

Design Manual: Ecological Clothes-Washing Station Incorporating Rainwater Harvesting and Greywater Biofiltration Constructed Wetlands

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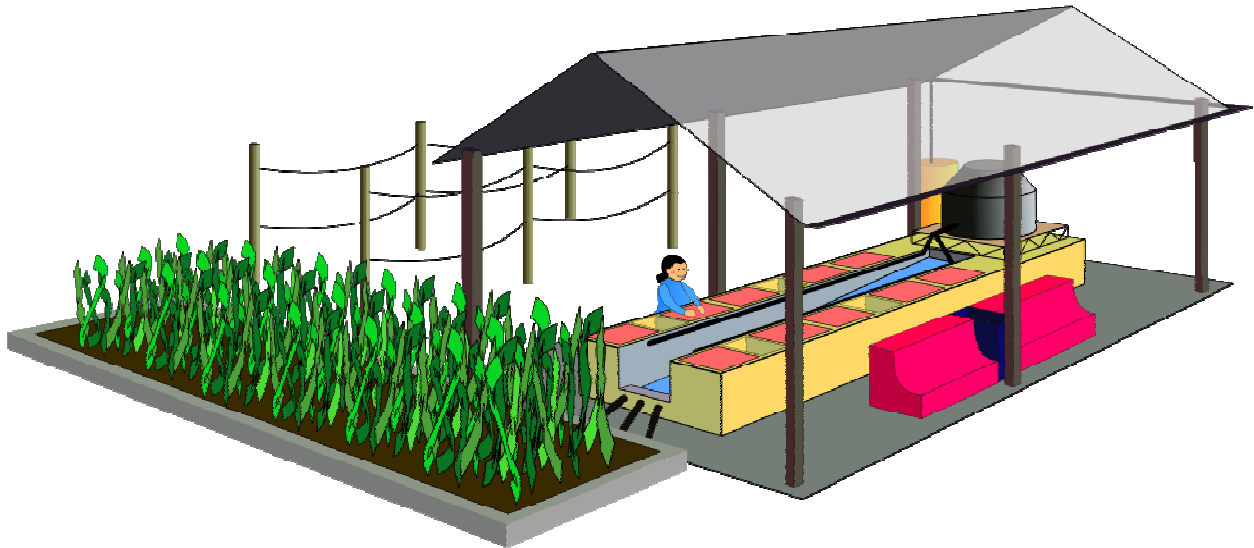


Figure 1. Three-dimensional view of the Ecological Clothes-Washing Station

Two of the most practical BMPs that this project identified for application in the San Cristóbal area were rainwater harvesting and water filtration using constructed wetlands. In the following original design, both management practices are incorporated into a community clothes washing station. The rainwater harvesting system provides a wash-water source while a greywater treatment system filters out detergents and other pollutants released during washing. This pilot system is in process of construction at the time of publishing this document (April 2007). Plans are in place to monitor the effectiveness of this system in terms of usability and ecological effectiveness to determine the scale of applicability.

This manual first explains the background information for the 2006-2007 implementation project in the target community and describes the purpose and functions of the system components. The second part lays out step-by-step instructions for system construction of the rainwater harvesting system, the clothes-washing station, and the greywater wetland, and concludes with recommended maintenance procedures. This document is meant to serve as a guideline for construction of the system, and includes important design considerations. The design should be adapted to local constraints where applicable in terms of exact measurements. It is important, however, to incorporate all main components of this system to achieve expected ecological effectiveness.

Background Information about the Target Community

The Colonia Cinco de Marzo is located on the outskirts of San Cristóbal de las Casas, in the southernmost Mexican state of Chiapas. San Cristóbal is a fast growing city with a population

that has increased rapidly in the past decade. The people of Cinco de Marzo lack improved water and sanitation services. This community of 450 families depends almost exclusively on 14 intermittently functioning community spigots to meet its water needs. Furthermore the community totally lacks any kind of formal waste water treatment. In addition to the pollution from human waste, chemical and organic pollution from laundry detergents also contaminates the surface water. Currently, many of the families are walking to the local stream to wash their clothes in the highly polluted stream. Several women have complained of skin rashes and irritations that are likely associated with this pollution. Other families take water from the spigots in the town and carry full buckets back to their homes to wash, which can be over 100 meters away.

Purpose

A clothes washing station with its own supply of water, coupled with a greywater treatment system, could have the following benefits to this community:

- It would centralize washing activity and provide a surface to scrub clothes
- It reduces the time devoted to clothes washing
- It provides clean water to wash clothes, decreasing the risk of skin irritations
- It removes significant amounts of pollutants from the greywater, reducing overall pollution to the environment
- It helps community members to develop a better understanding of how waste water streams should be separated and treated before being discharged back into the environment
- It helps community members to understand the value of using clean water in activities that could affect their health.

Below are the diagrams of the proposed clothes washing station with a complete description of its functions. The diagram (Figure 2) on the next page is an overhead view of the wash station, while to diagram on the subsequent page (Figure 3) provides a side view of the station.

Description of Functions

This clothes washing station design can be broken down into three sub systems:

1. Rain water harvesting system, with a supplementary well and an underground water storage cistern. The rainwater harvesting system is designed to capture and store over 40,000 L of water throughout the course of the wet season,. As water demand is likely to be higher than this, a well must also be constructed to provide a supplementary water supply during the dry season.
2. The physical wash station, with its plumbing and water conveyance infrastructure, washboards, and shared sinks. The design also includes benches, clothes folding counters, and clotheslines unattached to the central washing area
3. The biological greywater wetland. This final sub system is for the treatment of the soaps, oils, and detergents that result from clothes washing

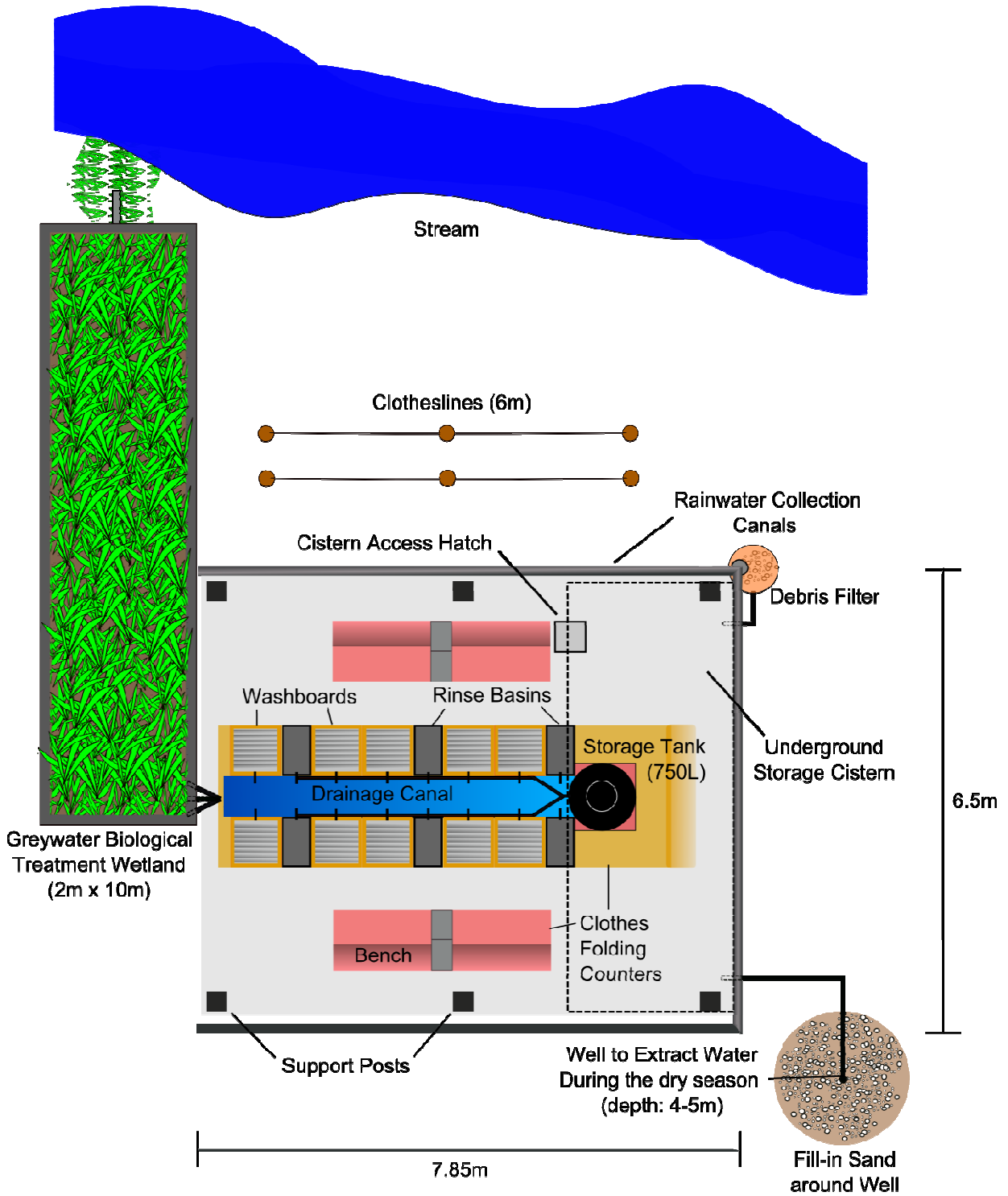


Figure 2. Top view of Clothes-Washing Station

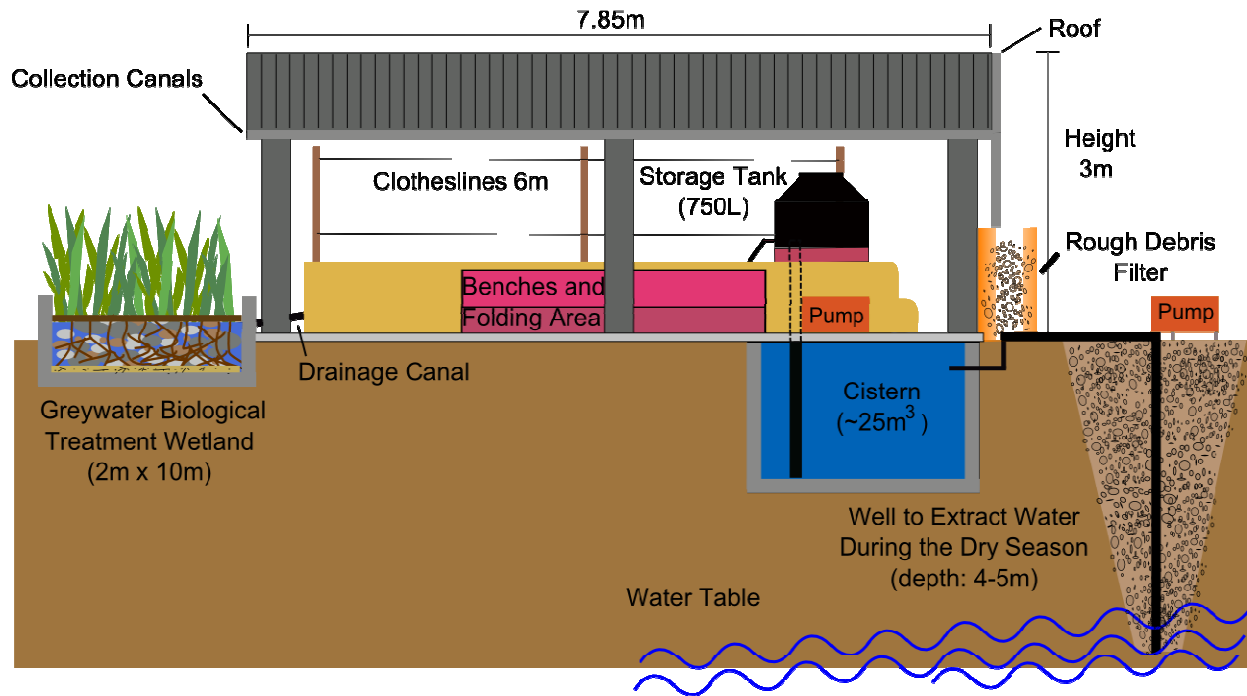


Figure 3. Side View of Clothes Washing Station

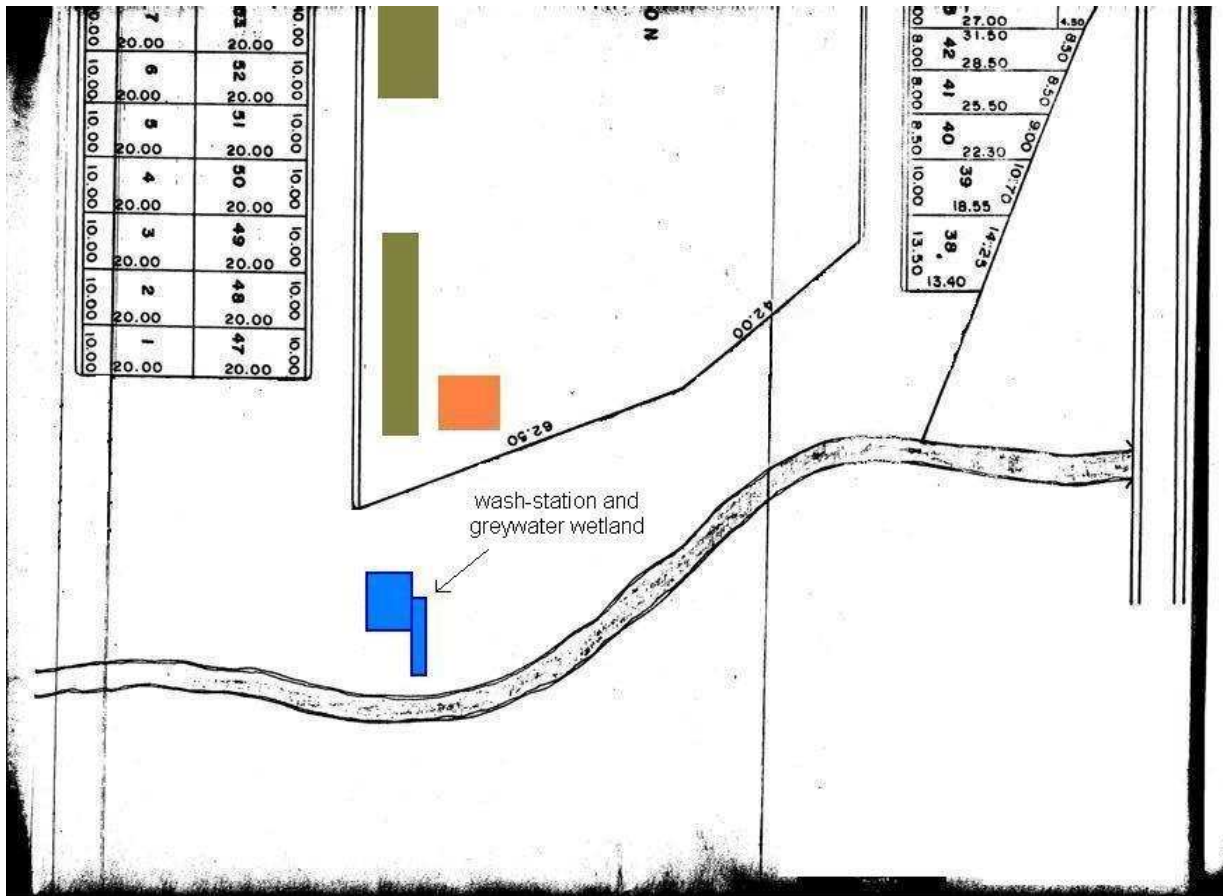


Figure 4. Location of Project within the Community

Rainwater Harvesting System

With a steady supply of rain (during the wet season):

Water that falls onto the corrugated metal roof of the clothes-washing station is collected in canals attached to eaves on both sides of the roof. Water is transported along the canals via gravity and down a pipe into a covered barrel. The inside of the barrel contains coarse gravel and rock as a means to keep animals and large debris such as leaves, sticks, and trash out of the cistern. Water will then flow by gravity into the underground cistern where it will be stored for later use.

Without a steady supply of rain (during the dry season):

During the dry season, people will still need to wash their clothes, but the system will not be capturing rainwater. Instead, water can be pumped out of a small well located near the wash station, into the covered drum, and then flow into the underground storage tank. This water is again can be stored until needed for washing

Wash Station

The wash station is centered on the storage tank and the two banks of rinse basins and wash boards. When water is needed for washing, an electrical or hand operated pump will be used to fill the raised water tank. When a spigot in front of each of the 6 individual rinse basins is opened (3 on each side), water will flow by gravity through galvanized metal pipes and down to that rinse basin. Community members can then transfer water from the rinse basin to the washboard and scrub their clothes clean. The soapy water from the washboards will exit into the angled central ramp that channels the water to the biofiltration wetland. Though the rinse water will have a lower concentration of detergent than the wash water, the remaining pollutants will still require filtration and will exit into the garden via individual washbasin drains.

Additional structures:

Additional structures include benches with an attached counter. These can be placed on one or two sides of the clothes-washing station and provide a space to rest and fold clothes. Trash cans should be placed between the benches to ensure a clean wash space and a clean play space for children. Ideally there would be trash cans for both organic waste and inorganic waste. The organic waste could then be composted. There is also counter and bench area at the end of the wash station right above the cistern (see Figure 3). One other convenient feature of this design are the clotheslines that can be placed in any open space around the clothes-washing station, preferably one with full sun.

Greywater Biofiltration Constructed Wetland

Soapy water will exit the wash station down the sloped central channel which will direct the water to the bio-filtration garden. The garden will be composed of native aquatic plants that provide habitat for beneficial bacteria and microbes. These microbes will decompose the pollutants in the effluent water. The plants will also absorb some of the metals and other elements that are dissolved in the water. Finally, the water will exit the system via a pipe or vegetated path that leads into the nearby stream.

Construction Steps and Design Considerations

The construction process for the clothes washing station can be broken down into six main stages.

1. Site preparation and ground excavation for the subsurface cistern
2. Cistern construction
3. Construction of the wash-station main bank and related structures (clothesline, benches, and tables)
4. Roof and rainwater harvesting infrastructure construction
5. Greywater biofiltration wetland construction
6. Establishment of plants used to filter the greywater in the garden

Construction Step 1 – Site Preparation

Before any construction project can commence the building site must be prepared and stabilized. There are a number of specific steps that must be taken in order to provide a solid foundation upon which to start construction.

1. Grade and Compact the Appropriate Building Site.
 - Ideally the site should be naturally well-drained and have no nearby trees
 - The earth on the building site must be leveled and compacted. This can be done using shovels and heavy blocks, or with machinery
 - The drainage path for the treated water should be determined and the ground slightly graded to slope downward in order to ensure that it flows out properly
2. Site Layout
 - The location of all structures should be laid out and marked to ensure that the site is ready for construction.
 - Use markers (such as long sticks or concrete blocks) that can remain in place relatively undisturbed during the construction process
3. Excavation for the Cistern
 - Material will need to be excavated to make room for the underground cistern.
 - Rocks and stones, even those buried but near the surface of the pit, must be removed so there are no obstructions in the first layer of soil
 - The cistern chamber will need to be firmly compacted and thoroughly inspected
 - It is very important to stabilize the ground around the cistern, as uneven or soft ground can lead to cracks or even cistern failure

It is extremely important that a lot of thought is put into site selection, as this will determine the success of the construction process. The ground must be free of things that will compromise the stability of the wash station, cistern, or biofiltration wetland (ant hills, old latrines, trash pits, tree stumps, etc). Rocks need to be removed because soils can settle and shift a bit when the great weight of a full cistern is put on them. The presence of rocks can also put pressure on specific points of the cistern leading to possible failure (Ludwig 2005). Trees should be at least 10 meters away as their roots will seek out moisture and possibly crack the cistern walls (Gould and Nissen-Peterson 1999). If trees are too close, leaves and dead animals can be blown or fall onto the catchment roof and subsequently clog up the gutters or the conveyance pipes. The ground must be solid, as future settling from un-compacted ground can lead to cracks and possible failure in the wash station, cistern, or the walls of greywater wetland. While not an issue with this design, cisterns that will hold water greater than 3 meters in height require professional engineering as they produce extreme pressure on the floor joints (Ludwig 2005).

Construction Step 2 – Cistern Construction

Once the site has been prepped and the cistern area excavated the first thing that should be constructed is the underground cistern. Figure 5 on the next page shows an exploded view of the cistern floor.

1. Preparing the Excavated Hole
 - The bottom and sides of the excavated pit should be allowed to dry before concrete is poured
 - The cistern pit should be fenced off to keep animals or children from falling into it
2. Pouring the concrete floor
 - The first layer concrete should be 7 - 10 cm thick.
 - It should be smoothed out and leveled to remove air bubbles by using long pieces of wood (i.e. a long 2x4) (2"x4" piece of wood is 5x10 in cm)
 - Once the first layer is poured, a wire mesh sheet should be rolled out over the concrete to reinforce the floor
 - Rebar rods should be inserted in, but not through this first layer of concrete, attached to the wire mesh, and held vertical against the earthen walls of the pit.
 - There should at least 3-4 cm of concrete between the bottoms of the rebar and the soil surface
 - These rebar rods should be in sets of four, and should be wired to themselves at equally spaced intervals
 - They should extend a few centimeters above what would be the top of the cistern walls
 - There should be two sets of rods on either side of the floor, spaced equally apart (about 2m), and a set of bars in each corner of the cistern floor
 - Next a second layer of concrete, again 7 - 10 cm thick, should be immediately poured over the top of the first layer and the wire mesh
 - Again this needs to be smoothed and leveled to remove air bubbles
 - Once the second layer has been poured all of the wire mesh should be covered in concrete
 - All of these steps should be carried out in quick succession so the concrete floor sets solidly as one unit.
 - The floor should be kept moist, not wet, using sponges or towels
 - The concrete in a cistern can take up to three weeks to completely cure

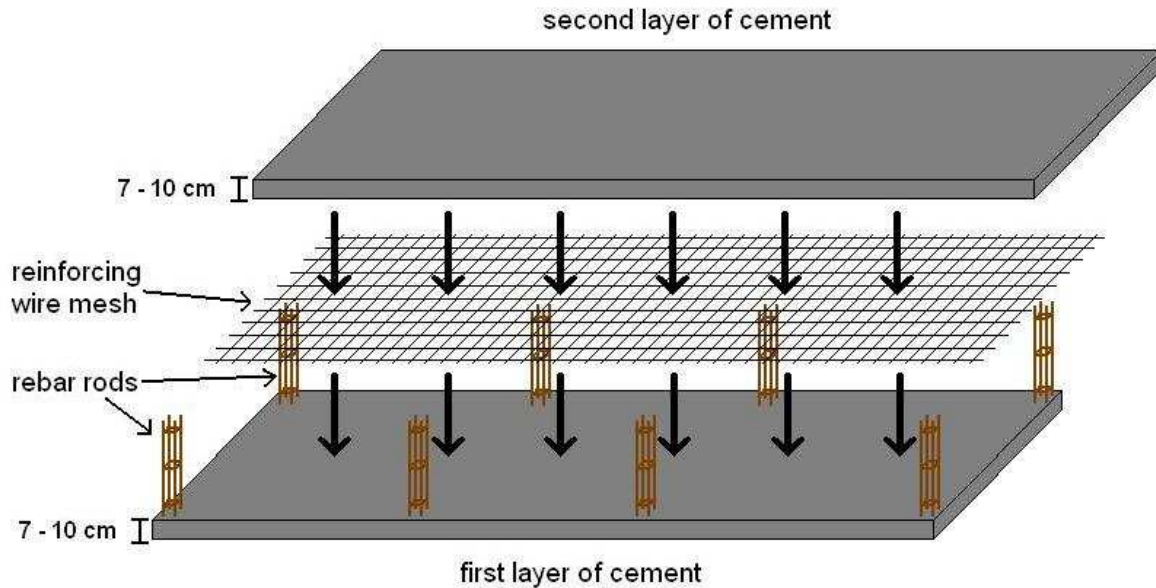


Figure 5. Cistern Floor Construction

3. Constructing the Cistern Walls. Figure 6 below represents graphically the steps described in this section.
 - The cistern floor should have cured enough (1-2 days minimum) so it can support the weight of the soon to be built walls
 - The cistern walls are built using solid concrete blocks, with cement mortar to bind it all together.
 - Cement mortar must fill all horizontal and vertical joints
 - The concrete blocks should be dipped in water right before they are placed on the bed of cement
 - Once the concrete blocks have reached their proper height, concrete is to be poured into the column spaces occupied by the sets of rebar rods
 - Wood forms/planks need to be placed up against the wall to keep the poured concrete in its vertical channel.
 - The wood forms will need to remain in place until the rebar reinforced columns have set

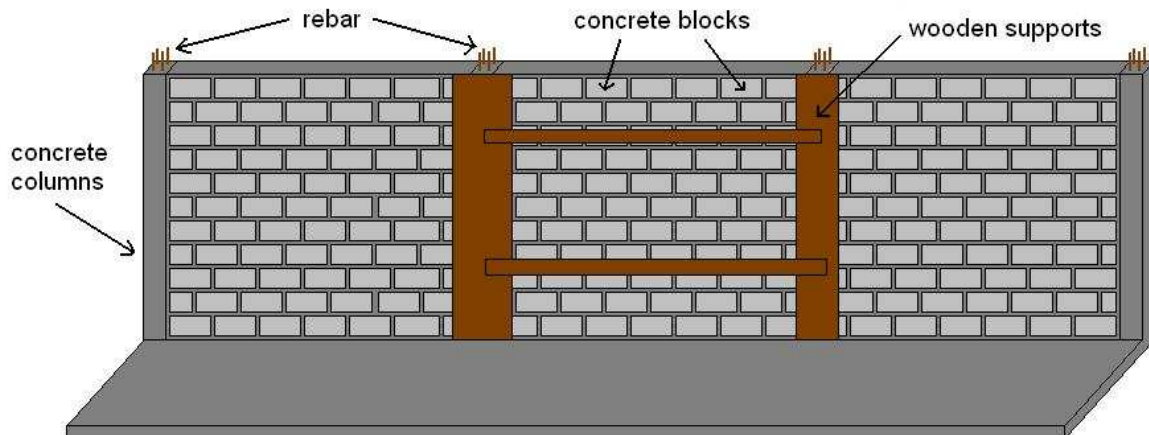


Figure 6. Cistern Wall Construction

4. Constructing the Cistern Roof

- Once the walls have set, the cistern roof can be poured.
- Wooden support columns and wooden base forms will need to be used to support the poured concrete roof while it sets.
- The roof should be poured in a similar fashion to the floor
- An initial base layer about 10 cm thick should be poured over the wooden forms.
- This layer needs to be leveled and smoothed out to remove air bubbles. Again, use long pieces of wood (i.e. a long 2x4) (2"x4" piece of wood is 5x10 in cm).
- Next, the reinforcing wire mesh should be embedded into this base layer
- The wire mesh is then attached to the exposed rebar of the vertical columns.
- Next, the second 10 cm thick layer of concrete needs to be poured
- This too should be leveled and smoothed out to ensure that all exposed metal (rebar and wire mesh) is covered
- After the roof has cured, the wooden columns and support forms can be removed

5. Installing the Access Hatch

- A square opening should be left unfilled in the roof of the cistern to accommodate the access hatch
- The opening must be big enough for a full grown man to fit through
- The metal access hatch should be installed above the opening and permanently secured to the cistern roof
- The hatch must be raised such that it creates a water tight seal
- A concrete step may need to be installed in the floor of the cistern to make access easier

6. Making holes for the Water Outlet and Inlet Pipes

- All water inlet and outlet holes should be laid out before the concrete is poured or hardens
- This can be done using a coffee can or similar cylindrical object of the correct diameter
- Inlet Hole: Make a hole in the concrete roof large enough to fit a 4 inch (10cm) diameter PCV pipe.
- The hole should be near the corner of the cistern close to the filter barrel

- Outlet Hole: Make a small hole in the concrete roof big enough to fit a 2 inch (5cm) diameter PVC pipe through
- The outlet pipe hole should be right at the edge of the roof where the wall and the roof meet (The outlet pipe will need to be attached to the wall of the cistern)
- The outlet pipe hole should be under the cage designed to hold the pump
- Overflow hole: Near the very top of the cistern, a horizontal overflow hole should be formed to allow water to exit the cistern when it has reached capacity
- This overflow hole should be large enough to fit a 4 inch (10cm) PVC pipe through
- Later, when the plumbing has been installed, the area around the holes must be made watertight using cement filler

7. Plastering the Inside of the Cistern: See figure7 below.

- Once the cistern is complete the whole inside should be coated with plaster cement
- The floor, walls, and roof should be slightly damp when the plaster is applied
- The plaster should be applied in multiple thin coats until a 2 cm thick layer is achieved
- The whole cistern should be covered quickly with one coat before the next coat is applied so that it dries as one unit.

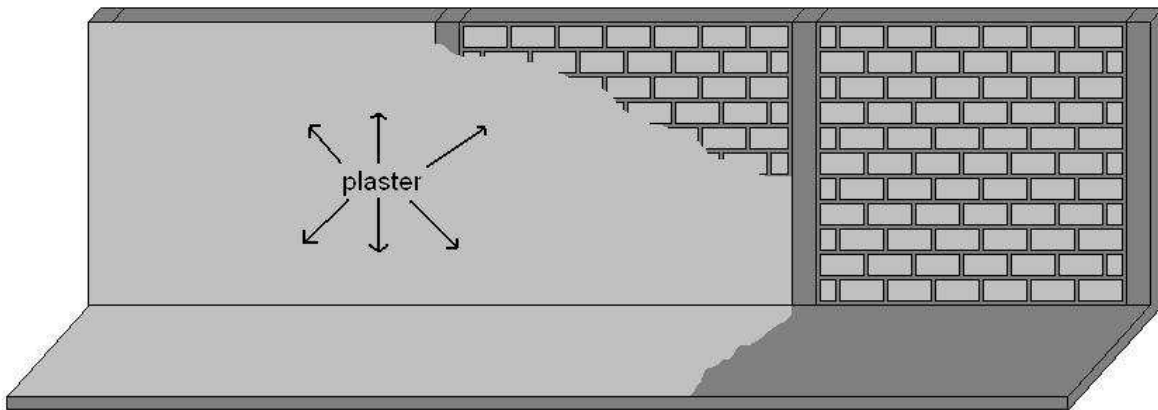


Figure 7. Plastering the inside of the Cistern

The excavated pit must initially be dry so that the concrete will cure properly. If the soil is moist or damp, the concrete will have weak points in it and not last as long as it should. When the floor is poured, the leveling and moving of the concrete helps to get large air bubbles out of the concrete. Air bubbles trapped in the concrete weaken the concrete once it has cured and can cause surface blistering. Concrete is very strong in compression but weak when under tension. Reinforced concrete with rebar and/or metal mesh is much better at withstanding high tension forces than concrete alone. The more slowly concrete cures the stronger it is, which is why it needs to be kept moist. The bricks must be wet and mortar placed in all the joints to ensure that all joints are water tight (Gould and Nissen-Peterson 1999). None of the rebar and wire reinforcing mesh should be exposed to the air or ground; it should all be covered by concrete. The iron in these products will rust if exposed to air or damp soil. The oxidation that is rust not only weakens the metal itself, but also causes it to expand. This puts stress on the concrete around it and eventually weakens the concrete. The rebar and wire mesh provide support for

the weight of the water and also the weight of the concrete roof. It is much easier to form the holes for the inlet, outlet, and overflow pipes before the concrete is poured. It is possible to drill holes through the concrete after it has settled, but this is difficult work and requires special tools. The outlet pipe hole needs to be close to the wall so that the pipe itself can be secured to the wall, as this will keep it stable and will be less likely to break. If the concrete is dry when the plaster is applied it will not adhere well to the surface. Also, if the plaster is applied in thick coats it will be brittle and more prone to break off the roof and walls. Adding lime, $Ca(OH)_2$, results in a more workable plaster mix and makes the final dry plastered coating more waterproof (Gould and Nissen-Peterson 1999).

Construction Step 3 – Wash Station Construction

Once the cistern has cured, construction the Wash Station itself can begin. This is the most technical part of the project as there are pumps, valves, and a tank that all need to be installed correctly and have all of their plumbing function properly.

1. Main Wash Bank (Sistema de Lavaderos)
 - The ground beneath the main wash bank should be prepared in a similar fashion to the floor of the cistern
 - A concrete foundation should be poured using reinforcing mesh as was done in the construction of the cistern floor
 - The actual wash station, with its wash boards and rinsing tubs, is made out of solid concrete blocks with cement Mortar to bind it together
2. Tank Support Pedestal
 - The area directly below the tank is built up of solid concrete blocks all the way to the foundation
 - The top of the wash bank here needs to be level and smooth
 - The blocks and cement should be given time to settle before the HDPE tank is placed upon them
3. The Wash Boards (Lavaderos). See figure 8 on the following page
 - Solid concrete blocks are laid so as to provide room for the wash boards
 - Wooden support boards are placed in the opening for the washboard
 - The front of each wash board station should not be filled in with blocks so that the support boards can be removed later.
 - Rebar rods are laid across the opening on top of the wooden support boards
 - The rebar should be spaced at 10 cm intervals as these rods can provide the base around which to form the wash board's ripples
 - Concrete is then poured around the rebar and sculpted to take the shape of a wash board.
 - When the concrete has cured, the boards can be removed out of the front opening
 - A 1 inch (2.5cm) diameter drain hole needs to be drilled through the back end of each wash board station
 - A piece of 1 inch (2.5cm) PVC pipe should be inserted into the drain hole, long enough to extend a few cm into the drainage ramp
 - The PVC pipe and drain hole are then sealed with cement

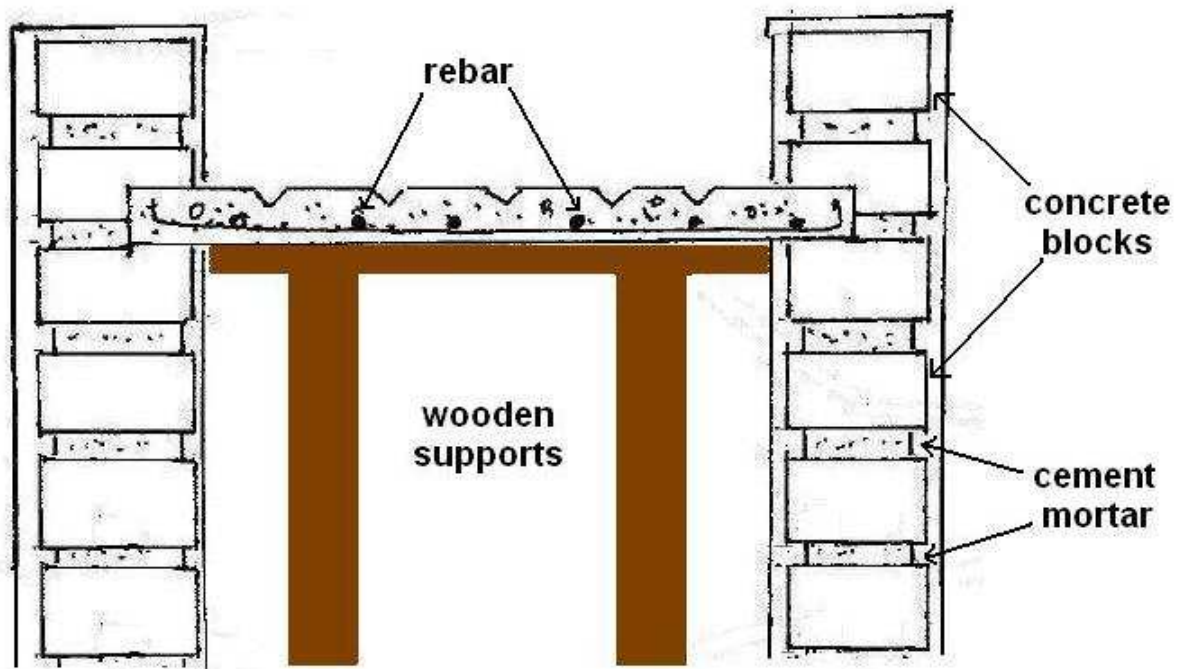


Figure 8. Wooden Supports for Wash Board Construction

4. The Rinse Basins (Pozillos)
 - Solid concrete blocks are laid to form the actual shape and depth of the wash basins
 - A 1 inch water inlet hole needs to be made at the top of the back end of the rinsing tub to accommodate the 3/4 inch galvanized water pipe and spigot
 - A 1 inch (2.5cm) drain hole is cut at the bottom of the back end of the rinse bin
 - A piece of 1 inch (2.5cm) PVC pipe long enough to extend a few cm into the drainage canal is inserted in the hole
 - The whole rinse tub and the outlet hole are covered and made watertight by a layer of cement plaster 1 - 2 cm thick
5. The Drainage Ramp. See figure 9 on the following page
 - Complete and partial concrete blocks are laid in the channel bed at differing heights in a "staircase" pattern
 - Concrete is poured onto this "staircase" and then graded to create the drainage ramp with the 5 – 6% slope needed
 - The ramp must be built such that it will discharge the wastewater into the greywater wetland at the first gravel layer, not on the top
 - A wire mesh screen can be attached at the inlet of the ramp to keep soil from the wetland from spilling onto the drainage ramp

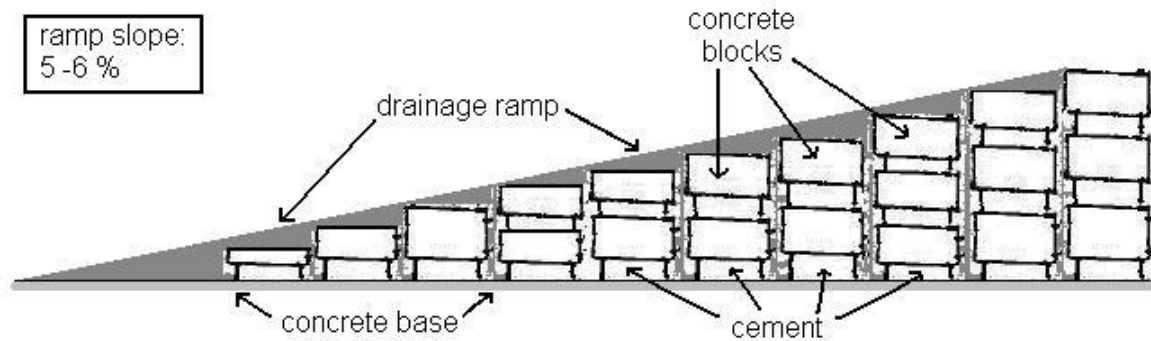


Figure 9. Drainage Ramp

6. Folding Areas and Benches (Repisas y Bancas), See figure 10 below.
- First a layer of concrete is poured on the level, dry, compacted ground
 - The bench portion in front is made using concrete blocks and cement
 - Wooden boards and small posts create a support structure similar to that used for the cistern roof (see Fig. X above)
 - These are placed on the back side of the bench
 - Along the length of the bench , a rebar rod is placed every 20 – 25 cm into the back of the bench and laid on top of the Support boards
 - Concrete is poured over the boards, completely covering the rebar rods
 - Once the concrete and cement have set, the entire outside of the bench and table are to be covered with plaster

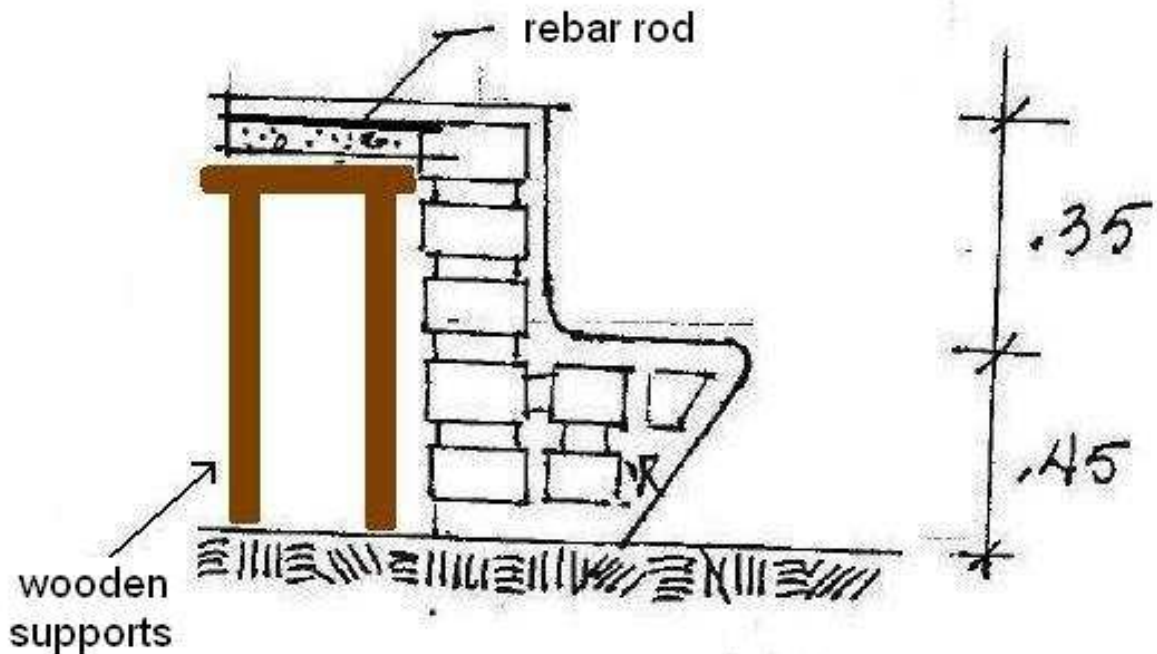


Figure 10. Close Up bench and clothes folding station

7. The Cistern Pump: see Figure 11 below

- NOTE: The pumps are the most expensive and fragile item in the wash station and therefore their handling and security should take the utmost importance
- The pump should be secured in a pre-fabricated metal cage fastened to the roof of the cistern using heavy duty anchor bolts and concrete
- The metal cage must be attached in a way that it is permanent and durable
- The piping running from the cistern to the pump can be PVC, copper, or galvanized steel depending on availability, preference, and the type of pump being used
- The plumbing from the pump to the tank needs to be solid and protected
- The pump needs to be a positive displacement pump, one that does not need to be primed in order to operate
- If the pump is electrical it can either be powered by from a local community source, or it can use a small set of solar cells
- If the pump is hand powered by the effort of a person, then it must be one that the people using the wash station will have the strength and ability to use.

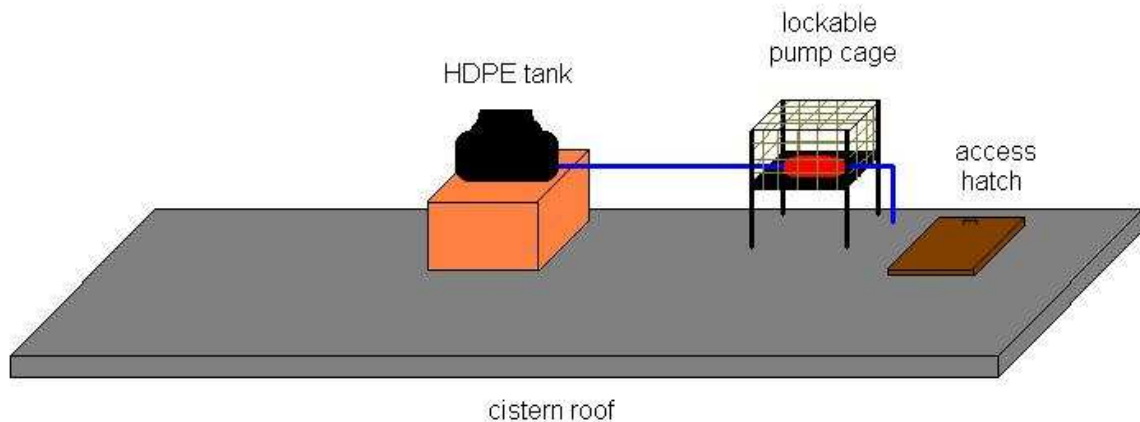


Figure 11. Cistern Pump, Access Hatch, and Tank

8. Tank and Sink Plumbing

- The pipes from the HDPE tank to the rinse basins should be either galvanized steel or copper
- T - joints will need to be soldered in-line so that spigots can be attached for each rinse basin
- Once the pipes are laid on either side of the drainage ramp, they should be covered with a thin layer of concrete to protect them (see figure 2)

9. Clothesline

- The clothesline(s) should be attached securely to sunken wooden or concrete posts
- Ideally the clothesline would face the morning and early afternoon sun (see figure 2)
- The flexibility in placement allows for any clothesline configuration

Similar to the cistern, having a solid foundation for the wash station is imperative to insure that it will last. Soft, non-compacted ground can shift and settle, leading to cracks or breakage of sections of the wash station. Solid concrete blocks were chosen because of their ease of use and because these blocks are generally stronger than the other types of concrete blocks that are hollow in the middle. When full, the HDPE tank will weigh over 750kg and therefore will need an extremely strong, solid, flat base. Each wash board station, and rinse tub, needs its own drain so that the soapy water from the wash board does not mix with the rinse water. This is important for saving water. With the drainage ramp, a grade of 5 – 6 % ensures that the wastewater and solids will flow freely down to the treatment wetland. It is also important that the ramp be wide enough (at least 0.60 m) so that a person can walk up it to perform maintenance. In both the washboards and the clothes folding ledge, rebar provides extra strength, which is very necessary for these lightly supported structures.

With the pump it is extremely important to get the appropriate type of pump. A centrifugal pump will not draw water if it is located higher than the water source that is being pumped. For both the cistern pump (and as we will see later for the small well pump), a positive displacement pump would work much better. It still produces suction and flow even if there is no water in the pump or in the lines. However, one must be careful because positive displacement pumps are much more likely to build up pressure that can blow out hoses, fittings, valves, and pipes if water is not able to flow and is blocked somehow.

Construction Step 4 – Rainwater catchment Surface and Dry Season Well

This wash station design calls for two different water sources. The primary and most important is the system of the roof, canals, and pipes that collect and transport water to the cistern. The other is the secondary well that is used during the dry season. The roof and rainwater infrastructure should be the final section of construction prior to the biological wetland.

1. Supplementary Well and Pump

- The well should be approximately 3 meters away from the cistern and filter barrel (see figure 2)
- The well in this case will likely need to be dug to a depth of 4-5 m (see figure 3)
- Similar to the pump for the cistern, this pump will need to be secured to a concrete base and enclosed in a metal cage
- It also should be a positive displacement pump
- The plumbing can be a combination of PVC, copper, or galvanized metal
- The pump's outlet should flow into the filter barrel before entering the cistern
- During the rainy season, there should be some way of storing the pump
- This pump can either be a electrically powered mechanical pump or one operated by hand

2. Filter Barrel: see Figure 12 on the next page

- The filter Barrel is simply a 55 gallon drum
- It should be placed near the inlet hole to the cistern

- 3 - 4" galvanized metal or PVC pipe should connect the exit hole in the barrel with the entrance hole to the cistern
- The filter barrel should have a removable lid that seals the barrel in order to prevent foreign objects from entering
- The entrance pipe to the filter barrel should be 2 – 3" in diameter and posses a shut-off vavle
- The entrance pipe should be installed so that it can be easily removed from both the gutter and the barrel in order to facilitate easy maintenance
- The filter barrel should be filled almost to the top with small particle gravel
- The pipe leading from the water gutter to the filter barrel should be screened with fine wire mesh at the top where the pipe connects to the gutter

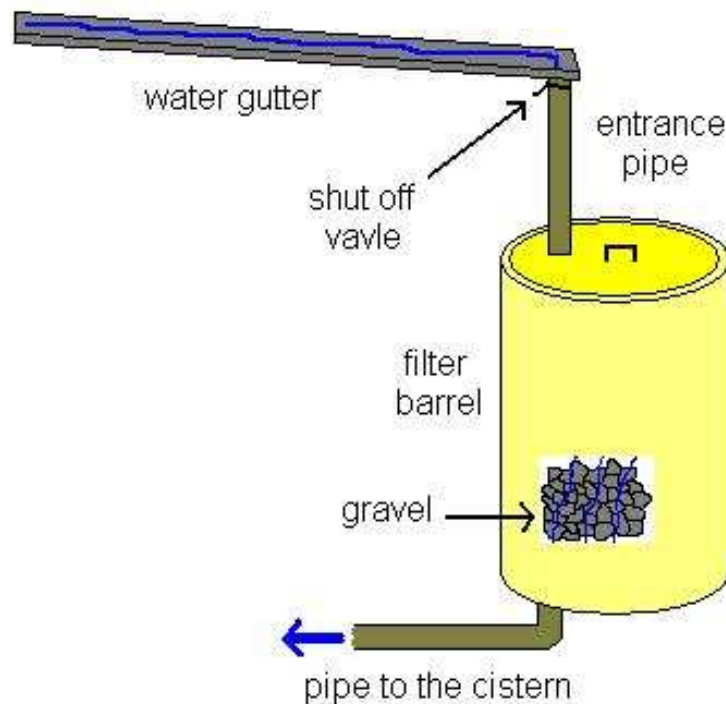


Figure 12. Water Collection Gutter and Filter Barrel

3. Roof/Catchment Surface: see Figure 13 on the next page
 - The roof is made from sheets of corrugated galvanized metal.
 - The sheets should be laid so that all seams have about a 5 cm overlap
 - Ideally, nails and screws should be coated with a sealing compound before they pass through the metal sheets and into the wooden ceiling beams
 - The nails should not be painted
 - The eaves of the roof should extend out 3 – 4 cm over the edge of the beams
4. Roof Frame
 - The roof framing is comprised of wooden posts and beams
 - The support posts from the ground to the roof can be either wood or concrete
 - The support posts should be sunk to a depth of at least 1 meter into solid ground
 - The roof cross members are long wooden beams
 - If full length beams cannot be obtained then metal bracing brackets will need to be used to secure to beams together

- Smaller wooden beams and metal “T” brackets are used to provide extra support for the roof

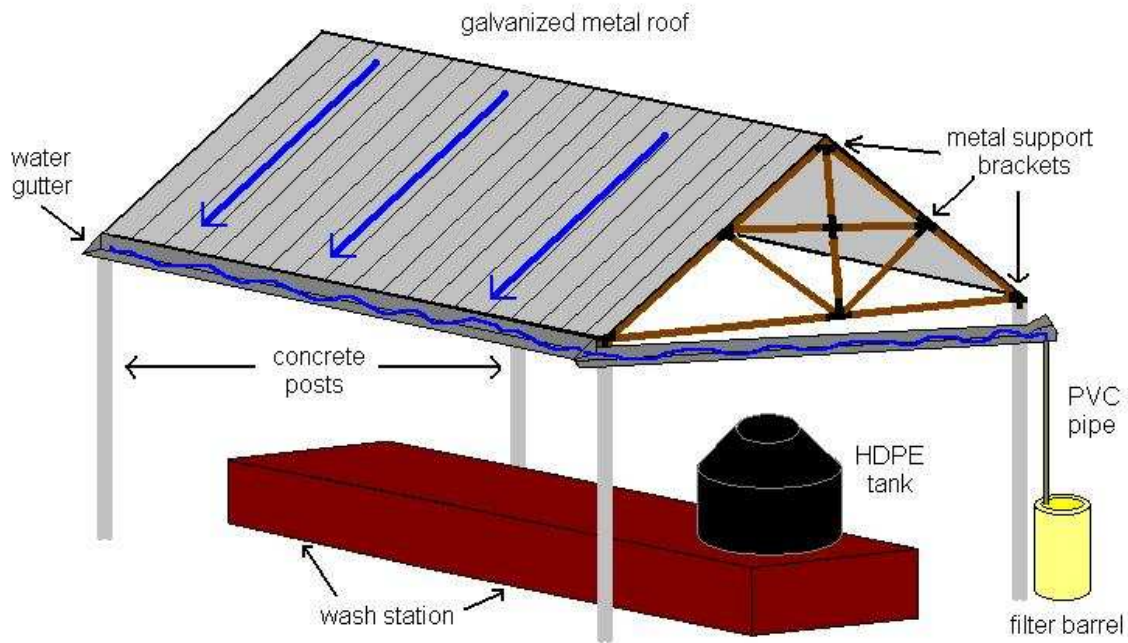


Figure 13. Catchment Surface and Water Transport Canals

5. Water Gutters

- Water canals should be made out of galvanized or rust resistant metal sheets
- The sheets should be bent into the shape of a “V” with a 90° angle at the base vertex
- Sharp bends in the gutters should be avoided
- The gutters should have a slope no less than 1cm down per 1 meter of run, and ideally 2cm drop per 1 meter of run
- There should be at least 1cm² of gutter cross sectional area for every 1m² of roof area (i.e. a V-shaped gutter with a cross sectional area of 98cm² can support a roof area of 98m²) (see Figure 14 b on the next page)
- Gutters should be placed in the gutter supports not attached to them (see Figure. 14a on the next page)
- There is no set size for gutter sections, however they should be short/small enough so that two people can easily remove a section for maintenance
- Gutter supports should be attached to the roof beams using strong, well-made screws, not nails
- Gutters supports should be installed no more than 1 meter apart along the run of the roof
- The metal roof should overlap the gutters by 3cm
- If water use is high, then an additional, adjacent catchment surface can be constructed to add to the regular inflow of water into the cistern

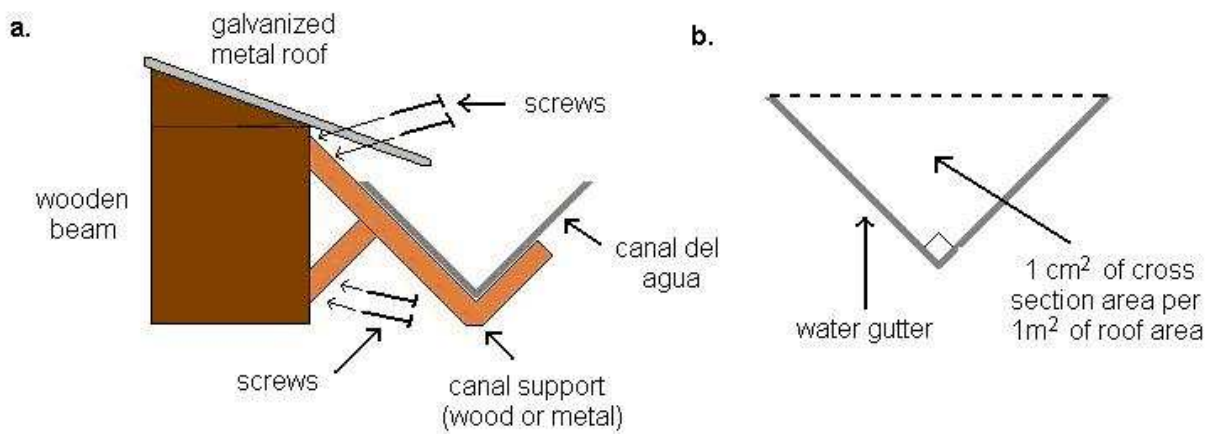


Figure 14. (a.) Water Gutter and Support Bracket (b.) Gutter Cross Section Formula

The well needs to be dug far enough away from the cistern so that its recharge and hydrology are not affected by the cistern. Furthermore, there needs to be enough space so that the well does not cause problems to the cistern. Depending on the height of the water table, the well may have to be dug deeper or shallower than the 4 – 5 m specified here. The risk of damage, vandalism, or theft can be reduced by storing the pump off-site during the dry season in a building. Depending on the filter barrel's construction (i.e. metal vs. plastic) one type of piping material may work better than another. Gravel in the barrel acts as a rough filter, helping to keep leaves or twigs or small animals out of the cistern. The barrel will periodically need to be emptied or cleaned. It is important to have inlet pipes that are easily removable. The roof/catchment surface can be made from many different materials. Corrugated galvanized metal sheets are recommended here because they are abundant and economical. The 5 cm overlap helps to guard against leaks. It is important to note that as water demand increases or if more supply is desired, it is not very difficult to add another catchment surface. This will increase the total volume of water that can be captured. Sealing the nail holes helps to reduce leaks and guards against rot of the wooden beams. It is imperative that the posts provide a solid sturdy base for the roof catchment area. Sharp bends in the gutters can lead to overflow during large rain events. Allowing the gutters to rest in the supports makes it easier to remove them for maintenance. Screws provide a stronger, more durable connection than do nails. During large rain events, the gutter brackets may have to support water flows of 75 kg. Nails would be more prone to being pushed out of the beams under this additional weight. By having the roof overlap the gutters, it is assured that the system will capture light rains and that heavy flows will not fall into the gutter and be forced over the other edge by water flowing behind it. If the roof overhangs too much the water from heavy rainstorms may have enough energy to shoot up and over the lip of the gutter.

Depending upon the water demand for a particular application, or the rainfall patterns of an area, it may be necessary to have a catchment surface of a different size. In the Cinco de Marzo application, it may be necessary in the future to expand the catchment area to accommodate greater usage. It is a fairly simple calculation to determine the volume of water that can be obtained from a certain catchment surface area.

[Equation 1]
$$S = (100R) \times A \times C_r$$

S = Total yearly volume of water supplied by the system in cubic meters (m³)

R = Average annual rainfall in centimeters (cm)

A = The total area of the catchment surface in square meters (m²)

C_r = The runoff coefficient

The runoff coefficient is merely the volume of runoff captured from the catchment surface divided by the volume of rainwater

[Equation 2]
$$C_r = \frac{\text{volume of runoff}}{\text{volume of rainwater}}$$

For a well maintained system with a corrugated metal roof such as this design calls for, a runoff coefficient of 0.8 – 0.85 is common. It is even possible to obtain a C_r of 0.9 in some cases.

Construction Step 5 – Constructing the Greywater Biological Filtration Wetland

It is important to treat the greywater that will be exiting the system in order to avoid negative environmental effects. Additions of grey water to surface water bodies can cause pH imbalances, increased oxygen demand and increased turbidity. The level of treatment a biological filtration system can achieve is dependent upon a number of factors, primarily the amount of time the soapy water spends in the constructed wetland cell, where the contaminants are degraded by microorganisms. Figure 15 illustrates the design of the greywater treatment constructed wetland.

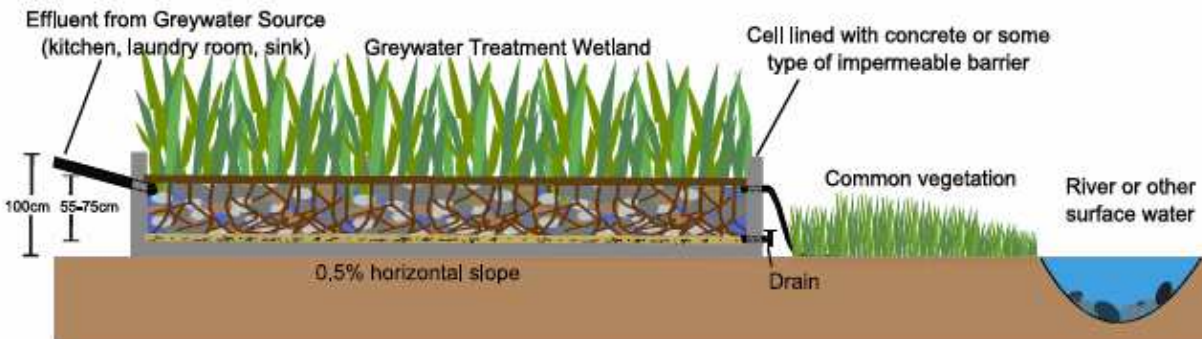


Figure 15. Design of Greywater Constructed Wetland

The following steps and considerations should be used to construct the greywater filtration wetland.

1. Choose the location of the greywater wetland.
 - The site for this case study is immediately adjacent to the clothes-washing station
 - The site is open, allows easy access, has plenty of space for multiple families to use at once, and room for expansion, should that be desired in the future
 - The ground has a natural gentle slope to it, making it easy to transport water through the biological filtration garden and out to the river
 - The site is in close proximity to the stream, which is an ideal discharge point for the treated greywater
 - The wetland catches the greywater effluent immediately, without letting water pool

2. Decide on the dimensions of the cell.
 - This system is designed to treat the wastewater produced from 40 families each week, using 240 L each, for a total of 9600 L per week
 - The recommended dimensions of the wetland cell are a width of 2 m and a length of 10 m
 - The following calculations adapted from Crites' and Tchobanoglous' book, *Small Decentralized Wastewater Treatment Systems* (1998), were performed to obtain the recommended size. The same calculations can be used to determine the size of a treatment wetland for use on a larger or smaller scale. This example can serve as a guide for your own calculation. These calculations are based on BOD removal, but can be adapted for nitrate removal by modifying the factors in the calculation of the reaction rate constant. Typically, however, the nitrogen levels in greywater are much less than in blackwater, and BOD is the primary parameter that should be targeted for removal.

Determine the minimum monthly average ambient temperature, T ($^{\circ}\text{C}$), that the system will work at (e.g. average for January). It was determined that the average low temperature in January in San Cristóbal de las Casas, Mexico, is 3°C .

Calculate the reaction rate constant, k_r (day^{-1}) for BOD at the appropriate temperature using the following equation. The reaction rate constant at 20°C (k_{20}) varies depending on the system. A range of values have been used in textbooks guiding design of subsurface flow wetlands. A larger k value indicates faster decomposition of BOD. Crites and Tchobanoglous (1998), a well-established source, estimate a k_{20} of 1.1 day^{-1} , while Tchobanoglous and Burton (1991) estimates a k_{20} of 1.35 day^{-1} for black water treatment wetlands. A study in Sweden (Olsen et al 1967) demonstrated that the reaction rate for greywater wetlands was 4.5 times higher than the black water reaction rate due to the more abundant availability of unprocessed organic matter. These values are based on the performance of the wetland, and cannot be accurately obtained until the system is built and monitored. It is recommended to use a conservative (low) value for this figure because much of the treatment depends on the activity of the microorganisms in the wetland, which cannot be determined before construction. More research is needed and encouraged to more accurately characterize the reaction rate and ideal design parameters. For this example, a semi-conservative value of 1.36 was used for the reaction rate.

[Equation 3]
$$k_r = k_{20}(1.06^{(T-20)}) \quad k_r = 1.36(1.06^{(3-20)})$$

$$k_r = 0.50 \text{ day}^{-1}$$

Calculate the detention time t (day), the time the water should remain in the system in order to reach desired BOD level with the equation

[Equation 4]
$$t = \frac{-\ln(C / C_o)}{k_r}, \quad t = \frac{-\ln(5 / 33)}{0.50}$$

$$t = 3.79 \text{ days}$$

where C_o is the BOD concentration of the water entering the system ($\text{mg/L} = \text{g/m}^3$) and C is the desired BOD concentration of the water ($\text{mg/L} = \text{g/m}^3$) exiting the system, or the goal. Estimates of typical BOD values of runoff water are shown in Table 1. A reasonable goal is from 3-7 mg/L , as a treatment wetland can decrease levels of BOD, but cannot eliminate it. Washwater in the Rio Navajuelos, which runs through the colonia of Cinco de Marzo, was tested to determine the BOD level of local washwater. The results, 33 mg/L is used in this example, and a reasonable goal of 5 mg/L was set as the BOD of the effluent from the greywater treatment wetland.

Table 1. Estimated BOD mean concentration for non point source loading from various land uses (Benaman 1996)

Land use category	High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren
BOD (mg/L)	9	15	4	6	6	6	0	13

Check the organic loading rate, L_{org} ($\text{g BOD/m}^2\text{-day}$), using the equation below. This number will indicate the mass of BOD per area per day that the system is expected to receive. As a general rule, the organic loading rate should not exceed 11.2 $\text{g BOD/m}^2\text{-day}$. This threshold will not be exceeded in practice with influent applied up to 5 cm per day. Almost all greywater systems will have an organic loading rate below this threshold.

[Equation 5]
$$L_{org} = \frac{(C)(d_w)(\eta)}{t} \qquad L_{org} = \frac{(33)(0.65)(0.4)}{3.79}$$

$$L_{org} = 2.26 \frac{\text{g BOD}}{\text{m}^2 * \text{day}}$$

Again, C is the BOD ($\text{mg/L} = \text{g/m}^3$) of the influent water, d_w (m) is the depth of the medium, which typically can be from 0.4 m to 0.85 m. One can try the calculation with depth varying from 55 to 85 centimeters to find an appropriate size. For instance, if there is a restraint on field area available for the constructed wetland, a depth of 85 cm will minimize the footprint of the system. The deeper the medium the more load the system can process, but if the medium is too deep, conditions at the bottom become anaerobic and may result in incomplete removal of the BOD and nutrients. Use the detention time calculated above in Equation 4 (t). The effective porosity of the medium, η , is defined as the proportion of the non-solid volume to the total volume of material, dimensionless, and can be determined from Table 2 according to the size of gravel chosen. In order to contain this wetland's footprint within the available space, a depth of 0.65 was chosen by trial and error. This will allow for 5 cm of sand on the bottom, 55 cm of medium gravel in the middle, and 5 cm of mulch on the top. An effective porosity of 0.4 (dimensionless) was chosen, which corresponds to the medium sized gravel. The organic loading rate of 2.26 $\text{g BOD/m}^2\text{-day}$ is much lower than the threshold, so there should be no anaerobic conditions forming in the wetland.

Table 2. Typical values of constructed wetland mediums (Crites and Tchobanoglous 1998). *d₁₀ is the diameter of a particle in a weight distribution of particles that is smaller than all but 10% of the particles.

Medium	Effective size d ₁₀ *, mm	Effective porosity η
Medium sand	1	0.3
Coarse sand	2	0.32
Gravelly sand	8	0.35
Medium gravel	32	0.4
Coarse gravel	128	0.45

Determine the necessary field area for the subsurface flow bed (m²)

[Equation 6]

$$A_s = \frac{(Q_{ave})(t)}{(\eta)(d_w)}, \quad A_s = \frac{(1.37)(3.79)}{(0.4)(0.65)}$$

$$A_s = 20 \text{ m}^2$$

where Q_{ave} is average daily flow through the wetland (m³/day), t is the detention time calculated above (day), and d_w is the depth of the medium (m). Use the same value for η determined for Equation 5. For larger systems, it may be helpful to convert the area to hectares using the conversion of 1 hectare = 10,000m². For this example, the average daily flow was calculated by estimating a weekly usage of 240 L (1000L=1m³) for each of 40 families, then dividing by 7 days per week (240 L/week * 40 families ÷ 7 days/week * 0.001 m³/L). All other values were previously stated or calculated.

And finally, to calculate the dimensions of the treatment wetland (m), use the following expression:

[Equation 7]

$$w = \left(\frac{A_s}{R_A} \right)^{1/2}, \quad w = \left(\frac{20}{5} \right)^{1/2}$$

$$w = 2 \text{ m}$$

where w equals width (m), A_s is the area of the wetland (m²), and R_A is the aspect ratio, as length/width. For subsurface flow wetlands, Crites and Tchobanoglous (1998) recommend that the aspect ratio is between 2:1 and 4:1, but Bounds et al. (1998) found no significant difference of nutrient and BOD removal in three 25m² reedbeds treating domestic effluent with aspect ratios ranging from 4:1, 10:1, and 30:1 over a two year period (qtd. in Dallas 2005). An aspect ratio of 5:1 was chosen for this treatment wetland due to space availability and aesthetics.

The length, l , of the constructed wetland (m) can be calculated by the expression:

[Equation 8]
$$l = \frac{A_s}{w}$$

$$l = \frac{20}{2}$$

$$l = 10 \text{ m} .$$

3. Excavate the land adjacent to the clothes washing station.
 - The canal should distribute the water into the treatment wetland just below the mulch layer
 - Grade the bottom of the cell so it has a downgradient of 0.5%. The resulting decrease in height of a 10 m cell is 0.05 m ($10 \text{ m} * 0.5 \div 100 = 0.05 \text{ m}$), or 5 cm
4. Construct the wetland cell.
 - It must be impermeable on the sides and bottom.
 - Cracks in the cement may compromise the block structure leading to leakage and groundwater contamination.
5. Integrate a drain valve into the bottom of the downgradient side of the cell. This valve will serve to lower the water level to encourage deeper plant root growth.
6. Incorporate the greywater inlet.
 - Greywater should be distributed evenly into the inlet area to promote even infiltration into the wetland just below the mulch layer.
 - For smaller wetland systems, a perforated pipe or a series of pipes can serve this purpose (Figure 2).
 - For larger wetland systems, gated pipes, slotted pipes or troughs with V-notch weirs can distribute the water along a wide inlet.
 - Secure a fine plastic mesh screen over the opening to deter clogging.
 - In this design, greywater freely flows from the central collection canal of the clothes washing station into the wetland.
7. Create an outlet pipe.
 - The pipe should be placed at the same height as the inlet - just below the mulch level.
 - Install a plastic fine mesh screen to prevent soil and gravel entering the pipe (Figure 16).
 - A hose can be attached to the outlet to lower the water down to surface level.
 - The effluent water should exit at ground level and flow as surface water through a vegetated area.

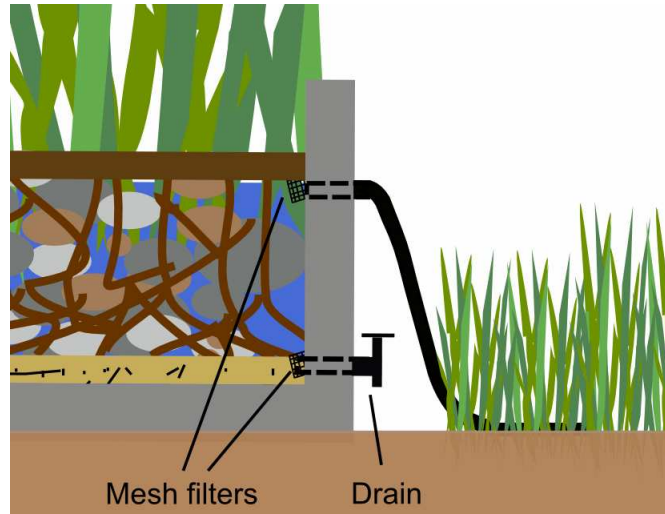


Figure 16. Detail of outlet, drain, and mesh filters

8. Lay medium for plants (Figure 17):

- Apply a layer of sand 5 cm thick.
- Place a layer of gravel on top of the sand layer. Gravel size within 50 cm of the inlet and outlet should be about 5 cm in diameter; this reduces risk of clogging as larger pieces of the suspended solids settle in this area. Throughout the rest of the system, gravel size should be between 0.5 and 3 cm. In order to ensure sufficient BOD removal in this design, lay a 55 cm layer of gravel, filling the cell up to a height of 60 cm.
- Top gravel with 5 cm of mulch or rich top soil.

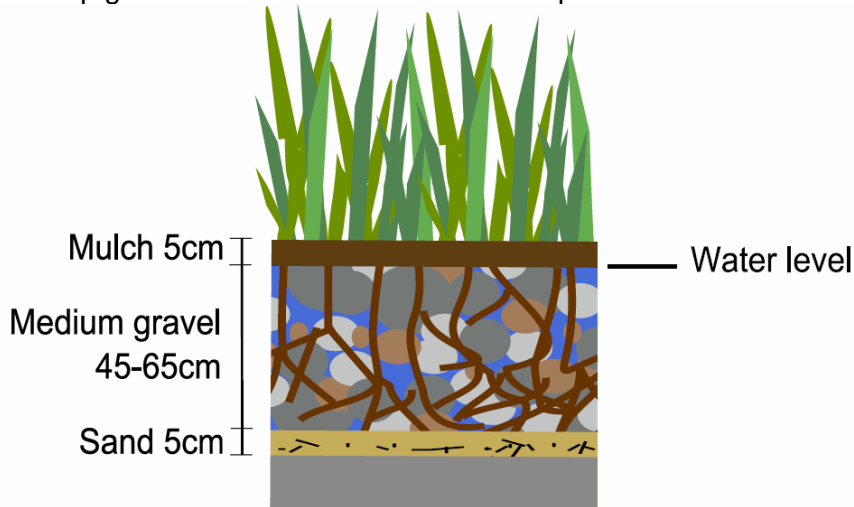


Figure 17. Cross-section of the constructed wetland

Construction Step 6 – Establish vegetation in the wetland

1. Transplant plants from a local natural wetland (recommended) or nursery.
 - This design uses local sedges, reeds, and bulrush that are available in the nearby wetland because they are already accustomed to the local climate.
 - The entire plant (leaves, stem, roots, and growing shoot) plus some soil should be transplanted (Figure 18).
 - The root end should be placed about 5cm below the surface.

- Above-water stems can be cut to about 20 cm tall.
- Cattails should be placed 0.25-1 m apart; reeds, sedges, and bulrush can be planted 15 cm apart.



Figure 18.(Left to Right) Cattails, Bulrushes, and Common Reed Grass

2. Irrigate the plants.
 - Saturate the soil with water to the surface (no farther) and allow to evaporate slowly, keeping the soil moist during the entire propagation period.
 - Plants should establish themselves within 2-3 months.
 - After plants are established, use the drain to adjust the water level in the cell to encourage deeper plant root penetration into the gravel medium.
 - Eventually the plant roots will extend to the bottom of the media.
 - Vegetation should be allowed to become established before wastewater applications begin. If wastewater must be used sooner, those plants that die due to shock can be replaced.

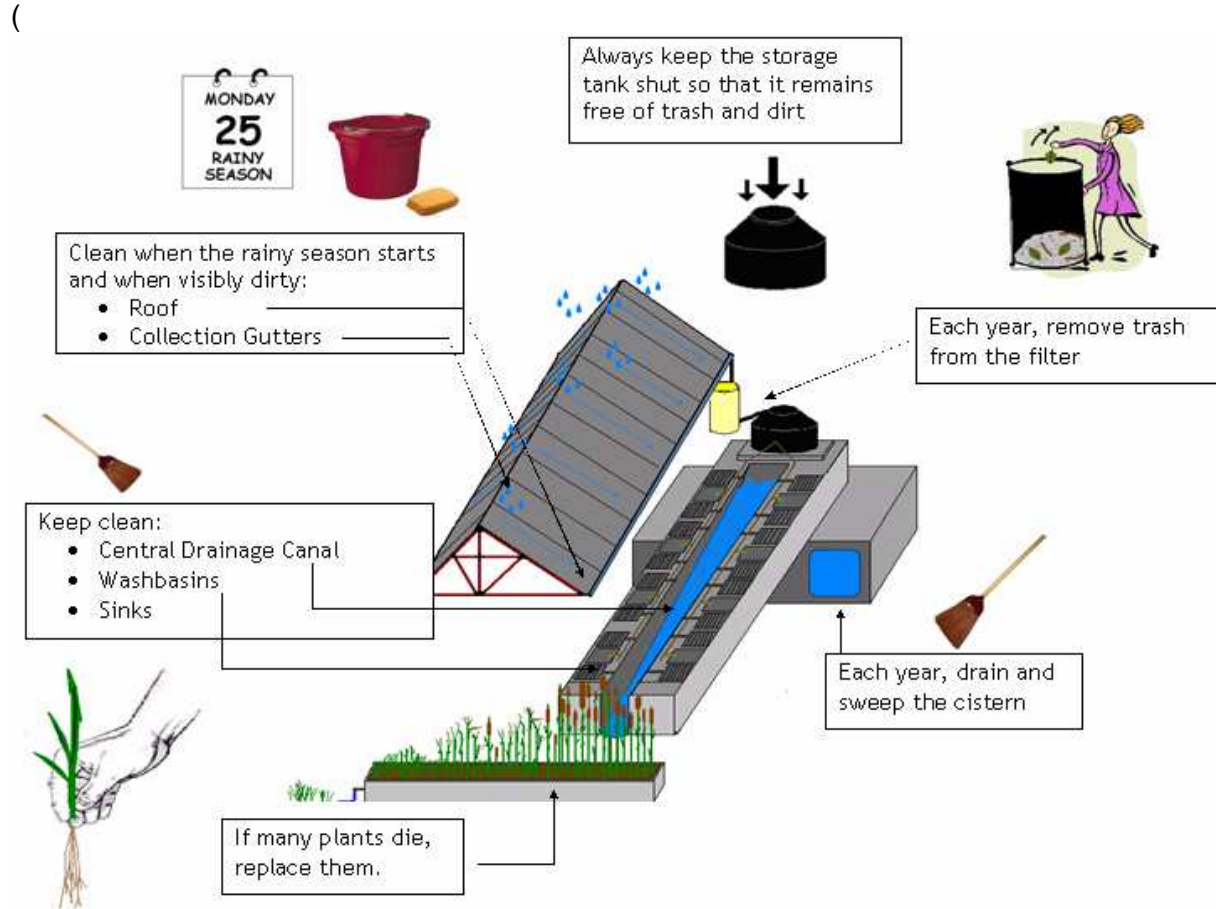
Maintenance

While a clothes washing station for the most part is a relatively basic structure, there is still important periodic maintenance that needs to be carried out.

- The cistern should be inspected for leaks and cracks or other types of damage on an annual basis
- The cistern should be cleaned on an annual or biennial basis
- The pumps will have to be cared for and maintained per the manufacturers' specifications
- The metal pump cages will need to be checked periodically to ensure that they are still secure
- The water transport gutters will need to be inspected and cleaned regularly
- The filter barrel will need to be inspected on a yearly basis
- The drainage ramp may have to be swept
- The HDPE tank will need to be cleaned and inspected periodically
- The roof will need to be inspected for holes and cleaned
- Loose gutter brackets will need to be re-secured

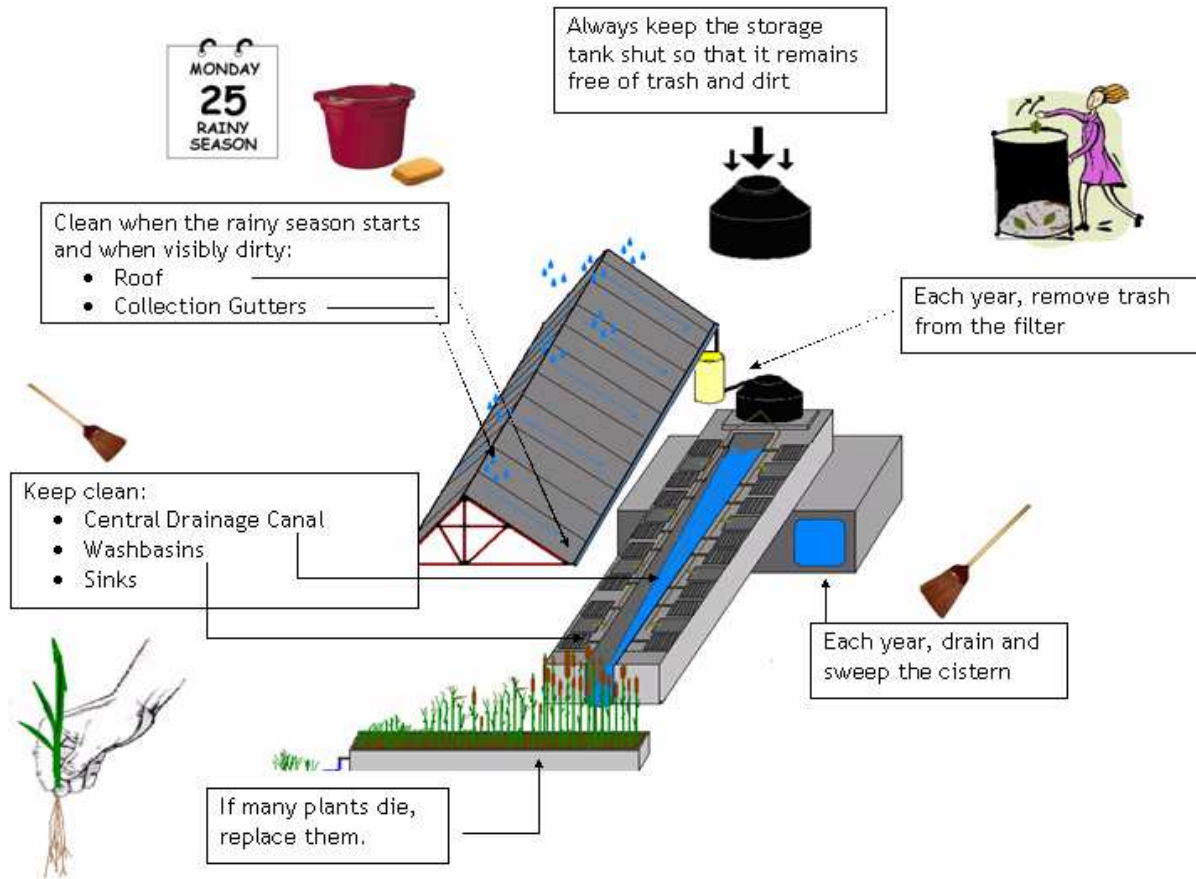
- Water will need to be constantly flowing through the wetland to maintain the plants
- The mesh on the inlet and outlet of the treatment wetland should be cleaned out when the flow is lower than usual to prevent further clogging.
- Clumps of wilting plants will need to be replaced, though seasonal harvesting is not necessary.
- Water monitoring: it is recommended that periodic monitoring of nutrient and BOD levels take place to estimate removal and identify potential problems. A local laboratory or research institution may be able to aid in organizing a monitoring program.

This is just a list of the major maintenance. A sign can be placed in the Ecological Clothes-Washing Station to remind users of the maintenance



Maintenance of the Ecological Clothes-Washing Station

Figure 19).



Maintenance of the Ecological Clothes-Washing Station

Figure 19. Example of a sign to remind users of maintenance

Materials

Below is a list of the required materials. All the major materials are listed in Table 3.

Table 3. List of materials for the Ecological Clothes-Washing Station

Materials	
750L HDPE storage tank	corrugated metal roofing
wooden posts (10)	metal gutters
water pumps (2)	PVC piping
sand (concrete qual.)	galvanized metal pipes
gravel (concrete qual.)	copper piping
cement (concrete qual.)	trash bins
solid concrete blocks	wood beams
55 gal water drum	water spigots
rebar	reinforcing wire mesh
wood support forms	plants and reeds
metal entrance hatch	mesh canal screens
screws & nails	lockable metal cages (2)
lime	clothes line
top soil	pad locks
sand (wetland qual.)	gravel (wetland qual.)

Other Considerations

There are a number of other issues that were considered when designing this system.

- It is not clear when this neighborhood will begin to receive water services. It could be a number of years. The wash station was designed to last and be able to be used productively for many years.
- In the future, the wash station and biological filtration garden may have to handle a heavier load as more community members realize its benefits and begin to use it. The design took this into account by providing an oversized biological filtration garden as well as a means to expand the rainwater harvesting catchment area.
- One issue that had to be dealt with delicately was the fact that the members of the neighborhood do not own the land they live on and the Colonia is not officially recognized by the city. This created an environment where discretion and independence during the construction period were paramount.

References

- Bounds, H.C., et al. "Effects of Length-Width Ratio and Stress on Rock-Plant Filter Operation." The Small Flows Journal 4.1 (1998): 4-14.
- Crites, Ron, and George Tchobanoglous. "Small and Decentralized Wastewater Management Systems." Water Resources and Environmental Engineering (1998).
- Dallas, Stewart C. "Reedbeds for the Treatment of Greywater as an Application of Ecological Sanitation in Rural Costa Rica, Central America." Murdoch University, Western Australia, 2005.
- Gould, John, and Nissen-Peterson, Erik. "Rainwater Catchments for Domestic Supply." ITDG Publishing. 1999.
- Ludwig, Art. "Water Storage: Tanks, Cisterns, Aquifers, and Ponds." Oasis Designs. 2005.
- Tchobanoglous, George, and Franklin L. Burton, eds. Wastewater Engineering: Treatment, Disposal, and Reuse. McGraw-Hill, Inc., 1991.
- UNEP. "Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean." Unit of Sustainable Development and Environment, General Secretariat, Organization of American States. 1997.