Low Flow SRSF Fabrication

Harrison Gill

December 5th, 2012

An Overview of the Technology

Filtration is the final step in water treatment before the clean water is chlorinated and sent to the distribution system. Stacked Rapid Sand Filtration makes used of a sand bed to remove the remaining particles at the end of the treatment process in an efficient manner. Unlike conventional Rapid Sand Filters, the SRSF uses multiple layers of sand and injection points to enable the filter to be backwashed using the same driving head that runs it during filtration. This eliminates the need for pumps, elevated storage tanks, and reduces the number of filters necessary to treat a given flow rate.

The possible flow rates in a given filter are dictated by the necessary backwash velocity to fluidize the sand bed and expand it by 15%. The dimensions of the filter are then dictated by the area necessary to achieve that backwash velocity at a given flow rate. Current filter dimensions are constrained by the area necessary in the filter bay for a person to move around to install and service the internal parts in the filter. This limits area of the filter to something on the order of a box 0.75 m on a side. The filter requires a backwash velocity of approximately 11 mm/s, this means that the lowest flow rate the current filter design can treat is about 6 l/s (1).

There is a strong demand for plants with flow rates on the order of 3 l/s. Because of the constraints on dimensions, it is not possible to build a viable filter for that flow rate using current fabrication techniques. It may be possible to build a low flow filter inside of a large diameter pipe in such a way that it could be assembled by reaching in from the top and bottom of the pipe. The filter would be limited to 1.5 m in length and the entire vessel would need to be kept air tight to ensure that the filter could backwash under negative pressure. Using such a design a 0.8 l/s filter can be built using 12" diameter PVC pipe.

An Overview of the Design

The body of the Low Flow Stacked Rapid Sand Filter is built in a section of 12" schedule 40 PVC pipe capped with 3/8" aluminum bulkheads. The internals

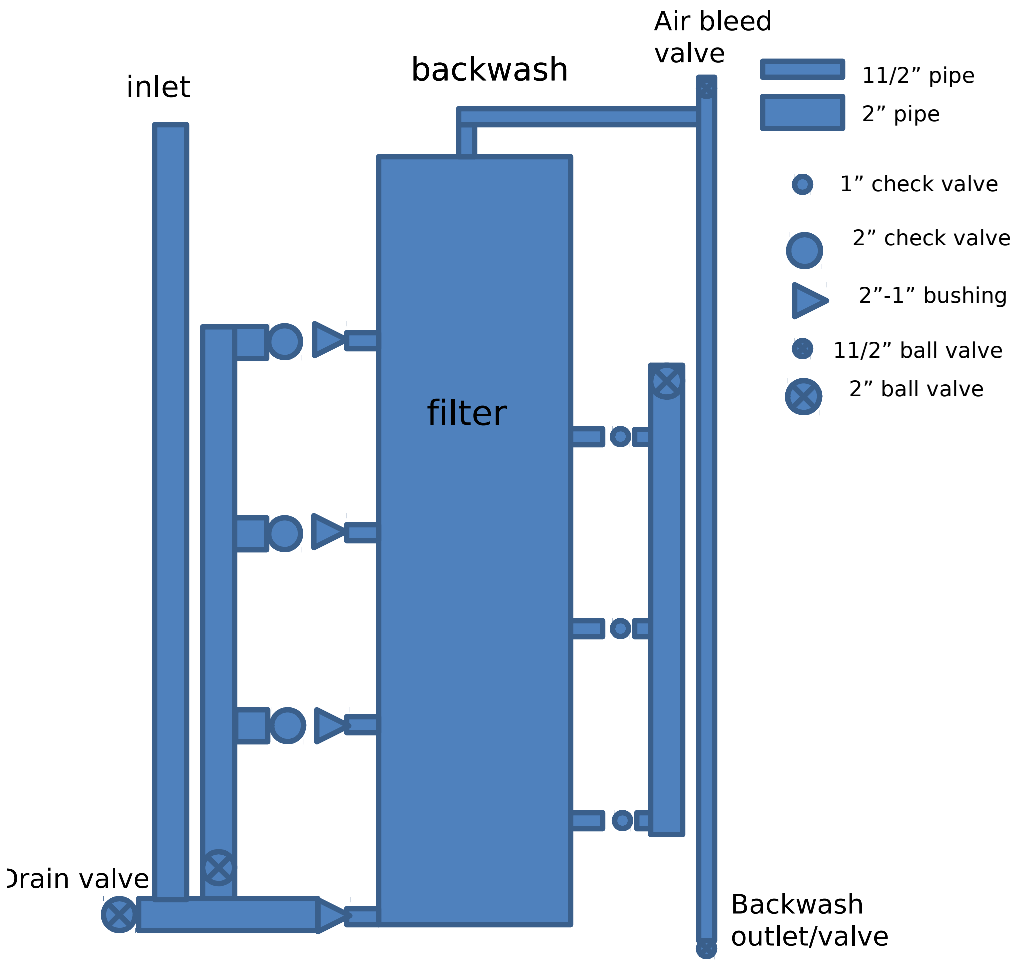

Figure 1: Picture of Filter

consist of 7 1" manifolds which each distribute water to six sections of slotted pipe. The layers are arrayed at 20 cm intervals on alternating sides of the filter. The side of the filter with the 4 manifolds is for the settled water and the side with the three outlets is for the filtered water. All the manifolds are connected to check valves except the bottom inlet to prevent short circuiting during the backwash cycle. The valves then connect to 2" pipes which act as manifolds to distribute water to the different layers. Water enters the system at the top of the inlet pipe via free fall from the sedimentation tanks to hydraulically disconnect the filter from the rest of the plant. The outlet pipe also allows water to leave via free fall to ensure that the filter does not back up and flood. Because the filter is a pressurized vessel, in theory, the only elevations that matter so long as all of the pipes remain full of water are the relative heights of the inlet free surface, the outlet free surface, and the backwash free surface relative to each other. The backwash exit height will determine the the height of water in the inlet pipe during backwash and the height of the outlet pipe will determine the height in the inlet pipe during filtration. This means that so long as the backwash pipe can be lowered sufficiently far, the filter can be placed at whatever elevation is convenient in the plant.

The inlet pipe and check valves are all 2" diameter PVC pipe. The outlet check valves are 1" PVC pipe that connects to a 2" outlet pipe. This is done to help ensure there is even flow distribution across the six sand beds. The 2" piping will help to reduce the headlosses on the inlet side of the filter and the 1" piping on the outlet side will help ensure that headlosses on the far side of the sand beds dominates. The even flow distribution is necessary to guarantee good performance by the filter.

To backwash the filter, the top three inlet manifolds will be turned off via a ball valve, this forces all the flow through the bottom manifold. The valve on the backwash outlet is then opened which forces all of the flow to exit through the top of the filter. The current design also includes a shutoff valve on the top of the exit manifold. Turning the valve off ensures that the flow will exit through the backwash pipe should the hydraulic connection be broken. The filter is sized so that the velocity in the main chamber will fluidize the sand bed and allow all of the trapped particulate mater to flow out of the filter. The backwash exit is submerged to ensure that there is a high enough pressure across the filter so that no addition head is required in the entrance pipe to drive the backwash cycle.

The Filter Design

The internal manifolds

The manifolds are made of 1" PVC pipe which is drilled to accept 1/2" PVC pipe along their lengths. The manifold pipes are 8-1/2" long and the holes are drilled at 1-3/4" 4-3/4" and 7-3/4" from the end of the pipe. The far end of the

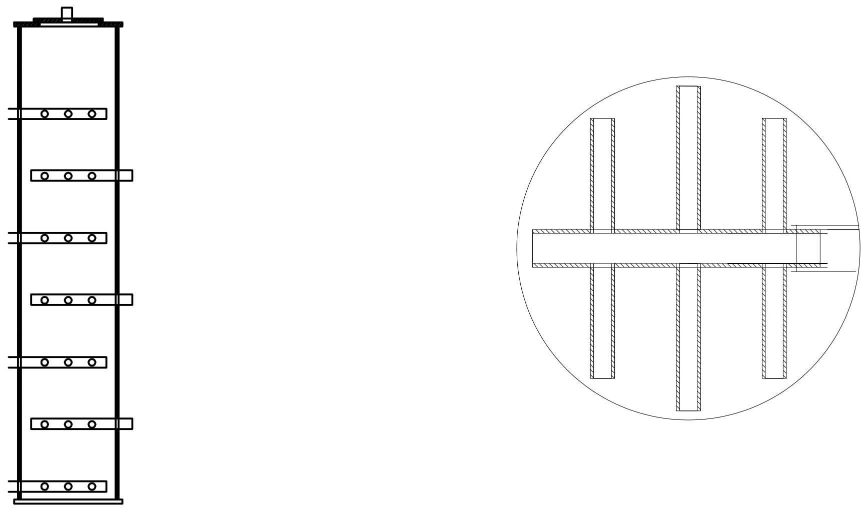

Figure 2: Manifold top view

manifold is capped and the near end connects to a coupling. The holes should be drilled with a 27/32" wood cutting drill bit and should be drilled through both sides of the pipe. It is possible to do this on a drill press but the bit has a tendency to grab and pull the pipe out of the vice. It is better to drill the holes using a milling machine with an adjustable table. In either case, it is important that holes are drilled cleanly since the slotted pipe will be glued into them. The current design utilizes a section of rubber sheet and a hose clamp to seal the end of the manifold. A shallow glue on cap or rubber cap would make the design cleaner and easier to assemble. Plastic caps are inappropriate because the need to slide too far onto the manifold and run into the last pair of slotted pipes. They also have a domed end which takes up too much length across the body of the filter and makes them difficult to install.

Each of the manifolds requires 4 sections of 1/2" slotted pipe 4" long and 2 sections of 1/2" slotted pipe 5" long. The slotted pipe should slotted at 1/8" intervals with a 2 mm slot that is 1/2" long. The slotted pipe needs to be capped so that sand cannot come in through the ends. The cap needs to be low profile on the end of the pipe so that the manifolds will fit inside the filter and not take up much pipe length so that the minimal number of slots are covered. The lab prototype uses tapered plastic caps that are epoxied on to the end of the slotted pipe and then cut down so that the cover one slot or less. The slots are then glued into the manifolds using PVC cement. They should be oriented such that the strong axis is parallel with the central axis of the filter. The should be inserted into the manifold just far enough that they will remain in place. If any PVC cement gets on the slots run a razor blade through the slot to remove it.

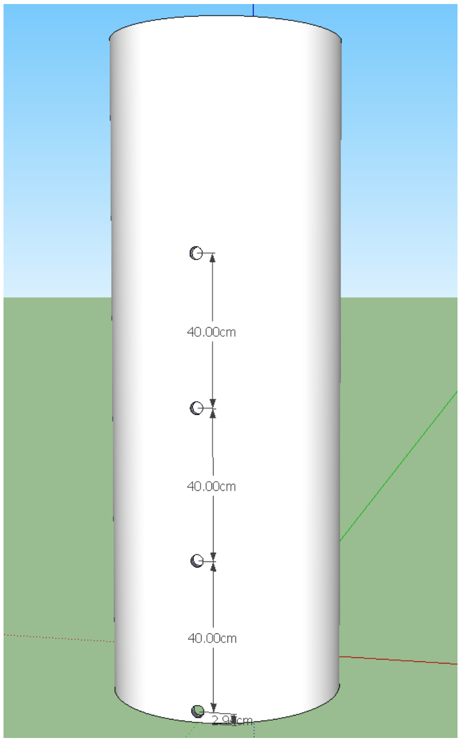

Figure 3: The filter body: Made of 6' of 12" schedule-40 PVC pipe.

The filter body

The filter body is made of 12" schedule 40 PVC pipe which was purchased from flexpvc.com. In order for the caps to seal on the ends of the pipe it is important that the ends are cut extremely cleanly. The cut should be square to the body of the pipe and be smoothed so that there is no evidence of teeth marks. The inlet and outlet holes are drilled on opposite sides of the pipe and should be perpendicular to the surface of the pipe. The first inlet is drilled at 3 cm from the end of the pipe the other three inlets are drilled at 43 cm, 83 cm, and 123cm. The three outlets are drilled at 23 cm, 63 cm, and 103 cm. All of the inlets and outlets should be drilled using a 1-5/16" forstner bit. The holes in the prototype filter were drilled using a milling machine however it is likely possible to do on a drill press. As with the manifolds, the holes need to be drilled cleanly and accurately so that the pipes will seal in them. The diameter of the body is determined by the backwash velocity and the available flow rate. This design is for a filter that can process a flow rate 0.8 L/s but it is possible to adapt the design to 8", 10", and 14" pipes.

The caps seal on to the body with rubber gaskets. The gaskets are cut from sheets of rubber and are about 1" in width. In order to minimize the pressure required to seal against the gaskets the lip of the 12" pipe should be beveled so that the lip is about 3/16" thick. If there are any sawtooth marks on the end of the pipe they should be filed down so that they blend into the lip. Once this is done the pipe stubs can be glued into the holes in the walls of the pipe for the manifold connections. The pipe stubs are 4-1/2" sections of 1" pipe with a coupling pressed onto one side. The pipe stubs should be primed abutting the end of the coupling along with the inside of the holes through the filter body. The pipe stubs should be inserted into the filter wall from the inside so that the coupling protrudes into the interior of the filter and butts against the filter wall. This should leave several inches of pipe stub protruding from the outside of the pipe. To glue the stub in place, liberally apply PVC cement to the primed region abutting the coupling and then insert the stub into the filter wall from the inside of the filter. It may be helpful to use a mallet to drive the pipe stubs through the holes.

The filter cap

The initial design for the caps for the filter called for two 13-3/4" diameter 1/2" PVC plates. They were designed to connect to each other with six 1/4-20 rod and clamp on to the filter body. The plates were clamped on to the ends of the filter body. Unfortunately the PVC tended to deform under the tension required to seal the pipe walls against the gasket. The decision was made to remake the caps out of 3/8" aluminum plate instead.

Several different options were considered for the caps. The first was to purchase socket-weld flanges which would be glued onto the ends of the filter body and then to manufacture PVC plates that bolted onto the flanges. This would have made it extremely easy to remove the caps to access the internals of the filter and would have eliminated the need for the steel rods. This plan however was rejected due to the cost of the flanges, about $750 a piece. However if cheaper flanges could be found it might be a viable option.

The new aluminum caps are 14" in diameter and are made from 3/8" aluminum plate. The same six threaded rods connect the two caps and hold them in compression on the filter body. The bottom cap requires six clearance holes for 1/4-20 rod arrayed radially at 6.684" from center. The top cap requires the same six holes as the bottom cap for the 1/4-20 rods. It also has a 10" hole so that operators can access the internals of the filter should they need to. To attach the cap for the access hatch six holes tapped for 5/16-18 thread are drilled radially around the access port at 5.6525" from center.

The studs to hold the access port cap cover in place should be fully threaded, stainless steel, 5/16-18 bolts which are 1-1/2" long. They should have a rubber o-ring at the head so that when they are bolted into the inside of the top cap, they will seal. They should also be coated with locktite so that they will not loosen when the cap it tightened on to them. The cap is also made from 3/8" aluminum plate and is 12" in diameter. The cap bolts on to the studs and should be drilled with clearance holes designed to match with the studs on the

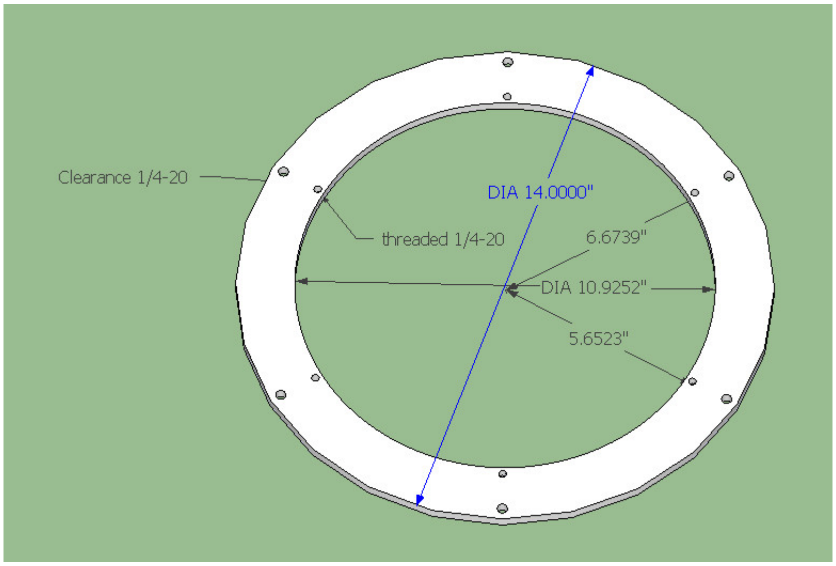

Figure 4: Top ring

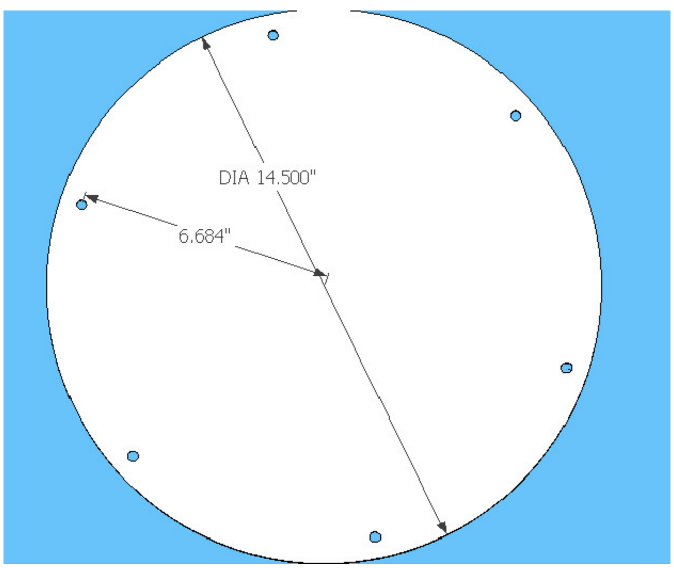

Figure 5: Bottom Cap

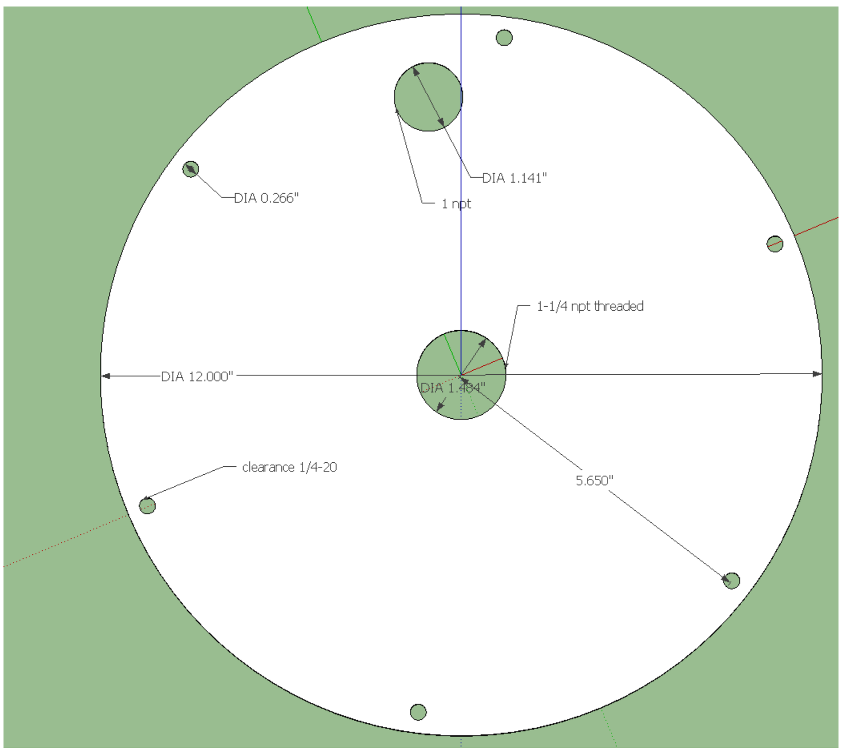

Figure 6: Access cap

top cap. The cap should have a 1-1/2 NPT threaded hole in the center to attach the backwash pipe. The cap should also have a 1" NPT threaded hole for the connection for the bed tester. (see drawing) A 1-1/2" threaded male to male socket weld adapter should be threaded into the central hole in the cap for the backwash system. A 1" threaded male to socket-weld male adapter should be threaded into the bed tester hole.

The bottom, top, and access caps all seal to their respective surfaces with rubber gaskets or O-rings. The access cap is sealed with a 10-1/2" 1/8" o-ring. The gaskets for the top and bottom caps are cut from 1/16" rubber sheet such that they cover the ends of the pipe when the caps are tightened against them. The first design of the aluminum caps called for channels to be cut in to them. These channels would hold o-rings instead of rubber gaskets which would make assembly of the filter easer and eliminate the need to bevel the ends of the pipe. Unfortunately the channels made the machining of the parts considerably more expensive and provided little additional performance benefit.

Attaching the caps and manifolds to the filter body

The manifolds are relatively easy to insert into the body of the filter. To do so, first ensure that all caps are on all of the manifolds. Next, take a manifold and reach as far into the filter as possible and insert the manifold into the coupling. Push the manifold into the coupling as tightly as possible, this will be the only thing holding it in place. Check that the manifold is square in the body. It should be perpendicular to the central axis of the body. Continue inserting manifolds in the same manner until the last one is reached. At this point turn the filter over and repeat the process with the manifold that is farthest inside the body. It should be possible to insert all of the manifolds in this manner.

Attaching the caps to the filter body is a critical step since the connections between the plates and the pipe lip are the most likely places to leak. Before attaching the caps, ensure that the lip of the pipe is flat and free of burrs and dents. If there are burrs, gently smooth them out using a fine file. If there are dents, it may be possible to fill them with epoxy. Once the epoxy dries, file it down until it is level with the lip of the pipe.

To ensure the gaskets line up with the lips of the pipe, lay them out on the end caps and then tape them to the caps by using small tabs of tape that cover the outer edge of the gasket just enough to hold it in place. Lay two short sections of 2X4 on the floor and then place the bottom cap on them. Position the 2X4s such that all of the holes for the threaded rods are accessible from below. Place the filter body on to the cap. Ensure that the body is centered and the entire pipe lip is on the gasket and not covering the holes for the threaded rods. The gasket will have a tendency to move around on the bottom cap and fall of the lip on the top cap. This can be prevented by taping the outside edge of the gasket to its cap. The top cap is placed on the top lip of the body and oriented so that the bed tester will not intersect with the manifolds. The holes for the threaded rod should be lined up by rotating the bottom cap and then the rods inserted. The bottoms of the rods should be threaded with a washer and then two nuts. The nuts should be threaded on just far enough that they are on the end of the rod, they should then be locked against each other. The rods should then be inserted into the top cap and have washers and nuts threaded on them. The caps should be tightened in a star pattern and the tension should be kept even across all rods. The rods will have a tendency to spin when tightened. This can be prevented by holding the rod below the cap with a set of vice grips.

The bed tester is attached to the top cap via a flexible pipe coupling. The tester itself is made of a 5' section of 1/2" PVC pipe which is glued into a 1" to 1/2" reducer with the lip removed on a lathe. The coupling is attached to the cap by inserting the 1/2" pipe into the bed tester port and securing the bushing with the flexible coupling. Some space should be left between the bushing and the end of the pipe stub so that the pipe can be wiggled. a 1/2" ball valve is connected to the opposite side of the bushing so that the bed tester can be used to remove the sand from the filter if necessary.

The Inlet Manifold

The inlet manifold distributes water from the hydraulic disconnect at the top of the filter and into the slotted pipe manifolds in the body of the filter. The manifold must have minimal headloss to allow the sand bed to and downstream plumbing to determine the flow distribution. It must prevent short circuiting during backwash. It must be easy to replace valves should the break or need servicing.

1Shows the general piping schematic into the filter. The inlet pipe consists of a 2" pipe which is slightly taller than the highest point on the backwash system and drops to the bottom of the filter. There it intersects a 2" Tee fitting. The Tee connects on one side to a ball valve which is used to drain the filter, the other side connects to a second tee. The second Tee connects to a short section of 2" pipe which connects via a flexible 2" coupling to the reducing bushing on the filter body. The perpendicular leg of the second tee connects to a 2" ball valve and then the rest of the inlet manifold. The rest of the inlet manifold consists of sections of 2" pipe which connect to tees to distribute water to the remaining three inlet manifolds. The perpendicular leg of each tee connects to a 2" swing check valve. These valves prevent short circuiting during the backwash cycle which will be discussed below. The check valves connect to a 2" elbow, then a short section of 2" pipe which enables the manifold to connect to the reducer bushings on the filter body via flexible couplings.

Issues in the manifold design and construction.

In order for backwash to be successful the full filter flow rate must flow through the entire sand bed. This requires that all of the flow be diverted through the bottom manifold and a single path through the filter bed. To ensure that all of the flow goes through the bottom manifold it must be on a separate leg the

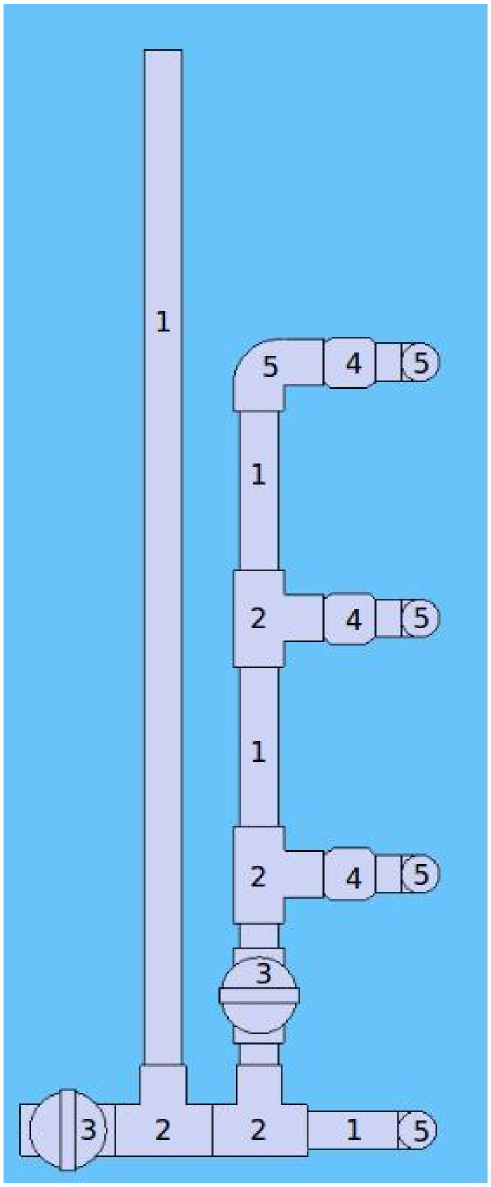

Figure 7: The Inlet Manifold: (1) 2" PVC pipe (2) 2" tee (3) 2" ball valve (4) 2" swing check valve (5) 2" elbow

manifold, hence the second tee. It must also be possible to shut off flow to the other inlets, hence the ball valve on the upper leg of the manifold.

The lengths of the various sections of pipe in the manifold will depend on the specific fittings used and thus are not specified here. The important parts of the manifold design are the flow path (down from the top and then up to the manifolds), the relative placement of components, and the fixed positions of the connections to the slotted pipe manifolds. The design used in the AguaClara lab apparatus and in the test filter in Honduras uses elbows to position the manifolds closer to the filter body to save on horizontal space but there is no reason the elbows could not be eliminated and the manifolds be built in a plane instead.

The manifold in the laboratory has the split between the bottom slotted manifold and the upper three at the top of the manifold columninstead of at the bottom. This sets a minimum water height in the filter such that the water get distributed to all four slotted manifolds. The manifold was redesigned for the prototype filter in Honduras with the plans contained in this design report.

The Outlet Manifold

The outlet manifolds are designed to cause more headloss that than the inlet manifolds to help even out the flow distribution across the six sand beds. The pipe stubs from the slotted pipe manifolds connect to elbows and then 1" swing check valves. As with the inlet manifolds, the swing check valves prevent short circuiting during the backwash cycle. The swing check valves then connect to 1" to 2" bushing which plugs into 2" tees. The tees are connected to 2" pipe to join them together and create the manifold. As with the inlet manifolds, the elbows are there to save lateral space around the filter but could be removed to create a 'winged' design.

Above the last outlet on the manifold is a 2" ball valve. This is there to shutoff the outlet to ensure that the filter goes into backwash. As long as the backwash pipe remains full, this valve should be unnecessary. There is a tee above the ball valve which acts as a weir and sets the water level throughout the rest of the filter. This should allow filter water to travel to the storage and distribution network via a hydraulic jump which will prevent downstream water levels from setting the height of water in the filter.

The Backwash System

The backwash system is designed to remove the dirt and clay particles from the filter bed once it has been filled. The system works by fluidizing the sand bed and allowing the particles to be resuspended and flow out of the system. To do this, the full flow entering the filter must be set through the bottom inlet manifold and out the top of the filter bed.

During backwash there is a significant amount of headloss. This is largely

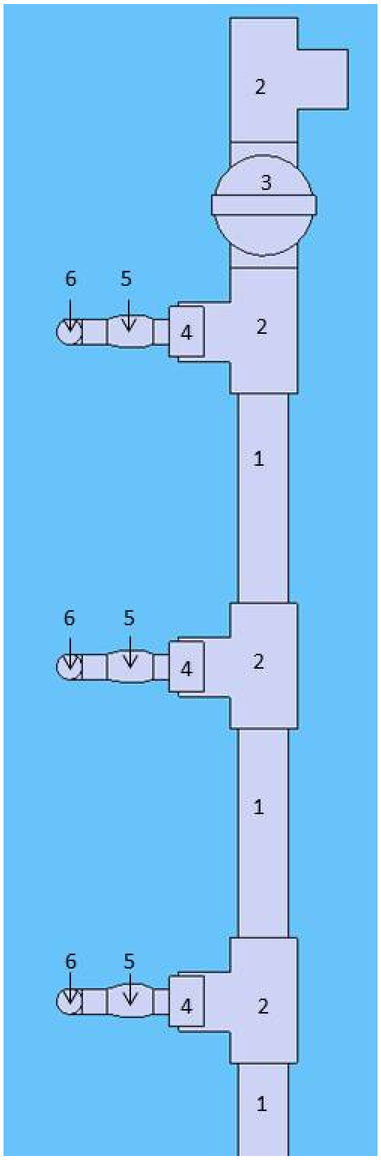

Figure 8: Outlet plumbing:(1) 2" PVC pipe (2) 2" tee (3) 2" ball valve (4) 2" to 1" reducing bushing (5) 1" swing check valve (6) 1" elbow

Figure 9: The backwash system:

due to the sand in the filter bed which causes nearly one meter of headloss for every meter of sand that must be fluidized. In order to limit the height difference between the free surface in the inlet manifold during terminal headloss while filtering, and the sedimentation tanks, the exit of the backwash pipe needs siphon water from the filter. Based on reports from the Fall 2012 filter team[2], the lab filter experienced approximately 200 cm of headloss during backwash. This means that the free surface at the end of the backwash pipe needs to be more than 200 cm below the point where the influent enters the filter system.

Because the backwash exit is lower than the filter, the filter system is under negative pressure relative to the atmosphere. This means that if the inlet manifold did not drop to the lowest point of the filter and then go back up (creating an u-bend) to the slotted manifolds, the manifolds would suck air into the filter and break the hydraulic connection. The negative pressure also sets the maximum distance below the bottom manifold the backwash outlet can be set, namely 200 cm before the bottom manifold also sucks air into the system.

The backwash pipe connects to the top of the filter through the 1-1/2" threaded hole in the access cap. The 1-1/2" pipe should connect to the male to male adapter via a flexible coupling or other removable connection so that the backwash pipe can be removed if the access cap needs to be removed. The valve used to turn on and off the filter should be at the lowest point on the backwash pipe. This is to facilitate the removal of air from the pipe should the hydraulic connection be broken. There should also be an air bleed valve at the highest point on the pipe to allow the air to escape the filter system when the backwash pipe is being filled. See the Fall 2012 filter team report for more details[2].

It is important that the outlet of the backwash pipe be visible to the operator. This is for two reasons. The first is to observe the quality of the effluent during backwash to determine when backwash should cease. The second is to check to see if sand is escaping the filter during backwash. If sand is escaping it could cause failure of the filter.

The final component of the backwash system is the bed tester. The bed tester is designed to confirm that the sand bed is fully fluidizing during backwash. The system consists of a 170 cm length of 1/2" PVC pipe buried in the sand bed. The pipe passes up through the 1" threaded NPT adapter and terminates in a 1/2" to 1" reducer bushing which is machined such that it has the same OD a 1" PVC pipe along its entire length. The pipe should not be glued into this fitting in order to ensure that the cap can be removed without removing the pipe from the sand bed. The threaded male adapter in the cap and the bushing should be connected together with a flexible coupling so that the pipe can be wiggled. The pipe should then be capped to seal the system. If it is possible to easily wiggle the pipe during backwash, the bed is fluidized.

Operation

Filtration

During filtration the valve on the inlet manifold should be open to allow water to flow to all of the slotted inlet manifolds. The backwash valve should be closed as should the air bleed valve on the top of the backwash pipe. The shutoff valve on the outlet manifold should be open to allow water to flow to the distribution system and prevent the filter from backing up. During operation unfiltered water will travel through the inlet manifold and into the slotted manifolds. It will then split and flow through the six sand beds and enter the three outlet slotted manifolds. It will flow out and up the outlet manifold and leave via the hydraulic disconnect at the top of the pipe.

Backwash

Backwash occurs once the filter reaches terminal headloss, roughly 30 cm on the lab apparatus although this number will change depending what point the filter experiences breakthrough. The first step to backwashing is to ensure that the backwash pipe is full water. If the the water level in the inlet manifold is above the highest point in the backwash system the air bleed valve can be opened. If the water level in the inlet manifold is lower than the highest point in the backwash system, the valve on the outlet manifold should be slowly closed until the water level in the inlet manifold is high enough. In either case, the air bleed valve should be open until air ceases to come out and then closed. Next the backwash valve should be opened fully and then the valve on the inlet manifold closed to ensure that all of the flow is diverted through the bottom manifold. This sequence is important because forcing all of the flow through the bottom manifold causes much greater headlosses than spreading it over four manifolds and if all of the flow is diverted through the bottom manifold without the backwash valve opened, the filter will likely overflow. Once backwash is complete, approximately 5 minutes based on experimentation from the Spring 2012 filter team[3], the valve on the inlet manifold should be open and then the backwash valve closed. At this point the filter will resume filtration. It is important that the first minute or so of filter water also be wasted since there will be residual backwash water in the slotted pipes which could contaminate the clean water in the storage tank.

References

[1] Stacked Filters: A Novel Approach to Rapid Sand Filtration, Journal of Environmental Engineering doi:http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000562 Michael J. Adelman, Monroe L. Weber-Shirk, Ph.D., M. ASCE, Anderson N. Cordero, Sara L. Coffey, William J. Maher, Dylan

Guelig, Jeffrey C. Will, Sarah C. Stodter, Matthew W. Hurst, and Leonard W. Lion, Ph.D.

[2] filter team final report.

[3] filter team spring 2012