Grit Removal Innovative Technologies (GRIT) Final Report - Spring 2015

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Abstract

The current AguaClara plant design requires a large entrance tank to settle out grit particles prior to the flocculator. Grit removal by horizontal flow sedimentation prevents the settling of these large particles in the flocculator (a phenomenon that has been observed in several AguaClara plants to negatively affect plant flow and operation). The purpose of the Grit Removal Innovative Technologies (GRIT) team is to redesign the current grit settling system by introducing plate settlers prior to the flocculation unit. In doing so, the plan-view area needed to settle out grit will be greatly reduced, decreasing construction costs and overall AguaClara plant size. This paper outlines the GRIT team's process exploring plate settler design options that act either as sedimentation units only, or as combined flocculation and sedimentation units.

There is no other literature on the topic of designing such grit removal systems, and not all of the relevant parameters are well understood. This team's design process has therefore been based on a series of reasonable assumptions and equations currently used in flocculator and sedimentation tank design. Many constraints (detailed in this report) were found to impact the design of the grit removal unit, including grit particle "roll-up" effect, optimal head loss, optimal plate spacing and angle, settle capture velocity, and optimal unit depth needed for minimizing unit length. In addition to the design of the grit removal unit itself, this team explored the corresponding designs of rapid mix, linear flow orifice meter (LFOM) placement, and coagulant dosing, in order to create a fully integrated system.

Over the course of the Spring 2015 semester, the GRIT team has developed three potential grit removal designs, created visual mock-ups of each, and even sent a detailed design of the best iteration to Honduras for implementation in a small-scale plant. The first iteration, a combined grit removal and flocculator system, integrated grit removal capabilities into the flocculator baffles, but was ruled out early in our design process due to potential loss of coagulant to grit (as the coagulant would be dosed before grit would be removed), inefficient use of space, and construction and cleaning impracticalities. The second and third iterations were both based on the idea of creating a tightly packed series of plate settlers (we call this a Grit Removal Unit, or GRU), analogous to the ones used in current sedimentation tank design, used before the flocculation process and designed to settle out grit specifically. The second iteration placed this GRU inside the entrance tank, while the third iteration placed it within the first flocculator channel. After analyzing space needed, flexibility of design, and capacity for rapid mix/ coagulant dosing integration, the third iteration was chosen as the optimal grit removal design and is well on its way to being constructed in Honduras!

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Introduction

The current entrance tank design, which is effectively a large horizontal flow sedimentation tank, could be made much smaller by creating a more effective and compact grit removal system using plate settlers. By reducing the size of the entrance tank (or virtually eliminating it), the size of the overall plant will decrease. This means a decrease in plant construction costs and no more grit build-up within the flocculator.

Background Information

There is little precedent for using plate settlers as a primary settling unit before or during flocculation. Most treatment plants utilize primary settling clarifiers (much like the current AguaClara entrance tank design), which do not include plates or baffles. Therefore, no literature regarding the potential design of such a specific grit chamber was found, but other background information was consulted to inform this semester's design process. Design calculations were based on first-hand information and inferences from the field where the problem of settled grit is observed. For example, the density of grit was assumed to be similar to that of sand ($\rho = 2650\,\frac{kg}{m^3}$). The same fluids equations used in previous AguaClara flocculation and sedimentation tank designs drove the design of the grit removal units. Construction and operation restrictions, costs, and head loss constraints were all taken into account.

Other constraints originated from practical considerations of the overall plant design. The width of the proposed grit chamber was set as the minimum width of the flocculator channel to simplify construction. The minimum width of the flocculator channel was designed to be 53.34 cm, to allow operators space to work inside the channel and to minimize waste of plastic baffle material. (The plastic sheets currently used for AguaClara baffles are 42 inches long, therefore $W_{FlocMin} = \frac{42in}{2} = 53.34cm$ gives a width that minimizes plastic waste.) The length of the flocculator channel was designed to be the same as sedimentation tank length to ease construction.

Methods

Iteration 1: Combined Grit Removal Chamber and Flocculator: "GRF"

The combined Grit Removal Chamber and Flocculator (Grit Removal Flocculator, or GRF) combines the grit removal capabilities of angled plates with the flocculation abilities of baffles, as shown in the diagrams below.

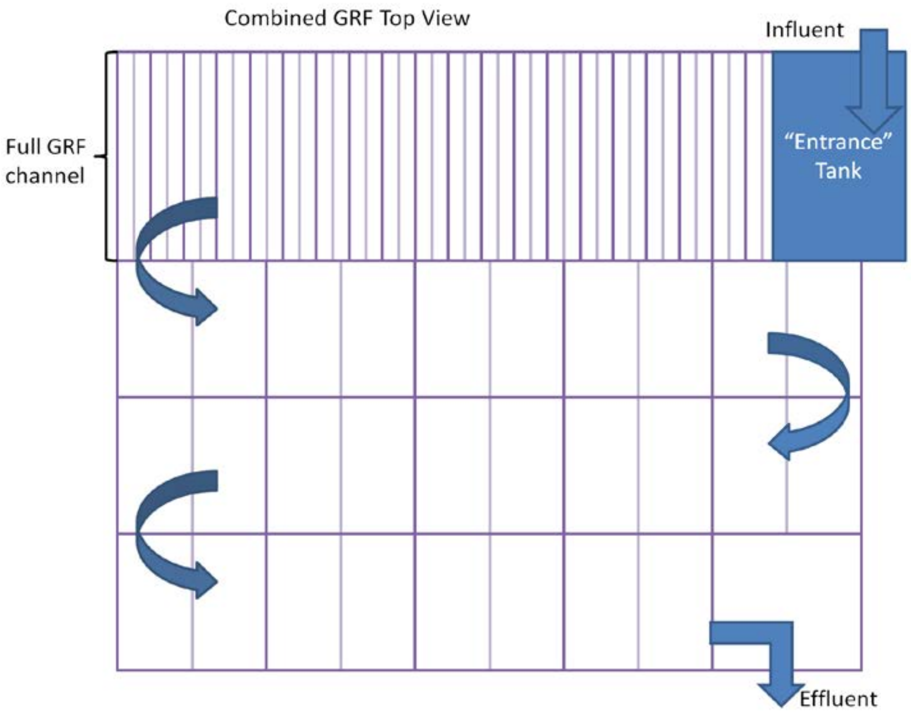

Figure 1.a. Top view of a GRF implemented in the first channel of a four-channel flocculator.

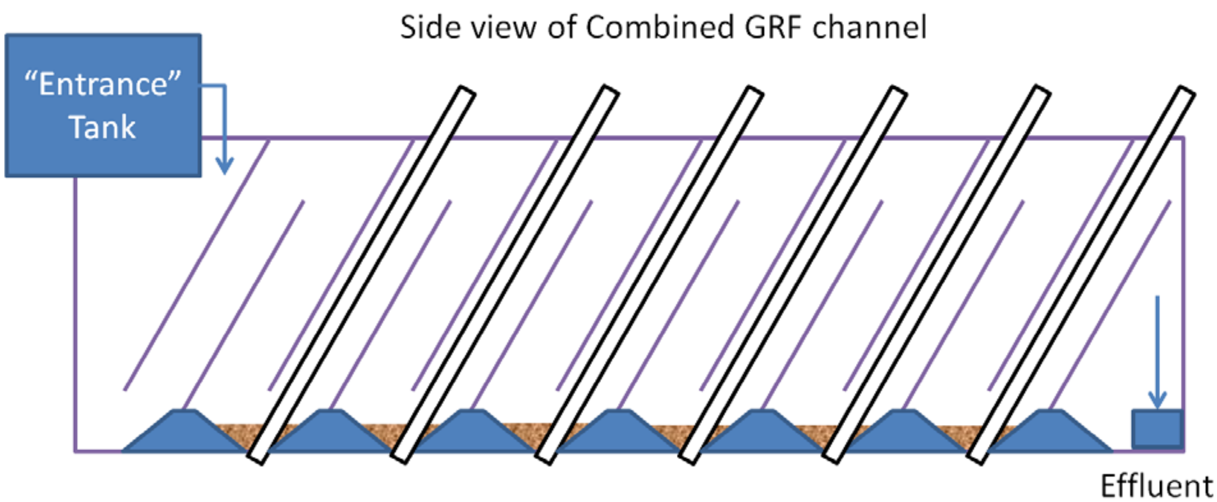

Figure 1.b. A side view of the first channel from Figure 1.a.

Overview

This first iteration, the GRF, explored the option of creating a combined grit removal chamber that provides both preliminary flocculation AND grit sedimentation. Our first step was reaching out to the AguaClara engineers in Honduras, Walker Grimshaw and Jonathan Christensen, and asking them about problems they have witnessed with grit and characteristics of the grit material. They were able to confirm that “grit” is mainly heavy sand and dirt particles, and that the density of silica sand, 2650 kg/m^3, is a fair estimate of grit density. They did not know how often plant operators typically have to clean a flocculator of grit build-up, but they are investigating this question. Finally, they did not believe that grit makes a significant impact on coagulant consumption, but we still thought it would be wise to explore possibilities of dosing coagulant after the grit chamber to minimize the amount of coagulant potentially lost as the grit settles. Once we had gathered this grit information, we defined several important design constraints for the GRF. We know that for a flocculator, the H/S ratio of each baffle section must be optimized, the total minimum collision potential in the flocculator must be achieved, the minimum channel width is set, and the plan view area must be cost-efficient and compatible with the sedimentation tank. We know that for a sedimentation tank, the settle capture velocity must be appropriate to the particles being removed, and the plate settler design must prevent particle “roll-up”. From these general constraints, we were able to deduce certain findings on the potential design of a combined flocculation/sedimentation grit chamber-- particularly on the spacing of the baffles. It is important to note that for this first iteration we mainly designed for a **50 L/s** treatment plant, because it was suggested by Professor Weber-Shirk as a reasonable design target. Please see all the equations for the following analyses in our corresponding Mathcad file, “15.05.06 final GRIT team research”.

Designing for Good Flocculation

We first determined a baffle spacing (S) based on the constraint that a head loss of 50 cm must be generated by the flow through a flocculator to achieve a collision potential of 70 $m^{2/3}$, which returned $S_{headloss}$ = **35.94 cm**. (The 50 cm value could be adjusted and residence time or EDR changed instead to meet the target collision potential.) We then determined S based on the constraint that the H/S ratio for flocculator baffles is ideally less than 5 in our current plant design, which returned S_{HS} = **40.00 cm**.

The target collision potential for flocculators and therefore for a flocculator-based grit chamber is also set ($\psi = 70m^{\frac{2}{3}}$); this has decreased from the previously assumed value ($\psi = 75m^{\frac{2}{3}}$), since the high efficiency flocculation being achieved in the sedimentation tank’s floc blanket reduces the need for as much flocculation in the flocculator.

Designing for Good Sedimentation

We then determined S based on the constraint that grit roll-up must be prevented through the baffles, which returned an S_{rollup} value that is too small to manufacture, showing that grit roll-up will not be a constraint. Finally, we determined a baffle spacing based on the capture velocity constraint (16 mm/s) in combination with the fact that current flocculator design allows space for 1.5*S above and below each baffle, which returned $S_{1.5abovebelow}$ = **5.65 cm**.

After conducting each analysis, we created an array of $S_{headloss}$, S_{rollup}, S_{HS}, and $S_{1.5abovebelow}$. We created a function to call the maximum of these values and defined that as our minimum baffle spacing for all further calculations. At first our results showed that the largest S value was S_{HS}, the baffle spacing based on the H/S constraint, 40 cm. However, after consulting with advisors, the team decided to **relax the H/S constraint from 5 to 7.5** (in the first channel only) because for this combined flocculation/sedimentation design, we realize that the flocculation can be less than ideal (as long as the total additive collision potential reaches our target). Changing the H/S constraint returned a $S_{HSrelaxed}$ of **26.67 cm**, which is a more realistic minimum value. We decided that the H/S ratio should not be our most important constraint in this first channel design, especially because we may be able to provide adequately uniform energy dissipation by simply adding extra flow restrictions to the flocculator.

After relaxing the H/S constraint, our new minimum baffle spacing became $S_{headloss}$, the spacing based on achieving target collision potential. **Thus we found that baffle spacing in the combined channel GRF at 50 L/s is most strongly constrained by flocculator design, not sedimentation design.**

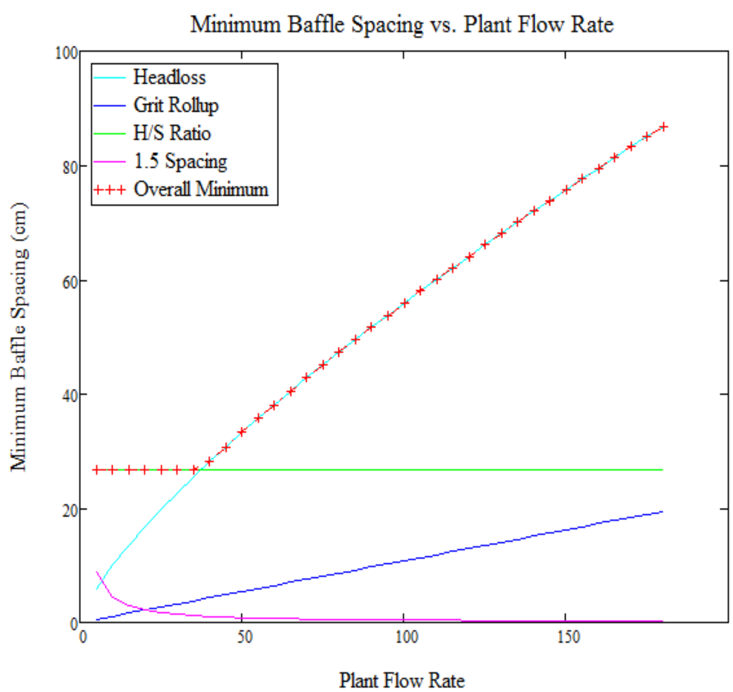

Figure 2. This graph shows the relationship between plant flow rate and the minimum baffle spacings that were calculated in this section of the report. At 50 L/s, $S_{headloss}$ is the overall minimum. At lower flow rates, the spacing in this design would still be driven by H/S ratio.

We also conducted terminal velocity calculations to determine the minimum diameter of a grit particle that would settle out in our grit chamber, assuming a capture velocity of 16 mm/s. It should be noted that this 16 mm/s capture velocity has been recently doubled from a previous 8 mm/s; this change is discussed in our “Analysis” section below. By Iteration 3, however, we decided to return to the previous 8 mm/s capture velocity to be conservative.

Why We Dropped It

The GRF design, while being a clever idea of combining two unit processes into one, had many disadvantages. First of all, the fact that it took up the entire first channel of the flocculator made it unnecessarily large and added a need for additional flocculator channels to achieve the full collision potential required. Secondly, this design would require many moving parts in the form of the removable pipe stubs after each baffle. Having so many pipe stubs to remove made us wonder how long it would take the plant operator to clean the flocculator, and how the drainage of each baffle space would connect underneath the flocculator. Thirdly, the fact that coagulant would be dosed before the grit chamber meant that the plates and grit would both consume unnecessary amounts of coagulant, resulting in higher costs and longer cleaning time. Finally, the size of the entrance tank would not be greatly reduced in this design since it would still be needed to house a chemical dosing float and a linear flow orifice meter. We concluded that attempting to combine a flocculator and a sedimentation tank resulted in very compromised versions of both.

Iteration 2: Separate Grit Removal Unit in Entrance Tank: "Entrance GRU"

The Entrance GRU is a designated grit removal unit with no intention for flocculation; it acts as a "rough sedimentation tank" prior to the flocculator, as shown in the diagrams below.

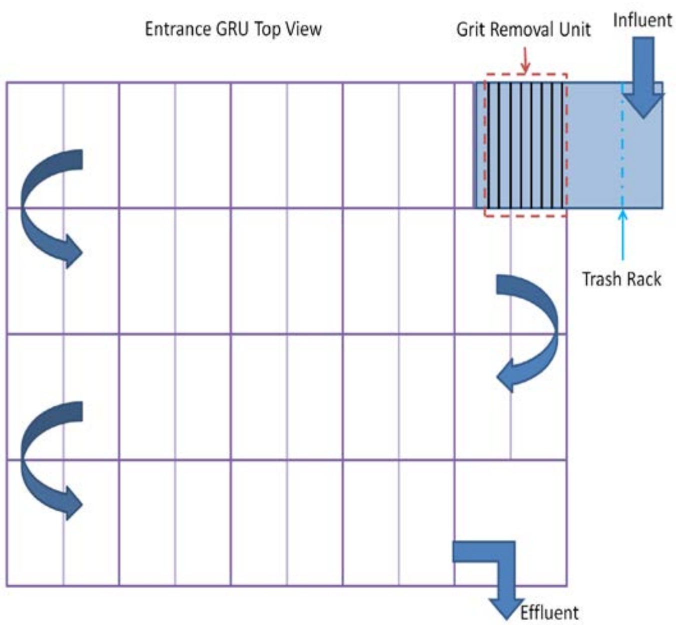

Figure 3.a.i. A schematic of the top view of flocculator that uses an entrance GRU. Note that the GRU is *inside* the entrance tank, not the flocculator.

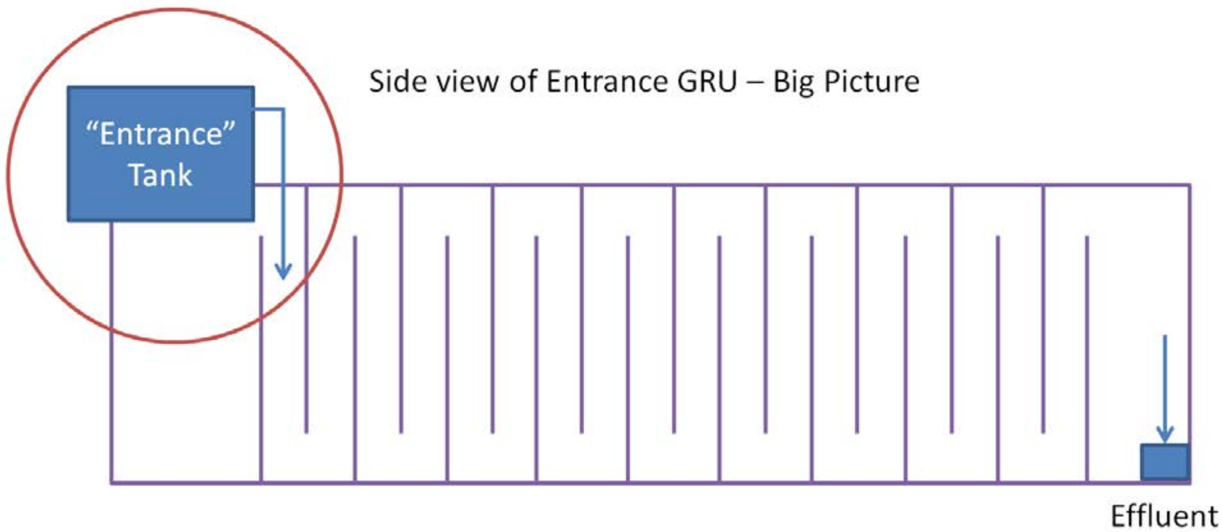

Figure 3.a.ii. The side view of entire flocculator channel, to show placement of entrance tank.

Overview

For the GRU design, we decided to try creating a very compact sedimentation unit that would fit easily within the entrance tank. We set a constant plate settler spacing of 2.5 cm and used our pre-determined V_{cGrit} to find the total plate settler length needed (before cutting the single sheet into several shorter plates). Because we were freed from any flocculation goals in this design (we were no longer trying to design a combined flocculator and sedimentation tank), we were able to focus only on the GRU's geometry and sedimentation capabilities. The resulting design is a more compact settling chamber that would decrease the size needed for the entrance tank and leave the construction process for the rest of the flocculator channel unchanged. The figures that follow give an idea of the design of this Entrance GRU, including the feature that coagulant would be dosed after the water leaves the GRU with a linear flow orifice meter (LFOM).

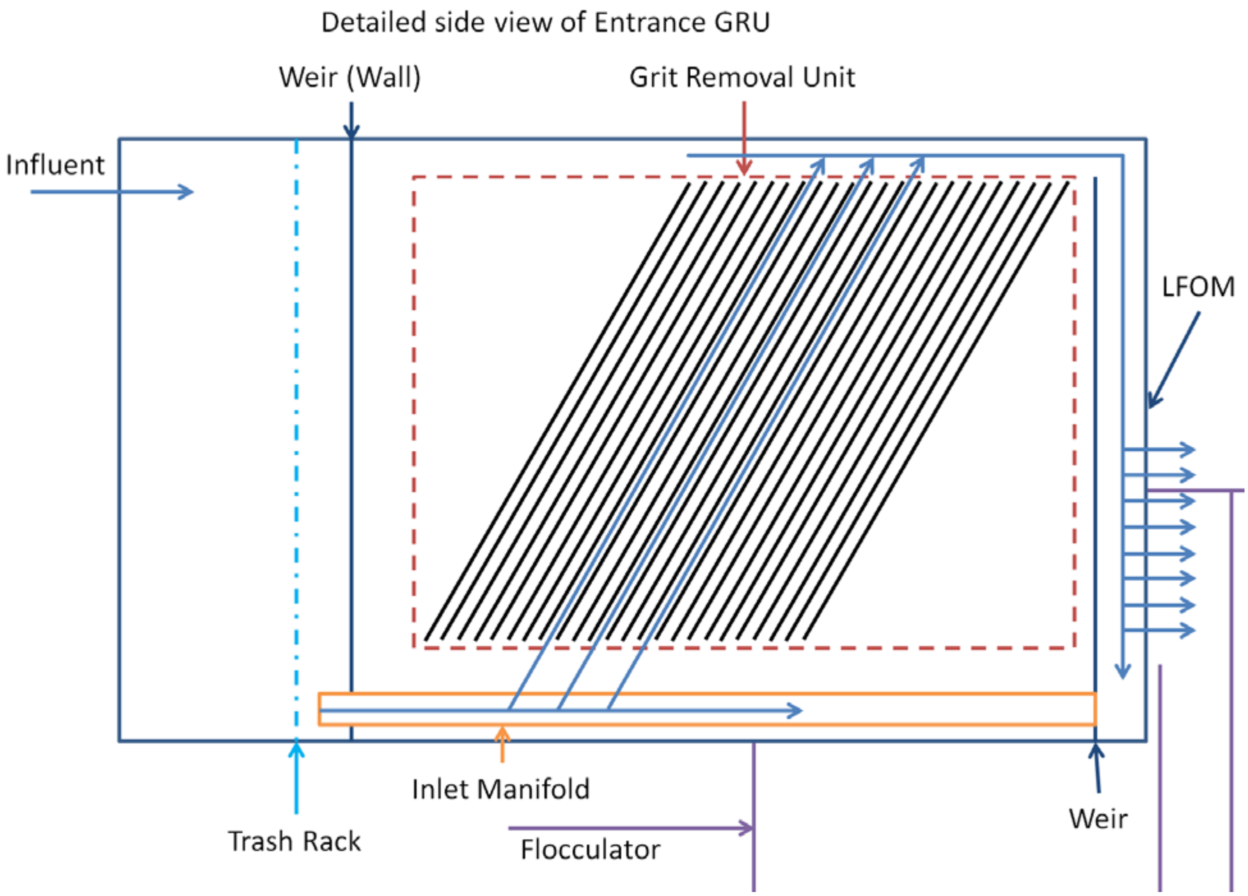

Figure 3.b.i. Detailed sketch of the inside of the entrance tank. The flow of the water through the bottom of the tank at the entrance and the top of the tank at the tank at the exit, which is necessary for flow distribution within the plates, would be regulated using weirs.

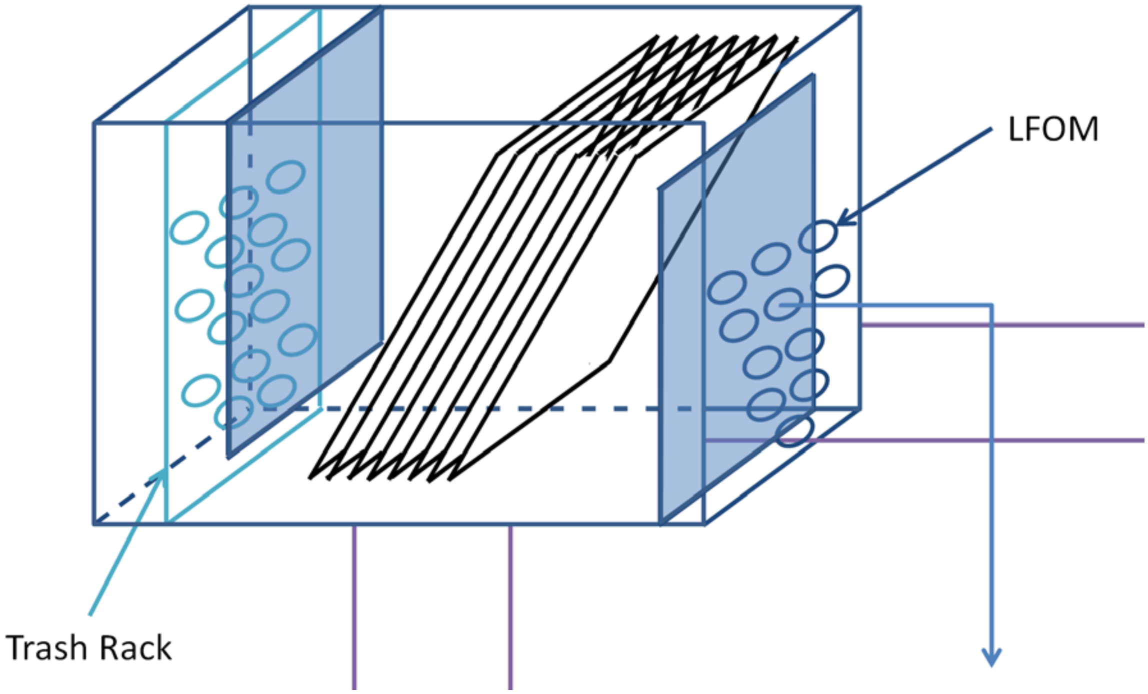

Figure 3.b.ii. Showing the same view as **Figure 3.b.i**, but at a slight angle to better see the different components of the entrance tank.

Why We Dropped It

The Entrance GRU had many advantages, especially the fact that it imposed no alterations to the flocculator design and the fact it could be placed before coagulant dosing. However, we quickly agreed that the inlet manifold system for even flow distribution would be too complicated for such a small space, and that the overall plant size could be further reduced if the entrance tank was virtually eliminated. To address these issues, we decided to move on from this design and instead pursue a GRU with a simpler inlet system and a location independent of the entrance tank.

Iteration 3: Separate Grit Removal Unit in Channel: "Channel GRU"

Overview

Using the same fundamental design parameters as the Entrance GRU, the Channel GRU is a bundled set of closely-spaced plate settlers dedicated to settling grit. However, as the name implies, the Channel GRU would be placed at the very beginning of the first flocculator channel, virtually eliminating the need for an entrance tank. To arrive at this new design, two main changes were made to the design from Iteration 2. The floor of the GRU was inclined to 50° and the plate settlers were angled to match in such a way that flow distribution requirements are met without the need for inlet and outlet manifolds. Additionally, the GRU was placed within the first flocculator channel (instead of in a separate entrance tank) so that flow metering for chemical dosing can occur in a more compact space. Sketches of our most recent design of the Channel GRU are shown in the diagrams below.

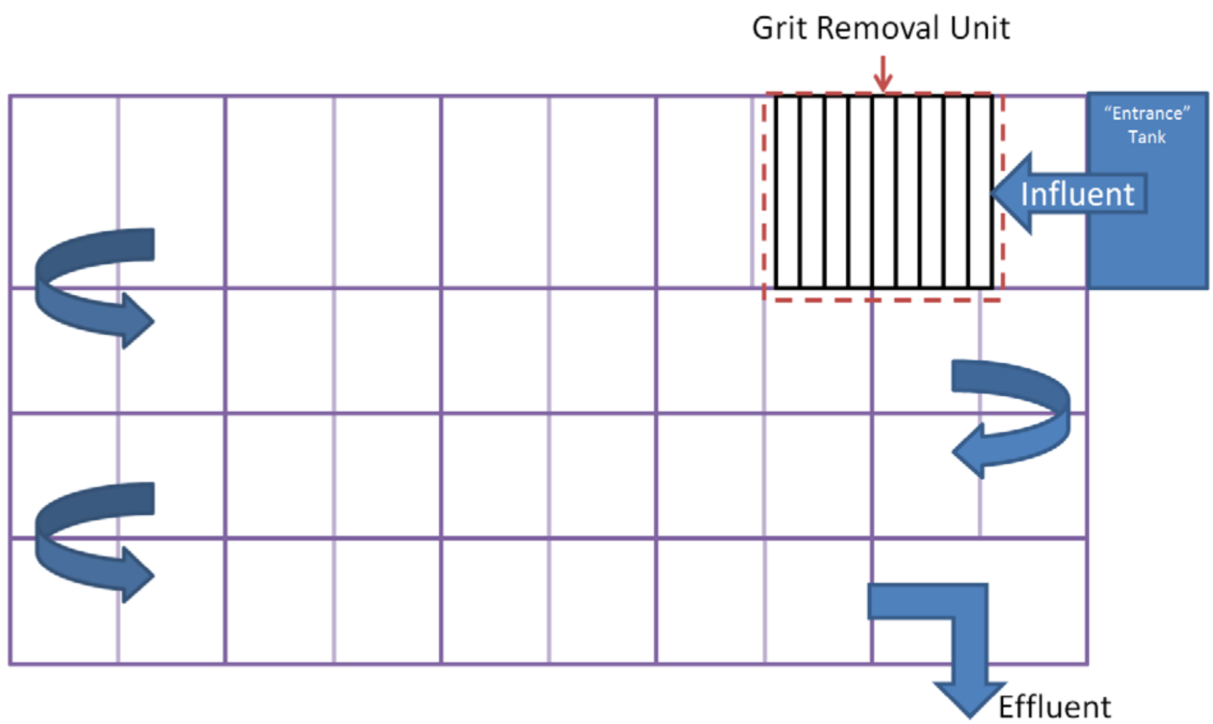

Figure 4.a. Top view of a flocculator with a GRU at the entrance of the first flocculator channel. The entrance tank, like in the GRF design, would consist only of vestigial elements, such as the trash rack.

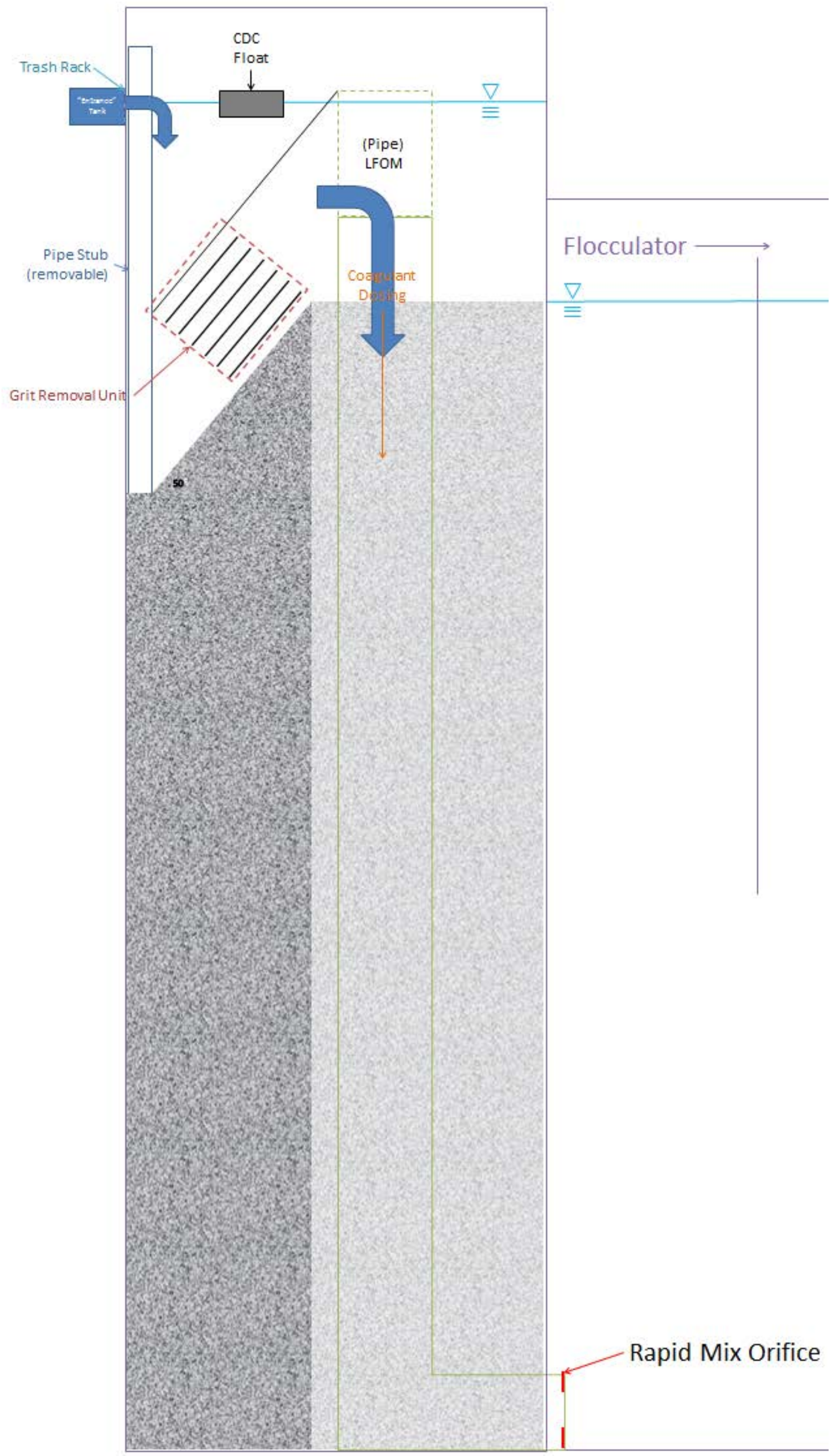

Figure 4.b.i. A big-picture side view of how the Channel GRU may look. This is a to-scale diagram of a 4L/s design, given a flocculator depth of 2m.

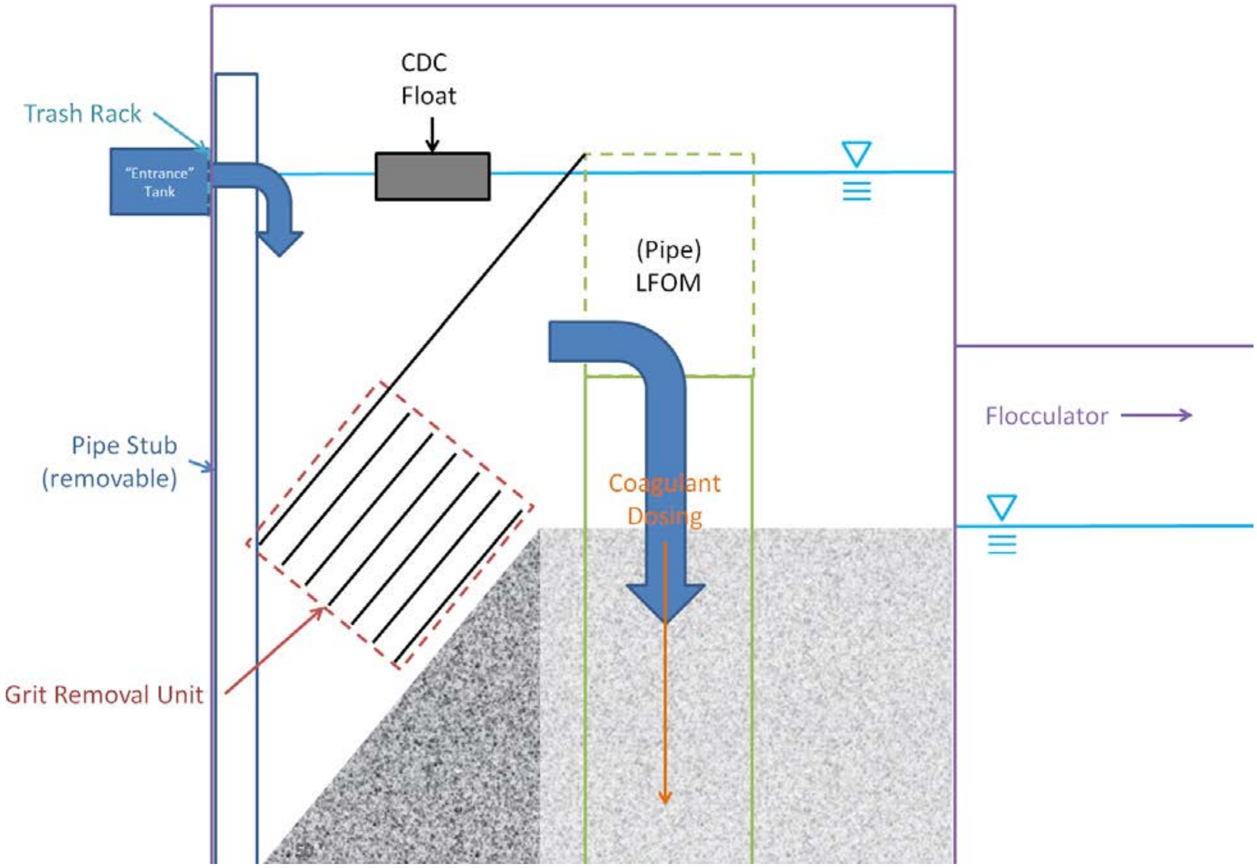

Figure 4.b.ii. A detailed view of the design shown in **Figure 4.b.i.**

Plate Angle

There have been several noticeable design changes to this Channel GRU that have diverged from typical sedimentation tank design. Firstly, the 50° angle of the inclined floor is also the angle of the plate settlers and was set as a compromise between typical design angles for the plate settlers (60°) and hoppers (45°), whose purpose the inclined floor mimics.

Flow Distribution

In this design, the topmost plate purposefully extends above the water's surface to prevent preferential flow from the entrance tank above the plate settlers, forcing water to flow from the bottom of the plate settlers to the top, settling out grit in the process. While the current AguaClara sedimentation tank features plate settlers whose edges are aligned parallel to the floor, the Channel GRU will have plates whose edges are aligned perpendicular to the sloped floor of the GRU. This strategy of placing the plate settlers allows for even flow distribution; with this geometry, the pressure caused by flow across the tops and bottoms of the plate settlers will be the same throughout (the inclined floor acts as the last "plate settler"), and flow will not be preferential for certain spaces over others.

Optimal Depth (Based on Minimizing GRU Length)

Our recent investigations of plate geometry have shown that minimizing the horizontal length of the Channel GRU actually requires decreasing the GRU's depth. We want to minimize the GRU length in order to minimize disturbing the flocculator design. As shown in the graphs below, the GRU length increases with GRU height. From this, we have concluded that raising the floor level of the GRU with a measured layer of concrete (while keeping the angle of the slope the same) may be the most efficient way of distributing the GRU's area. Our updated design (in Figures 3.b.i and 3.b.ii) reflect this conclusion, showing many short plates within a shallow area. Minimizing the number of plates was a less stringent constraint than minimizing the GRU length, since the plastic sheet material is relatively cheap.

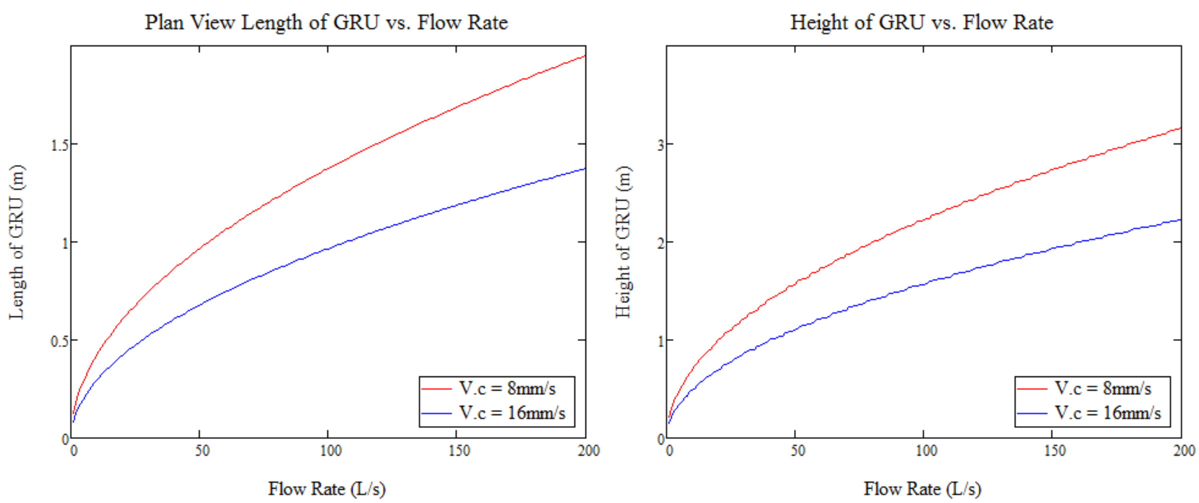

Figure 5.a.i. These two graphs relate the optimal length and height used by the GRU based on various plant flow rates.

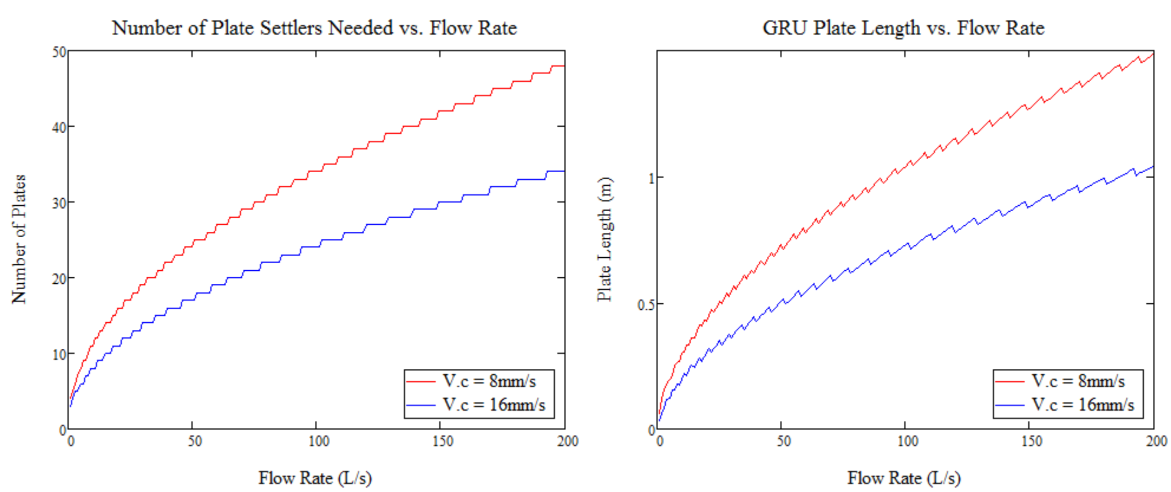

Figure 5.a.ii. These two graphs describe the relationship between flow rate and the number of plates needed based on geography, and therefore length of each plate based on this number.

Coagulant Dosing and LFOM Placement

Due to the small spacing between the plates (2.5 cm), we were concerned with coagulant loss to the plates' surfaces. Additionally, dosing grit with coagulant is wasteful because grit particles are already large and heavy enough to settle out by themselves. Therefore, it is more practical to dose coagulant into the water after the GRU in this design. Rapid mix may be achieved in the typical AguaClara fashion, with a rapid mix orifice at the junction of the inlet pipe to the flocculator. Chemical dosing is incorporated within that jet, saving coagulant and eliminating the need for a separate rapid mix unit. When flow through the plant is cut off, the water height in the flocculator will settle to the height of the sedimentation tank exit weir, while the water height in the GRU will settle to the height of the lowest row of LFOM holes. This constraint drives the elevation required for the plate settlers and LFOM in the Channel GRU. **Figures 4.b.i and 4.b.ii** show where we have placed the LFOM, CDC float, and trash screen components in this design.

Draining

The pipe stub that is used to plug the drain along that wall of the flocculator will not impede the flow, as the water can easily flow around it. The sloped floor of the GRU will be constructed such that, at the lower end, all of the grit will be funnelled towards the drain pipe, so that all grit can be removed at once. If this design is integrated into the layout of a plant as it is currently built, the drain that is covered by the pipe stop will empty into the drain channel that is already used by the flocculator and sedimentation drains. Future designs may change this configuration; if so, the issue of drainage and how to redirect the settled grit into wastestreams will have to be reconsidered.

Creating the 4 L/s Plant Design for Honduras

With about a month left of the semester, the team was asked to design a detailed and functional grit removal system for an actual plant to be built in San Juan Guarita, Honduras. The plant would be integrating various new technologies into its 4 L/s design, along with grit removal. We decided on utilizing the last iteration of our design, the Channel GRU, for this plant design after considering all the pros and cons of each iteration. The resulting design was coded into the design code, and AutoCAD representations of the entire plant, including the Channel GRU, were drawn. Below are the main functions we created to calculate the optimized number of plates, length of plates, length of GRU, and height of GRU. A plant flow rate of 4 L/s, and a capture velocity of 8 mm/s (to be more conservative) were used as inputs.

$$N_{PlatesSafe}(Q_{Plant}, V_c) := \text{ceil}\left[\sqrt{\frac{Q_{Plant}}{W_{Floc} \cdot V_c \cdot (S_{GRU} + T_{SedPlate}) \cdot \sin(\alpha_{GRU})}}\right]$$

$$V_{\alpha Grit}(Q_{Plant}, V_c) := \frac{Q_{Plant}}{N_{PlatesSafe}(Q_{Plant}, V_c) \cdot W_{Floc} \cdot S_{GRU}}$$

$$L_{Plate}(Q_{Plant}, V_c) := \frac{S_{GRU} \cdot \frac{V_{\alpha Grit}(Q_{Plant}, V_c) \cdot \sin(\alpha_{GRU})}{V_c} - S_{GRU} \cdot \sin(\alpha_{GRU})^2}{\sin(\alpha_{GRU}) \cdot \cos(\alpha_{GRU})}$$

$$L_{GRU}(Q_{Plant}, V_c) := \cos(\alpha_{GRU}) \cdot \left[L_{Plate}(Q_{Plant}, V_c) + \tan(\alpha_{GRU}) \cdot N_{PlatesSafe}(Q_{Plant}, V_c) \cdot (S_{GRU} + T_{SedPlate})\right]$$

$$H_{GRU}(Q_{Plant}, V_c) := \left[L_{Plate}(Q_{Plant}, V_c) + N_{PlatesSafe}(Q_{Plant}, V_c) \cdot (S_{GRU} + T_{SedPlate}) \cdot \tan(\alpha_{GRU})\right] \cdot \sin(\alpha_{GRU}) + N_{PlatesSafe}(Q_{Plant}, V_c) \cdot (S_{GRU} + T_{SedPlate}) \cdot \cos(\alpha_{GRU})$$

The graph below shows the Channel GRU Length for the 4 L/s design as a function of the number of plates, based on our $N_{PlatesSafe}$ function above. We took the derivative of the L_{GRU} function to find its minimum and used the corresponding plate number (7) as our design.

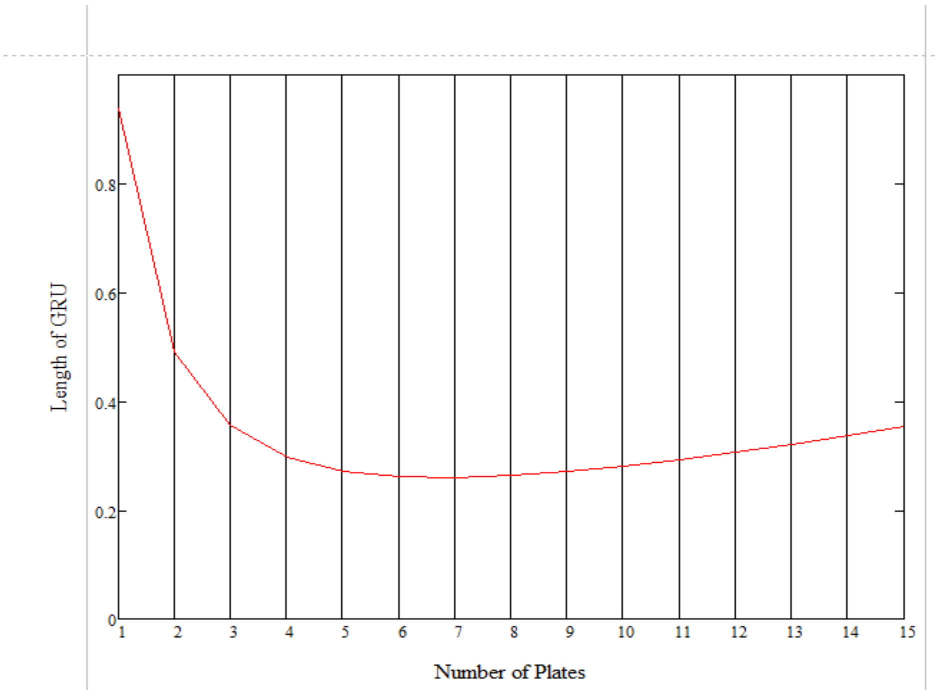

Figure 6. Length of Channel GRU as a function of plate number, plotted to find minimum.

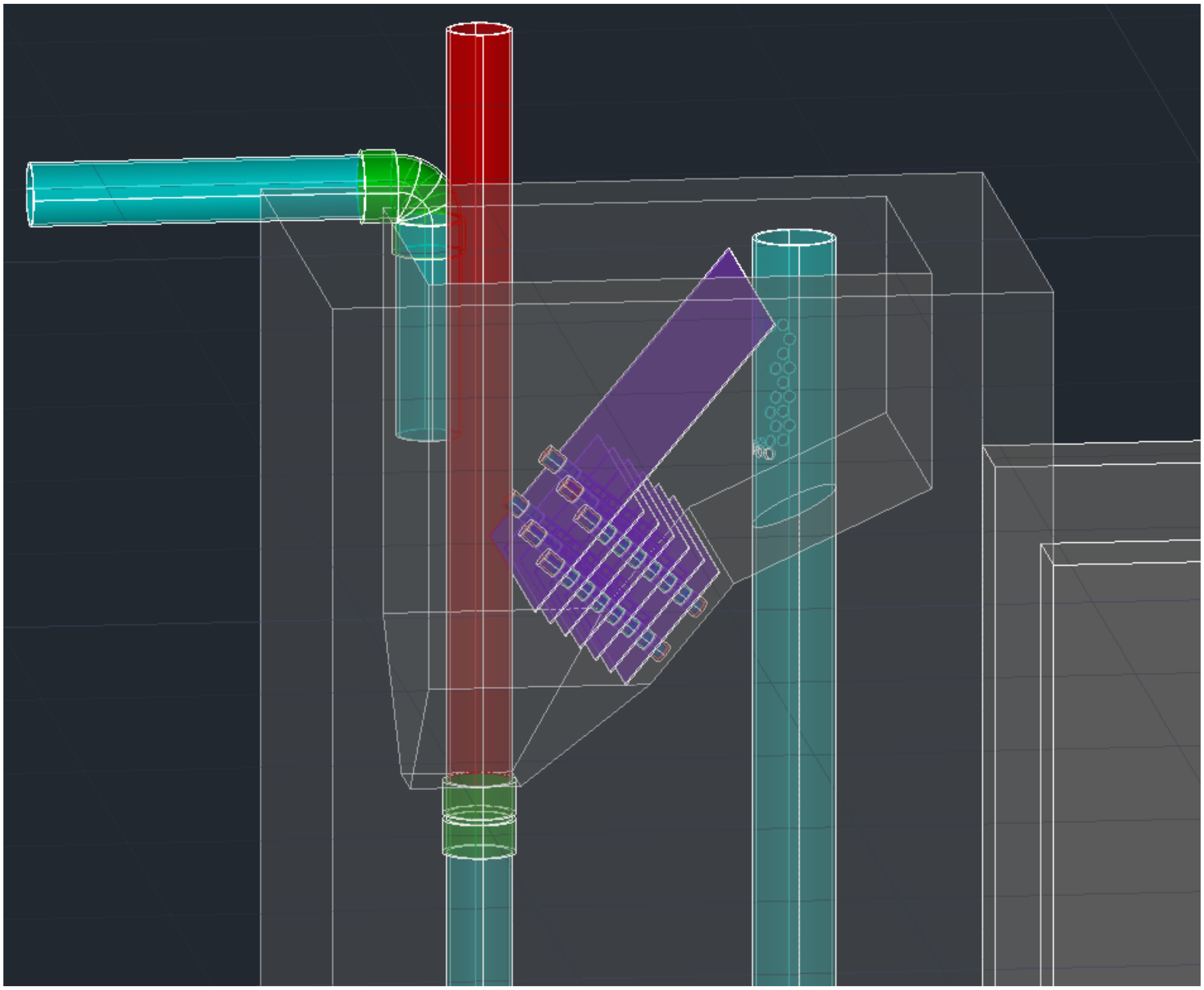

Figure 7.a.i. A zoomed-in view of the GRU, which is elevated above the rest of the flocculator channel (to the right). The red pipe is the pipe stop, the blue pipe on the left is the water inlet, and the blue pipe on the right is the LFOM.

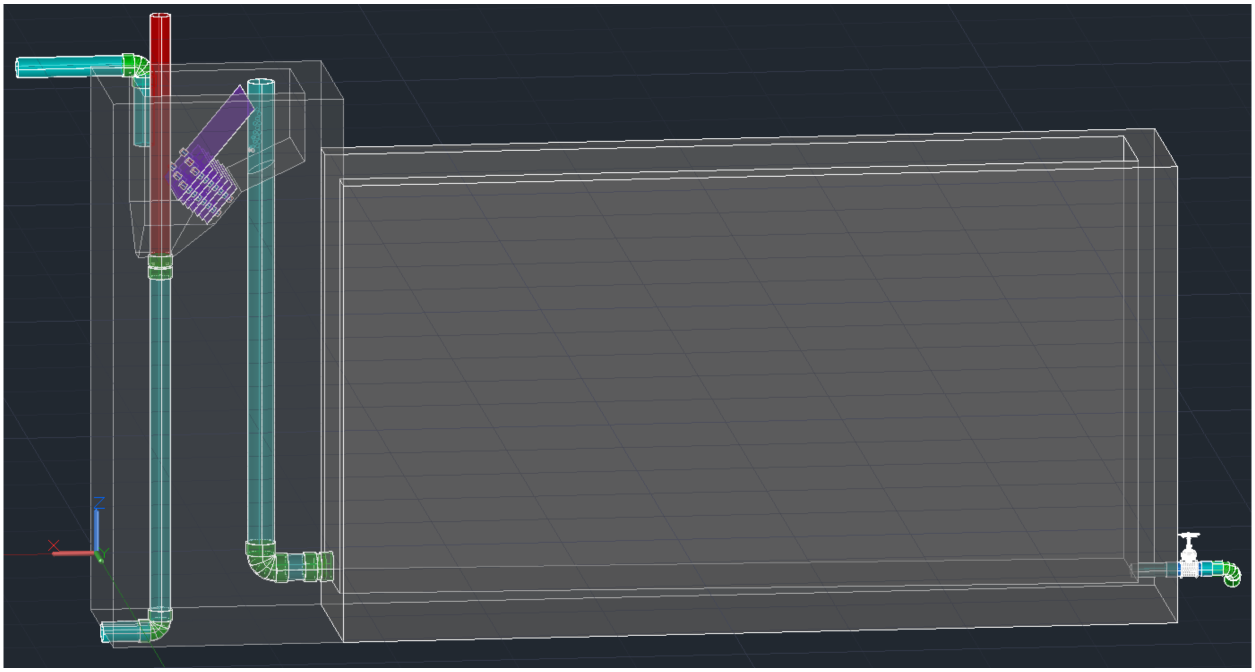

Figure 7.a.ii. The zoomed-out version of the entire flocculator channel, including the GRU, for scale. This length is the same length as the sedimentation tank (hidden).

The results of our calculations, as reflected in the AutoCAD drawings above, show that for a 4 L/s plant with a settle capture velocity of 8 mm/s, there will be 7 plates, most of which will be 17.9 cm long (the only exception being the long topmost plate, as shown in the drawings above). The overall planview length of the unit (not including the concrete walls, drain pipe, or LFOM) is 26 cm, while the total height is 43.1 cm. These dimensions are reflected in **Figures 7.a.i and 7.a.ii.**

Analysis of Capture Velocity Constraint

One assumption initially used in this design was setting the capture velocity of the grit chamber to 16 mm/s. Previously set at 8 mm/s, the new, doubled value reflects a proposed increase in the energy dissipation rate (EDR, or ε) through the plant. Recent research has shown that preventing large floc break-up may not be a crucial constraint as had previously been assumed, so future designs could be reworked to allow for a higher EDR that would then allow for a decreased maximum floc size. A higher EDR also results in a higher velocity through the flocculator or grit chamber, and therefore the size of the smallest particle that will settle out in the flocculator will increase (the increased velocity allows larger particles to be carried through the flocculator). However, after going through several iterations of the design, we realized that even when using a settling velocity of 8 mm/s for a conservative design, the dimensions of the GRU would be small enough that making it even smaller (with a 16 mm/s settling velocity) would hardly matter in the overall plant design. Therefore, we decided to keep using the original 8 mm/s settling velocity in our final design calculations, just to be on the safe side; we would rather settle out more particles than less.

Conclusions

Over the course of the semester, the two of us on the GRIT team gone through several iterations of design, inventing and exploring options for each, and improving upon them to optimize their effectiveness before comparing them. In the end, we have decided that our third design iteration, the Channel GRU, is the best of the three we have explored so far. It drastically decreases the plant's plan view area by reducing the entrance tank to nothing but a trash rack, elegantly ensures flow distribution through creative plate-to-floor orientation, and effectively incorporates chemical dosing and rapid mix *after* the grit removal plate settlers. We hope it functions as well as we anticipate in San Juan Guaritas.

Future Work

While this team has already created an effective design for grit removal in AguaClara plants, there is still work that can be done to improve our work. If future teams continue working on the grit removal issue, they should first keep in contact with APP and the engineers in Honduras, who are already working to implement the 4 L/s GRU designed above. As the construction and future utilization of our design occurs, feedback on its strengths and weaknesses will strongly help the process of tweaking it into a more efficient, more user-friendly design.

More research can also be done regarding the design of grit-removal systems for plants with large flow rates. As shown in **Figure 5.a.i** of our "Optimal Depth" section, once the flow rate reaches a certain maximum (**80 L/s** for an 8 mm/s capture velocity and **160 L/s** for a 16 mm/s capture velocity), the depth needed for the GRU becomes greater than the depth that the flocculator channel can allow. Excavating more into the ground would be expensive, so other types of designs may need to be considered if a plant with such large flow rates are ever built.

To better compare the new GRU design with the current AguaClara design, cost estimates of building the GRU versus building the the entrance tank can be calculated, and these figures can be taken into account when choosing which design would be better suited for the design of a future plant. Depending on the individualized needs of a population, the flow rate, and the "grittiness" of the water supply, engineers on site will be able make the decision as to which design is best suited for that plant.