High Flow Modifications

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Problem Definition

Introduction

Before the changes associated with this task were made, the Automated Design Tool (ADT) was able to create viable designs for plant flow rates ranging from about 6 L/s to about 40 L/s. The central goal of this task was to expand the flow rate for which we can design in order for our plants to serve both larger and smaller communities.

The first change needed was to the Linear Flow Orifice Meter (LFOM), which creates a linear relationship between the height of water in the entrance tank and the plant flow rate. For plants with flow rates 40 L/s and above, the LFOM pipe size required by the former design to properly model a Sutro Weir were too large to be accessible, affordable, and easy manipulated during construction. Changes have been made to allow for successful LFOM design up to 70 L/s, and the process of designing an LFOM for flow rates above 70 L/s is ongoing. At even higher flow rates, significant changes must be made to the geometry of the entrance tank, flocculator and sedimentation tanks in order to optimize treatment, reduce the cost and plan view area of the plant, and allow for ease of operation. As there is currently significant demand for plant designs in the range of 40 L/s to 70 L/s, I focused on the necessary flow control and dosing changes over the course of the summer. Significant work lies ahead to extend the range of flow rates beyond 70 L/s.

Design Details

Many changes must occur in order to design for higher flow rates. The following subsections discuss these specific changes in detail.

Flow Control and Doser Changes

Tall LFOM

At 39 L/s, the LFOM pipe required to create a linear relationship between the height of water in the entrance tank and plant flow rate has a nominal diameter of 15 in. This pipe size, if even accessible in Honduras, is expensive and difficult to work with during the construction process. The size of the LFOM pipe is calculated to prevent backup in the LFOM riser pipe - to make the average velocity at the bottom of the riser pipe slightly higher than the the plant flow rate divided by the cross sectional area of the pipe. Increasing the height of the LFOM also increases the average velocity at the bottom of the riser pipe, thus requiring a smaller diameter pipe. Thus, an intermediate solution (between 39 L/s and 70 L/s) for maintaining a linear relationship between flow through the plant and height of water in the entrance tank, while using pipes no larger than 12 inches in diameter, is to increase the head loss over the LFOM. The new algorithm designs LFOMs with head losses between 20 and 40 cm, increasing in discrete jumps of 5cm when the average velocity at the bottom of the pipe must be higher in order to avoid increase in pipe diameter. Additionally, once a 40 cm tall LFOM does not allow for a high enough velocity at the bottom of the pipe, the algorithm decreases the LFOM safety factor from 1.5 down to 1.15 in steps of 0.05. This allows for the 12 inch pipe to work with a decent safety factor up to 70 L/s.

The discrete jumps for LFOM height were chosen instead of allowing the designed height to increase continuously over the range of 20 cm to 40 cm in order to prevent the need for unrealistically precise fabrication of the LFOM and doser assembly. The end of the doser lever arm that extends into the entrance tank will increase in length with the increase in LFOM height.

It is important to note that, between 39 L/s and 70 L/s, the amount of orifices required in a single row does not exceed the number that can fit around the 12 inch pipe. This allows the 12 inch pipe with a tall LFOM to properly maintain a linear relationship between plant flow rate and the height of water in the entrance tank. The design for the tall LFOM for a 70 L/s plant can be seen in 1.

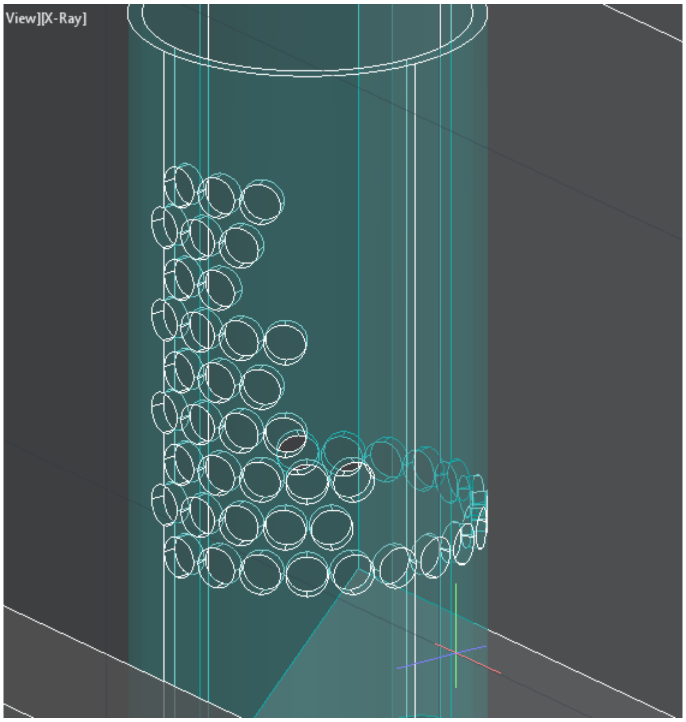


Figure 1: 70 L/s Tall LFOM

Linear Flow Orifice Meter Channel Design

Above 70 L/s, the LFOM height must extend beyond 40 cm or the LFOM safety factor must decrease below a reasonable value in order to still use a 12 inch pipe. To avoid using larger pipes for the LFOM, we will transition to an “LFOM channel” when any pipes with a nominal diameter larger than 12 inches are required. This LFOM channel will run along the last hopper in the entrance tank on the wall closest to the flocculator, and water will flow from this channel into a rapid mix closed channel that will go under the plant floor and deliver the water to the flocculator.

The LFOM channel itself will have a removable (and thus replaceable) mica sheet with orifices, the design of which is calculated using our current LFOM calculations, but removing the upper constraint of number of orifices in the bottom row, which requires that the orifices fit around the rapid mix pipe diameter. Instead, the length of the LFOM channel is determined by the size and number of orifices in the bottom channel. At flow rates more than approximately 125 L/s, the required LFOM channel length becomes longer than the length of an entrance tank hopper. Although the length of the LFOM channel does not have to be constrained to be less than or equal to the length of an entrance tank hopper, setting the length of a hopper as the highest allowed length of the

LFOM channel would prevent the entrance tank from becoming too long due to a long LFOM channel. Either this length constraint or another will need to be applied. The final pseudo-hopper that the LFOM channel will be placed in will contain the LFOM channel along the wall closest to the entrance tank, as mentioned above, and the float attached to dosing lever arms. The proposed design is shown in 2.

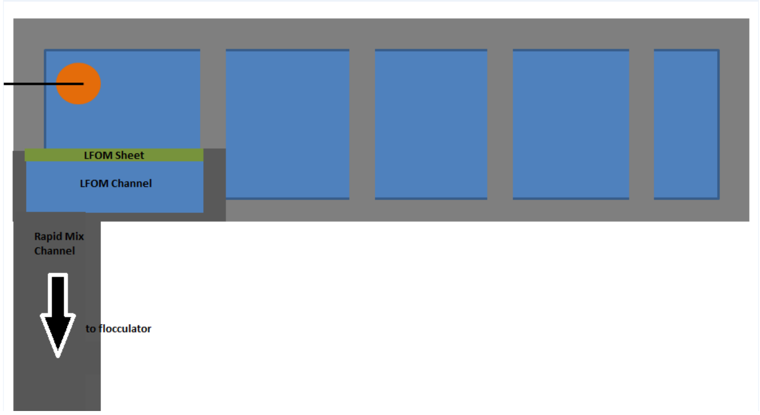


Figure 2: High Flow Entrance Tank with LFOM Channel

The depth of the water in the LFOM channel relative to the entrance tank water height must allow for free fall from the bottom of the bottom row of orifices; thus, the elevation of water in the entrance tank will be determined based on the elevation of water in the LFOM channel at high flows. The geometry of the LFOM channel and the succeeding rapid mix channel will be determined based on head loss and overall geometric constraints, with consequences of these decisions affecting entrance tank elevation. The elevation of the bottom of the LFOM channel is set to allow the closed rapid mix channel to flow straight to the bottom of the flocculator. A preliminary AutoCAD drawing of this design is shown in 3. Note that the rapid mix channel is open but will be covered in the final design.

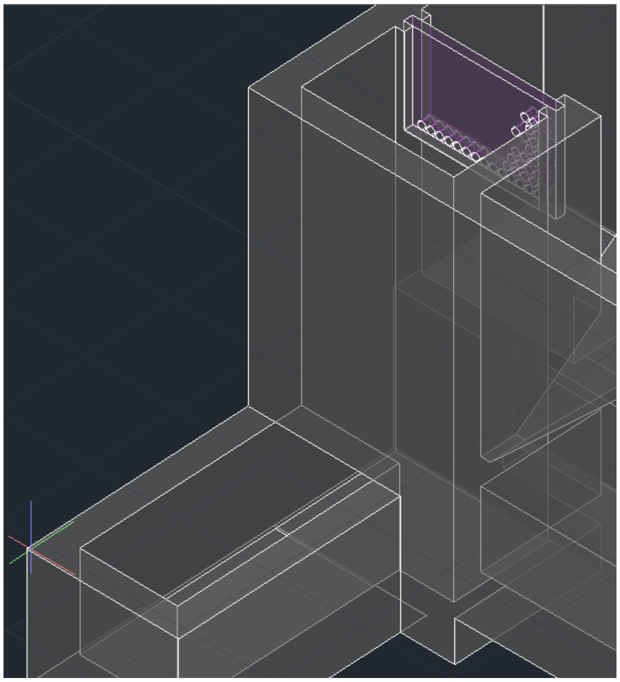


Figure 3: LFOM Channel Preliminary Design

The orifices are placed on the mica sheet so that water flows into the channel furthest from the turn into the rapid mix closed channel and close together; then, if coagulant is dosed at this location, the most mixing will occur. In the current design for rapid mix, an orifice plate is placed in the rapid mix pipe to allow for enough mixing to occur to deliver water with a properly distributed coagulant concentration to the flocculator. We do not currently have governing equations to estimate the amount of mixing caused by flow through this orifice plate aside from treating the macro mix orifice plate as a micro mix plate and calculating diameter based on desired energy dissipation rate. Part of the task of developing rapid mix for high flows will be finding the proper governing equations to measure mixing, and design a rapid mix channel with a micro mix orifice plate properly designed. Since a significant amount of mixing will occur with dosing occurring as water falls into the LFOM channel from the entrance tank, it is possible that macro mix will not be necessary; I must find a way to measure the mixing generated in order to determine whether or not a consequent macro mix orifice plate will be needed.

At 100 L/s, the six coagulant dosing flexible tubes are needed, according to the current algorithm. This is higher than any current plant, but not as unreasonable as the amount of tubes required for higher flow plants. Given the summer CDC team's new dosing design, it is possible to increase the upper constraint on the length of flexible tubing and thus allow for fewer tubes.

Linear Flow Meter Channel (Sutro Weir) Design

When the number of orifices needed for an LFOM channel to maintain a linear relationship between the entrance tank water height and the plant flow rate becomes larger than the length of an entrance tank hopper, we will transition to using an actual Sutro Weir, or a LFM channel, to control flow. This Sutro Weir design will be similar to the LFOM channel design in that the channel will still run along the entrance tank wall, and the Sutro Weir will be cut into a removable mica sheet on the side of this channel. Design equations for the Sutro Weir will be based on those found by previous AguaClara research team members. More will be added to describe the method by which the Sutro Weir will be designed in a future report, including the governing equations.

At a certain flow rate, the LFM channel will also not be a viable design, given the number and size of flexible tubing needed to carry the coagulant stock between the constant head tanks and the lever arm drop tube. Then, we will transition to a nonlinear doser.

Nonlinear Dosing

The number of flexible tubes between the constant head tanks and the lever arm drop tubes increases with plant flow rate, and, at a certain flow rate, linear dosing will no longer be practical. More investigation needs to be completed in order to determine when and why this transition will occur.

Extensive Amounts of Dosing Tubes

1 shows the number of coagulant dosing tubes required for linear dosing at various high flow rates. As mentioned above, it is possible that the summer CDC team's new dosing design may reduce the number of coagulant dosing tubes needed at higher flow rates by removing the constraint on flexible tubing length; this would allow for linear dosing to still be applicable at high flow rates.

Plant Flow Rate (L/s)	Number of Coagulant Dosing Tubes
50	3
100	6
150	9
200	11
250	14
300	10
350	11
400	13
450	14
500	16

Table 1: Number of Coagulant Dosing Tubes vs. Plant Flow Rate

Stock Tanks and Chemical Platform

At higher flow rates, the volume of prepared stock coagulant concentration needed (in order to prevent need for refill more often than every 30 hours) is more than that of the largest available Rotoplas tank. This means that several high volume coagulant stock tanks will be needed; in addition, the required coagulant stock concentration for high flow rates is high. While adding more stock tanks is a seemingly easy solution to fulfilling the necessary volume, having to fill and stir large, high concentration stock tanks would take a significant amount of time and be a burden to the operator. The use of a stock tank mixer and a ram pump may help to alleviate the burden on the operator, and it is important to discuss the possibility of incorporating these into new high flow designs, unless another solution is proposed to remedy this issue.

Also, since high concentrations of stock solution clog the float valve orifice, we will soon decrease the maximum stock concentration expert input from 400 g/L down to 200 g/L; this will increase the size of stock tanks and chemical platform needed.

Entrance Tank

Given the current design algorithm, the width of the entrance tank increases with plant flow rate. At high flow rates, this increasing width causes the back slope of the hoppers to decrease from 45 degrees, especially with the addition of the LFOM channel, which reduces the entrance tank that contributes to capture velocity. Hopper slopes significantly below 45 degrees would have negative effects on the ability of grit to settle down to the hopper drains. To solve this issue while also maintaining the necessary capture velocity and not increasing the length of the entrance tank beyond the length of the sedimentation tanks, it is possible to create a “double hopper” design that will include two rows of hoppers within one entrance tank.

Flocculator

The flocculator changes from vertical to horizontal at 199 L/s given the current design algorithm. The baffle placement algorithm has been corrected for horizontal flocculators to have 180 degree turns between after each baffle.

Almost exactly the desired collision potential (75 $\mathrm{m}^{2/3}$) is achieved for all vertical flocculators; however, after transitioning to a horizontal flocculator, the design creates flocculators with unnecessarily high collision potential. Further investigation into the cause of this is required in order to correct the algorithm to prevent it from overdesigning the flocculator.

Sedimentation Tanks

The algorithm for the upflow area of the sedimentation tanks does not need to be adjusted for high flow rates; if design flow rate increases, the number and length of sedimentation tanks properly scales. However, there are significant geometric problems with the sedimentation tank inlet and outlet channels and the floc hopper that arise for higher flow rates. Given the current design, the inlet channel becomes extremely wide for large flow rates in order to have a large enough area to have a avoid breaking flocs on their way into the sedimentation tank. A side view of the sedimentation tank channels and floc hopper for a 200 L/s plant is shown in 4, and dimensions calculated for the current sedimentation tank design are given in 5.

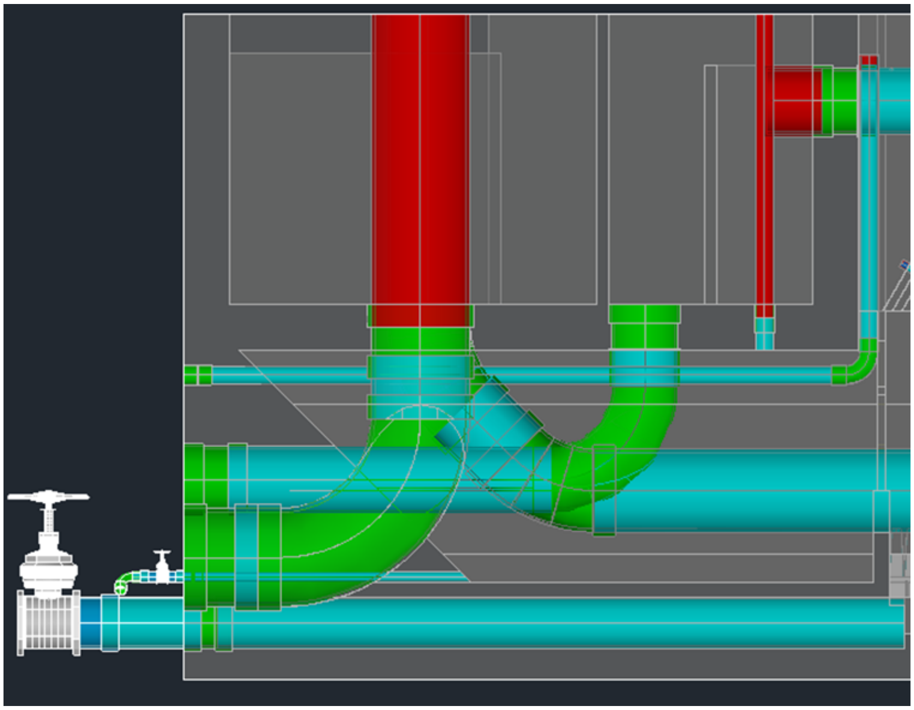
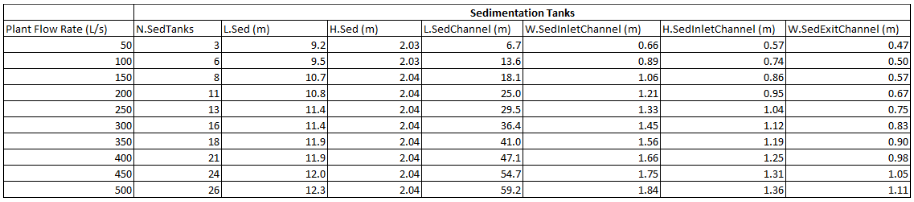


Figure 4: 200 L/s Sedimentation Tank Channels and Floc Hopper Side View



	Sedimentation Tanks						
Plant Flow Rate (L/s)	N.SedTanks	L.Sed (m)	H.Sed (m)	L.SedChannel (m)	W.SedInletChannel (m)	H.SedInletChannel (m)	W.SedExitChannel (m)
50	3	9.2	2.03	6.7	0.66	0.57	0.47
100	6	9.5	2.03	13.6	0.89	0.74	0.50
150	8	10.7	2.04	18.1	1.06	0.86	0.57
200	11	10.8	2.04	25.0	1.21	0.95	0.67
250	13	11.4	2.04	29.5	1.33	1.04	0.75
300	16	11.4	2.04	36.4	1.45	1.12	0.83
350	18	11.9	2.04	41.0	1.56	1.19	0.90
400	21	11.9	2.04	47.1	1.66	1.25	0.98
450	24	12.0	2.04	54.7	1.75	1.31	1.05
500	26	12.3	2.04	59.2	1.84	1.36	1.11

Figure 5: Sedimentation Tank Dimensions by Flow Rate

Instead of having a nearly square channel delivering water to the inlet manifolds, the inlet channel could be designed to have the same height as the entire sedimentation tank, and the width could be calculated as the minimum of the width required to avoid breaking flocs and to fulfill geometric constraints, including the human width constraint.

Also, having a long inlet channel connected to so many sedimentation bays would allow for low enough velocities at the end of the inlet channel that could allow settling to occur in the end of the inlet channel itself. The proposed solution for this issue is to taper the inlet channel by slowly raising the bottom of the channel, thus reducing the cross sectional area through which the water flows and preventing the water velocity from decreasing enough to allow settling in the end of the channel.

A drawing of a side view of the channels in the proposed design is shown in 6.

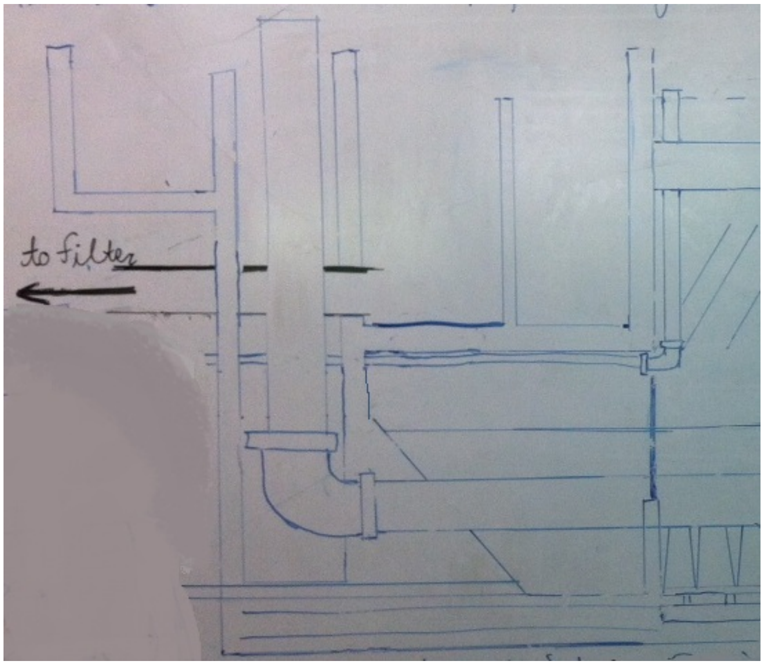


Figure 6: Proposed Channel Design - Side View

Inlet Manifold

Given the proposed design with the inlet channel extending over the entire height of the sedimentation tanks, the inlet manifold will be able to flow horizontally out of the side of the inlet channel for high flows instead of the regular flow plumbing extending from the bottom of the inlet channel. Given that it is still necessary to prevent flow through sedimentation bays to drain and clean them, there must still be a way to plug the inlet manifold. A flap gate could be used, but it would be difficult to be able to open and close the flap gate from above the water level in the inlet channel. Another alternative is to have elbows coming out of the inlet manifold into the inlet channel, turning up to the free surface, allowing for a long pipe to be inserted into the elbow to block flow to that sedimentation bay. This is the option that has been chosen. At high flows, the inlet manifold is constrained to be no larger than 10 inches, but placing and removing this size pipe from an elbow would not be easy for the operator. The fabrication team is working on creating a better device to block larger diameter pipes that will make blocking a sedimentation bay easier on the operator.

Tapered Inlet Channel

Design equations for the tapered inlet channel must be developed. Currently, the cross sectional area of the inlet channel is determined by the energy dissipation rate required to avoid breaking flocs; however, this equation only truly applies at the entrance into the channel. After the first inlet manifold, the flow rate through the inlet channel is less and thus the area of the channel required is less. It is possible that the proposed slope of the inlet channel would be high enough to decrease the channel's cross sectional area enough to break up flocs.

It is important to consider construction difficulties when designing this tapered inlet channel. Not only would it be difficult to construct a long inlet channel with a constant slope, but having many inlet manifold elbows embedded in the concrete would likely be a challenge construction-wise. We need to receive feedback from the our engineers and possibly our masons in Honduras to set guidelines for what is reasonable in terms of these inlet channel changes before we move forward with the design.

Inlet Channel Weir

As shown in the image above, the proposed design includes moving the inlet channel weir to be moved to outside of the actual sedimentation tank, cantilevered above the plant drain channel. This will allow for the sedimentation tank length to decrease and for there to be several pipes draining to the drain channel from the inlet channel weir instead of the one large pipe used in the current design. The depth of the inlet channel weir should be set to maintain the same water depth in the inlet channel when the water is flowing over the weir, as it is in the current design. The width of the inlet channel weir will only be constrained by geometric constraints to allow for the drain pipes and proper spacing.

Outlet Channel and Delivery to the Filter

The weir in the outlet channel will still act to control the height of water in the sedimentation tanks. Since the height of the outlet channel will no longer be set as the height of the inlet channel, new constraints must be set for the outlet channel. I propose that the design of the outlet channel will be set to by floc hopper design constraints. As shown in the image above, the floc hopper will be placed below the outlet channel; an iteration of height and width calculations (based on the horizontal channel functions constrained by maximum head loss in a channel) could be used to optimize outlet channel in terms of consequent floc hopper geometry. The goal for the floc hopper is to reduce the amount of flat space so as to allow for proper draining. Pairing the floc hopper and outlet channel design may become too complicated; also, there could be other possible constraints that we would want to prioritize instead.

Delivery to the filter inlet channel will be through several pipes from the sedimentation tank outlet channel, as before; however, the pipes will extend directly out of the side of the outlet channel instead of extending downward and into an elbow, as they do for regular flow. As the placement of these pipes are only constrained to avoid other sedimentation tank plumbing, their placement will not change.

Filters

Distribution Plumbing From the Filters

Designing distribution plumbing or channels from the filters has not been prioritized, given that the distribution plumbing already in place within a community will affect how this plumbing or channel will be designed. However, it is important to note that the distribution pipe from the filters becomes large at high flow rates. At 150 L/s, the nominal diameter of the filter plumbing is 15 inches, 20 inches for 200 L/s - 300 L/s, 24 inches for higher flow rates. I propose discussing the possibility of transitioning to filter distribution channels that could carry treated water to the distribution tanks and would like feedback from engineers in Honduras about the plausibility of including this in the design.

More Than One Treatment Train Possibility

High flow plants require more sedimentation tanks and filters, and a larger flocculator and entrance tank than plants designed for lower flow rates. Given that it is desirable to be able to take a part of the plant offline and still being able to treat a portion of the water usually treated, the idea of breaking high flow plants into two smaller plants has been suggested. A modification of this idea to have one entrance tank, dosing system, and flocculator, and then separate sedimentation tank and filter "units" for higher flow plants. This change would simplify many of the issues faced by higher flow; for instance, by reducing the number of sedimentation tanks fed by one sedimentation inlet channel, this solution would automatically fix issues associated with a large sedimentation tank inlet channel.

While this idea is not currently being carried out in the design tool, it may be desirable to code add this in the future. More discussion with APP and evaluation of this possibility in the context of other higher flow water treatment plants around the world is necessary in order to evaluate the benefits and disadvantages for such a design. For now, it is being set aside in order to create high flow designs that are the most operator friendly (having two treatment trains, especially two dosers, may be difficult for one operator to manage) and cost effective (separating treatment trains, especially if also separating the flocculator, would significantly increase plan view area and require more materials).

Future Work

There are many aspects of designing for high flow plants that have yet to be completed.

The LFOM design now has a viable output up to 70 L/s, but the LFOM channel design must be finalized in order to design for higher flow rates. Once constraints on the LFOM channel length are identified or set, a transition to a Sutro Weir channel must be established. In conjunction with the CDC team, it must be decided when the transition to nonlinear dosing will take place.

The flocculator design is already viable for most high flow rates. The high flow sedimentation tank modifications are being made by Maysoon Sharif, the AguaClara Design Engineer and Program Assistant (ADEPT).

Discussion must continue about how to relieve the operator of the burden of mixing many large, high concentration stock tanks and how to reduce the size of the chemical platform for high flow plants.

Lastly, improving the design of the distribution plumbing from the filters has not been focused on. This is has been placed as a lower priority, since distribution plumbing already in place will likely affect the design of this plumbing. It is possible that this will be resolved in the future through extensive communication with APP and AguaClara engineers.