AguaClara Specifications

This document specifies the design goals, the raw water quality parameters, and the design and construction requirements for an AguaClara drinking water treatment plant to treat water that may be contaminated with particles, pathogens, and dissolved organics and produce safe, potable drinking water.

General Outline

A. Water Quality Parameter Requirements for AguaClara Treatment Plant Operation
B. Components of an AguaClara Plant
    1. Chemical Dosing System
    2. Entrance Tank
    3. Flocculators
    4. Clarifier including floc filter and plate settlers
    5. Stacked Rapid Sand Filters

AguaClara Plant Design Goals

AguaClara drinking water treatment technologies remove turbidity and pathogens from raw water and to deactivate remaining pathogens before distribution. AguaClara technologies are best suited for centralized water treatment in communities of at least 200 people. AguaClara technologies would not be appropriate for treatment of low-turbidity groundwater where the primary contamination issues are chemical, such as nitrate or heavy metals. AguaClara technologies are gravity-driven and do not require electricity. The AguaClara treatment systems installed in India use pumps to raise groundwater to the elevation necessary for filtration, chlorine application, and water distribution.

AguaClara treatment technologies include chemical dosing, rapid mix, flocculation, floc filter, plate settlers, filtration, and disinfection. An AguaClara treatment plant may be designed with all of these processes, or if raw water turbidity is low due to groundwater use, the treatment plant may be designed without flocculation, floc filter, and plate settlers.

Water Quality Parameters

The tables below summarize the raw water quality parameters for which AguaClara treatment technologies are appropriate.

Table 1: Water Quality Parameters Treated by Ag

Water Quality Parameter	Comments
Turbidity	Raw water with turbidity up to 1,000 NTU can consistently be treated to less th
Color/Dissolved Organic Matter (DOM)	For raw water with high color or total organic matter content, pilot studies are r
pH	pH can be lowered to prevent calcium carbonate scaling in distribution piping or
Microbiological contamination	The AguaClara treatment processes are designed to remove pathogens through p

AguaClara plants are only designed to treat the water quality parameters listed above. All other parameters should be within acceptable ranges in the raw water or should be treated by other means.

Before beginning construction of an AguaClara treatment plant, bench-scale jar testing should be performed to confirm that polyaluminum chloride or another proposed coagulant is able to successfully form flocs that settle.

Chemical Dosing System

1. Design goals for chemical dosing system

(a) The system will be capable of dosing chemicals for the following purposes. All materials shall be compatible with the chemicals being dosed.
(b) Disinfectant (normally sodium or calcium hypochlorite)
(c) Coagulant (typically polyaluminum chloride [PACl], but other coagulants such as alum can be used if justification is provided. Bench-scale jar testing should be performed to confirm that the proposed coagulant is able to successfully form flocs.)
(d) pH adjustment (if necessary)
(e) The chemical dosing system shall function by gravity and not depend on pumps or electrical power.
(f) The chemical dosing shall be flow-paced, meaning that the rate of chemical application is automatically adjusted proportional to the flow rate of water moving through the plant.
(g) The system shall be easily disassembled by the plant operator for cleaning with vinegar to remove calcium carbonate deposits.
(h) The chemical dose (mass chemical per volume water passing through the plant) shall be easily adjustable by the plant operator.

2. Linear Flow Orifice Meter (LFOM) or equivalent

   (a) The plant entrance chamber shall be equipped with a device that will result in a linear relationship between the plant flow and the water level in the entrance chamber. The Linear Flow Orifice Meter (LFOM), which is a pattern of orifices through which flow exits the entrance chamber, is described below. An equivalent device, such as a Sutro weir, can also be used if demonstrated to function equivalently.
   (b) The pattern of orifices shall be designed so that the water level in the entrance chamber (equal to the hydrostatic head pushing water through the offices) is linearly proportional to the total flow through the orifices (equal to the plant flow). An example of an LFOM is shown in `figure_spec_LFOM`. The orifices may be drilled in a flat plate or in the walls of a vertical pipe.
   (c) The LFOM shall be capable of measuring flow ranging from 10 percent to 100 percent of the maximum plant design flow.
   (d) To ensure that plant flow is measured with adequate resolution but avoid excessive head loss through the LFOM, the water level should change a minimum of 20 cm from no flow to the design flow rate.
   (e) Depending on the plant flow, the LFOM may consist of orifices in one or multiple riser pipes or in a flat plate.

3. Chemical storage

   1. For each chemical, the plant shall include two or more storage tanks. The tank and fitting materials shall be compatible with the chemical. Storage tanks can be plastic or concrete, as long as they are confirmed to be compatible with the chemical being stored.
   2. The combined volume of all tanks used for a chemical shall allow for storage of sufficient chemical to supply the plant at maximum flow and maximum chemical dose for at least 48 hours.

4. Chemical dose controller
5. The plant shall be equipped with a chemical dose controller configured as shown in Figure 2.

Figure 2: Chemical dose controller

2. Materials that will be in contact with chemical must be compatible with the chemical and suitable for use with potable water.
3. Key components
4. Constant head tank
5. From the chemical storage tanks, the chemical passes via gravity to a constant head tank. The chemical enters the constant head tank via a float valve, which maintains a constant level of chemical in the

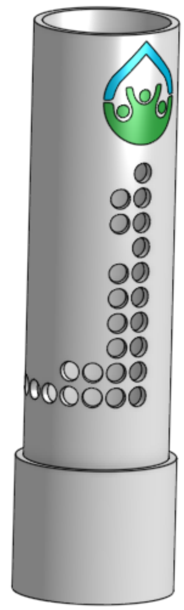

Figure 1: Example of a Linear Flow Orifice Meter

constant head tank, providing a constant head to drive the chemical through the doser.

6. The chemical level in the constant head tank shall be level with the fulcrum of the dosing lever.
7. The vertical distance from the constant head tank level to the end of the dosing hose at max flow and max dose shall be 20 cm.
8. Dosingtubes
9. Chemical flows from the constant head tank into dosing tubes, which terminate in a free discharge at the dose slider on the doser lever.
10. The dosing tubes shall be straight, to minimize minor losses and maintain a nearly linear relationship between flow and driving head.
11. There shall be three dosing tubes functioning in parallel, and the diameter of the tubes shall be designed to provide laminar flow over the desired range of chemical flows. Given the laminar flow, the flowrate through the dosing tubes will be directly proportional to elevation difference between the chemical level in the constant head tank and the dose slider.
12. The plant shall have a spare set of dosing tubes on hand so that one set of tubes can be cleaned while the other set is in use.
13. Headloss through all other tubes and fittings other than the dosing tubes shall be minimal and far less than the headloss through the dosing tubes.
14. Lever
15. One end of the doser lever is connected to a float in the plant entrance chamber. The dose slider and thus the ends of the doser hoses are located on the other end of the lever.
16. For proper proportions relative to the variation entrance tank level, the doser lever shall be 60 cm long.
17. Function
18. The doser is designed so that the operator can select a chemical dose (mass of chemical per volume of water) by moving the dose slider to a specific position along the lever. The lever, LFOM and constant head tank then work together to adjust the chemical flow proportional to the plant flow to maintain a constant chemical dose.
19. When the plant flow is zero, the lever is horizontal and chemical flow is zero.
20. When plant flow increases, the water level in the entrance tank increases (due additional headloss through the LFOM), causing one end of the doser lever to rise. This, in turn, causes the other end of the lever, and the dose slider, to fall, increasing the elevation difference between the chemical level in the constant head tank and the dose slider. The greater driving head increases the chemical flow

through the doser hose.

21. Because the entrance chamber level (due to the LFOM) is directly proportional to the plant flow rate, the dose slider elevation is directly proportional to the entrance chamber level, and the chemical flow is directly proportional to the dose slider elevation, the chemical flow is directly proportional to the plant flow.

Flocculator (Link to textbook chapter)[e]

1. Design Goals: The AguaClara flocculator is a hydraulic flocculator that can be designed as either a horizontal or vertical flocculator. The AguaClara flocculator is designed with the following goals:
2. Velocity gradient and residence time to aggregate individual particles and small flocs into flocs large enough to settle out in the sedimentation tanks. The product of velocity gradient (G) and residence time ( ) isa dimensionless numberknown as collision potential or G .
3. Minimize retention time to reach a design G of approximately 37,000. This determines the minimum total volume of the flocculator. The design volume of the flocculator may be larger due to construction constraints, such as making the length of the flocculator the same as the length of the sedimentation tanks or keeping the flocculator channels wide enough to fit a human body for ease of cleaning and maintenance.
4. Minimize "dead zones" in the flocculator and reduce the opportunity for short circuiting of the flocculator.
5. Facilitate the draining of sludge and maintenance manually by one person
6. Flow paths
7. The length of the flocculator channels is determined by the length of the sedimentation tanks plus the inlet and outlet channels for the sedimentation tanks.
8. The width of each flocculation channel is determined by material constraints and to facilitate cleaning and maintenance.The flocculator baffles are made of polycarbonate sheets, so the width of the channel should be no larger than the width of a polycarbonate sheet. The width of the channel should be no smaller than50 cm so an operator can safely enter the tank. Large plants treating more than 100 L/s may be designed with horizontal flocculation channels and may use ferrocement baffles, but they should still be easily drained and cleaned.
9. The depth of the flocculation channels is determined by construction constraints and to minimize the planview area of the flocculators and thus the plant.
10. The overall volume of theflocculator is determined by the individual constraints on each dimension of the flocculator, but the collision potential,G , of the flocculator must be at least 37,000.
11. The velocity gradient G for each flocculator baffle is calculated based on minor losses through the baffles as detailed in theFlocculator section of the AguaClara textbook linked above.[f] Otherobstacles can also be added to the flocculator to increaseheadloss under low flow conditions.
12. The ports between flocculator channels should be designed with the same velocity gradient constraints as the baffles so that the port improves flocculation without breaking flocs.
13. Port between channels to maintain energy dissipation rate
14. Flocculator Channel Construction
15. The walls of the flocculation channels should be vertical, maintaining the channel width along both the length and height of each flocculator channel.
16. The floor of each flocculation channel should be sloped toward the drain channel, and one or more drain valves should be installed to periodically remove sludge from the flocculator. The slope and valves also allow the flocculation channels to be completely emptied for more in-depth maintenance.
17. The drain valve or valves to drain the flocculation channel[g][h][i]smust be large enough to empty the flocculation channels in a reasonable time.
18. The flocculation channels should have sufficient lighting for the operator to observe floc formation. The operator should also have a flashlight to observe floc formation during power outages.
19. Baffles
20. The flocculation baffles must be constructed to be removable. A baffle module should be raisable by one operator working alone so that water can flow beneath the baffle and drain from the flocculator channel. Large flocculators may have baffle modules that require more than one person to completely

remove from the flocculator channel.

21. The flocculation baffles should be constructed from polycarbonate sheets, and the frame for holding together baffle modules should be made from PVC. Other materials may be used if justification is provided, including the use of ferrocement baffles for horizontal flocculators in large plants.
22. Baffle modules may also include other PVC obstacles to increase flocculation efficiency and reduce the volume and residence time of the flocculator.

Sedimentation Tank (Link to textbook chapter)

1. Design Goals: The AguaClara sedimentation tank is a high-rate vertical flow sedimentation tank that is designed with the following goals:
2. To produce a stable floc blanket (suspended layer of flocs) that acts like a primary filter that reduces the settled water turbidity
3. To provide evenly distributed low-velocity flow through the plate settlers
4. To prevent accumulation of sludge that would tend to become anaerobic and release both dissolved organics (taste and odor issues) and methane bubbles that would carry flocs to the top of the sedimentation tank
5. To remove the solids without requiring power or moving mechanical parts
6. To provide a mechanism for the operator to dump poorly flocculated water before it enters the sedimentation tank. This is important to reduce the recovery time when there is a flocculation failure.
7. To ensure easy operation and maintenance.
8. To be able to take any sedimentation tank offline for maintenance while the other sedimentation tanks continue to operate.
9. Influent Channel: Flocculated water enters a pipe in the bottom of the influent channel. Water flows down the pipe, through a 90-degree bend, into the influent manifold.
10. Influent manifold:Water exits the influent manifold through a series of orifices and diffusers in the bottom of the pipe. The end of the influent manifold is capped.
11. Diffusers:The orifices and diffusers point down to the bottom of the sedimentation bay and extend along the length of the pipe at regular intervals to ensure that water is evenly distributed within the bay. Diffusers are designed to introduce 1 cm of head loss to uniformly increase the head loss through all flow paths in the sedimentation tank.
12. Diffusersare shaped so that one end is a circular pipe that fits into the influent manifold orifice, and the other end is deformed to the shape of a thin rectangle. This deformation is done to create a line jet entering the jet reverser in the bottom of the sedimentation tank.
13. Jet reverser:The jet reverser consists of a longitudinally-cut half-pipe that is laid in the bottom of the bay. It functions as a way to keep flocs suspended in the sedimentation tank by ensuring that any sludge that settles will be propelled back up by the force of the diffuser jet.
14. The diffusers are offset from the jet reverser centerline. This is intentionally done to promote the resuspension of flocs, which form a floc blanket for primary filtration.
15. Currently, AguaClara plants use an upflow velocity of 1 mm/s.
16. Primary Filtration (Floc Blanket):Floc blankets improve the performance of a sedimentation tank and reduce settled water turbidity by a factor of 10.
17. The line jet from the diffusers enters the jet reverser to force flow up through the sedimentation bay. The vertical upward jet momentum is used to resuspend flocs that have settled to the bottom of the sedimentation tank. The resuspended flocs form a fluidized bed which is called a floc blanket. The bed is fluidized because flocs are kept in suspension by the upflowing water.
18. For a floc blanket to form, a sedimentation system requires that:
19. All flocs are returned to the bottom of the sedimentation tank.
20. All settled flocs are resuspended by incoming water.
21. Sloped bottom geometry:The AguaClara sedimentation tank bottom geometry prevents sludge accumulation while also ensuring good flow distribution.
22. Theslope on either side of the diffusers is at a 50 degree angle above horizontal. The bottom geometry allows for smooth flow expansion to the entire plan view area of the bay, and ensures that all flocs that settle are transported to the jet reverser. The diffusers do not touch the bottom of the tank so

that flocs on both sides of the diffuser can fall into the jet reverser for resuspension. Thus, there is no accumulation of settled flocs in the main sedimentation basin.

23. Floc Hopper: The floc hopper provides an opportunity for floc consolidation. The floc weir controls the depth of the floc blanket because as the floc blanket grows, it will eventually reach the top of the floc weir. Because flocs are more dense than water, the flocs "spill" over the edge of the floc weir which allows the floc blanket to stay a constant height while sludge accumulates and consolidates in the floc hopper. There is a manual valve at the drain of the floc hopper. Operators can open the floc hopper drain valve whenever they want to easily drain the sludge. The floc hopper allows for a self-cleaning sedimentation tank. Operators only have to clean the sedimentation tank once every three to six months because there is no stagnant accumulation of anoxic sludge.
24. Plate Settlers: After flowing through the floc blanket, flocs reach the plate settlers. Plate settlers are sloped surfaces that provide additional settling area for flocs, thereby increasing the effective settling area of the sedimentation unit without increasing the plan view area. AguaClara plate settlers are sloped at 60 degrees. The spacing between plates is 2.5 cm.
25. Material of construction - Clear polycarbonate sheets, to allow operators to observe floc formation in the sedimentation tank
26. PVC Frame - A PVC frame is constructed in the sedimentation tanks. The polycarbonate sheet modules are placed on top of the PVC frame.
27. Plate SettlerDesign Parameters:

Parameter	Determined by:	Determines	Value
Upflow velocity	Floc blanket	Plan view area of tank	1 mm/s
Capture velocity	Target turbidity	Particle size distribution	0.12 mm/s
Plate angle	Self-cleaning requirements	Plate settler length	60 deg
Plate spacing	Clogging and floc rollup constraints	Plate settler length	2.5 cm
Plate settler length	Upflow velocity Capture velocity Plate angle Plate spacing	Tank depth	Calculated for each plant

10. Submerged Effluent Manifold:The submerged effluent manifold, sometimes called a launder, collects settled water from the sedimentation tank. It is a horizontal pipe that extends along the length of the tank and is located above the plate settlers but below the surface of the water. The submerged pipe has orifices drilled into its top; water enters the pipe through the orifices and the pipe leads out of the sedimentation tank.
11. Exit Weir:The submerged effluent manifold transports water from the sedimentation tank to a channel that runs perpendicular to the sedimentation bays. The channel collects water from all of the sedimentation bays. Water leaves this channel by flowing over a small wall, called the exit weir. The height of the exit weir controls the water levels in the flocculator and sedimentation tank.
12. Effluent Channel: After the water flows over the exit weir, it is collected in the effluent channel. The effluent channel has pipes embedded in the bottom of it which lead the settled water to the filter inlet box.

Stacked Rapid Sand Filter[j] (Link to textbook chapter)

1. Description

Stacked Rapid Sand, StaRS, filters were invented in 2010 by the AguaClara Cornell program in response to the need for a new technology that would both eliminate the need for backwash pumps and not require the construction of 6 filters for small towns. As shown in the figure below, StaRS filters use six 20 cm deep layers of sand with the layers stacked vertically. The six layers give a total sand depth of 1.2 m.

2. Operation:

3. The filter operates with the same design flow rate for both backwash and filtration modes and uses settled water for backwash. This eliminates the startup problem for rapid sand filters that do not have an initial source of backwash water.
4. Filtration Mode:
5. Backwash Mode:
6. Design Goals
7. Stacked Rapid Sand (StaRS) filters were developed to eliminate the need for backwash pumps and minimize the plan area required.
8. The filters should be designed so that the process of emptying the sand from the filter, removing the modules, cleaning the modules, replacing the modules, and replacing the sand is as easy as possible.
9. The filters should be able to be backwashed at the beginning of the filtration cycle if needed.
10. During backwash, all outlets and all inlets besides the bottom most inlet must be closed so all flow enters through the bottom inlet and flows out through the backwash pipe.
11. The plant shall have a minimum of two StaRS filters so that one of the StaRS filters can be in operation while the other is offline for maintenance or repairs.
12. Configurations:
13. Open StaRS (OStaRS) - used for flow rates greater than 8 L/s
14. Minimum plan view area of 85 cm x 85 cm (minimum size that can be constructed with a human working inside the filter)
15. Enclosed StaRS (EStaRS) filters - used for lower flow rates
16. Does not require excavation because filter is operated under vacuum for backwash
17. Assembled using PVC pipe as the body of the filter
18. Inner plumbing accessed through openings in the top and bottom of the main filter body

Enclosed Stacked Rapid Sand Filters (EStaRS) (Left)

Open Stacked Rapid Sand Filters (OStaRS) (Right)

5. Sand -StaRS filters use (6) six 20 cm deep layers of sand (no dual-media required) with the layers stacked vertically. The six layers give a total sand depth of 1.2 m.
6. Grain size[k]
7. Filter Modules
8. Each layer of sand sits in between an inlet and outlet filter module. Each module consists of a large diameter trunk inlet/outlet pipe, which branches off into rows of smaller branch pipes. The branch pipes are supported along the filter walls by receptor pipes.
9. Inlet Filter Module
10. Small holes (orifices) are drilled into the inlet branches. The orifice diameter is selected based on constructability and not being too small to risk clogging (between 4 and 10 mm).
11. During filtration mode, water flows into the inlet filter modules through the inlet trunk and into the branches. Water flows out of the branches through small holes and into the sand layer.
12. During the transition from the backwash to filtration modes, water flows back into the inlet pipes. The "wings," PVC pipes cut longitudinally are affixed to the inlet branches to prevent sand from flowing into the inlet pipe. Wings are only included on the inlet filter modules.
13. Outlet filter module
14. The slots in the outlet branches should be designed so they are small enough[l]to prevent sand from passing through. The filter modules shall be adequately supported to limit deflection of any of the module pipes to 2 millimeters or less to prevent significant opening or closing of the slots.
15. During filtration mode, water flows from the filter media into the slots and then through the branches and into the trunk pipes.
16. During backwash mode, the outlet trunks are closed or isolated and water does not flow through the outlet modules.
17. Backwash Siphon
18. The siphon should be designed so that it is triggered when the filters are ready to be backwashed.
19. Backwash Flow Control Weirs
20. The backwash flow control weirs ensure there is adequate flow to backwash one filter at all times

21. Removing the flow control weir in front of the desired backwash filter will create the desired backwash flow rate for the filter, while evenly distributing the remaining flow rate to the other filters
22. Sand Dump Pipe
23. A sand dump pipe shall be installed in the filter box to allow for the filter media to be removed when the filter is in backwash mode and the media bed is expanded.
24. The sand dump pipe must be designed so that if the flow of the sand slurry is stopped, that the sand doesn't collect at one location in the pipe and cause a clog.

[a]Does anyone know where the images in the technical brochure are saved? They could be very useful for this specifications document: https://static1.squarespace.com/static/59836e25f5e231bc4fdb06a4/t/5f88c82efce9e23ae01b0f81/160

[b]They are saved here - let me know if you can access this: https://drive.google.com/drive/folders/1wB1Cl_ocSZjxW_SR1Eh

[c]moved list of specs under IP responsibility here for now: https://docs.google.com/document/d/1tlV2dqH6ysCXvLNj6YlXxY g9VDNqO3JvFQ/edit?usp=sharing

[d]should get someone who doesn't know anything about AguaClara plants to read through this and make sure it makes sense

[e]@walker.grimshaw@gmail.com @ctsang@aguaclarareach.org

I reviewed the flocculator section. All looks great to me, except I think some more work is needed to clean up the end of the Flow paths section (2d-2f). I could probably spend some time on that section tomorrow or this weekend depending on how you're feeling Walker. Just let me know.

[f]@monroews@gmail.com the textbook mentions that we don't want high local G values that will shear flocs, and we address this with Gmax/Gcs and H/S. Is there a Gmax value that we always want to be below though, in case other designers approach this differently?

[g]@walker.grimshaw@gmail.com @mwebershirk@aguaclarareach.org

Does each flocculation channel always need to have its own separate drain pipe and valve, or can the drain pipes all lead to one larger drain pipe with a big valve on it? I'm guessing you need separate valves because with a combined manifold you'd get short-circuiting. If so, might be good to emphasize that here.

[h]I actually don't think it would be a problem to have a sort of manifold with one large valve to drain the flocculation channels for maintenance. Since the plant would be offline when draining the flocculators, I think any kind of short circuiting would be fine, and the water level will remain at the same level in each channel.

[i]But even if the combined large-diameter valve is shut, won't the manifold still be connecting the floc channels to one another? Seems to me you could still get short-circuiting, which would only be limited by the headloss through the drain pipes?

[j]@mwebershirk@aguaclarareach.org - We made some assumptions based on the changes to the textbook, can you give this section a quick read through to make sure we explained everything correctly? Thanks!

Assigned to Monroe Weber-Shirk

[k]Question for APP - Specifications for sand grain size

[l]Question for APP - size of slots?