -0.6 |
| 4/4/2017 | 9:25:00 AM | 1040 | -6.5 | -0.2 |
| 4/4/2017 | 10:41:00 AM | 1116 | -6.5 | -0.2 |
| 4/4/2017 | 11:10:00 AM | 1145 | -6.5 | -0.2 |
| 4/4/2017 | 11:27:00 AM | 1162 | -6.5 | -0.2 |
| 4/4/2017 | 11:46:00 AM | 1181 | -6.5 | -0.2 |
| 4/4/2017 | 12:00:00 PM | 1195 | -6.5 | -0.2 |
| 4/5/2017 | 9:58:00 AM | 2513 | -6.4 | -0.1 |
| 4/5/2017 | 10:14:00 AM | 2529 | -6.5 | -0.2 |
| 4/5/2017 | 10:31:00 AM | 2546 | -6.3 | 0 |
| 4/5/2017 | 10:49:00 AM | 2564 | -6.6 | -0.3 |
| 4/5/2017 | 7:45:00 PM | 3100 | -6.5 | -0.2 |
| 4/5/2017 | 8:10:00 PM | 3125 | -6.6 | -0.3 |
| 4/5/2017 | 8:30:00 PM | 3145 | -6.5 | -0.2 |
| 4/5/2017 | 9:12:00 PM | 3187 | -6.6 | -0.3 |
| 4/5/2017 | 9:40:00 PM | 3215 | -6.5 | -0.2 |
| 4/6/2017 | 9:30:00 AM | 3925 | -6.6 | -0.3 |
| 4/6/2017 | 11:05:00 AM | 4020 | -6.6 | -0.3 |
| 4/6/2017 | 11:29:00 AM | 4044 | -6.6 | -0.3 |
| 4/6/2017 | 11:56:00 AM | 4071 | -6.5 | -0.2 |
| 4/7/2017 | 9:06:00 AM | 5341 | 0 | 0 |
| 4/8/2017 | 2:00:00 PM | 7075 | 0 | 0 |
| 4/8/2017 | 2:15:00 PM | 7090 | 0 | 0 |
| 4/8/2017 | 2:37:00 PM | 7112 | 0 | 0 |
| 4/8/2017 | 2:57:00 PM | 7132 | 0 | 0 |
| 4/8/2017 | 3:17:00 PM | 7152 | 0 | 0 |
| 4/8/2017 | 3:31:00 PM | 7166 | 0 | 0 |
| 4/8/2017 | 3:52:00 PM | 7187 | 0 | 0 |
| 4/8/2017 | 5:07:00 PM | 7262 | 0 | 0 |

# APPENDIX F: Drip Rate Raw Data

| IV Restrictor, Bobber Trial 1 | | | | | |
|---|---|---|---|---|---|
| Date | Time | Time (min) | Volume (mL) for 3 Minutes | Drip Rate (mL/min) | IV Setting |
| 3/29/2017 | 8:55:00 AM | 0 | 2.7 | 0.900 | 95 |
| 3/29/2017 | 6:19:00 PM | 564 | 2.9 | 0.967 | 95 |
| 3/29/2017 | 6:48:00 PM | 593 | 2.7 | 0.900 | 95 |
| 3/29/2017 | 7:44:00 PM | 649 | 2.8 | 0.933 | 95 |
| 3/29/2017 | 10:20:00 PM | 805 | 2.7 | 0.900 | 95 |
| 3/29/2017 | 10:42:00 PM | 827 | 2.7 | 0.900 | 95 |
| 3/29/2017 | 11:19:00 PM | 864 | 2.7 | 0.900 | 95 |
| 3/30/2017 | 9:33:00 AM | 1478 | 2.6 | 0.867 | 95 |
| 3/30/2017 | 11:28:00 AM | 1593 | 2.7 | 0.900 | 95 |
| 3/30/2017 | 2:20:00 PM | 1765 | 2.8 | 0.933 | 95 |
| 3/30/2017 | 4:32:00 PM | 1897 | 2.7 | 0.900 | 95 |
| 3/30/2017 | 9:31:00 PM | 2196 | 3 | 1.000 | 95 |
| 3/30/2017 | 10:15:00 PM | 2240 | 3 | 1.000 | 95 |
| 3/30/2017 | 10:55:00 PM | 2280 | 2.9 | 0.967 | 95 |
| 3/31/2017 | 9:52:00 AM | 2937 | 2.5 | 0.833 | 95 |
| 3/31/2017 | 2:35:00 PM | 3220 | 2.5 | 0.833 | 95 |
| 4/2/2017 | 1:35:00 PM | 3880 | 2.5 | 0.833 | 95 |
| 4/2/2017 | 2:05:00 PM | 3910 | 2.4 | 0.800 | 95 |
| 4/2/2017 | 2:20:00 PM | 3925 | 2.4 | 0.800 | 95 |
| 4/2/2017 | 2:35:00 PM | 3940 | 2.4 | 0.800 | 95 |
| 4/2/2017 | 3:00:00 PM | 3965 | 2.3 | 0.767 | 95 |
| 4/2/2017 | 3:15:00 PM | 3980 | 2.4 | 0.800 | 95 |
| 4/2/2017 | 3:30:00 PM | 3995 | 2.3 | 0.767 | 95 |
| 4/2/2017 | 3:50:00 PM | 4015 | 2.3 | 0.767 | 95 |
| 4/2/2017 | 4:05:00 PM | 4030 | 2.4 | 0.800 | 95 |
| 4/2/2017 | 4:30:00 PM | 4055 | 2.4 | 0.800 | 95 |

| IV Restrictor, Bobber Trial 2 | | | | | |
|---|---|---|---|---|---|
| Date | Time | Time (min) | Volume (mL) for 3 Minutes | Drip Rate (mL/min) | IV Setting |
| 4/3/2017 | 4:05:00 PM | 0 | less than 1 | | 150 |
| 4/3/2017 | 8:25:00 PM | 260 | 7.3 | 2.43 | 250 |
| 4/3/2017 | 8:45:00 PM | 280 | 7.3 | 2.43 | 250 |
| 4/3/2017 | 9:10:00 PM | 305 | 7.5 | 2.50 | 250 |
| 4/3/2017 | 9:34:00 PM | 329 | 7.5 | 2.50 | 250 |
| 4/3/2017 | 10:05:00 PM | 360 | 7 | 2.33 | 250 |
| 4/4/2017 | 9:05:00 AM | 1020 | 7.5 | 2.50 | 250 |
| 4/4/2017 | 9:25:00 AM | 1040 | 7.6 | 2.53 | 250 |
| 4/4/2017 | 10:41:00 AM | 1116 | 7.4 | 2.47 | 250 |
| 4/4/2017 | 11:10:00 AM | 1145 | 7.4 | 2.47 | 250 |
| 4/4/2017 | 11:27:00 AM | 1162 | 7.5 | 2.50 | 250 |
| 4/4/2017 | 11:46:00 AM | 1181 | 7.4 | 2.47 | 250 |
| 4/4/2017 | 12:00:00 PM | 1195 | 7.3 | 2.43 | 250 |
| 4/5/2017 | 9:58:00 AM | 2513 | 7.3 | 2.43 | 250 |
| 4/5/2017 | 10:14:00 AM | 2529 | 7.3 | 2.43 | 250 |
| 4/5/2017 | 10:31:00 AM | 2546 | 7.3 | 2.43 | 250 |
| 4/5/2017 | 10:49:00 AM | 2564 | 7.3 | 2.43 | 250 |
| 4/5/2017 | 7:45:00 PM | 3100 | 7 | 2.33 | 250 |
| 4/5/2017 | 8:10:00 PM | 3125 | 7 | 2.33 | 250 |
| 4/5/2017 | 8:30:00 PM | 3145 | 7 | 2.33 | 250 |
| 4/5/2017 | 9:12:00 PM | 3187 | 7 | 2.33 | 250 |
| 4/5/2017 | 9:40:00 PM | 3215 | 7 | 2.33 | 250 |
| 4/6/2017 | 9:30:00 AM | 3925 | 7.3 | 2.43 | 250 |
| 4/6/2017 | 11:05:00 AM | 4020 | 7.4 | 2.47 | 250 |
| 4/6/2017 | 11:29:00 AM | 4044 | 7.4 | 2.47 | 250 |
| 4/6/2017 | 11:56:00 AM | 4071 | 7.4 | 2.47 | 250 |
| 4/7/2017 | 9:06:00 AM | 5341 | 6.8 | 2.27 | 250 |
| 4/8/2017 | 2:00:00 PM | 7075 | 6.5 | 2.17 | 250 |
| 4/8/2017 | 2:15:00 PM | 7090 | 6.6 | 2.20 | 250 |
| 4/8/2017 | 2:37:00 PM | 7112 | 6.5 | 2.17 | 250 |
| 4/8/2017 | 2:57:00 PM | 7132 | 6.4 | 2.13 | 250 |
| 4/8/2017 | 3:17:00 PM | 7152 | 6.6 | 2.20 | 250 |
| 4/8/2017 | 3:31:00 PM | 7166 | 6.5 | 2.17 | 250 |
| 4/8/2017 | 3:52:00 PM | 7187 | 6.5 | 2.17 | 250 |
| 4/8/2017 | 5:07:00 PM | 7262 | 6.8 | 2.27 | 250 |

IV Restrictor, Toilet Valve

| Date | Time | Time (min) | Volume (mL) for 3 Minutes | Drip Rate (mL/min) | IV Restrictor Setting |
|---|---|---|---|---|---|
| 4/3/2017 | 4:05:00 PM | 0 | less than 1 | | 150 |
| 4/3/2017 | 8:30:00 PM | 265 | 1.2 | 0.40 | 250 |
| 4/3/2017 | 8:50:00 PM | 285 | 1.1 | 0.37 | 250 |
| 4/3/2017 | 8:55:00 PM | 290 | 4.1 | 1.37 | 250 |
| 4/3/2017 | 9:12:00 PM | 307 | 2 | 0.67 | 250 |
| 4/3/2017 | 9:34:00 PM | 329 | 1.21 | 0.40 | 250 |
| 4/3/2017 | 10:05:00 PM | 360 | less than 1 | -- | 250 |
| 4/4/2017 | 9:05:00 AM | 1020 | less than 1 | -- | * changed valve |
| 4/4/2017 | 9:15:00 AM | 1030 | 8.5 | 2.83 | 200 |
| 4/4/2017 | 9:27:00 AM | 1042 | 7.7 | 2.57 | 175 |
| 4/4/2017 | 10:36:00 AM | 1111 | 7.5 | 2.50 | 175 |
| 4/4/2017 | 11:10:00 AM | 1145 | 7.4 | 2.47 | 175 |
| 4/4/2017 | 11:30:00 AM | 1165 | 7.5 | 2.50 | 175 |
| 4/4/2017 | 11:49:00 AM | 1184 | 7.3 | 2.43 | 175 |
| 4/4/2017 | 12:03:00 PM | 1198 | 7.4 | 2.47 | 175 |
| 4/5/2017 | 10:01:00 AM | 2516 | 4.8 | 1.60 | 175 |
| 4/5/2017 | 10:17:00 AM | 2532 | 5 | 1.67 | 175 |
| 4/5/2017 | 10:34:00 AM | 2549 | 5 | 1.67 | 175 |
| 4/5/2017 | 10:52:00 AM | 2567 | 5.2 | 1.49 | 175 |
| 4/5/2017 | 7:48:00 PM | 3103 | 2.2 | 0.73 | 175 |
| 4/5/2017 | 8:14:00 PM | 3129 | 2.2 | 0.73 | 175 |
| 4/5/2017 | 8:35:00 PM | 3150 | 2 | 0.67 | 175 |
| 4/5/2017 | 9:15:00 PM | 3190 | 2.6 | 0.87 | 175 |
| 4/5/2017 | 9:43:00 PM | 3218 | 2.7 | 0.90 | 175 |
| 4/6/2017 | 9:33:00 AM | 3928 | 7.6 | 2.53 | 175 |
| 4/6/2017 | 11:05:00 AM | 4020 | 7.5 | 2.50 | 175 |
| 4/6/2017 | 11:33:00 AM | 4048 | 7.5 | 2.50 | 175 |
| 4/6/2017 | 12:00:00 PM | 4075 | 7.6 | 2.53 | 175 |
| 4/7/2017 | 9:01:00 AM | 5336 | 3.2 | 1.07 | 175 |
| 4/8/2017 | 2:00:00 PM | 7075 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 2:20:00 PM | 7095 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 2:40:00 PM | 7115 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 3:00:00 PM | 7135 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 3:20:00 PM | 7155 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 3:35:00 PM | 7170 | 7.5 | 2.50 | 175 |
| 4/8/2017 | 3:55:00 PM | 7190 | 7.6 | 2.53 | 175 |
| 4/8/2017 | 5:10:00 PM | 7265 | 7.5 | 2.50 | 175 |

| Needle Valve, Bobber Valve | | | | | |
|---|---|---|---|---|---|
| Date | Time | Time (min) | Volume (mL) for 3 Minutes | Drip Rate (mL/min) | Valve Notes |
| 4/3/2017 | 4:05:00 PM | 0 | 3.2 | 1.07 | |
| 4/3/2017 | 8:25:00 PM | 260 | 11.5 | 3.83 | |
| 4/3/2017 | 8:45:00 PM | 280 | 11.5 | 3.83 | |
| 4/3/2017 | 9:10:00 PM | 305 | 9 | 3.00 | closed |
| 4/3/2017 | 9:34:00 PM | 329 | 4.5 | 1.50 | closed |
| 4/3/2017 | 10:05:00 PM | 360 | 4.5 | 1.50 | |
| 4/4/2017 | 9:05:00 AM | 1020 | 3.5 | 1.17 | |
| 4/4/2017 | 9:25:00 AM | 1040 | 5.5 | 1.83 | opened |
| 4/4/2017 | 10:41:00 AM | 1116 | 6 | 2.00 | |
| 4/4/2017 | 11:10:00 AM | 1145 | 5.8 | 1.93 | |
| 4/4/2017 | 11:27:00 AM | 1162 | 6.2 | 2.07 | |
| 4/4/2017 | 11:46:00 AM | 1181 | 6.2 | 2.07 | |
| 4/4/2017 | 12:00:00 PM | 1195 | 6.2 | 2.07 | |
| 4/5/2017 | 9:58:00 AM | 2513 | 5.2 | 1.73 | |
| 4/5/2017 | 10:14:00 AM | 2529 | 5.2 | 1.73 | |
| 4/5/2017 | 10:31:00 AM | 2546 | 5.2 | 1.73 | |
| 4/5/2017 | 10:49:00 AM | 2564 | 5.4 | 1.80 | |
| 4/5/2017 | 7:45:00 PM | 3100 | 5 | 1.67 | |
| 4/5/2017 | 8:10:00 PM | 3125 | 6.1 | 2.03 | |
| 4/5/2017 | 8:30:00 PM | 3145 | 6 | 2.00 | |
| 4/5/2017 | 9:12:00 PM | 3187 | 5.8 | 1.93 | |
| 4/5/2017 | 9:40:00 PM | 3215 | 5.6 | 1.87 | |
| 4/6/2017 | 9:30:00 AM | 3925 | 4.6 | 1.53 | |
| 4/6/2017 | 11:05:00 AM | 4020 | 4.6 | 1.53 | |
| 4/6/2017 | 11:29:00 AM | 4044 | 4.6 | 1.53 | |
| 4/6/2017 | 11:56:00 AM | 4071 | 4.8 | 1.60 | |
| 4/7/2017 | 9:06:00 AM | 5341 | 2.8 | 0.93 | |
| 4/8/2017 | 2:00:00 PM | 7075 | less than 2.5 | 0.67* | |
| 4/8/2017 | 2:15:00 PM | 7090 | 3 | 1.00 | |
| 4/8/2017 | 2:37:00 PM | 7112 | less than 2.5 | 0.67* | |
| 4/8/2017 | 2:57:00 PM | 7132 | less than 2.5 | 0.67* | |
| 4/8/2017 | 3:17:00 PM | 7152 | less than 2.5 | 0.67* | |
| 4/8/2017 | 3:31:00 PM | 7166 | less than 2.5 | 0.67* | |
| 4/8/2017 | 3:52:00 PM | 7187 | less than 2.5 | 0.67* | |
| 4/8/2017 | 5:07:00 PM | 7262 | less than 2.5 | 0.67* | |