Tamara Design Report Fall 2007

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Abstract

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A new AguaClara drinking water treatment plant has been designed for the town of Támara, Honduras. The plant has a maximum flow rate of 740 liters per minute and features a vertical flocculation tank with one turn, three sedimentation tanks, and a new plant leveling tank.

Keywords: AguaClara, Design, Támara

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Introduction and Objectives

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AguaClara is a team of students from Cornell University who work to design sustainable water treatment plants in Honduras. The goal of the team is to design and disseminate water treatment plants globally that are easy to build and maintain, that are economical to operate, and that can be prepared using locally
available materials.

To date, two AguaClara water treatment plants have been built in Honduras. The first was built under the supervision of Fred Stottlemeyer in La 34, Honduras (Figure 1). This plant featured a horizontal hydraulic flocculator. The second AguaClara plant was built in Ojojona and its initial construction was completed in Fall 2006. The Ojojona plant (Figure 2) was designed by the AguaClara team, and Ted Segal completed the structural design. This was an experimental plant with both a vertical and horizontal flocculator.

Figure 1. La 34 AguaClara Plant.

Figure 2. Ojojona Plant.

The next AguaClara plant was planned to be built in the town of Moroceli, Honduras. However, due to transmission pipeline problems, design of this plant was delayed so that it would not sit idle as the transmission line is repaired. The next AguaClara plant will be built in Támara, Honduras.

The Támara design team was only responsible for the environmental engineering design consideration for this plant because Agua Para el Pueblo has hired a civil engineer to deal with all structural aspects.

The Támara plant was partially designed using programs created by the AguaClara team during previous semesters. In Fall 2006, Monroe Weber-Shirk's CEE 454 class created algorithms for the unit processes involved in the plant. In Spring 2007, these algorithms were combined into a Main Program that would begin to design a plant. The program is written in MathCAD, and accepts user inputs such as flow rate and tank width to calculate output design parameters such as tank length and baffle spacing. In Fall 2007, the CEE 454 class created new programs to design pipes and flow measurement structures. These programs were used by the Támara design team as well.

The team also made use of the automated drawing capabilities developed by the Fall 2007 automated design team. This allowed the team to produce AutoCAD commands for drawing of the sedimentation tank by inputting design constraints to a MathCAD program.

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Design Flow Rate

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The Támara plant flow rate was determined using an initial town population of 5,500 people. The flow rate was based on the projected population and associated water demand in 20 years. Population was calculated using a linear growth model with a 3.5% growth rate. Water demand was estimated as 114 Liters per person per day. The minimum plant flow rate was initially estimated as half of the maximum flow rate. However, after discussion with John Erickson and Carol Serna, the AguaClara engineers in Honduras, it became clear that the town did not currently have a population of 5,500. At the time of design, 570 homes were hooked up to the transmission line. With an average of 6 people per house, this population was 3420 people. This would result in a water demand of 463 L/min in 20 years. The potential for 120 new connections in the near future exists.

However, the engineers in Honduras believe that source at Támara can provide at least 740 L/min. It was decided that 740 L/min should remain the maximum plant flow rate because the actual demand for water is uncertain, and the extra size of the plant would not be too costly. Initial baffle spacing in the flocculation tank will be designed in a way to ensure that the current flow rate, possibly as low as 270 L/ min could be handled.

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Plant Layout

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The Támara plant layout has a few major changes from the layout of the previous Ojojona plant.

1. The horizontal flocculator was removed. Testing in Ojojona confirmed that the vertical flocculator worked well The vertical flocculator is less costly to build because it does not need to be elevated, so the horizontal flocculator will no longer be used in AguaClara plants.

2. At the request of plant operators in Ojojona, a "bodega" was added to the plant. This walled-in, roofed area is to be used for chemical storage, mixing of chemicals, and possibly a cot for night-time operators.
3. A plant leveling tank was added to replace the pipe elbow level control feature in Ojojona.
4. Chemical barrels were separated. The alum and chlorine barrels will be located on different tables to allow for open walkways without tubes stretching across them, and to allow the tables to be at different heights as necessary.
5. Tanks will be built of brick. APP is more familiar with brick, they believes it is less porous than concrete, and they can build more cheaply with brick.
6. The plant will be more protected. There are two possible scenarios. The first is to have a fence around the plant with a roof over the platform. The second is to have open walls that start at the platform and stretch partway up to a roof. These walls would eliminate the need for a railing around the plant or extra sunlight protection for thetanks. Overall, this decision and design will be left to the plant operators and engineers inHonduras.
7. A catwalk may be added to span the flocculation and sedimentation tanks. Because brick walls will be thin, a catwalk would allow for safer access to these tanks. The AguaClara team envisions a sturdy, metal catwalk that could slide from one end of the tank to the other. .The tank walls need to have a ledge inside the external walls of the building covering the plant so there is a place for the catwalk to rest.
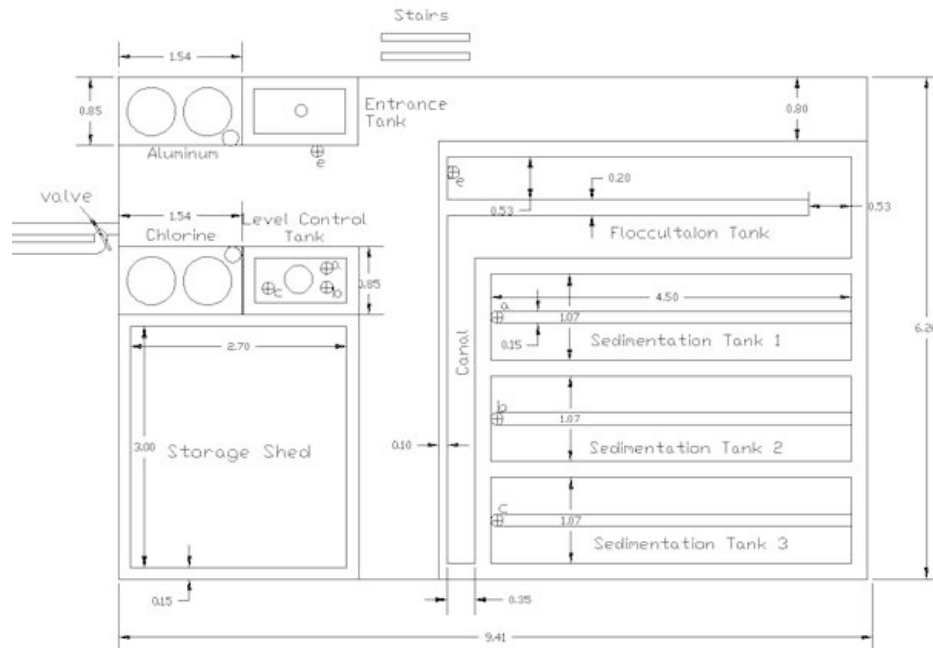

Figure 3. Támara Plant Layout

The new plant layout will be ideal for scaling of future AguaClara plants. As long as baffle materials remain available to allow for the same width of tanks, the width of the plant should not change. When a new plant is designed, the only necessary change to the layout will be the length of the tanks. This will allow for more rapid design, easier automated design, and more uniform future plants. Another important feature of the new layout is that many of the pipes will be under the platform. While this may be somewhat more difficult to build, it allows for easier access with no obstructions to walkways. The area under the platform should be secured so that all of the valves and pipes are protected

Although not shown in the above drawing, all four major tanks will have drains that leave from the entrance side of the tanks. These pipes will go to a waste collection tank under the platform where the operator will be able to see the water that is leaving the plant. In this way he may know when all the dirty water has been flushed out. This will be especially useful when cleaning out the sludge from the bottom of the sedimentation tanks.
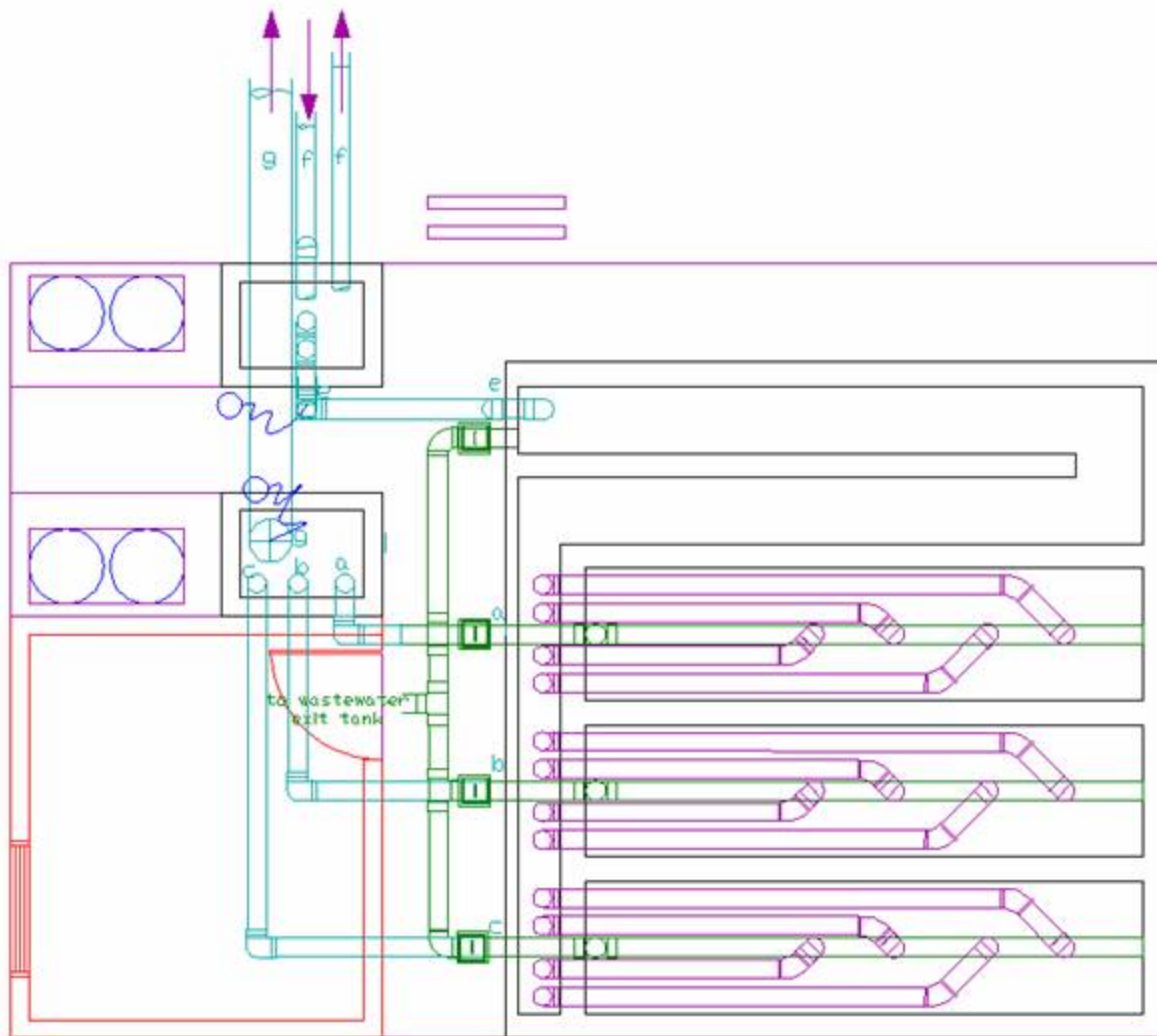
Figure 4. Támara Plant Layout, modified from a drawing by APP engineer Ing Serrano. Magenta pipes in sedimentation tank represent sedimentation tank inlet pipes. Green Pipes are for the sludge drainage.

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Pipe Design

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A major part of designing an AguaClara plant is sizing the pipes in the plant. A pipe design program was created so that all pipes could be designed quickly and correctly. The program returns a pipe diameter given a length, allowable headloss, and number of elbows, tees, valves, etc. A table of the K values used and a table of input pipe sizes used can be found in the Appendix as Table 2 and Table 3.

The program uses functions defined in the Fluids Functions program developed in the Fall 2007 CEE 454 class. In order to find the proper diameter the program iteratively solves for the flow that can fit through a pipe of the given diameter with the given headloss until a large enough diameter is found.

Headloss values are calculated using the following set of equations.

$$Re = \frac{4Q}{\pi D \nu}$$

Re = Reynolds Number, to determine if flow is turbulent or laminar
Q = Flow Rate
D = Pipe Diameter
ν = Kinematic viscosity of water

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \qquad f = \frac{64\mu}{\rho V D} = \frac{64}{Re}$$

f = Friction factor, equation for either turbulent or laminar flow
¿= Roughness factor of PVC

$$h_{major} = f \times \frac{8}{g \cdot \pi^2} \times \frac{L \cdot Q^2}{D^5}$$

hmajor = Major head loss
hminor = Minor head loss
Values for all constants used may be found in the Appendix

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Grit Chamber and Rapid Mix

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A simple new design is in place for the rapid mix. It was decided that the mixing elements used in past designs were not necessary, and that if the rapid mix pipe from the grit chamber to the flocculation tank has at least 2 90° elbows enough mixing would occur. This was determined using the rapid mix pipe parameters and determining the G¿ value for the rapid mix. A G¿ value of at least 600 was desired. The G¿ and G values were determined using the following set of equations.

$$\bar{G} = \sqrt{\frac{g h_l}{\nu \theta}}$$

h_l = headloss in pipe
Assuming that major losses may be neglected:

$$\varepsilon = \frac{g \cdot h_l}{\theta}$$

V = Velocity in pipe = Q / (¿D2/4)
L = Length of pipe

$$\bar{G} = \sqrt{\sum K_{minor} \frac{V^3}{2 L \nu}}$$

$$\bar{G}\theta = \sqrt{\sum K_{minor} \frac{V^3 L}{2 \nu}}$$

This two 90° elbow minimum after alum addition is easily met. The current design has three 90° elbows: the turn from vertical to horizontal along the underside of the platform (1), the turn down along the side of the flocculation tank (2), and the turn back to horizontal to release the water into the flocculation tank(3). See figure number 5 for a depiction of these turns. The first baffle in the flocculation tank will be resting on the bottom of the tank and will direct water upwards. The pipe from the grit chamber will enter the flocculation tank near the bottom The first baffle will be a bottom baffle so the flow must turn over it. This means the pipe should enter near the bottom of the floc tank so the water will have further to travel.
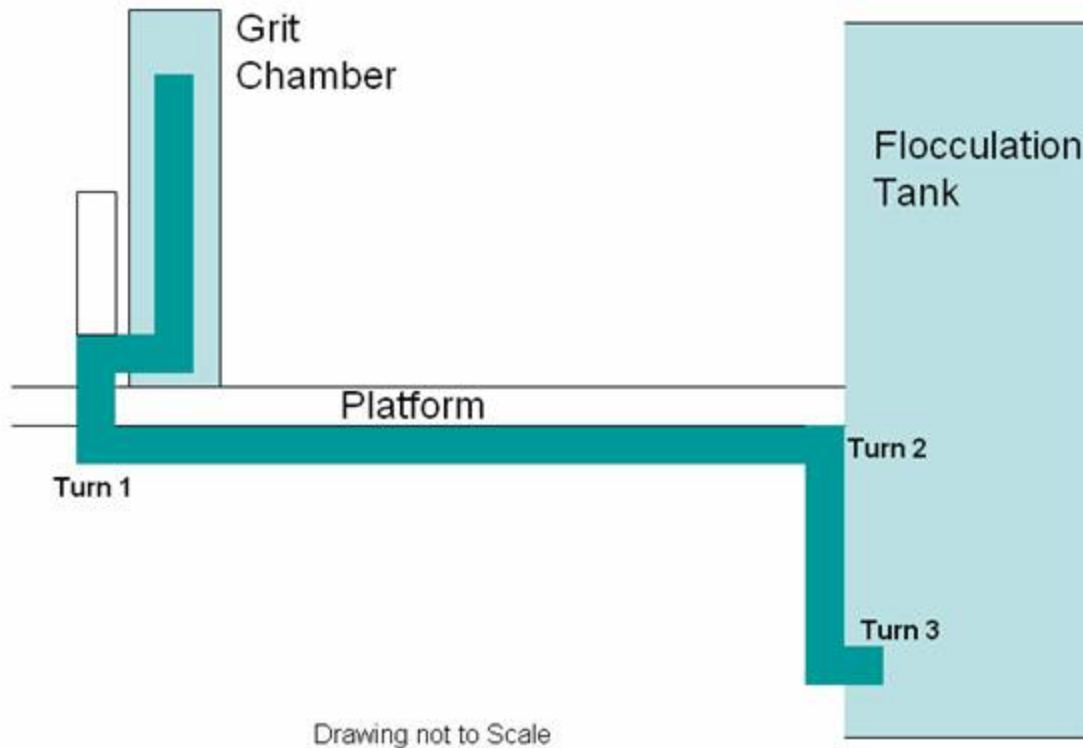
Figure 5. Turns in Rapid Mix after alum addition. Alum addition occurs through the white pipe outside of Grit Chamber.
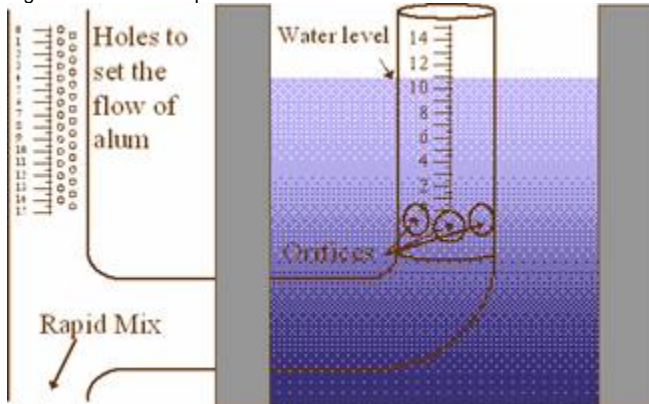

Figure 6. Grit Chamber with one riser pipe leading to the rapid mix. Picture from CEE 454 Homework 4, Plant Measurement written by Monroe Weber-Shirk, Fall 2007.

The pipes for the grit chamber and rapid mix were designed using a program developed by the CEE 454 class in Fall 2007. This flow measurement program designed a grit chamber with two riser pipes that have orifices to allow for flow measurement.

The two riser pipes in the grit chamber contain orifices that will cause the water level to build up above them. This means that the plant flow rate may be determined based on the height of water above these orifices. Then water will free fall for a space and go down through the rapid mix. The open air pipe above the rapid mix, with alum flow holes, will allow for alum addition.

For the rapid mix pipe a maximum headloss, ¿horifice, of 20 cm was set for a pipe with 4 total turns, including 2 turns after alum addition and two turns before alum addition. The diameter of the pipe was determined using methods discussed in the "Pipe Design" section of this paper.

The riser pipe design algorithm set the height of water above the orifices at the design flow rate to be 20 cm. The diameter of the orifices in the risers was set to 1.5 inches, the same value as in Ojojona, and the area of the orifices was limited to 0.3 times the area of the pipe to ensure that orifice flows did not interfere.

The total area of orifices needed was determined using the above constraints and the orifice equation below. The Korifice is 0.63.

$$Q_{orifice} = K_{orifice} A_{orifice} \sqrt{2gh}$$

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The number of riser pipes needed was determined from the total orifice area needed, the area of the pipe, and the ratio of pipe to orifice area. Finally, the total number of orifices was determined by dividing the total area of orifices by the area of one orifice and rounding up.

The footprint of the grit chamber was set to the same size of the plant leveling tank. The height of the walls was set to the depth of water in the grit

chamber, as detailed in the "Water Levels" section of this paper, plus 10 cm of freeboard. This grit chamber tank will sit on the platform of the plant. The final parameters for the grit chamber are below.

- Height of Water Above Orifices: 20 cm
- Head Loss through Rapid Mix Pipe = 20 cm
- Total Number of Rapid Mix Elbows: 4
- Number of Rapid Mix Elbows After Alum Addition: 2
- Length of Rapid Mix Pipe: 3 m
- Rapid Mix G¿ Value: 1662
- Rapid Mix Average G Value: 375 /sec
- Diameter of Orifices: 1.5"
- Area of Orifices/ Area of Pipe ratio: 0.3
- Diameter of Riser Pipes and Rapid Mix: 6"
- Number of riser pipes: 2
- Total Number of Orifices: 9 => 4 on one pipe and 5 on the other
- Footprint of Grit Chamber: 1m x 0.70 m
- Height of Grit Chamber Walls: 1.25 m

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Flocculation Tank

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The initial flocculation tank design was completed using the "Main Program" developed by the Spring 2007 design team. However, due to changes in the lamella design and length of the sedimentation tanks, it had to be revised. The current total flocculation tank length is twice the length of the sedimentation tanks.

The flocculation tank is 21 inches wide, half the width of the sedimentation tank and doubles back to form a u-shape. This means that the polycarbonate plastic roofing material sheets will need to be cut in half in order to make baffles. The reason for the shape of the flocculation tank is that increasing the length of the tank and decreasing the width causes the tank to need less baffle material. This is ideal because in the past baffles have bent and broken. Additionally, smaller baffles will be more stable, and the design will require the baffles to be spaced farther apart.

Baffle spacing will be determined in Spring 2008 when a better understanding of baffles and flocculation has been achieved An assessment of the actual water demand for Tamara should be made early next year and if possible the flocculator should be designed to handle the range of flow from the current demand to the plant design..

Two drainage pipes have been added to the flocculation tank for emptying the tank. These pipes are located at the very beginning and very end of the tank and will flow into the waste collection tank under the platform. Due to the nature of the baffles in the flocculation tank, water will not be able to freely flow out of the tank. A system will need to be set up to raise these baffles while the tank is draining. One suggestion is tying string to the PVC pipes that attach the baffles to each other. The string would be tied on each side of each baffle. This string could loop over a long pole spanning the length of each tank. When the tank was being emptied, a brick could be placed under each end of this pole to keep the baffles raised off the bottom of the tank and allow water to flow out.

Sizing of the flocculation drainage pipes was based on a time to drain tank of 30 min. The initial flow rate was found as two times the average flow rate. This means that:

$$Q_{initial} = \frac{L_{tank} \cdot Depth_{avg} \cdot Width}{15 min}$$

Where L_{tank} is the length of one-half of the tank, and the average depth is found as 2 m plus half the expected headloss, or 2.1 m. The drain size was determined using the pipe sizing program with a headloss of 200 cm and flow rate of $Q_{initial}$.

The wall heights of the flocculation tank are based on the assumption that there will be 20 cm of headloss in the flocculation tank. The wall heights were set to approximately 10 cm above the water level in the tanks. The first half of the tank will have walls 20 cm higher than the second half of the tank because the majority of the headloss comes from the first half of the flocculation tank where the baffles are closer together
The turn in the flocculation tank was modeled as one baffle. The opening in this turn was calculated to have the same area as the opening left by a baffle at the end of the flocculation tank with a G value of 15/sec. This baffle opening area was determined the Fall 2007 CEE 454 flocculation solution. The program iterates to solve the following equations.

$$R_h = \frac{w \cdot b}{2 \cdot (w + b)}$$

R_h = Hydraulic Radius
w = Width
b = Baffle spacing

Vup

$$V_{up} = V_r \times \left(1 + \frac{L_{baffle}}{b_{baffle}} \cdot \cos(\alpha) \cdot \sin(\alpha)\right)$$

$$V_{up} = \frac{Q_{tank}}{L \cdot a}$$

In this equation it is assumed that dissipation occurs over approximately the length of baffle spacing, b.

V_{max} = Maximum velocity needed to produce proper G
f = Friction factor, new equation for $f_{turbulent}$ because not using pipes

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

$$Re = \frac{4 \cdot V \cdot R_h}{\nu}$$

$$b = \frac{Q/_{chan}}{a}$$

$$gap = 1.5 \cdot b$$

gap= Distance between baffle and floor for top baffle

$$Area = gap \cdot b$$

Area = Area left by a bottom baffle

The opening will be left at the bottom of the wall separating the two halves of the tank. This will allow water to drain out of the tank more easily. The width of this opening was set to be the space between two baffles with G = 15/sec, the same as b calculated above. Because the opening is at the bottom, the top baffle next to the opening must be removed
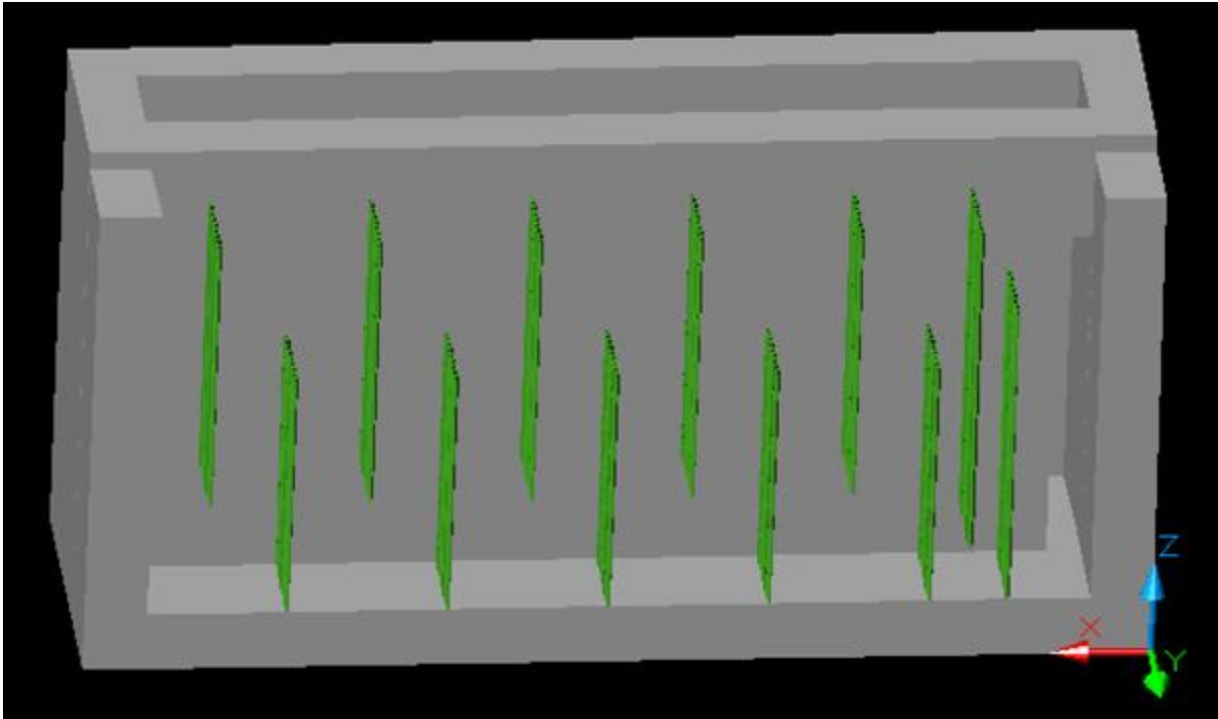
Figure 7. Drawing of second half of Flocculation Tank. Notice the opening in the dividing wall on the right. Drainage pipes will leave from the bottom left side of the tank in this view.

Design parameters for the flocculation tank are below.
Initial Inside Dimensions: 4.2 m long, 21" wide on each side

- Updated Inside Length (based on sed tank length): 4.6 m
- Maximum Head Loss: set at 20 cm
- Depth at End of Tank: 2 m
- Gap for Baffle at end of tank: 0.445 m
- Area Left by Baffle at end of: 0.445 m * 21 in = 0.238429m2
- Tank Turn Opening Dimensions: 0.30 m x 0.80 m
- Wall Height: 2.1 m in second half and 2.3 m in first half
- Initial Drainage Flow Rate: 343.3 L/min
   *Drainage pipes: 2 inches

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Due to the team's limited knowledge of the mechanisms behind flocculation, the baffle spacing for Tamara was not designed at the same time as the rest of the plant. Since the tank dimensions were determined first, the baffle spacings and number of baffles were subject to certain constraints.

Design Parameters

- Number of channels: 2
- Flocculator Dimensions
   Length(per channel): 4.6 m
   Width (per channel): .52 m
   Depth of water at end of 2nd channel (determined by sedimentation tank): 2m
- Dimensions of hole between first and second channels (the hole is located at the bottom of the wall between the tanks):
   Width: 0.3m
   Height: 1m
- Design flow rate (max): 150 gal/min
- Low flow rate: 75 gal/min
- Ratio between high and low flow rate: 0.5
- Slope of floor: 8cm/4.6m = 0.017 (each channel has the same slope with the heighest part where the water passes between the two channels)
- First baffle spacing: 0.355 m

Using the flocculation algorithm developed during spring '08 the baffle spacing was determined. For further information into how this file was developed, see the flocculation sections of both the Automated Design Final Report and the Automated Design Final Algorithm report.

Baffle Spacing	Number of Baffles	Gtheta
11 cm	7	1158

16 cm	7	1158
33 cm	18	2971
sum	32	5287

Attached is an excel file with the coordinates and lengths for each baffle. Polyarbonated is purchased in sheets that are 12 ft by 42 in. These sheets are cut in half to create baffles with a width of 21in (.52m). Two baffles are cut from each 12 ft sheet. The spreadsheet also contains information on how each sheet should be cut since some baffles are longer than 6 ft. Each baffle is a different length due to the slope of the floor.

The tank was built with walls 2.42m tall. Upper baffles, baffles with water runnning under them, should not be installed at this height because they will be too long and 8 polycarbonates sheets will not be enough. Instead upper baffle should be installed at a height of 2.38 m. This includes 5 cm of headloss and 33 cm of freeboard. In the future, more baffles could be installed near the front of the tank, and the extra freeboard will ensure that the tank does not overflow due to the increase in headloss.

The first baffle was placed a distance of 35.5 cm from the start of the first channel. Additionally, the last baffle in the first channel and the first baffle in the second channel are 35 cm from the tank wall to allow space for the uturn hole. The hole has an area of 0.3m^2 which is a sufficient size to guarantee that it will not break up the flocs. The hole is at the bottom of the tank, however, due to it's size it shouldn't matter rather the last baffle is an up or down one. The gtheta value for the entire tank is 5287. This value is acceptable.

Attached is the MathCAD file used to design the tank.

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Flocculation To Sedimentation Channel

The design of the channel connecting the flocculation tank to the sedimentation tank, while a seemingly simple connection, has many constraints.

- The most important constraint: the channel cross-sectional area must be large enough that it will not break up flocs at max flow.
- The channel must be shallow enough that the operator can reach the caps to the sedimentation inlet pipes.
- Ideally the channel would fit in the otherwise unoccupied triangular space above the first plate settlers.
- The bottom of the channel will be the level of the platform. The height of the platform will dictate whether a bucket may be filled from the plant leveling tank in order to mix chemicals.

More information on the bucket problem is included in the "Plant Leveling Tank" portion of this report.   However, easy solutions to constraints #2 and #3 were found. In order to provide easier access to the sedimentation inlet pipe caps in the bottom of the channel, a new design for the caps will be used. A conceptual drawing of the caps is shown in Figure 8 below. The top of the sedimentation inlet pipes (shown as the tall pipes in the figure) will be flush with the bottom of the channel so there will be a smaller entrance loss.   The caps will use slip fittings rather than threaded fittings. The threaded fitting at Ojojona are beginning to break, so slip fittings will provide a more sustainable design. Thin handles, made of smaller PVC pipe, will be attached to the tops of the caps so that the operator can easily pull and push the caps off and on. This will eliminate the need for the operator to reach his hands into the water, and this will eliminate the depth constraint.
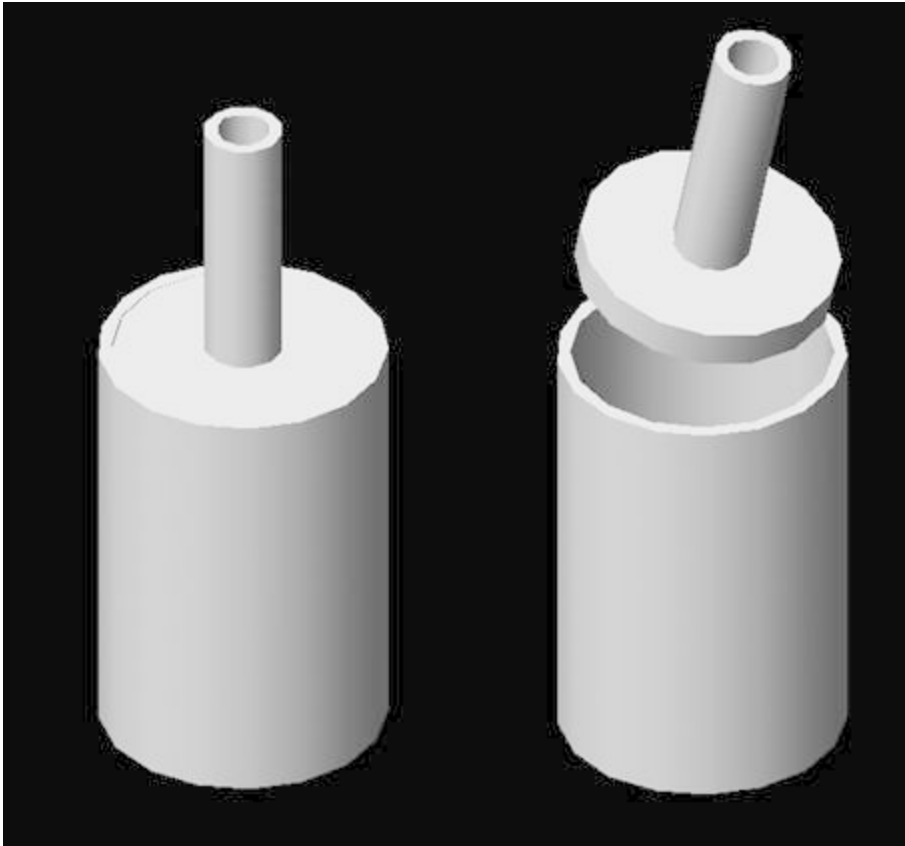
Figure 8. Drawing of Caps for Pipes leaving the Channel

The lamella constraint was solved by simply lengthening the sedimentation tank to allow for replacement of lamella that the channel would interfere with. However, it was desired to keep the tank as short as possible, so an attempt was made to interfere with as few lamella as possible.

A range of channel dimensions that would not break up flocs was determined using the "Channel_Dimensions" program created for the Marcala plant design. This program looked at the shear caused by water making the 90 degree turn into the channel. First the velocity required to achieve the given value of G, 15/sec, was determined.

$$V = G^{\frac{2}{3}} \times \left[\frac{2\nu L}{\Sigma K_{minor}} \right]^{\frac{1}{3}}$$

Where is simply the entrance loss coefficient of 0.5. The length of dissipation, L, was set to 2 times the width of the channel. This estimated value was used because the actual dissipation length was unknown. The determined velocity was used to find a depth for the input channel width given the continuity equation below.

$$Depth = \frac{Q}{V \cdot Width}$$

A range of channel dimensions that would not disturb the lamella was determined based on the geometry of the tank. The geometry of the sedimentation tank may be seen in Figure 9 and Figure 10.

An equation was developed to describe the total width of the channel that would not hit the lamella given a height of the channel. The total channel height included 20 cm of freeboard plus 12 cm for the thickness of the platform beneath the channel. The total channel width included 15 cm for the width of the brick wall.

$$Width_{total} = (Depth_{lamella} - Height_{total}) \times \tan(90 - \alpha)$$

Depthlamella is the distance from the top of the tank walls to the lamella, 120 cm. ¿ is the angle of the lamella, 60 degrees.
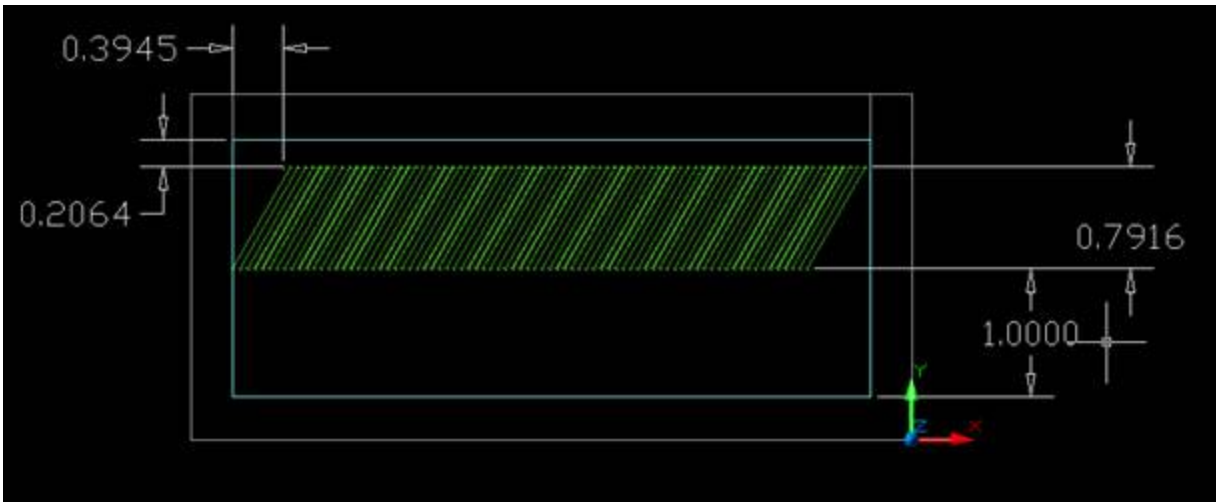
Figure 9 . Side view of a Sedimentation Tank. The blue outline represents the water level at 2 m of depth and the green lines represent lamella. Dimensions are in meters
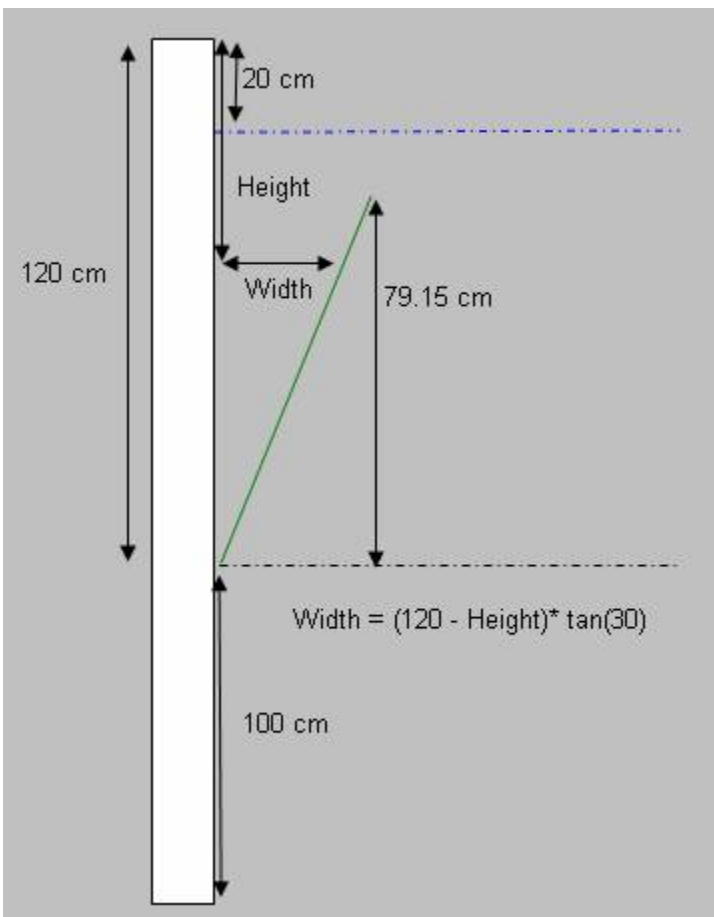

Figure 10. Side view of one Lamella in the Sedimentation Tank. Lamella shown as green line.

A graph was made by combining the dimensions determined from each method.
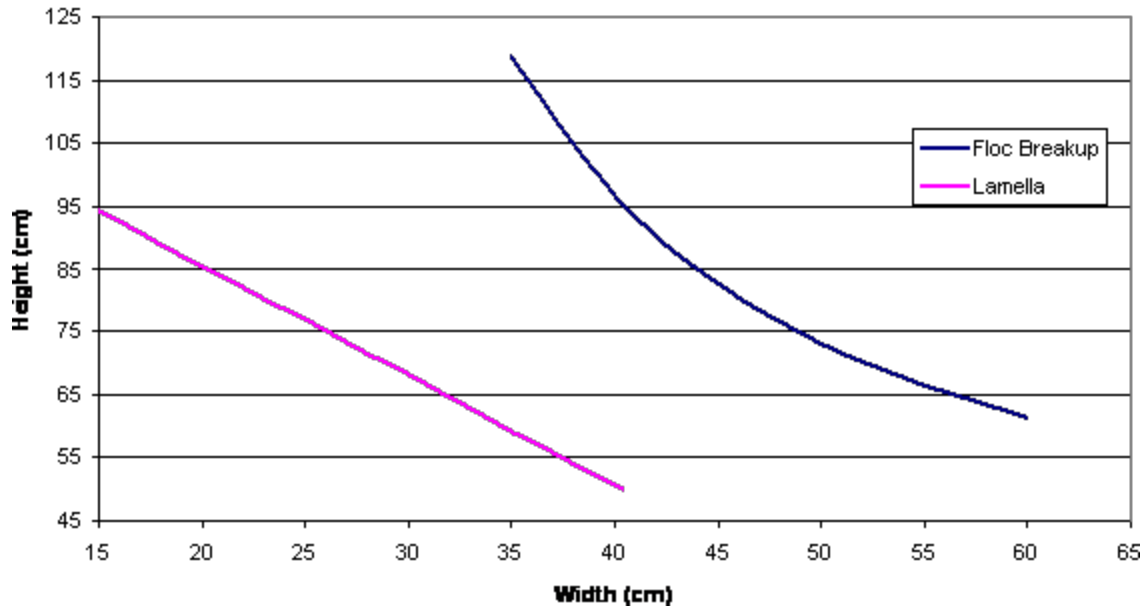
Channel Dimensions

Figure 11. Graph comparing Channel Dimension Constraints from the floc break-up and lamella constraints (Constraints #1 and #3)

Preliminary design of the plant leveling tank suggested that bucket would be able to be filled if the channel water depth was approximately 50 cm; with a platform thickness of 12 cm and a freeboard of 20 cm, this would correspond to a channel height of 75 cm. Figure 11 shows that a height of 82 centimeters is right near the ideal range of the graph where the floc breakup line and lamella line are nearest to each other.

For the designed channel, the difference between the width of the channel that would fit in the triangle above the lamella (23.35 cm) and the actual outer width of the channel (45 cm) is 23.35 cm. This value must be added to the length of the sedimentation tank so that the same amount of lamella may be included.

Design parameters for the channel are below.

- G value: 15 / sec
- Dissipation Length: 2 x width
- Channel Inner Dimensions: 30 cm wide x 50.5 cm deep (depth of water)
- Channel Outer Dimensions: 45 cm wide x 82.5 cm deep (Depth from top of wall to bottom of platform)

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Sedimentation Inlet Pipes

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The sedimentation inlet pipes were designed using the method described in the "Pipe Design" portion of this paper. In order to keep the pipes to a manageable size, it was decided that long radius turns, with a K-value of 0.45, must be used. These pipes will create less shear during turns so that a smaller G value may be maintained. Long radius pipes are available in Honduras.

The constraint for these inlet pipes was, again, to not break up flocs. In order to keep flocs intact, the G-value had to be below 15/sec in the pipes. A dissipation length equal to the diameter was used in calculations. This meant that the limiting portion of the entrance pipes will be the entrance to the pipes which have a K-value of 0.5. The equations used to find the G values are listed below.

$$\bar{G} = \sqrt{\frac{gh_i}{\nu\theta}}$$

Equation 24
Equation 25
Equation 26
Equation 27
Equation 28
Equation 29

The K value is 0.5 for the entrance and 0.45 for a pipe turn. Thus the 0.5 for the entrance is used in calculations because it will achieve the highest G value. The flow rate is equal to 1/12 the total plant flow rate.

However, this will result in a pipe diameter slightly over 6 inches (6.13in). Using the dissipation length of one diameter, a 6 inch pipe will reach a G value of 16.2. If instead the dissipation length is set to 2 times the diameter, then the pipe size will be 6 inches (5.55 in) with a maximum G value of 2.9. The pipe sizes found in Honduras have a slightly larger inner diameter than the nominal diameter which they are listed under, as may be seen in Table 3 in the Appendix. The 6 inch drainage pipe will be used because there are long-radius turns available for it. The diameter of this pipe will be large enough.

There has been some concern that the inlet pipes will be difficult to anchor. The anchoring system in Figure 12 is recommended.
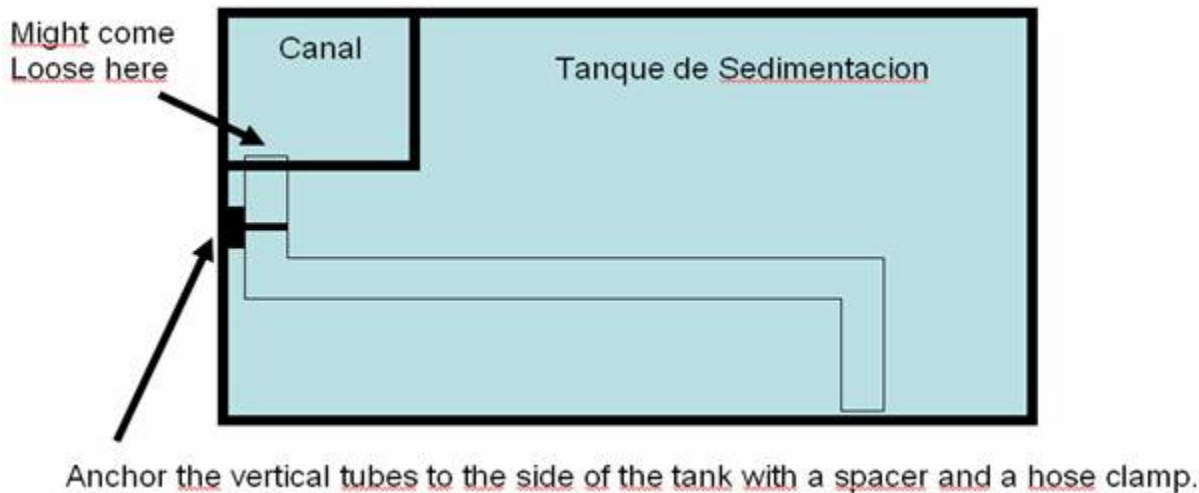

Figure 12. Anchor for Sedimentation Inlet Pipe. Picture drawn by John Erickson.

The design parameters for the inlet pipes are below:

- G value: 15 / sec
- Dissipation Length: Pipe Diameter or 2 x Pipe Diameter
- Number of Inlet Pipes per Sedimentation Tank: 4
- Diameter of Inlet Pipes: 6 in
- Horizontal Lengths: 0.95 m, 1.7 m, 2.45 m, and 3.2 m (see Figure 14)

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Sedimentation Tank

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The original design of the sedimentation tank was determined using the "Main Program" developed by the Design Team in Spring 2007. The sedimentation tank was set to a water depth of 2 m, the same depth as the tank in Ojojona. A settling velocity, Vc, of 10 m/day was used as this seemed to work in Ojojona.

The width of the sedimentation tank was set to 42 inches, the width of available lamella material. The length of the tank was determined from the upwards velocity in the tank.
Equation 30
Where Llamella is the length of the lamella, blamella is the space between the lamella, and ¿ is the angle of the lamella. This Vup value was used with the flow rate to determine the necessary active length of the tank using the continuity equation. However, part of the length of the tank is not used because the space after the bottom of the last lamella cannot be used by water moving upward. So the total length of the tank was calculated.

$$L_{total} = L_{active} + L_{lamella} \cdot \cos(\alpha)$$

The number of lamella was simply the number of lamella that would fit into the tank.
However, due to the space used by the channel and by the sedimentation tank exit pipes, the length of the sedimentation tank had to be increased as follows.

- Initial Inside Dimensions: 4.2 m long, 42" wide
- Add on 23.35 cm for channel
- Add on 16 cm for 6" sedimentation exit pipe
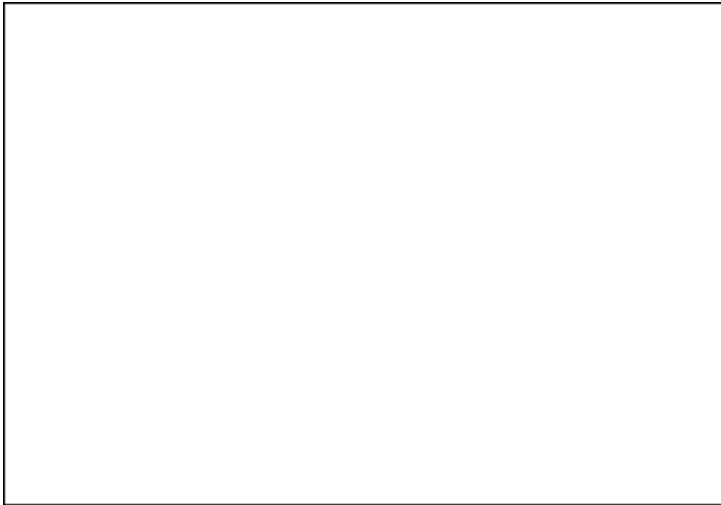- Total Length: 4.6 m

Figure 13. Sedimentation Tank length additions due to the channel and launder. Black lines represent lamella and dotted lines represent displaced lamella.

The wall height of the sedimentation tank was set to the wall height of the end of the flocculation tank.

The ends of the four inlet pipes in the sedimentation tank were spaced out evenly by determining the active length of the tank and dividing by the four pipes. Given the increase in tank length it is easiest to determine the active length as.

$$L_{active} = L_{original} - L_{lamella} \cdot \cos(\alpha)$$

The spacing between each pipe will be Lactive/4 and the spacing at the ends will be half this value.
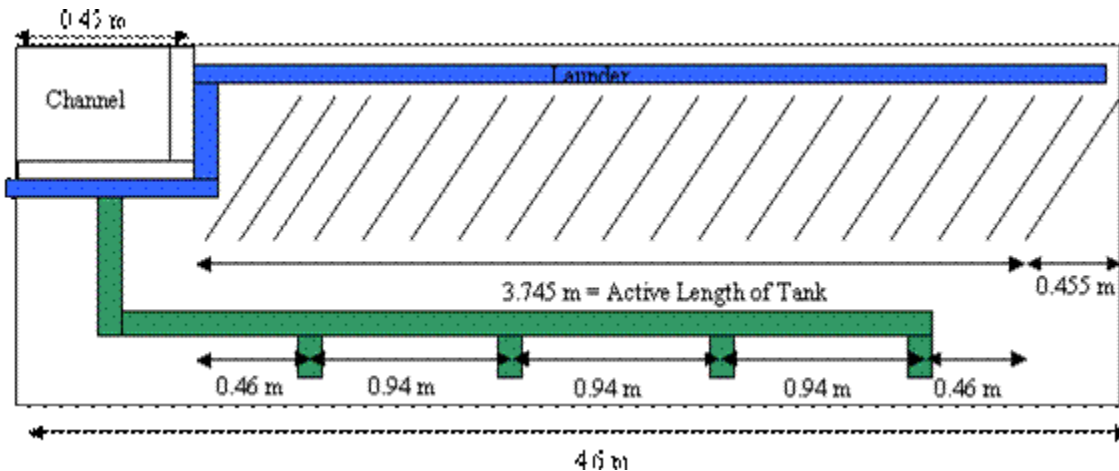

Figure 14. Side view of a Sedimentation Tank. The approximate location of entrance pipes can be seen.
Design parameters for the sedimentation tanks are below.

- Depth: 2 m
- Wall Height: 2.1 m
- Vc: 10 m/day
- ¿: 60 degrees
- Llamella: 40 in , 91 cm
- Width: 42 inches
- Total Length: 4.6 m
- Active Length: 3.745m
- Lamella Spacing : 5 cm (measured as the normal distance between the lamella)
- Lamella Horizontal spacing: ????
- Number of Lamella: 64 per tank
- Spacing between Inlet Pipes: 0.94 m

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Sedimentation Sludge Manifold

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The sedimentation tank in Ojojona has had problems with sludge building up in the bottom of the tank. For the Támara water treatment plant, a new sludge drainage system will be put in place to allow for drainage of the sludge at the bottom of the tank without draining the entire tank. The drainage system will

consist of one pipe in the bottom of the tank with orifices for the sludge and water to enter. This pipe will be in a channel in the sedimentation tank floor so that it will not interfere with the lamella support structure. The lamella will sit on a table resting on the bottom of the sedimentation tank, as they did in Ojojona. It is desirable to limit any extra pipes on the floor of the sedimentation tank.

The sludge manifold was designed using the "Manifolds" program developed by the Fall 2007 CEE 454 class. This program sets the spacing between orifices in the manifold at ten centimeters, and uses the length of the tank to determine the number of orifices. The time to empty the tank is set at 30 minutes, and the initial flow rate through the drain is found as twice the average flow rate through the drain (the constant rate required to drain the tank in 15 minutes). The diameter of the sludge manifold is found by an iterative process using the following equation.

$$D_{manifold} = \left(\frac{8Q^2_{manifold}}{gh_l\pi^2} \frac{1 + \left(f\frac{L_{manifold}}{D_{manifold}} + \sum K \right)\left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2}\right)}{1 - Q^2_{ratio}} \right)^{\frac{1}{4}}$$

The headloss through the manifold, but not through the orifices is calculated as follows.

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HLpipe is the headloss through a normal pipe as shown in the Pipe Design section of this paper, and n is the number of orifices. Finally, the size of the orifices is found using the orifice equation. The allowable headloss in the orifice equation is the height of water in the sedimentation tank, minus the head loss in the manifold, and minus the velocity head at the end of the manifold.

Equation 35

The diameter for a sludge line, which would drain only the sludge from the tank, was found using the Pipe Design method. This sludge line would be attached to the sludge manifold right before the main drain valve so that it could be opened to let a smaller flow through. The maximum headloss for this pipe was set at 200 cm with two 90 degree turns. Both the sludge line and sludge manifold pipes will empty into the waste collection tank underneath the platform. The valve to open these pipes will be under the platform as well so that the operator may open and close them while looking at the water quality leaving the tank.

Design parameters for the sedimentation sludge manifold are as follows.

- Space between Orifices: 10 cm
- Time to Empty Tank: 30 min
- n - Number of Orifices: 45
- Qratio - Ratio of flow between first and last orifice: 0.95
- Dmanifold - Diameter of Pipe: 4 in
- Orifice Diameter: 0.9 cm
- Sludge Line/ Drain Line Diameter: 1.5 in
- Qdrain - Maximum drain flow rate: 652.93 L/min
- Head loss through the manifold: 2.43 cm
- The velocity head: 9.2 cm
- Head loss through the orifices: 1.88 m

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Sedimentation Tank Launder / Exit Pipes

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The launders leaving the sedimentation tanks were designed in a similar manner as the sedimentation sludge drain manifold. The length between the orifices was assigned a value of 4 times the space between lamella, and the launder flow rate value was simply the plant flow rate divided by three. Because there was concern about the launder pipes obstructing access to the channel, the launders will turn and run below the channel, as shown in Figure 14, passing through the sedimentation tank wall below the platform. After exiting the sedimentation tank, the pipes will travel below the platform and up into the plant leveling tank. The diameter of these exit pipes between the launders and the plant leveling tank will be the same size as the launders.

Design parameters for the sedimentation tank launders are as follows.

- Head loss through the orifices: 3.1cm
- Qratio: 0.95
- Total head loss between the sedimentation tank and the level control tank: 5.4 cm
- Launder Length: 4.2 m
- Launder/ Exit Pipe Diameter: 6 in
- Orifice Spacing: 20 cm (on each size)
- Number of orifices: 36 (18 on each side)
- Orifice size: 2.2 cm
- Exit Pipe Lengths: Pipe a- 3.6 m, Pipe b- 4.4 m, Pipe c- 6.0 m
- Number of Turns in Exit Pipe: Pipe a- 5, Pipes b & c- 4

(Pipe numbering is shown in Figure 4)

The flow distribution between the three tanks was compared in the following way:
First, the loss coefficient for orifice flow was determined in the following way:

K = 1 * dpipe4 _
Kor2 d or4 nor2

Using the dimensions of the launder, this becomes

$$K = 1 * \frac{(0.1524m)4}{(0.63)2\ (0.022m)4\ (36)2} = 4.47.$$

The other minor losses are 90 degree elbows (Kelbow = 0.9) and exit losses from a pipe that is smooth with the bottom of the flow control tank (Kexit = 1). Major (frictional) losses are insignificant over these short distances.

In the case of four elbows, the sum of the minor losses is 9.07, and the case of five elbows, the sum of the minor losses is 9.97.

The following shows the relationship between loss Ktotal and flow (Q)

$$hL = k\ V2\ /2g$$

and Q ¿ (hL /Cp),

where ¿CP = f Lmanifold/Dmanifold + ¿K
So, Q ¿ (1/ (¿K)^(1/2))

Given this, the difference between the flow between the paths with four elbows and the paths with 5 elbows is 4.8%. This is an acceptable difference, but it can be improved by putting the same number of elbows (5) for all of the pipes, even if it is not necessary spatially. It is worth one extra elbow to make sure that the flow is equal between the three sedimentation tanks.

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Plant Leveling Tank

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A newly designed plant leveling tank will be used to control the water levels in the Támara plant. After dissatisfaction with the Ojojona pipe elbow system was expressed, this new design for a small tank with a weir exit was developed. Water from the three sedimentation exit pipes will enter through the bottom of the tank. These pipes will be flush with the bottom of the tank so that they may be capped with a slip fitting similar to the sedimentation inlet pipes to make it possible to isolate a sedimentation tank for draining and cleaning. Water will collect in the tank and leave through a pipe sticking up through the base of the tank. The rim of this pipe will function as a weir to control the level of the water. If the flow rate of the plant is changed, or if a change in the plant water level is desired, the height and shape of this weir may be changed to adjust the water level of the plant. The weir pipe will go down through the platform and lead to the distribution tank.
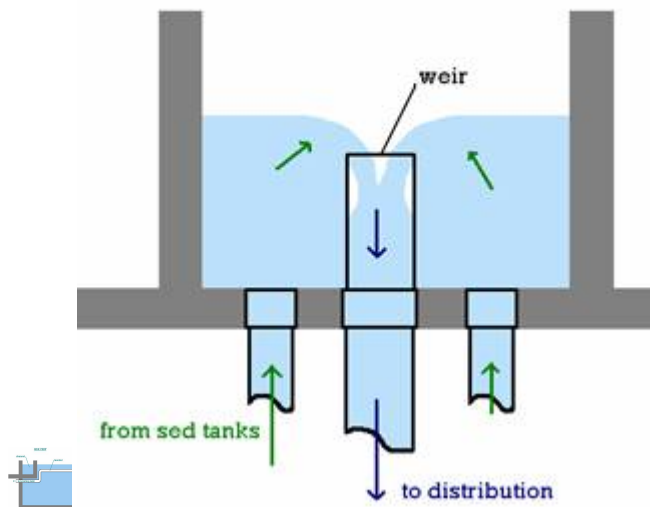

Figure 15.Left: Launder Pipe exiting a Sedimentation Tank. Right: Depiction of the Támara Plant Leveling Tank.

The pipe leading to the distribution tank will also have a branch opened by a valve that would allow the operator to direct the outgoing water to the waste collection tank under the platform instead of the distribution tank. The pipe to the distribution tank must slope slightly upward to ensure that no water will flow to the distribution tank when the valve is opened.

SIDE VIEW
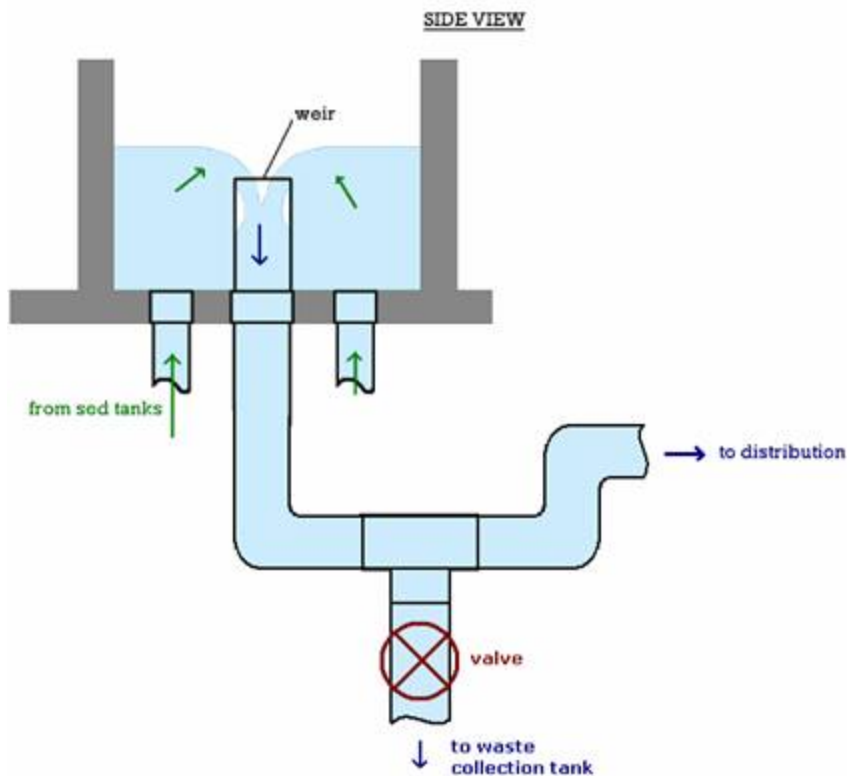
The weir pipe will also be used for chlorine addition. Chlorine will be dripped directly into the center of this pipe to mix with the water leaving the plant.

All pipe sizing was done using the pipe design program. To determine the water height above the weir, the weir equation for a sharp-crested weir was used. PVC is closer to a sharp-crested weir than a broad-crested weir.

Equation 36

Where V1 represents the upstream velocity, which is very small. This means that the equation may be reduced.

Equation 37

Setting the length factor b to the circumference ¿D and solving for the water height above the weir, H, the final equation is arrived at.

Equation 38

The weir height was chosen to keep the 2m level of the sedimentation tank and to ensure that a bucket could be filled from the tank.

Once water goes over the weir, it must freefall before flowing to the distribution tank. This is an important consideration in designing the piping to the distribution tank. A free fall distance of 15 cm is recommended. This design constraint must be considered when calculating the head loss in the pipe between the weir and the distribution tank.

The flow rate out of a tap on the plant leveling tank was determined to ensure that a 5 gallon bucket could be filled from the tank. This is an important consideration because the plant operator will need to fill buckets with clean water to mix the alum and chlorine solutions. The height of a five gallon bucket was measured to be 35.6 cm tall. The water height in the plant leveling tank is 47.7 cm (see Table xx) The water height above this bucket would be at least 8.7 cm. If a two inch pipe with one gate valve and one ninety degree turn is installed at the level of the bucket, the flow rate through the pipe, as determined by the pipe design program, will be 70 L/min. A five gallon bucket will fill in less than one minute. This calculation ignores the possibly loss of height in the tank due to the water removed. However, this change should be very small.

Figure 17. Picture of a bucket being filled from the Plant Leveling Tank. Drawing not to scale.

The constraint on the size of the plant leveling tank is simply that it must be large enough to hold all of the pipes while leaving room for the pipes to be capped. The current design would accommodate the four 6" pipes (xx cm OD) lined up next to each with yy cm between the pipes . This will leave sufficient space in the tank. The wall height of the tank was set to the wall height of the channel.

The design parameters of the plant leveling tank will be as follows.

- Tank Size (Inside Dimensions): 1m x 0.70 m x 70.5 cm (tall)
- Weir Height from top of platform: 42.8 cm
- Height of Water Above Weir: 4.9 cm
- Exit Pipe Diameter: 6 inches

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Water Levels

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The water level throughout the plant is an extremely important consideration to ensure that the plant will function correctly. A "Támara Water Levels" program was created to determine the water elevation throughout the plant. The program defines the elevation reference point, Z=0m, as the top of the weir because the weir controls the level of the plant. Thus it is simple to determine the affect of weir height adjustment on the rest of the plant levels.

From the height of the weir, the water elevation of the plant leveling tank and the elevation of the platform are determined. Using the headloss through each portion of the plant and the heights of each tank relative to the platform, the water elevations and depths throughout the plant can be calculated as a function of plant flow rate.

All headloss values are calculated within the program using methods presented throughout the paper. However, the headloss through the flocculation tank is set at 20 cm. The true headloss in the flocculation tank is not yet known because the baffle design has not been created. The value of 20 cm was chosen because it will leave enough headloss to achieve good flocculation. Headloss is negligible through the sedimentation tank and channel.

Headloss through the launders is taken as an average between all three launders because each exit pipe portion has a different headloss due to the different lengths. However, headloss from the the orifices into the launder and the headloss through the turns to the plant leveling tank are much more significant than major losses in this case.

A minimum free fall height of 10 cm was set between the grit chamber orifice level and the water surface in the rapid mix .

The program will calculate the water level for any given flow rate and up to three sedimentation tanks. The number of sedimentation tanks and the flow rate have been varied to ensure that the plant will still run properly.

The program outputs a graph showing the different water heights through the plant.

Figure 18.Graphical output of Támara Water Levels program.

Water levels and depths for the proposed plant design are in Table 1. These levels are shown in Figure 19.
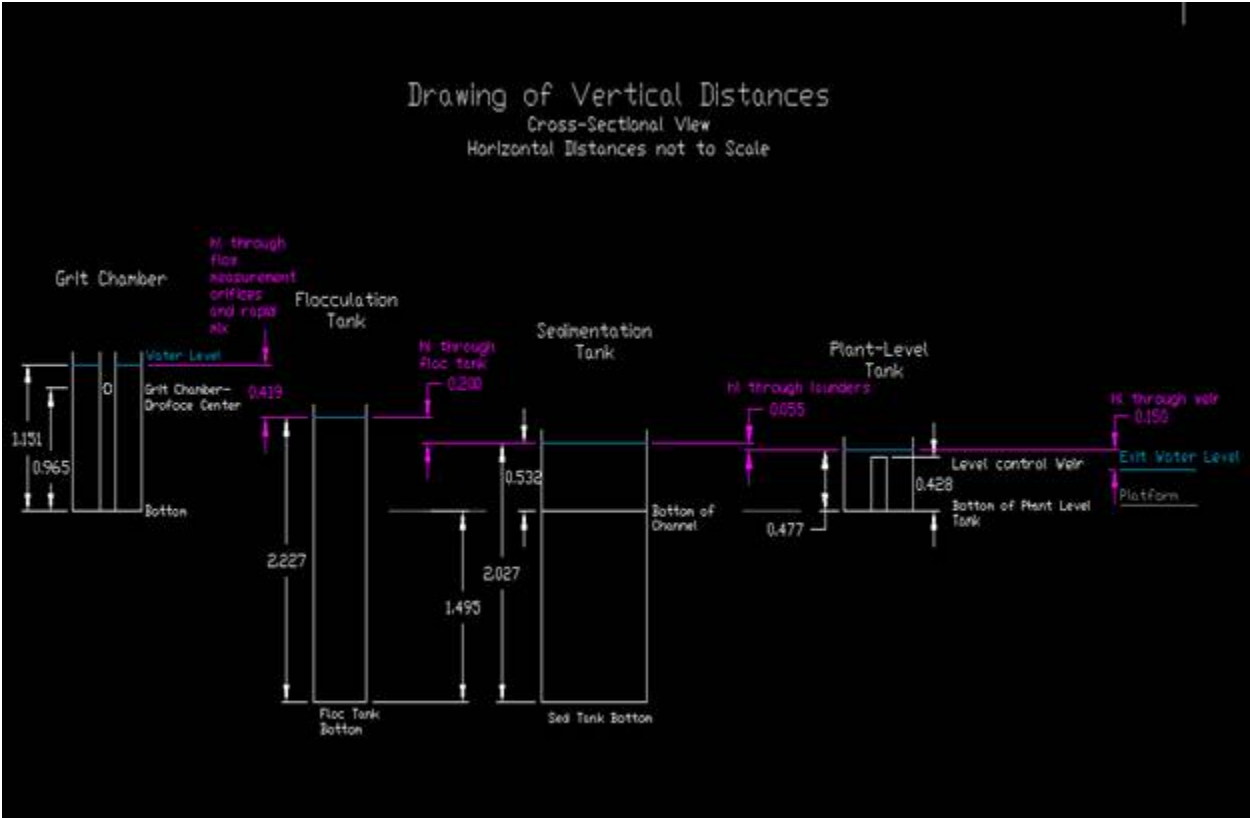
TABLE 1

Figure 19. Drawing of Vertical Distances including Water Heights

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Conclusions

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A basic design of the Támara water treatment plant has been completed. However, not all details could possibly be included in this report. A 3-D drawing will be created, which will show how all the pipes will fit in and where they will lead. Furthermore, some design considerations are left until next semester.

The first is the baffle spacing, as detailed earlier.

The second is the level and detail of the alum feeder and chlorine feeder. The alum feeder and chlorine feeder will both be located on tables in the plant. The plant operator in Ojojona has expressed the desire for the feeder and chemical barrels to be propped up above the tables so that the operator may easily stand on the tables. This table height has been specified by the APP engineer, though the AguaClara team has been unable to find its exact value. The chemical feed process is being worked on by an AguaClara team this semester. Since the design may be improved and it is not a permanent poured in concrete design, this will be left for a later date.

The piping from the plant leveling tank to the distribution tank must be designed as well. When the final pipe design is put together it should be noted that freefall from the weir is necessary. If possible, up to 2 m of freefall should be designed for to include the possibility of adding in a rapid sand filter in the future.

Throughout the report, a few design considerations have not fit in any detailed sections, so they are included here to ensure they are not forgotten.

- Tank Wall Thickness: 1 brick = 15 cm
- Waste Collection Tank Size = Size of Plant Leveling Tank, 1m x 1m x 70.5 cm
- Platform thickness = 12 cm

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