Low Flow Plant Design

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December 5, 2012

Part I
Problem Definition

Introduction

Currently the design tool can only design plants in the range of 6 L/s to 70 L/s. AguaClara wants to be able to extend the range to be able to provide water treatment to smaller towns as well as large cities. In order to do this in smaller communities, a better design is needed for flow rates under 6 L/s. This includes a new design for the flocculator, sedimentation tank, and stacked rapid sand filter as well as optimizing the overall layout of the plant.

Design Details

Low Flow Flocculator

The current flocculator design is effective and efficient at mid and high range flows, but due to the constraints for construction purposes (the length of the flocculator must equal the length of the sedimentation tank, and the width of the channel cannot be smaller than the width of the human hip) this design is very inefficient for low flow rates. At low flows the ratio of water depth to spacing between baffles (H/S ratio) is too high. This does not optimize the amount of collision potential per baffle space. To optimize collision potential per baffle space a H/S ratio of 4 is needed. This ratio is based on computational fluid dynamics research.

The current design for a low flow flocculator includes a tank that is the width of the human hip and is the same length as the sedimentation tank. Instead of a few long channels separated by thick walls there will be small, short channels separated by ferrocement baffles 5 cm wide. Although this will lower the H/S ratio, the H/S ratio will still be too high. Therefore, we need to create more collision potential in order for the flocculator to be more efficient. To do this oversized pipe spacers will be added to the baffle modules (see Figure 1). These will act as an extra obstacle for the water to go around and therefore create more collision potential. The outer diameter of the pipe spacers need to take up around 60% of the upflow area (top view area of each channel) to be effective. See below (Figure5) for a drawing of this design.

An estimate for the spacing between baffles, S.FlocBaffleEst, is calculated using Equation 1 below.

$$S_{FlocBaffleEst} = \left(\frac{K_{FlocBaffle} Q_{Plant}^3}{\Pi_{HS} ED_{Floc}} \right)^{1/7} \tag{1}$$

Where K.FlocBaffle is the minor loss coefficient around the baffle, Pi.HS is the H/S ratio, and ED.Floc is the energy dissipation in the flocculator.

The number of baffles per channel is then calculated by dividing the width of the flocculator tank (human minimum width) by the spacing calculated, rounding this number to the nearest even number and subtracting 1 to ensure that there are always an odd number of baffles and an even number of spaces.

$$N_{FlocBaffles} = ceil \left(\frac{W_{FlocTank}}{S_{FlocBaffle}}, 2 \right) - 1 \tag{2}$$

The actual spacing between the baffles is then calculated by dividing the width of the flocculator tank by the number of baffles plus one.

The next step is to figure out how many pipe spacers, N.PipeSpacersPerChannel, will be needed per channel. The following calculation can be found below (Equation **??**).

$$N_{PipeSpacersPerChannel} = max \left[ceil \left(\frac{H_{Floc}}{S_{FlocBaffle} \Pi_{HS}} \right) - 1, 2 \right] \tag{3}$$

This equation will produce the number of pipe spacers such that after the water goes around a pipe spacer it will have enough space to return back to its normal flow path before hitting the next pipe spacer. It also ensures that there are at least 2 pipe spacers to ensure stability of the flocculator baffle modules. The distance needed for the flow path to return to normal is calculated and the height of the flocculator (H.Floc) is divided by this calculated distance. The width of the channels need to be calculated. Below is the equation used to calculate the width of a channel for a regular flow flocculator (Equation 4).

$$W_{Channel} = \frac{Q_{Plant}}{S_{FlocBaffle}} \left(\frac{K_{FlocBaffle}}{HW_{FlocEnd} ED_{Floc}} \right)^{1/3} \tag{4}$$

Where S.FlocBaffle is the spacing between each baffle in the channel, K.FlocBaffle is the minor loss coefficient around the baffle, Pi.FlocBaffle is the vena contracta around the flocculator baffle, and H.PlantFreeboard is the height of freeboard added to the water height in the flocculator. .For the low flow channel width equationHW.FlocEnd (which is the height of the water at the end of the flocculator) is the distance between changes in flow direction which in the low flow designs is the distance between pipe spacers(See equation 5 below)

$$W_{ChannelLowFlow} = \frac{Q_{Plant}}{S_{FlocBaffle}} \left(\frac{K_{FlocBaffle}}{\frac{H_{Floc} - 2\Pi_{FlocBaffle} S_{FlocBaffle} + H_{PlantFreeboard}}{N_{PipeSpacersPerChannel} + 1} ED_{Floc}} \right)^{1/3} \tag{5}$$

The collision potential is then calculated per channel. The collision potential per channel includes the collision potential produced by the pipe spacers and the baffles. It is assumed that both the pipe spacer and the baffles are both obstacles that the water must go around. Therefore the pipe spacer collision potential is calculated using the same equation used to calculate baffle collision potential. This means that the flocculator baffle minor loss coefficient is used to calculate the collision potential of the pipe spacers. This assumption will need to be evaluated in the future to make sure that it holds. The collision potential per channel is then calculated (Equation 6).

$$\psi_{Channel} = (1 + N_{PipeSpacersPerChannel}) \times (1 + N_{BafflesPerChannel}) \times \psi_{FlocObstacle} \tag{6}$$

To ensure that the flocculator has sufficient collision potential, the target collision potential (75 $m^{2/3}$) is divided by the collision potential per channel to find the number of channels needed.

For ease of construction and plant layout, we would like the length of the flocculator to be equal to the length of the sedimentation tank. Also, the last channel of the flocculator has to be wide enough to include the diameter of the manifold. This is because the flocculated water will enter the manifold straight from the flocculator instead of entering a channel first (see Figure 6). To satisfy the condition that the last channel be wide enough, the last channel width is set to be the outer diameter of the manifold plus two times fitting space. This width plus the width of each channel times the number of channels minus one is subtracted from the length of the sedimentation tank. This length is then distributed evenly throughout the channels (except the last channel) so that the length of the flocculator equals the length of the sedimentation tank.

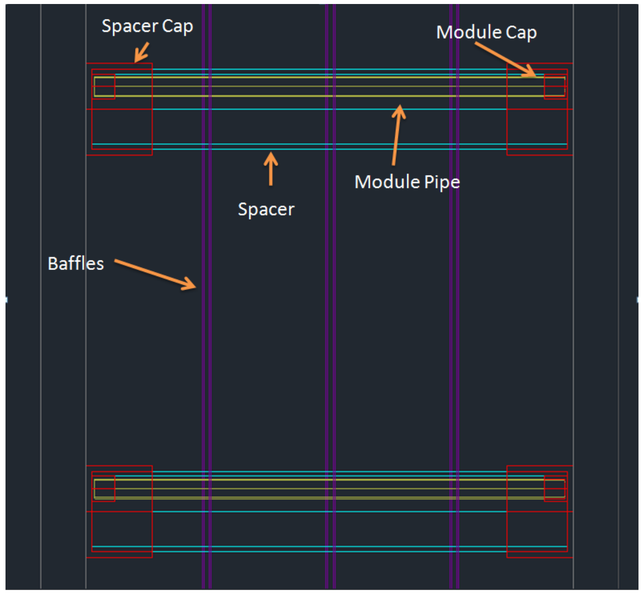

Figure 1: Diagram of flocculator modules

Low Flow Sedimentation Tank

The current sedimentation tank design (Figure 2), though it functions at low flows, is not economically practical and creates more unnecessary opportunity for floc breakup and additional head losses. Because there will only be one sedimentation tank, there is no need for an inlet and exit channel. These channels deliver water to all of the sedimentation tanks, collect the clean water and then pipes leaving the exit channel sends that water to the filters. Instead of using these channels, water will enter the manifold straight from the flocculator and leave the launder and enter a pipe that will deliver the settled water to the filter. Eliminating these channels will decrease construction costs as well as shorten the tank. The current floc hopper is located under the inlet and exit channels, and because the channels will be eliminated in the low flow design a new floc hopper geometry design is needed. The new length of the hopper is the projected horizontal length of the last angled plate settler (Equation 7). This makes the total length of the sedimentation tank the length of the hopper plus the upflow length needed to create the correct upflow velocity (Equation 8). The upflow length is calculated using the same method as in the regular flow sedimentation tank file. The length of the launder is calculated using Equation 9, where L.Sed is the length of the sedimentation tank (from inner wall to inner wall), CapThickness(ND.SedLaunder) is the height of the cap of nominal diameter ND.SedLaunder, SocketDepth(ND.SedLaunder) is the length of the pipe of the same nominal diameter that will be inserted into the launder coupling, and S.Fitting is the spacing (5cm) needed in order for the pipe to fit into the tank.

The current sedimentation tank design can be seen Figure 6.

$$L_{SedHopper} = L_{SedPlate} cos(AN_{SedPlate}) \tag{7}$$

$$L_{Sed} = L_{SedHopper} + L_{SedUpflow} \tag{8}$$

$$L_{Launder} = L_{Sed} - CapThickness(ND_{SocketDepth}) + SocketDepth(ND_{SedLaunder}) - S_{Fitting.} \tag{9}$$

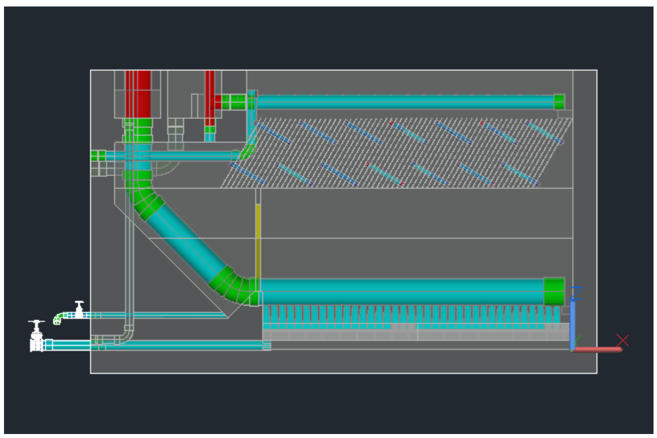

Figure 2: Previous design for 2 L/s sedimentation tank

Low Flow Entrance Tank

The current entrance tank design functions for low flow plants end up being as large as the flocculator and sedimentation tank. In the regular flow plant the entrance tank usually is a fraction of the size of the sedimentation tank. We would like to design the entrance tank so that we can minimize the plant footprint as much as possible. To do this a new entrance tank design has been proposed (Figure 3). The width of the entrance tank will be set to be just wide enough to hold the chemical dose controller's lever arm and the float (about 32 cm). The length of the entrance tank will be set by the diameter of the LFOM as well as the diameter of the float, sufficient spacing between the LFOM and the float, length needed for grit removal, and the length needed for the inlet pipe. Some sort of baffle (ferrocement or plastic) will be added right after the water enters. This should still the turbulence of the entering raw water. The trash rack will be placed on the middle ledge.

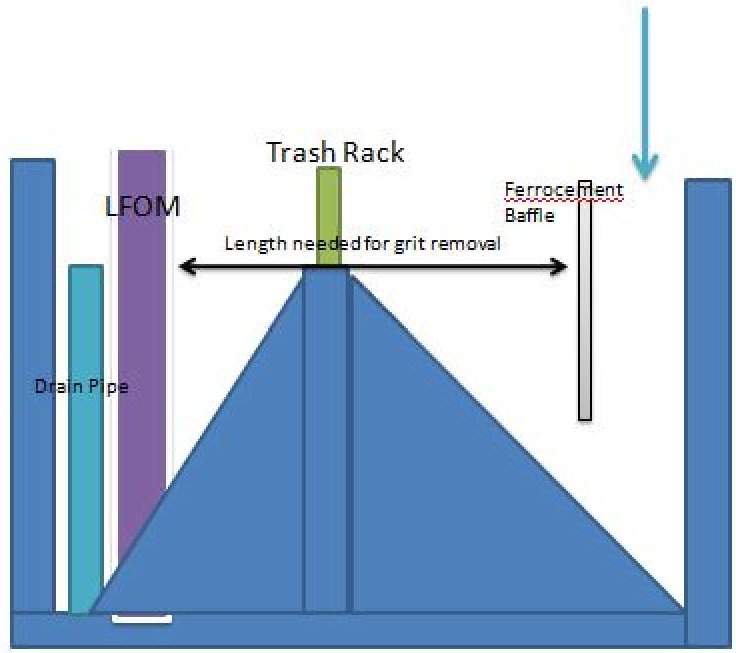

Figure 3: Side view of proposed low flow entrance tank design

If the minimum LFOM hopper length is less than the total length divided by two then the length of the hopper will be half the length of the total length minus the thickness of the hopper ledge. This will make sure that the hoppers are even, but if this is not the case the hoppers will be two different lengths in order to make sure that the length of the entrance tank is no larger than the length of the flocculator and sedimentation tank and that the minimum LFOM hopper length is met. The height of the hoppers is set to be the length of the hopper times the tangent of 30 degrees. Although 45 degrees is usually set as the minimum angle needed for particles to settle out, at these low flow conditions Monroe believes that setting the angle at 30 degrees will not create problems. Making the tank as shallow as possible will reduce construction costs and make it easy for the operator to reach his/her hand into the tank to clean out any grit that might not have settled out.

Low Flow Stacked Rapid Sand Filter

A low flow stacked rapid sand filter has been designed and is being tested in the lab. The filter is a pressurized filter consisting of a 12 in pipe with similar inlet and outlet manifolds to the regular filter. One filter can handle a flow rate of 0.8 L/s therefore the low flow plant will increase in size in 0.8 L/s increments

(0.8 L/s, 1.6 L/s, 2.4 L/s, 3.2 L/s). An Autocad sketch of the filter that the low flow filter research team created can be seen below in Figure 4. This will eventually need to be coded into the Design Tool.

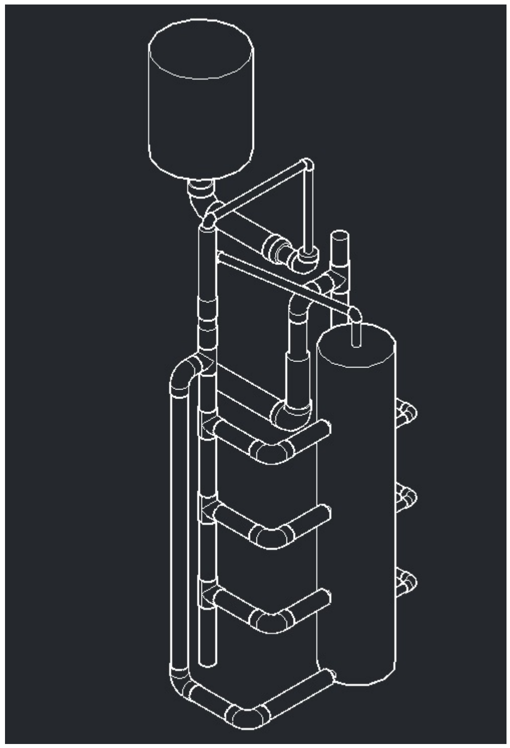

Figure 4: Low Flow Stacked Rapid Sand Filter Drawing

Part II

Documented Progress

Flocculator

The low flow flocculator design explained before has been added to the Design Tool. The current code produces the drawing shown below in Figure 5 for a 1.6 L/s plant. The low flow flocculator consists of one human width tank split into smaller channels separated by ferrocement baffles. Each channel has flocculator baffle modules connected by the pipe spacers. The last channel is wide enough so that the coupling connecting the flocculator to the sedimentation manifold fits with space on either side. The flocculator is set to be the same length as the sedimentation tank.

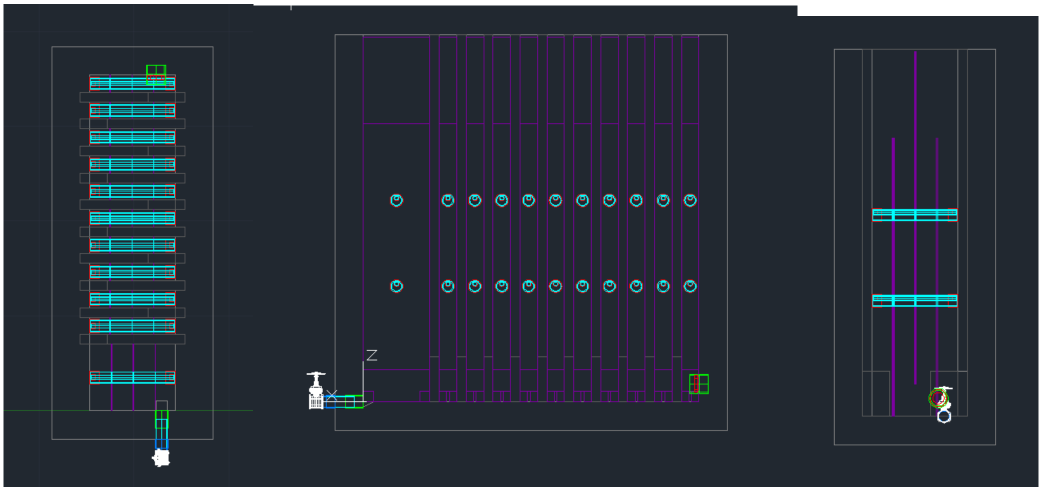

Figure 5: Top, side, and front view of low flow flocculator

Sedimentation Tank

The sedimentation tank code has been added to the Design Tool. The current code produces the drawing shown below in Figure 6 for a 1.6 L/s plant. The low flow sedimentation tank does not have channels and will receive the flocculated water directly into the manifold from the flocculator. The plate settlers were mirrored to make sure that the plate settler effective area is maximized. This design also includes the new hopper geometry that was described previously.

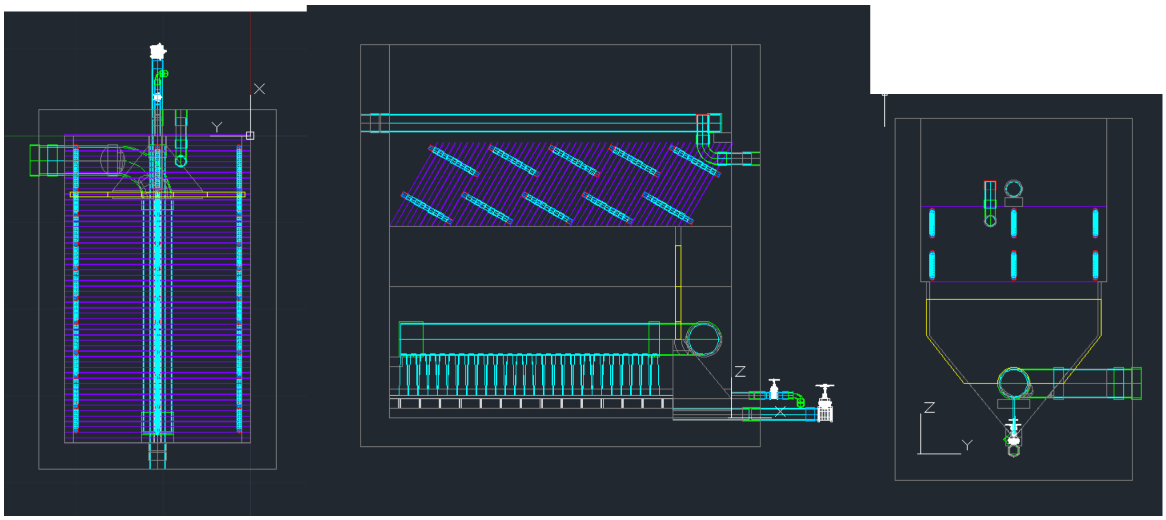

Figure 6: Top, side and front view of low flow sedimentation tank

Entrance Tank

The most current drawing of the entrance tank with the chemical dose controller can be found below in Figure 7. The hoppers are drawn correctly and there are drain pipes in each of the hoppers. The LFOM is located in the back right corner of the last hopper. Currently the chemical dose controller is drawn hanging off of the left wall of the tank, but this may be changed depending on the location of the chemical platform. The baffle to reduce turbulence has been added as well as slots in the wall to hold it in place. I assumed that the thickness of the baffle would be based on a few plastic baffles (plate settler material) which are screwed together. This would be the cheapest option and would take up less space than a ferrocement baffle. This exact material should be confirmed in the future.

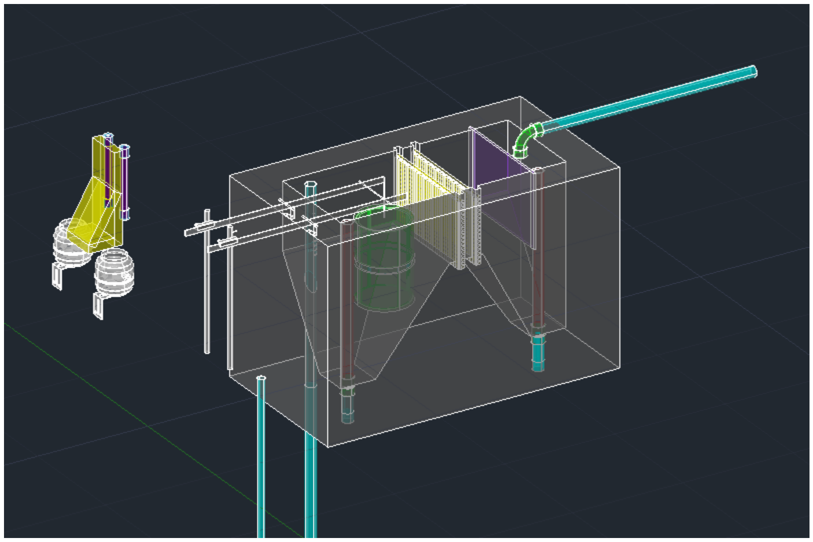

Figure 7: Current drawing of the Entrance Tank (0.8 L/s)

Plant Layout

The current full plant drawing can be found in Figure 8 and below. Because these tanks are so small, it was decided that the walkway between the entrance tank and the flocculator was unnecessary. Also because the entrance tank will be a lot smaller and shallower than the flocculator it will be cantilevered off the side of the flocculator to reduce construction costs. Also the chemical tank platform should be reduced significantly. Smaller size tank dimensions for a 5 gallon bucket and 35 gallon drum were added to the tank matrix to account for the smaller flows. This reduced the size of the chemical platform somewhat but it is still too large due to the stairs. Because the chemical storage tanks are a lot smaller the stairs may not be necessary because the operator does not need to transport large amounts of chemicals to the top of the platform. In this case a simple ladder on the side of the platform may be sufficient. This will reduce the size of the platform significantly and the total plant footprint as well.

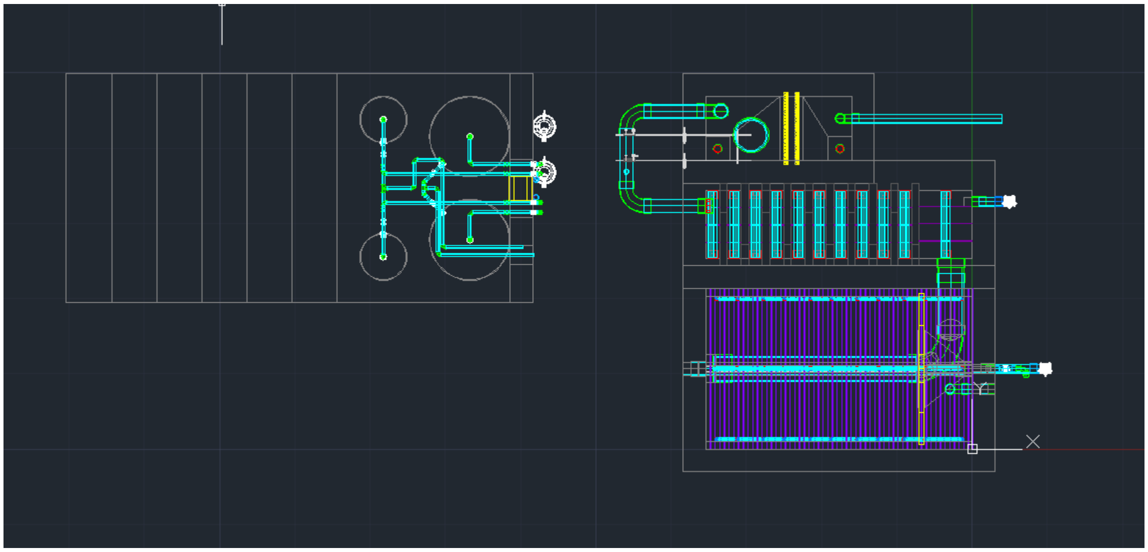

Figure 8: Top view of current plant layout (1.6 L/s)

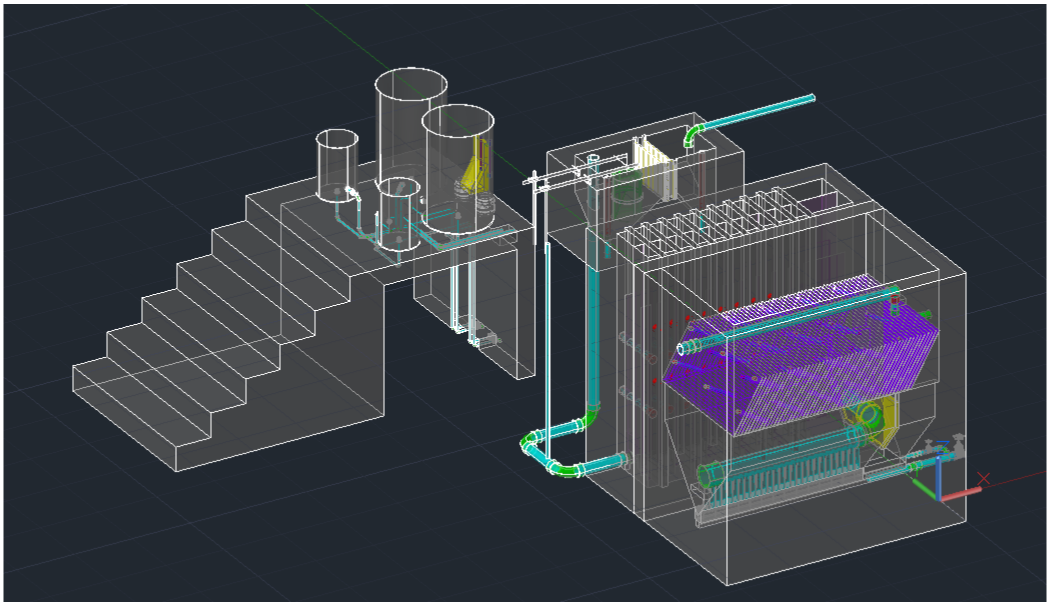

Figure 9: Current plant layout (1.6 L/s)

Future Work

In the near future, it will need to be decided how the drain system will work. Since there will be no drain channel under the entrance tank the drains will need to be piped to a central location. How the drain pipes are set up will depend on where this central location will be. The flow control valve will also depend on this. This central location will depend a lot on what the final plant layout will be. Also the assumption made that the minor loss coefficient for water going around a baffle is about the same as the minor loss coefficient for water going around a pipe spacer should be verified to make sure that their is sufficient collision potential in the low flow flocculator. The design for the low flow stacked rapid sand filter will need to be added to the design code. The filter had been tested in the lab throughout this semester and there are also plans for field testing during the trip to Honduras this January. The basic design for the filter is pretty much set but the distribution system from the sedimentation tank to the filters and the placement of the filters and the distribution system will need to be determined. It will also be necessary to implement the code in a way such that EtFlocSedFiLow is unnecessary and makes changing design code that affects all the different flow rates easiest. Therefore, all of the files will be referenced and EtFlocSedFi will choose which AC variables to stack based on flow rate. This will also help with flow rates like 4 - 6 L/s where the low flow flocculator would be more efficient but the regular sedimentation tanks would need to be used because you would need more than one tank. Finally the low flow designs will need to be incorporated into the design specifications.