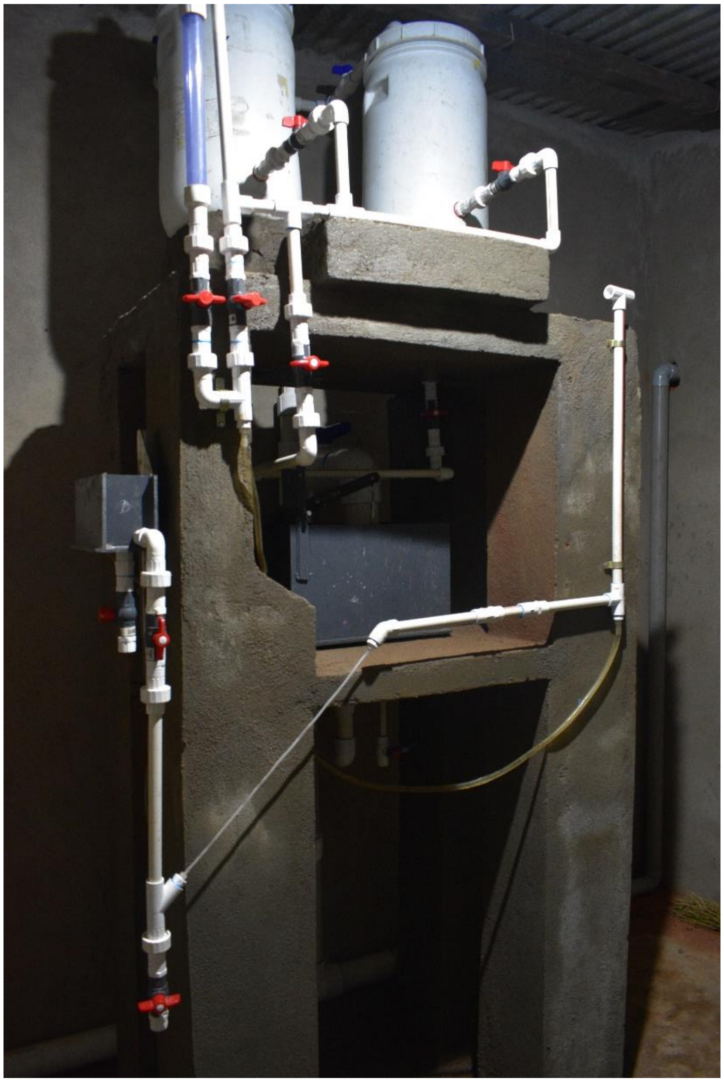
HYDRODOSER SYSTEM REPORT

Village of Patimul



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AguaClara Reach

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1. DISCLAIMER

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2. OVERVIEW

In January 2020, a Hydrodoser was installed in Patimul, a village located in the Gajapati district of Odisha. This was the second system of its kind to be implemented in the world, and included a number of updates made to the design piloted in the Village of Lahanda in 2018. During the construction process, Gram Vikas staff were trained in the design and functioning of the system, so that similar Hydrodosers can quickly be implemented across Odisha. These systems are operated and maintained by local operators, providing for sustainable safe water.

This document summarizes all of the processes involved in completing this project: design, implementation, calibration, and training. For detailed explanation of each process, refer to the separate documents referenced in each section. The purpose of this report is to document the project activities and results, so that it can be a useful educational resource for those implementing future Hydrodoser systems.

2.1 OBJECTIVES

The purpose of the Hydrodoser system is to simplify the water disinfection process. This modular design automatically regulates chemical flow based on fluctuations in raw water flow. The chemical flow rate (the amount of chlorine injected per unit time) varies linearly with raw water flow (the amount of source water flowing per unit time); if raw water flow rate increases by 5%, chemical flow rate will also increase by 5%. However, chemical dosing, or the amount of chlorine injected per liter of water, is set manually by adjusting a slider. Once the dose has been fixed, this value will not vary unless manually changed; fluctuations in raw water flow rate will only change the chemical flow rate, not the chemical dose.

2.2 VILLAGE PROFILE

This Hydrodoser system serves the village of Patimul and is a component of a comprehensive community engagement program led by Gram Vikas for the residents there. Patimul is located in the Gajapati district of Odisha. At the time of the Hydrodoser's construction, there were 52 households in the village with an approximate population of 230 people. Since toilets and bathrooms have been built for all households, and hand-washing and other sanitation programs were conducted in the village, the Hydrodoser system was a good next step in improving the villagers' health and quality of life.

The village has a dual water supply, with a majority of water pumped from a dug well and a secondary, gravity-fed source coming from a mountain spring. The villagers were particularly keen on the Hydrodoser because they'd like to use the gravity-fed source to save on electricity costs, but felt that it was too dirty to drink untreated.

2.3 MAJOR COMPONENTS

The Hydrodoser, shown in Figure 1, is made up of various components that dose raw water with chlorine before carrying it to the storage tank. Locally sourced parts are used to create the major components of the Hydrodoser system, which are listed below with a brief overview of their purpose.

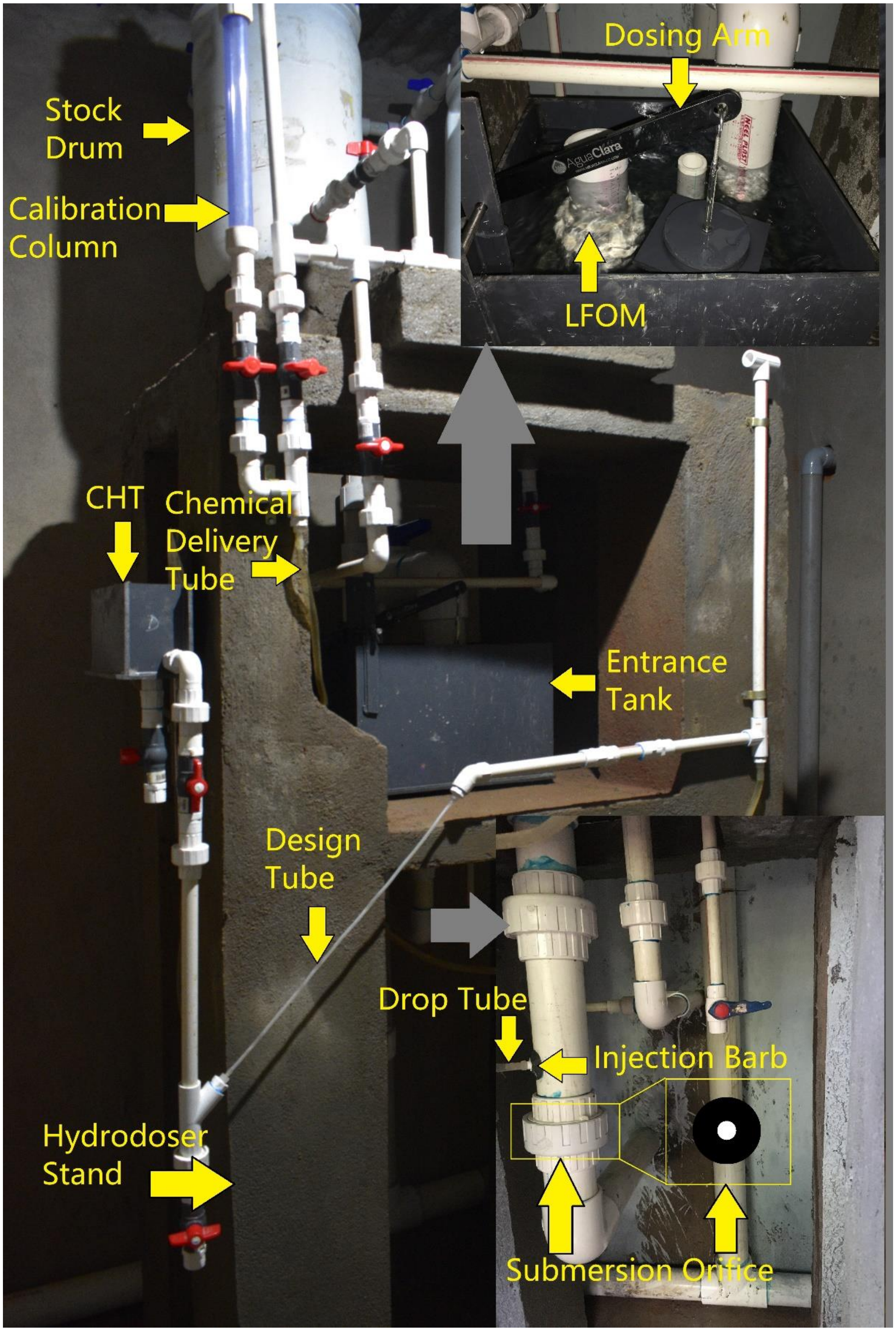

Figure 1: A labeled picture showing the full Hydrodoser system. Listed below are the associated functions of each component.

- The **Hydrodoser Stand** holds the Hydrodoser system. It is made of brick and mortar. On the top level sits the chemical stock drums and on the lower level sits the entrance tank. Attached on the left leg of the stand is a slider with an angle plate. The Constant Head Tank (CHT) is attached to the angle plate and the slider allows for elevation adjustments of the CHT, which will be necessary during system calibration.
- The **Chemical Stock Drums** are 10 gallon (approximately 40 L) HDPE buckets that will hold the chlorine stock solution. During Hydrodoser operation, one drum is used while other serves as a standby drum until the solution runs out. The chemical delivery and chemical drainage plumbing start from these drums.
- The **Calibration Column** is a 1" ND clear PVC column that is attached to the chemical delivery plumbing. This column can be used to measure the chemical flow rate in the system.
- The **Constant Head Tank (CHT)** is a tank made of 1/4" thick rigid PVC sheets that is part of the system that regulates the amount of chemical flowing through the Hydrodoser using a float valve.
- The **Chemical Delivery Tube** is a 3/8" ID flexible tube that connects the delivery plumbing to the CHT.
- The **Design Tube** is 1/8" ID flexible tubing that is the smallest diameter plumbing in the Hydrodoser system. This straight, small diameter tube linearizes the relationship between the driving head of chemical and the chemical flow rate.
- The **Drop Tube** is the 3/8" ID flexible tubing that connects the tee attached to the slider of the dosing arm to the injection barb.
- The **Dosing Arm** is a lever consisting of percentage markings from 0% to 100% corresponding to chlorine dose concentration. The dosing arm pivots on the edge of the entrance tank and the fulcrum is aligned with the maximum chemical level in the CHT to provide the appropriate energy to drive chemical flow.
- The **Entrance Tank** is a tank made of 1/4" thick rigid PVC sheets that holds water from the pump and delivers it to the storage tank after chemical is dosed at the injection point just below.
- The **Linear Flow Orifice Meter (LFOM)** is a 3" ND PVC pipe that has been drilled with a specific pattern of holes that serves to linearize the relationship between the height of water above the bottom holes and the flow rate through the holes. The LFOM pipe has a scale printed on the side that makes it easy for the operator to determine the plant flow rate at any given time.
- The **Submersion Orifice** is circular PVC plate with a small hole cut in it. It is placed inside the second union below the LFOM, close to the floor of the Hydrodoser room. The hole creates a backup of water in the pipe, ensuring that the chemical injection point stays submerged.
- The **Injection Barb** is a 3/8" barb attached on the 3" ND pipe that extends under the LFOM. This barb connects to the drop tube plumbing to serve as the chemical injection point.

3. FABRICATION PROCESS

Fabrication of the Hydrodoser in Patimul was completed in January 2020. The GV technicians installed the system in only 3 days once the stand was completed by the villagers.

3.1 HYDRODOSER STAND

The stand for previous Hydrodosers' was made from aluminum, with the idea being that it could be easily reconfigured if changes were made to the system. In order to lower costs and use locally sourced labor and materials, the stand in Patimul was made of brick and mortar.

Gram Vikas staff went to the village a week before installation of the Hydrodoser started to layout the stand dimensions (shown in Figures 2, 3, and 4). The villagers first created the bottom legs for the stand, while simultaneously pouring two slabs, one without holes (for the top slab) and one with a square opening in the center for the entrance tank. Once the slabs were dry, the middle slab was set on the bottom legs and the top legs were made. The top slab wasn't fixed to the stand until after Hydrodoser installation began. This way the distance between stock drum drains could be measured and the holes drilled at ground level, ensuring they were placed correctly. Once these holes were drilled the top slab was fixed to the rest of the stand.

Since this was the first time a brick and mortar stand was used, there were some modifications needed to the stand during Hydrodoser installation. The updated stand design is shown in Figures 5 and 6, and the changes are listed below:

- The height between slabs was increased to give more space for the stock drum drain plumbing.
- A slot was added on both sides of the entrance tank so the dosing arm could move through its full range of motion without it or the drop tube hitting the stand. Putting slots on both sides gives technicians flexibility to orient the dosing arm at the time of installation.
- The entrance tank slot was moved towards the back of the stand, so the dosing arm, which is towards the front of the entrance tank, would line up in the center of the stand legs.
- Slab length and width were increased to give a larger margin for error with the spacing of the stock drum drain plumbing and the location of the dosing arm mounting block on the entrance tank.
- The CHT holder was removed from the middle slab and replaced by a bracket which is bolted directly to one of the front legs of the stand. This was required for the design tube to maintain its 0.5 m length.

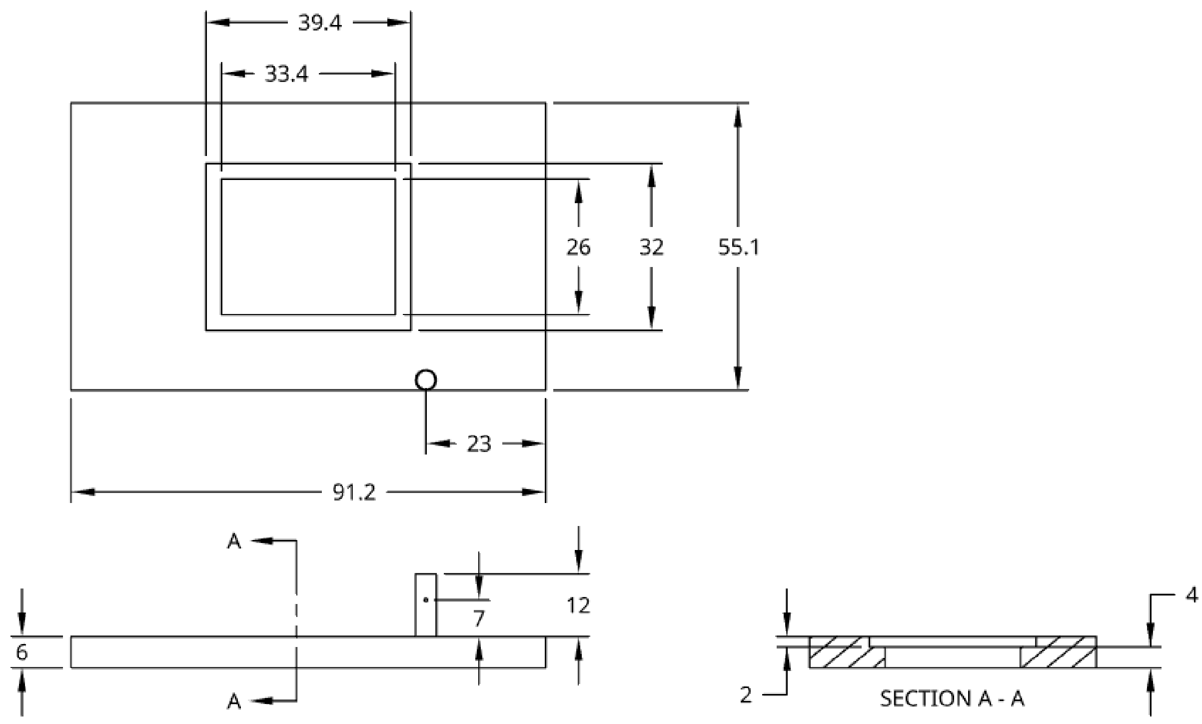

Figure 2: A dimensioned drawing of the middle slab of the Hydrodoser stand as originally constructed in Patimul

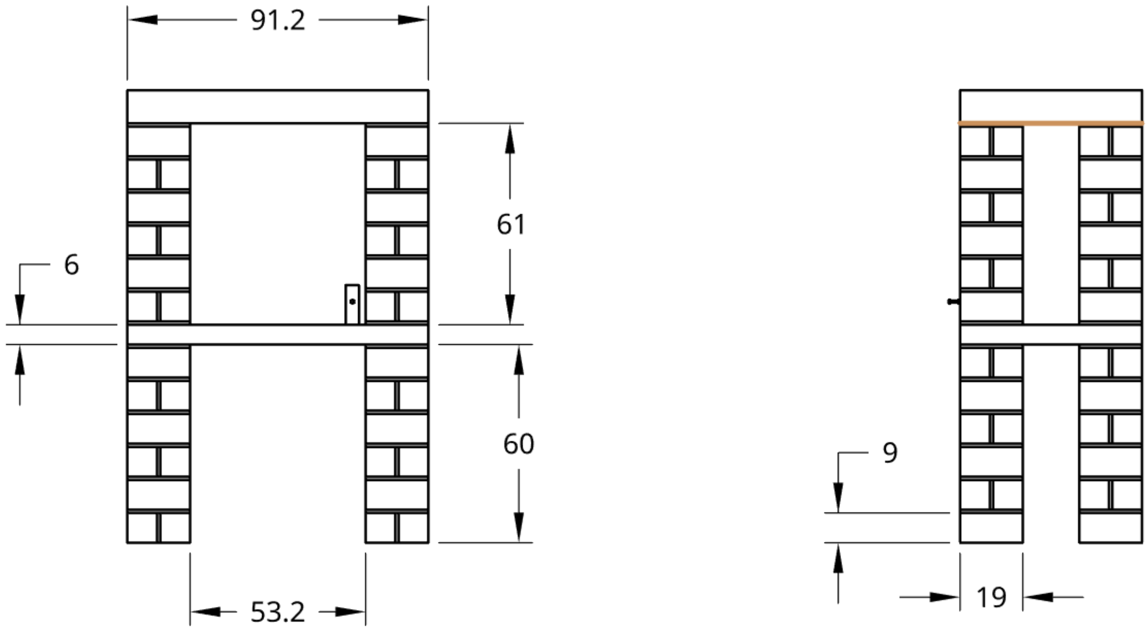

Figure 3: A dimensioned drawing of the entire Hydrodoser stand as originally constructed in Patimul

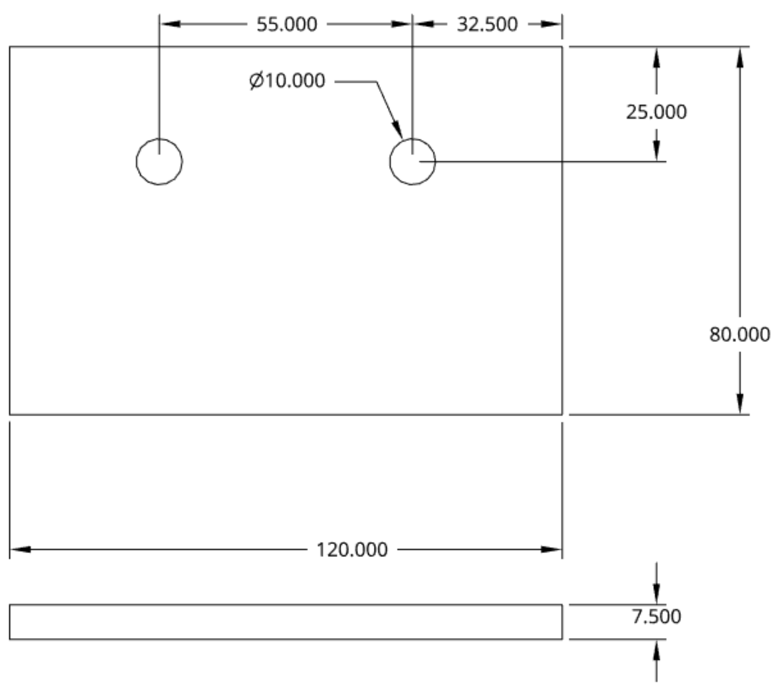

Figure 4: A dimensioned drawing of the top slab of the Hydrodoser stand as originally constructed in Patimul. No changes were needed to this part of the stand

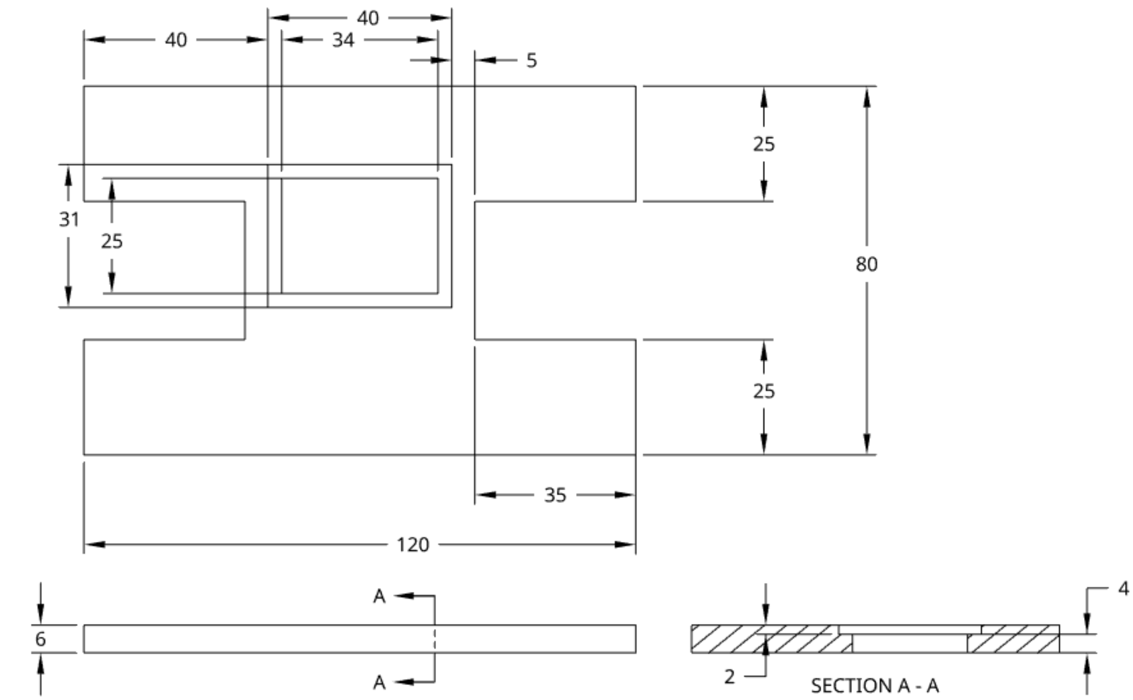

Figure 5: A dimensioned drawing of the updated middle slab design which was used in Majhi Ukhura. The Patimul stand was modified to accomplish the same functions as this design, but was not identical since certain changes could not be made once the concrete dried.

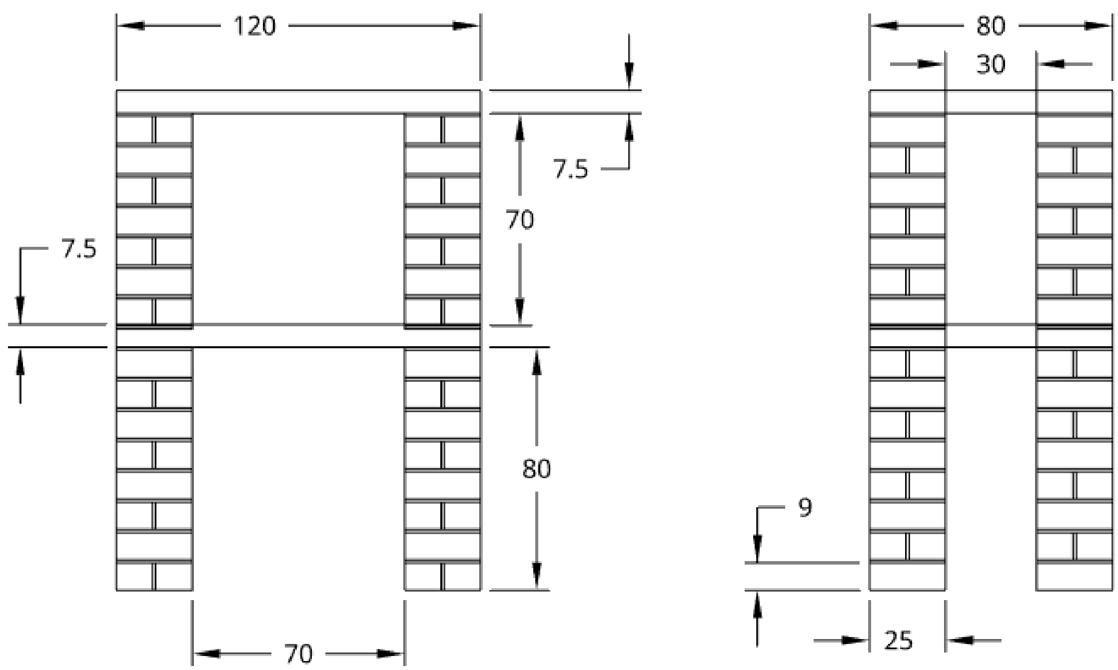

Figure 6: A dimensioned drawing of the updated overall stand design which was used in Majhi Ukhura. The dimensions on the Patimul stand could not be increased so the legs were cut to accommodate the plumbing which would not fit in the original design.

3.2 CONSTANT HEAD TANK (CHT)

The Constant Head Tank (CHT) is the chamber that from which chemical is delivered to the Hydrodoser system. The chlorine solution will enter the CHT through a float valve, which maintains a constant fluid level in the CHT. The chlorine will flow out of the CHT and eventually enter the drop tube, which is fixed to the slider of the dosing arm. From the drop tube, the chlorine will be carried to the injection barb, where it enters the water supply and disinfects the raw water on its way to the storage tank.

The elevation of the CHT will be set so that the maximum chemical elevation is level with the fulcrum of the dosing arm attached to the entrance tank. This calibration step is necessary to ensure the chemical flow automatically turns on and off when flow through the plant starts or stops. In more detail, this means that once the flow stops and the water level in the entrance tank drops to the bottom of the bottommost row of orifices of the LFOM, the chemical flow stops as well. When flow starts again, the chemical flow rate will vary linearly with plant flow rate.

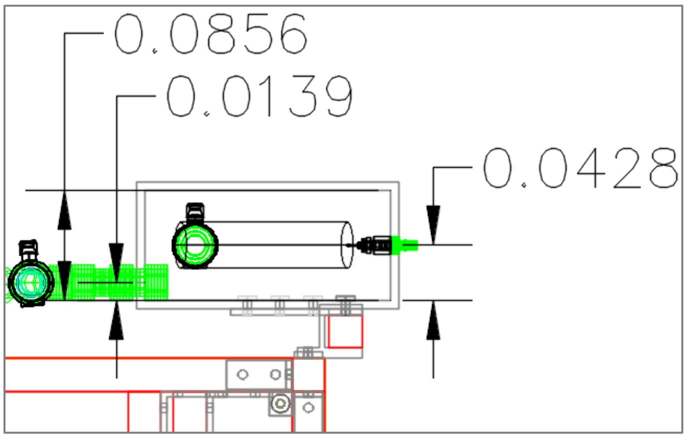

Figure 7: Top view of CHT with dimensions

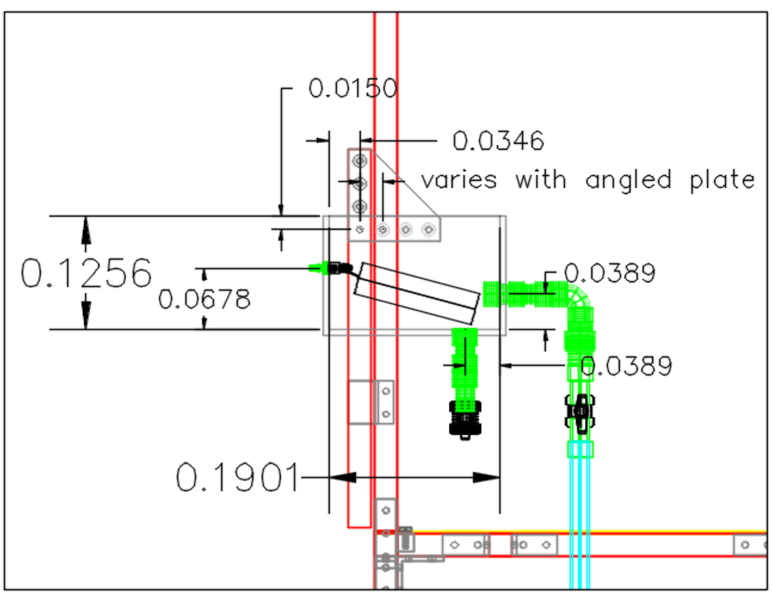

Figure 8: Front view of CHT with dimensions

The CHT was fabricated by Gram Vikas staff before the arrival of AguaClara Reach staff in January for the Hydrodoser installation. More information on the procurement of PVC sheets for the CHT can be found in **Complete System Report – Lahanda**. The process described there follows the **Fabrication Guide**, which was followed with minor deviations for the fabrication of the CHT in Patimul.

The largest of these deviations caused a minor maintenance issue; the drain coupling was welded so that it stuck through the bottom of the tank rather than flush. This makes it quite difficult to clean the CHT, requiring the float valve to be removed which in turn necessitates recalibrating the CHT elevation.

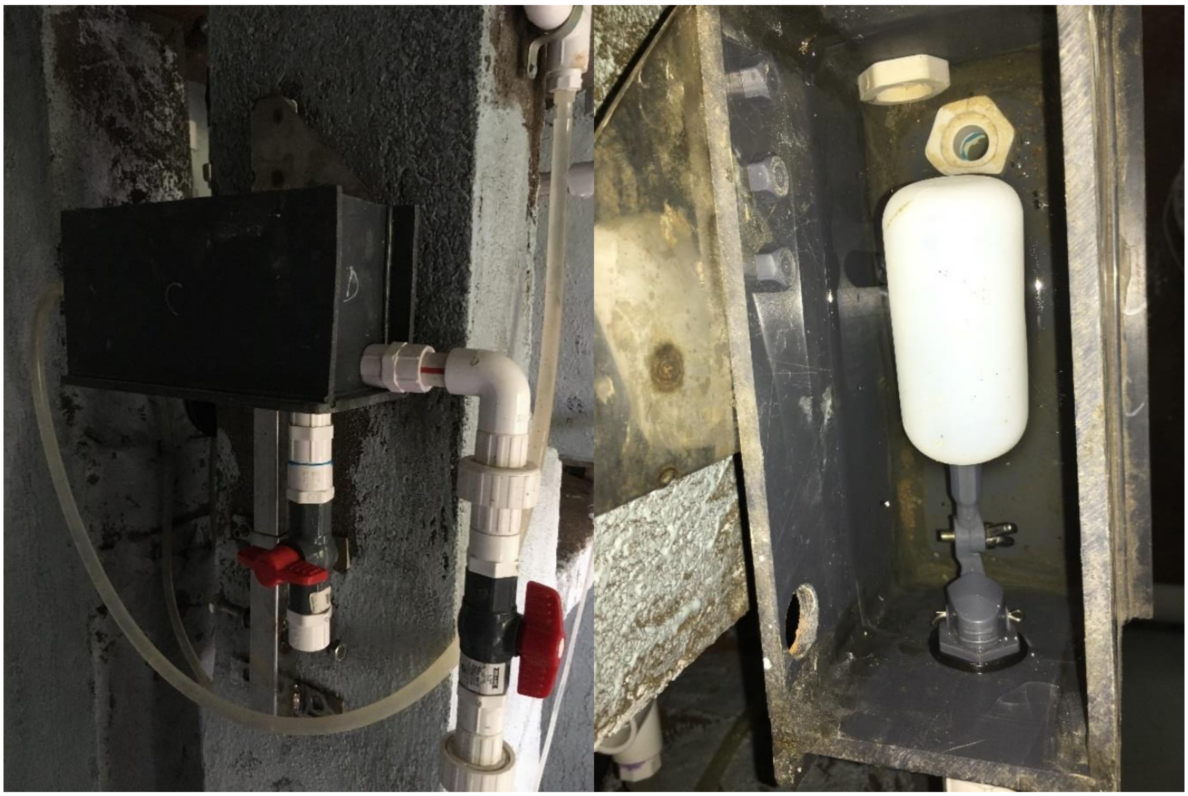

Figure 9: (Left) Front view of CHT installed in Patimul. The chlorine solution enters via the chemical delivery tube on the left and exits to the design tube (not pictured) via the outlet on the right. (Right) The top view of the CHT shows the float valve which maintains a constant fluid level in the tank. The drain and outlet are shown below the float.

The CHT is fixed to a slider and angled plate which were attached to the old stand using hose clamps. Since the new stand is brick and mortar, a bracket was fabricated along with the slider and angled plate, all of stainless steel. This bracket and slider took about 3 hours to fabricate from stainless steel at a shop in Bhubaneswar.

3.3 ENTRANCE TANK

The entrance tank of the Hydrodoser is the vessel in which water is collected immediately before disinfection. The entrance tank contains a Linear Flow Orifice Meter (LFOM), an overflow drain pipe, and a drain valve. A dosing arm that controls the chlorine dosage is attached to the side of the entrance tank, which is connected to a float that rests on the water surface inside the tank and a counterweight outside the tank. A change in inclination of the dosing arm indicates a change in water level in the entrance tank and will cause an proportional change in chemical flow to the injection point.

The entrance tank was fabricated by Gram Vikas staff before the arrival of AguaClara Reach staff in January for the Hydrodoser installation. More information on the procurement of PVC sheets for the entrance tank can be found in **Complete System Report – Lahanda**. The process described there follows the **Fabrication Guide**, which was followed exactly for the fabrication of the entrance tank in Patimul.

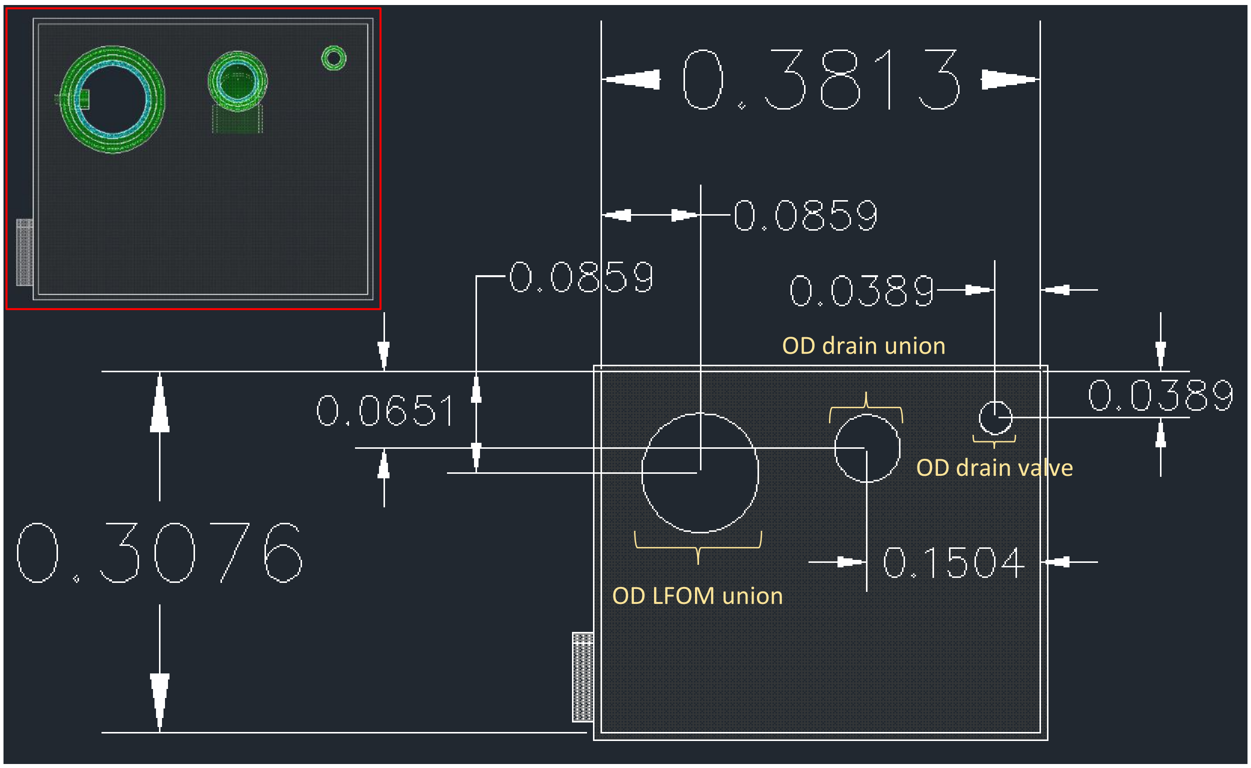

Figure 10: Top view of entrance tank with specifications. (Inset) Entrance tank with through-wall fittings shown. On the left is the LFOM union, in the middle is the entrance tank drain union, on the right is the drain valve coupling. These must be spaced such that the unions can be easily removed by hand.

Figure 11: Entrance tank as installed in Patimul. In the back row, from right to left are the LFOM, overflow weir, and submerged inlet pipe. In the front is the dosing arm with float attached via turnbuckle. (The drop tube and slider are on the left side of the dosing arm, out of frame)

3.4 CHEMICAL DELIVERY PLUMBING

Once Gram Vikas and AguaClara Reach staff reached the construction site in Patimul, the first step was to assemble the chemical delivery plumbing. The **Fabrication Guide** was closely followed, and Figure 12 and the below list describe the places where fabrication deviated from the manual.

- ***CHT Location.*** As previously mentioned, the CHT was anchored to the stand with a bracket in place of the hose clamps used in Lahanda. In this case the CHT was placed on the left side instead of front of the stand due to the modifications made to the stand making it too narrow for the CHT to be fixed to the front
- ***Horizontal Plumbing.*** the horizontal pipe between design tube and air release tee had to be lengthened significantly because the CHT was placed on the left side of the stand and the air release tee between the design tube and drop tube needed to be fixed to the stand leg.
- ***Air Release Tee.*** Air release tees were used in place of valves because the tees will accomplish the same goal for a fraction of the cost. To accommodate this change, the first tee must go above chemical stock tanks to ensure that it doesn't overflow.
- ***Barbs and Flexible Tubing.*** Due to availability, the barbs and flexible tubing used was 3/8" instead of the 1/4" mentioned in the manuals. This will not affect Hydrodoser performance since the 1/8" design tube is still the smallest diameter, and therefore drives head loss.

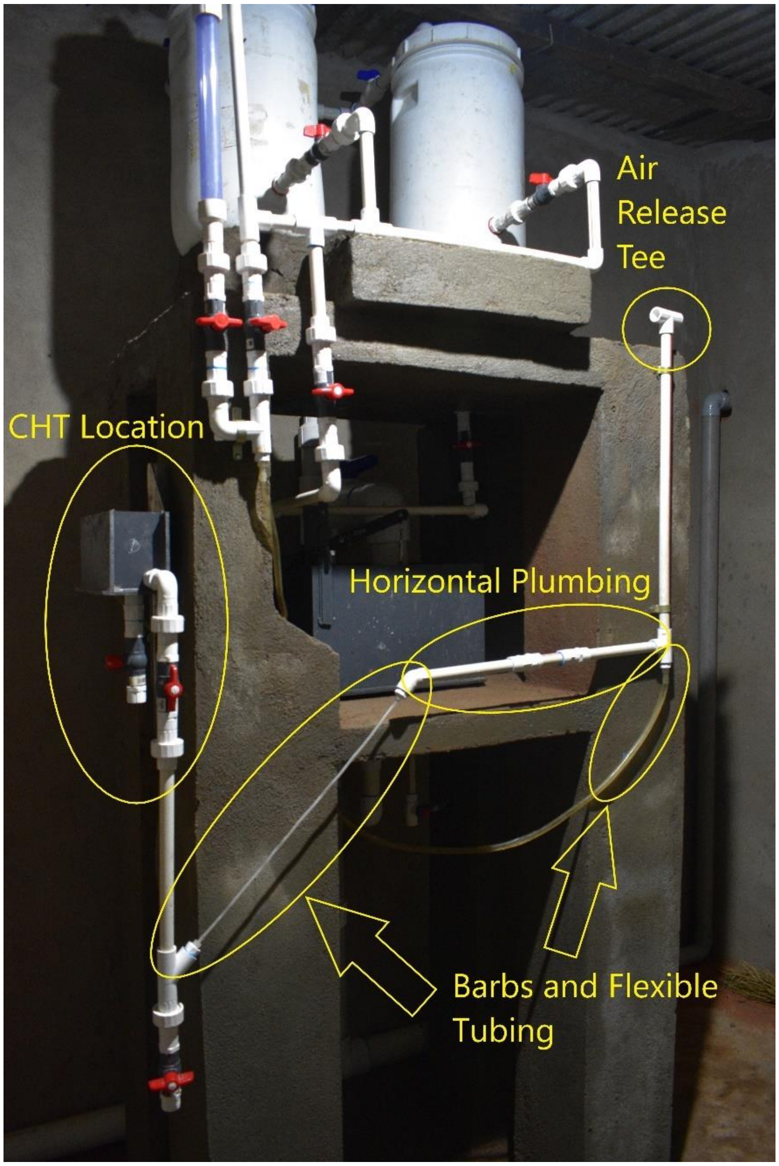

Figure 12: Major adjustments made in the field to chemical delivery plumbing design. Note that there is an additional air release tee above the doser and some barbs and flexible tubes which are not pictured.

3.5 INLET AND OUTLET PLUMBING

Inlet and outlet plumbing was installed immediately after the chemical delivery plumbing was completed. Similarly to the chemical delivery plumbing, the installation followed the **Fabrication Guide, Installation Guide** and **Patimul Construction Plan**. As a result, only major deviations from the design are listed below.

- ***Inlet Valve.*** MTAs and unions surrounding the inlet valve were removed so that it could fit in the space between Hydrodoser and wall.
- ***Drain Tee.*** For easier fabrication and since it was support well-enough already, the drain tee was not embedded into the wall.

- ***Added Unions.*** A number of unions were added and to allow for easier maintenance and replacement of plumbing. For example, a union was added beneath the overflow weir so that the elbow at that location which was previously unglued for maintenance purposes could be glued.
- ***Outlet Elevation.*** The outlet was designed to be placed on the floor of the Hydrodoser room, but was placed about 10 inches off the floor because top of storage tank was 10 inches above the Hydrodoser.
- ***Gravity Source.*** Two design changes were made regarding the gravity-fed inlet. First, the plumbing was changed from 3” ND to 2” ND because 2” pipe was used in the existing pipeline. Second, a tee and valve to divert the gravity source were added just outside the Hydrodoser room. This valve will be useful when the Hydrodoser needs to be operated with only the pumped source, such as when maintenance is required or turbidity is high.
- ***Submersion Orifice.*** The submersion orifice was inserted in the outlet pipe just above the union rather than inside the union itself. Also, the orifice was enlarged to 6 cm because it was backing up water close to the LFOM at its designed 4 cm diameter.
- ***Room Drain.*** The room drain was moved to the NW Corner (from the east wall where doser is located).
- ***Bush Fittings/Reducers.*** Bush fittings were used in place of reducers because that’s what was locally available in Paralakhemundi.

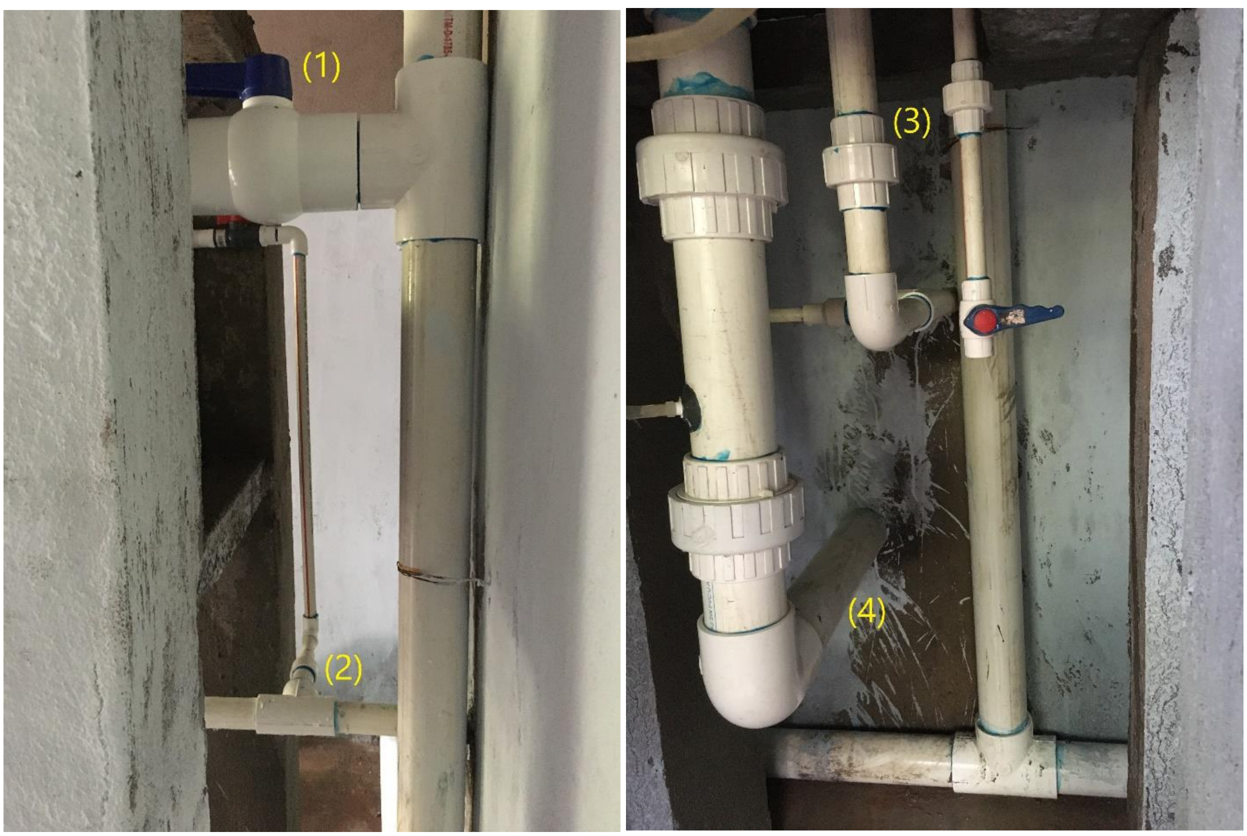

Figure 13: (Left) Outlet plumbing as seen from the right side of the Hydrodoser. Shown are (1) changes to inlet valve fittings and (2) unembedded drain tee. (Right) Outlet plumbing viewed from the front of the Hydrodoser. Shown are (3) an additional union for easier maintenance and (4) the elevation of the outlet above the floor. The union in the upper left corner leaked when first installed.

3.6 FINAL LEAK TEST

Once the inlet and outlet plumbing was installed, a final leak test was conducted by turning on the pump, drying off the whole system, and identifying where drops of water appeared on the exterior.

This test identified two leaky fittings: the stock drum drain bulkheads and the union just above the submersion orifice. The leaks were fixed as follows:

- Araldite and extra Viton Fluoroelastomer washers were placed between the bulkhead fittings and the stock drums, which sealed the leaks there.
- Water should be in freefall below the LFOM, where the leaking union (which can be seen in Figure 13) was located. The leak indicated that there was pressure built up in the union and water was not actually freefalling. To fix this, the submersion orifice was enlarged to lower the height that water backed up to while the pump was running.

3.7 LEACH FIELD

In the latest Hydrodoser design, a leach field replaced the stock drum. This leach field is placed beneath the end of the drain pipe which exits the Hydrodoser room right next to the larger outlet pipe which leads to the storage tank. The villagers built the leach field with a base of fine sand, gravel, and charcoal covered with progressively larger rocks which will dissipate the force of the water draining from the entrance tank.

3.8 KEY LESSONS

During the fabrication process, the following useful lessons were learned that should be kept in mind for future Hydrodoser installations:

- Ensure drains are flush with the bottom of entrance tank and constant head tank (CHT)
- Remember to unscrew unions when adjusting plumbing. We did not and an MTA snapped inside of a ball valve, ruining those fittings.
- Use the updated stand design to avoid the modifications being made to the stand like in Patimul
- Organization of materials would help to speed up the process. For example, we waited for a while for hose clamps to attach some of the chemical delivery plumbing to the stand
- Air release tees will are far cheaper than valves and serve the same purpose, so continue to use them
- When the pump was turned off, a vacuum formed between pump and check valve (which was installed just outside the Hydrodoser room). To avoid this, future check valves should be placed as close as possible to the pump and an air release mechanism should be installed along with the check valve.
- The outlet of doser was routed through hole for old inlet of gravity source to enter storage tank. It's good to save work in ways like this!

4. CALIBRATION AND TESTING

Calibration and testing of the Hydrodoser in Patimul was conducted in January 2020. First the CHT elevation and dosing float and counterweight of the dosing arm were calibrated. Once these calibrations were completed, the linearity of the plant and chemical flow rates were tested.

4.1 DOSING ARM

The dosing arm was calibrated to determine the proper weights of the float and the counterweight and set the float chain length. This is important to system performance, as the change in dosing arm height directly causes changes in chemical flow to the injection. An improper calibration might lead to inaccurate dosing.

The weight of the float and counterweight must be determined such that when the plant is off, which is when the water is at the level of the bottom of the bottommost row of orifices, the dosing arm is completely horizontal regardless of slider position (0% to 100% dose). In other words, increasing or decreasing the chlorine dose should not affect the inclination of the dosing arm, or the moment around the pivot point of the dosing arm should be zero at all times.

The float and counterweight were both made of 1/4" thick PVC sheets. The float was made up of three 10 cm x 10 cm squares and two 8 cm diameter circles. The counterweight was two of the 8 cm diameter circles. These weights were determined by first placing the slider at 100% and then adding enough weight to the float so that the dosing arm tipped towards the entrance tank. Then, the slider was shifted to 50% and enough counterweight was added to make the dosing arm horizontal at that setting as well.

The length that the float extends from the dosing arm must be set so that when the dosing arm is at the zero setting (completely horizontal), the center of the float lines up with the bottom of the bottommost row of orifices on the LFOM pipe. The float attachment to the dosing arm uses a turnbuckle, which allows for easy adjustment to the float chain length in the event that recalibration is necessary.

For further assembly details of the moment balance of the dosing arm and the float chain length, refer to the **Hydrodoser Operation and Maintenance Manual** under the “Calibration” section.

4.2 CHT ELEVATION

The elevation of the CHT must be set so that the maximum chemical level directly aligns with the pivot point of the dosing arm. At this setting, when the dosing arm is completely horizontal and therefore no water is running through the plant, no chemical will be injected. The **Hydrodoser Operation and Maintenance Manual** lists the procedure to properly set this height. This procedure was exactly followed to ensure the CHT was set to the proper elevation. In the event that the elevation needs to be readjusted, the listed testing procedure can be easily replicated in the field.

4.3 LFOM LINEARITY TEST

The LFOM linearity test was performed in the field, once the system had been installed. This was done by unscrewing the union beneath the LFOM, rotating the entrance tank, and placing a bucket underneath the open outlet. The linearity test is important in determining the maximum flow rate of the LFOM and if the LFOM accurately linearizes the relationship between water level in the entrance tank and the flow rate of water through its orifices.

4.3.1 PROCEDURE

1. Use a fine marker to mark a line at the bottom of the bottommost row of orifices on the LFOM pipe. Label this line as 0 cm. Use the measuring tape to mark additional lines at every ½ cm interval from 0 cm to 10 cm, making

smaller lines for half numbers and longer lines for the whole numbers. Label only the major lines from 1 cm to 10 cm.

2. Obtain a bucket with volumetric markings or put your own markings on a 20 liter bucket.
3. Unscrew the unions below the entrance tank; now rotate the tank so that a bucket can be placed beneath the LFOM outlet.
4. Turn the pump on so that the water level reaches 10 cm. Wait for the water level to equalize at this mark.
5. Once the water level has equalized at this mark, record this water level in the chart.
6. Place the marked bucket underneath the LFOM pipe of the entrance tank. Orient it to be able to read the volumetric markings on the inside.
7. Start the timer once the bucket fills to the 5 L line. Stop the timer once the bucket reaches the 20 L line.
8. Close the valve and record the time in the chart. Empty the 20 L bucket.
9. Repeat steps 5-8 at least two more times until the recorded time is approximately the same.
10. Open the valve slightly less this time, so that the water level in the entrance tank reaches a slightly lower mark than the previous measurement.
11. Repeat steps 7- 12 several times until measurements have been made for a range of water levels between 0 cm and 10 cm.
12. Calculate and record the flow rates for each water level using the equation Q = Vol/Time
13. Plot the resulting flow rates against the head loss over the LFOM. The expected result should have a zero intercept, with more inaccuracies at lower flows than higher flows. Check the R^2 value to confirm linearity.

4.3.2 RESULTS AND ANALYSIS

While creating the LFOM scale, it was noted that the LFOM's total height was only 9 cm, not 10 cm. This will affect the maximum flow rate of the Hydrodoser, but should not break the linearity of the system. Once testing began, it was difficult to adjust the plant flow rate using the inlet gate valve due to the power of the pump installed in Patimul. As a result, data was obtained at only 3 heights: 0.5 cm, 6.5 cm, and 9 cm.

The full data collected during the tests can be found in **Appendix A**, and a plot of the data is shown in Figure 14. Once the data was analyzed, the maximum flow rate was determined to be about 2.65 L/s. When plotted, the data had a y-intercept of -0.127 rather than zero. The reason the y-intercept was negative is that at lower heights the flow rates were lower than expected from a linear relationship. This loss of linearity at low flow rates is expected of a sutro weir (of which the LFOM is a variant).

As can be seen from the R^2 value of 0.9962 in Figure 14, these anomalies were small enough to not affect plant operation. Therefore, the test was considered successful!

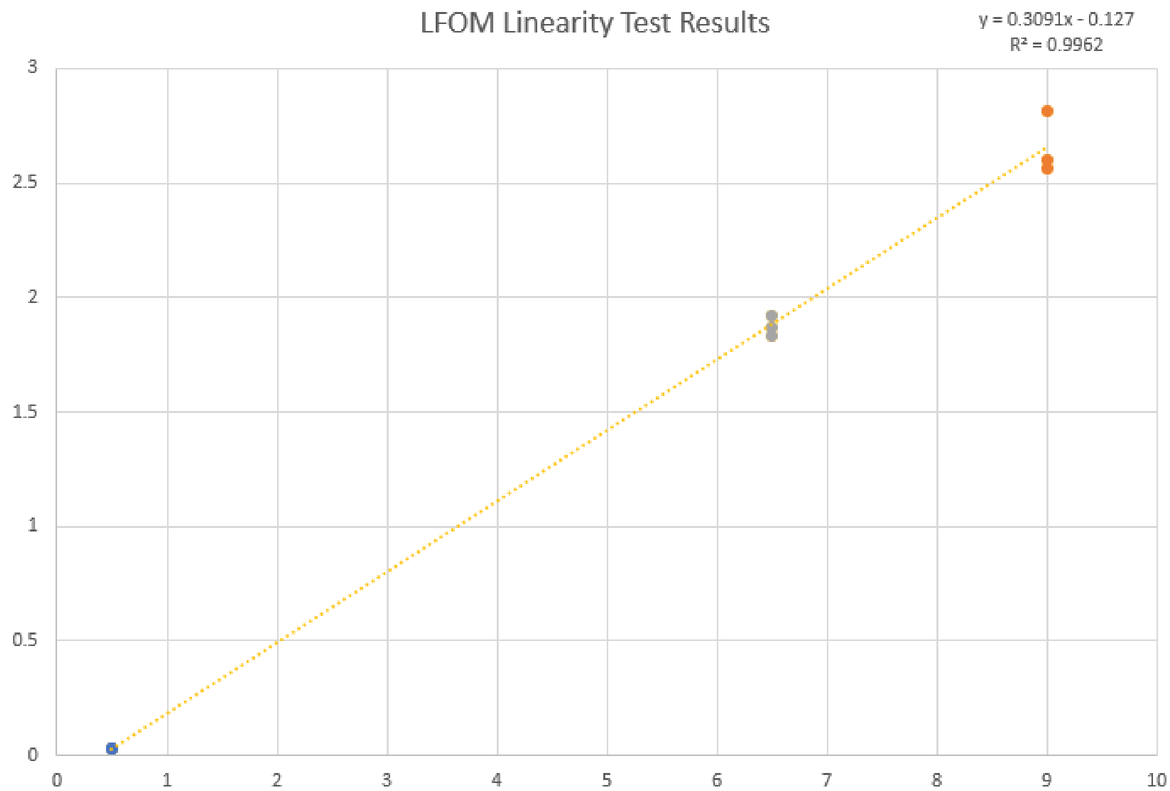

Figure 14: Plot of LFOM Linearity with flow rate (L/s) on the y-axis and height of water over LFOM (cm) on the x-axis

4.4 CHEMICAL LINEARITY TEST

Chemical linearity testing determines the maximum chemical flow rate, the stock solution concentration, and the relationship between chemical flow rate and pump flow rate. In other words, it is used to calibrate the stock concentration and will serve as a benchmark for expected chemical flow rate of the Hydrodoser. Just like with the LFOM linearity testing, chemical linearity testing was conducted in the field in Patimul. Since chlorine solution has a viscosity similar to that of water, raw water was used while conducting the tests.

In more detail, what needs to be verified is that as the float on the dosing arm moves up and down due to changes in plant flow rate (whose linearity was already confirmed in the LFOM linearity test), the chemical flow rate changes linearly with the dosing arm's eleveation. By tracking the time it takes for a known volume to drain from it, the calibration column is used to measure chemical flow rates during system testing (and operation).

4.4.1 PROCEDURE

1. Fill a stock drum with raw water, and open the normal configuration of valves such that water will flow from the stock drum to the CHT, through the design tube, and down the drop tube to the injection barb.
2. Check that the slider is set to 100%.
3. Ensure the inlet valve is open and turn the pump on.

4. Once the system has reached equilibrium (marked by a uniformly maintained water level in the entrance tank for the pump), fill up the calibration column. Turn the calibration column valve ON while the main delivery valve is ON so that fluid starts to fill the column. Once the fluid level passes 0 mL, turn the column valve OFF.
5. Simultaneously turn the main delivery valve OFF and the column valve ON. Prepare the stopwatch.
6. Start the stopwatch once the level reaches the 0 mL marking. After 30 seconds, simultaneously turn the column valve OFF and the main delivery valve ON.
7. Note down the final volume (marked by the level in the column after testing) in the linearity testing data sheet.
8. Repeat steps 4-7 to refill the column and conduct testing to record at least two additional data points.
9. Close the inlet valve a small amount to simulate a lower plant flow rate. Repeat steps 4-8 to test chemical linearity at this new flow rate.
10. Calculate the chemical flow rates for each of the data points (divide the final volume by testing time).
11. Plot the resulting chemical flow rates against the head loss over the LFOM (height above the bottommost holes in the LFOM). The expected result should have a near-zero intercept. Check the R^2 value to confirm linearity.

4.4.2 RESULTS AND ANALYSIS

Just as with LFOM linearity testing, the strength of the pump made it difficult to adjust the flow rate for testing. As a result, only three flow rates could be used for testing. To get more data points, the standard procedure was modified slightly and tests were conducted with the slider at lower doses, not just 100%.

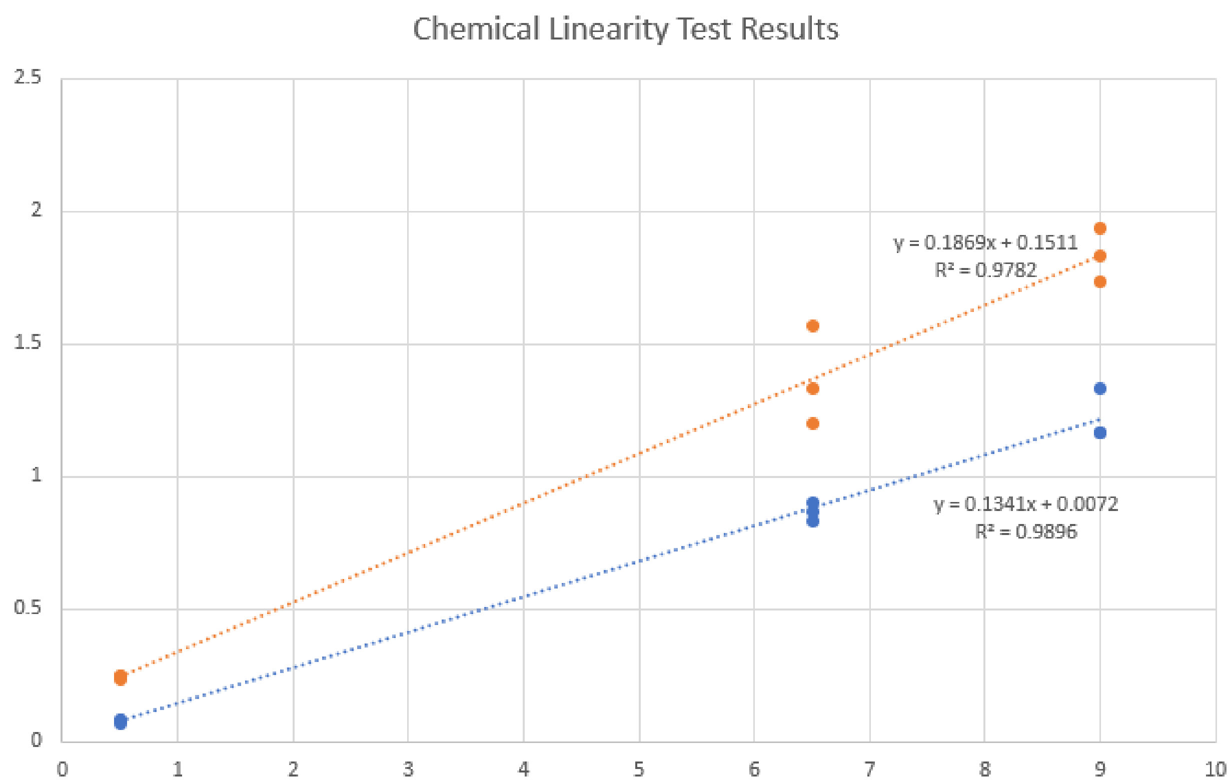

Figure 15: Plot of Chemical Linearity with flow rate (L/s) on the y-axis and height of water over LFOM (cm) on the x-axis. Results with the slider at 100% are shown in orange, and results at 50% are shown in blue

The full table of results is shown in **Appendix B**, and a plot of the data is shown in Figure 15. With the slider at 50%, the y-intercept was nearly zero (0.0072) and the R^2 value of 0.9896 confirmed the system was operating linearly. At 100%, the results were a bit less accurate, but the general linear relationship still held with an R^2 value of 0.9782 and y-intercept of 0.1511.

The largest concern from the chemical linearity testing was the maximum chemical flow rate of 1.93 mL/s. This was 50% of the designed maximum flow rate was 3.88 mL/s! There are some known causes for this error, like the LFOM being 1 cm short reducing the available head by 10% or the float valve submerging to different depths because it relatively thick. However, these known causes cannot account for all the error seen in the max chemical flow rate in Patimul.

4.5 STOCK CONCENTRATION CALCULATION

The stock solution concentration was calculated based on the following set of equations:

$$Concentration_{Stock} = \frac{Q_{Plant} * Concentration_{Dose}}{Q_{Stock}}$$

$$Mass_{Bleaching\ Powder} = \frac{Concentration_{Stock} * Volume}{Purity}$$

Values of 2 mL/s for Q_{Stock}, 2.6 L/s for Q_{Plant}, and 2.0 mg/L for $Concentration_{Dose}$, a stock concentration of 2.6 g/L was calculated. Assuming a bleaching powder purity of 35%, this 2.6 g/L of chlorine is equivalent to 7.43 g/L of bleaching powder, which is 288 grams in a 10 gallon drum.

4.6 KEY LESSONS

During the testing process, the following useful lessons were learned that should be kept in mind for future Hydrodoser calibrations:

- A lighter slider would minimize how much the slider position changes the moment of the dosing arm, therefore lessening the amount of weight required in both float and counterweight.
- Perform LFOM linearity test before gluing all outlet plumbing in place. This will allow for easier positioning of the entrance tank during the test.
- To simulate a lower plant flow rate during linearity testing, open the entrance tank drain partway and allow the height of water in the entrance tank to equilibrate.
- The LFOM orifice pattern was scaled incorrectly. The design height of the orifices is 10cm, but the actual height is 9 cm. This would result in a 10% reduction in the maximum design flow. This can be remedied by ensuring that the LFOM orifice pattern scales appropriately when printing.
- The maximum chemical flow rate is 50% of its designed value. More investigation is needed to determine the cause of this error!

5. OPERATOR TRAINING

Operator training in Patimul was conducted between 7th and 14th of February 2020. In attendance were 3 men and 3 women from the village. The following schedule was followed in conducting the trainings:

February 7th: Hydrodoser Overview and Math
February 8th: Units, Flow Rate, and Concentration
February 14th: Chlorine Dose/Testing, Operation & Maintenance, and Troubleshooting/Repair

The planned schedule was more condensed, but the villagers were busy with weddings and other events for a week so could not attend trainings at the originally planned times.

5.1 MODIFICATIONS TO MATERIALS

Based on operator feedback in both Patimul and Majhi Ukhura, all 8 operator training modules were comprehensively updated as follows:

- Some English text was removed and figures enhanced.
- More math examples and questions were added based on operator feedback.
- Added content for turbidity measurement and schedule of activities.
- Diagrams were updated to include changes made to materials as a result of the Product Line Design Reflection.
- A training worksheet was created to accompany the first 4 modules. Topics covered included decimal rounding, fractions, flow rate, concentration, and chlorine dose.

Similarly, the **Hydrodoser Operation and Maintenance Manual** was updated as follows:

- Sludge drum was removed from the design as it was infeasible for a ground level tank. It was replaced with a description of the implemented leach field instead.
- Updated the valve configuration based on design changes to reduce costs and accommodate a dual-source inlet
- Updated the materials list to reflect the latest Hydrodoser design, which includes a brick-and-mortar stand instead of the stainless steel stand to utilize local labor

5.2 KEY LESSONS

During the training process, the following useful lessons were learned that should be kept in mind for future Hydrodoser operator trainings:

- Stress the importance of training to the villagers. They were extremely involved in the construction but less committed to training. Remind them that without properly trained operators the Hydrodoser system can't function!
- Not all villagers will learn at the same pace or be as vocal, so it's good to ask specific students questions to test the understanding of every student in the class.

6. MONITORING

On February 15th, the Hydrodoser in Patimul was inaugurated and responsibility for its operation and maintenance passed to the community. The monitoring plan below was laid out in **Complete Hydrodoser Schedule**.

Week 1: Stand construction
Week 2: Hyrdodoser system installation
Week 3: Calibration
Week 4: Operator Training
Week 5: Monitoring by local GV staff
Week 6: Monitoring by local GV staff
Week 7: Monitoring by local GV staff
Week 8: Monitoring by GV engineer
Week 9: Monitoring by local GV staff
Week 10: Monitoring by local GV staff
Week 11: Monitoring by local GV staff
Week 12: Monitoring by GV engineer
Week 13: Monitoring by local GV staff
Week 14: Monitoring by local GV staff
Week 15: Monitoring by local GV staff
Week 16: Monitoring by GV engineer

Week 4 of the schedule was completed on February 15th, which means weekly monitoring should occur until at least May 8th. The monitoring visits should follow the guide from the **Complete Hydrodoser Schedule**:

1. Conduct chlorine trace tests at nearest and farthest taps
2. Measure turbidity of the raw water
3. Examine the logbook:
3.1 Record the chlorine trace test and turbidity measurement results
3.2 Ensure the operators are filling out the logbook daily
3.3 Check that vinegar cleaning is happening regularly (at least once every 2 weeks)
4. Talk to the operators, asking if there are any recent issues with the system

4.1 FIRST MONITORING VISIT

On February 28th the first GV engineer monitoring visit since inauguration was conducted. The solution was being mixed daily, but the chlorine trace test failed. After investigation, it was determined that the low chlorine dose was being caused by a lower than expected chemical flow rate. Precipitate had built up in the flexible tubes, especially the design tube, limiting the maximum flow rate. When the tubing was cleaned with vinegar, the chemical flow rate returned to normal. In addition, the logbook was not being filled out, so an example entry was created and each column was reviewed with the operators.

4.2 KEY LESSONS

During the first stage of the monitoring process, the following useful lessons were learned that should be kept in mind for current and future monitoring of Hydrodoser systems:

- Because precipitate quickly builds up when chlorine solution is exposed to air, cleaning the system frequently is vital to successful operation of the Hydrodoser. It would be good to remind the villagers to clean the system by creating a poster of the cleaning steps and schedule of activities.
- If possible, GV staff should attend the operator training sessions so that they will be familiar with the Hydrodoser system and more helpful as a first point of contact in case of system failures.

A. LFOM LINEARITY TEST RESULTS

Table 1: The recorded values of water level, volume, and time along with calculations of measured and expected flow rate from LFOM linearity testing.

Water Level (cm)	Trial #	Volume (L)	Time (s)	Measured Flow Rate (L/s)	Expected Flow Rate (L/s)
9	1	20	7.8	2.564102564	2.5
9	2	20	7.7	2.597402597	2.5
9	3	20	7.1	2.816901408	2.5
6.5	1	20	10.4	1.923076923	1.805555556
6.5	2	20	10.7	1.869158879	1.805555556
6.5	3	20	10.9	1.834862385	1.805555556
0.5	1	5	156	0.032051282	0.138888889
0.5	2	5	170	0.029411765	0.138888889
0.5	3	5	185	0.027027027	0.138888889

B. CHEMICAL LINEARITY TEST RESULTS

Table 2: The recorded values of water level, volume, and time along with calculations of measured and expected flow rate from LFOM linearity testing.

Water Level (cm)	Doser Setting (%)	Trial #	Volume (mL)	Time (s)	Chemical Flow Rate (mL/s)	Estimated Pump Flow Rate (L/s)
9	100	1	52	30	1.733333333	2.6
9	100	2	55	30	1.833333333	2.6
9	100	3	58	30	1.933333333	2.6
9	50	1	40	30	1.333333333	2.6
9	50	2	35	30	1.166666667	2.6
9	50	3	35	30	1.166666667	2.6
9	30	1	21	30	0.7	2.6
9	30	2	24	30	0.8	2.6
9	30	3	25	30	0.833333333	2.6
6.5	100	1	36	30	1.2	1.87
6.5	100	2	40	30	1.333333333	1.87
6.5	100	3	47	30	1.566666667	1.87
6.5	50	1	27	30	0.9	1.87
6.5	50	2	26	30	0.866666667	1.87
6.5	50	3	25	30	0.833333333	1.87
6.5	30	1	22	30	0.733333333	1.87
6.5	30	2	21	30	0.7	1.87
0.5	100	1	15	60	0.25	0.03
0.5	100	2	14	60	0.233333333	0.03
0.5	100	3	15	60	0.25	0.03
0.5	50	1	5	60	0.083333333	0.03
0.5	50	2	5	60	0.083333333	0.03
0.5	50	3	4	60	0.066666667	0.03
0.5	20	1	2	60	0.033333333	0.03
0.5	20	2	3	60	0.05	0.03
0.5	20	3	2	60	0.033333333	0.03

C. CONTACT INFORMATION

For troubleshooting or questions regarding the Hydrodoser system in Patimul, reach out to the following individuals:

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