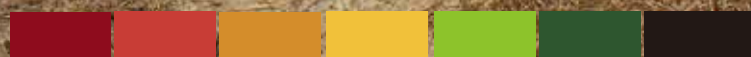


TRANSPORTING, STORING AND FILTERING WATER USING LOCAL RESOURCES: A DESIGN MANUAL

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INBAR, ABARI and SWALLOW
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INTRODUCTION

In July 2012, the Canadian Federal Department of Environment awarded INBAR a new project working with communities in Ethiopia and Nepal to develop new technologies for storing, transporting, and filtering water resources. The project aims to scale up the use of local resources, such as bamboo, gravel and sand to alleviate the pressures caused by erratic rainfall patterns, which are under threat of further exacerbation by climate change.

For this reason, water management in both rural Ethiopia and Nepal is becoming an increasingly vital issue for local communities. While the minimum daily water needed for drinking, cooking and cleaning is considered to be 50 litres per person, in many regions of Ethiopia and Nepal, where water is transported purely through manual labour, daily consumption is often limited to just 20 litres or less. Collecting water has become a daily chore, primarily for women and children, who often spend hours every day collecting barely enough water for household consumption. For these households and many others like them across the developing world, there are very few cheap alternatives available for transporting and storing water other than physically carrying it in plastic or earthen jars.

Furthermore, this transportation process also carries a heightened risk of major microbial contamination, resulting in water borne diseases and infection. In order to address these issues, INBAR designed this Environment Canada-funded project in order to explore the possibilities for more affordable means to store, transport, filter and recycle water, which would allow poor rural communities to utilise their own locally available resources.

This manual showcases the lessons learned from the project and is designed for entrepreneurs, development and water resource management professionals working with rural communities to adopt and adapt these new technologies within their own work.

The manual covers the design process for the following items:

1. Construction of a 5,000 litre capacity water storage tanks using bamboo as the main structural element.
2. Transport water using renewable energy and mechanical pumps.
3. Building a biosand filter to purify stored water.
4. Recycling water using a reed bed filter.

Using these four components it is possible to develop an integrated system for storing, transporting, filtering and recycling water (see Figure 1). This has the potential to allow rural communities to improve their water management options, using materials that can primarily be sourced locally and at a low cost.

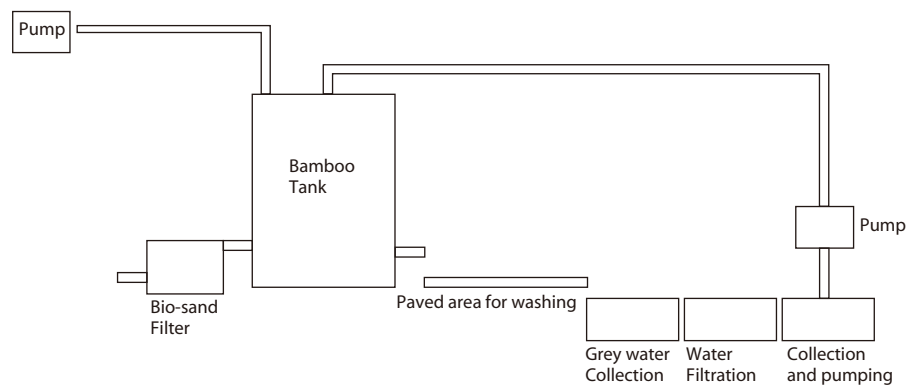


Figure 1: Diagram of an integrated bamboo tank water storage, transportation, filtering and recycling system

CHAPTER 1

BAMBOO WATER TANK CONSTRUCTION

In the early 1980s, the idea of using water tanks made with bamboo as the main structural element was widely explored across South-East Asia. Although the idea was very promising, it failed to gain momentum amid concerns that over time the bamboo would be susceptible to bacterial and fungal degradation. Nevertheless, widespread interest remains in using bamboo in tanks as it is one of the fastest growing plants on earth, has very high tensile and compressive strength along its fibres, and is found in many regions of the world. Another major advantage is its cost compared to available alternatives. For example, the cost of a plastic water tank is roughly US\$12 per litre while a concrete tank is about US\$20. Although this project is still in an exploratory phase, the long term aim is to bring costs down to US\$4-8 per litre. Meanwhile, INBAR used this opportunity to re-evaluate the potential for using bamboo to build water storage tanks by taking advantage of major advances in our understanding of treatment techniques over the last 30 years.



TANK SPECIFICATIONS

In this project, we developed a tank design capable of holding 5,000 litres. This tank size would be adequate to serve the needs of a typical family living in Nepal or Ethiopia during the dry season. The 5,000 litre tanks are approximately 1.5 meters tall and 2 meters in diameter, making them easily scalable depending on the needs of the family. It should also be noted that only mature culms should be used in construction. The maturity of bamboo culms and their suitability for use in construction also depends on species and location. Potential managers should consult local experts before selecting species and culm age for their projects. In Ethiopia, we used African Highland Bamboos (*Yushania alpina*) of 3-4 years in age, while in Nepal we used *Bambusa balcooa* of 3 years of age.

BAMBOO TREATMENT

Before using bamboo in construction, it is important to treat the material. Without treatment, bamboo will decay in around 3-4 years, while properly treated bamboo can last for over 25 years. There are many industrial and non-industrial systems available to treat bamboo. However, among these, the authors have found the boucherie treatment system is the cheapest, easiest and most effective way of treating bamboo in rural settings. Through the Modified boucherie Technique, (which is also known as the sap displacement technique), a pressurised preservative solution is applied on the basal end of a bamboo culm, which pushes the sap contained in the vascular bundle out and then replaces it with the preservative. This technique is only possible on a freshly cut bamboo, while the vascular bundle is still open and must therefore be applied within 24 hours of harvesting bamboo.

BOUCHERIE TREATMENT EQUIPMENT SET UP

A typical boucherie treatment kit consists of a big cylinder (in this project we used 50 litre capacity cylinders) fitted with:

- Pressure gauge: The pressure inside the cylinder is always kept at 30-35 psi, which is enough to send the solution inside the bamboo.
- Solution inlet: The mixed solution is poured through this inlet.
- Solution regulator: This regulates how much solution is let out of the cylinder.
- Hand pump: A simple manual pump to put pressure into the cylinder. An electric compressor can be used if labour is expensive, and electricity is available.
- Pressure regulator: To regulate how much pressure is to be let inside the cylinder.
- Solution outlet: In our project we split this into 7 outlets, to let the solution out (see Figure 2-4).



Figure 2: Modified boucherie treatment plant



Figure 3: A nozzle connecting bamboo



Figure 4: –A closer look at a nozzle connecting bamboo

THE TREATMENT PROCESS

This very simple technique can be operated by almost anyone. In addition, we have taken our treatment plant to rural areas where more than 50% of the operators are women.

TREATMENT STEPS

1. The cylinder is $\frac{3}{4}$ filled with preservative using boric acid, borax and water at a ratio of 1:1:10.
2. The cylinder is pressurized (up to 30-35 psi) using a simple manual pump or a motor where ever electricity is available.
3. The valve in the nozzle is pressed open for a split second to let the air out.
4. The nozzle is connected to the bamboo, which is made airtight using a customised rubber hose (see Figure 4).
5. Sap starts dripping from the branch after approximately 5 minutes. It takes about half an hour for the preservative to come out from the opposite end.
6. Treatment should last for at least an hour so that the preservative can reach all parts of the bamboo.
7. The bamboo is then stored horizontally in a rain-protected area for 21 to 30 days until it fully dries.



Figure 5: Men and women using the treatment plant

BAMBOO FLATTENING

One of the key innovations the project made in the construction of the water tanks is to flatten bamboo into strip boards (see Figure 6), which can then be used to make the tank walls. Traditionally bamboo tanks had been made using woven bamboo. However, this has a number of weaknesses. Firstly, to weave bamboo it must be fairly immature and green (i.e. wet and usually untreated). This bamboo is more susceptible to fungal and bacterial attacks, as previous experiences from the 1980s have shown. Secondly, weaving is also a craft skill that is not so easily accessible to all and takes time to master. Using flattened bamboo on the other hand, makes construction of the tank's walls fairly simple for labourers and artisans to adopt, enabling the production of treated tanks from well seasoned mature bamboos that have a much longer lifespan at over 25 years.



Figure 6: Picture of flattened bamboo



Figure 7: Hammer, mallet and chisel hand tools used to flatten bamboo

THE FLATTENING PROCESS

The process for flattening bamboo is very simple and can be done using hand tools such as a hammer, mallet, and chisel (see Figure 7). Bamboos of any length can be flattened depending on the size requirements of your tank. However, it should be noted that, to date, the research team has only built tanks that can hold up to 5,000 litres and further testing and research is needed before validating the feasibility of larger tank capacities.

FLATTENING STEPS

1. Cut a treated bamboo of the required size. To aid ease of splitting, make sure that the selected bamboo culms have a small wall thickness of 15mm or less.
2. Once a culm is selected, proceed to make small incisions of 30-40mm length around the nodes at roughly 10mm intervals by using a combination of hammer, mallet and chisel (see Figure 8).
3. Repeated this process on all the nodes along the length of the bamboo culm.
4. Once all the nodes have had incisions inserted, the chisel or a large machete (if available) can be used to split the bamboo on one side (See Figure 9).
5. Once the bamboo is split along one side, the next step is to pull it open flat using a combination of your body and the mallet to make it fully flat (see Figure 10).
6. Once flattened, the final step is to remove the interior nodes along the culm (see Figure 11) and make evenly placed splits along the length of the culm.



Figure 8: Incision being made at the node



Figure 9: Splitting the bamboo open on one side



Figure 10: Pulling the bamboo open flat



Figure 11: Interior nodes of the culm removed

WALL CONSTRUCTION

In this project we use a new method of wall construction that requires limited materials and is quick and easy to erect. The technique involves splitting bamboo into flattened strips, which are then reinforced using steel hoop stress rings. The walls for the tanks were finished in just a matter of days using only a few bamboos. Variations to this design could be made, including the use of different diameter steel bands. In addition, cheaper steels could be employed, such as rebar, rather than more expensive metal strips. This method of building can also be used to create shelters or low-cost housing.

PREPARATION

All of the bamboo used in the construction of the tank wall should be fully seasoned and treated. In our demonstration tank a boron compound pressure treatment using the boucherie method was employed prior to the construction of the tank. Thirty flattened bamboo boards were used for the walls of the two meter diameter tank. A total of five bamboos split into six pieces were used for the strips. Bamboo posts were also utilised in the initial construction of the tank walls before eventually being removed.

It is important to have an idea of the moisture content of your bamboo when preparing the bamboo strips. For this two meter diameter tank, a great deal of flexibility is demanded for the strips to fit into place. Flexibility can be increased by either making thinner strips or soaking the strips in water, as shown in Figure 12.



Figure 12: Soaking bamboo strips



Figure 13: Positioning steel strips

The bamboo boards should always be fully seasoned and free of any damage caused by bugs. This will ensure they will be at maximum strength.

THE BUILDING PROCESS

The walls of this type of tank are built in a four step process. First, metal bands are set in place at the correct vertical spacing and secured in place using binding wire. The bands are fixed using 10 bamboo posts that are attached to the ground. The bamboo posts and the bands create the frame work on which the rest of the tank can be built. For this reason, it is essential that the bands are level and plumb before further construction. This principle is demonstrated in Figure 13.

After the metal bands are secured in place, the bamboo boards can be attached to the frame. This is done using bamboo strips and binding wire to sandwich the boards between the metal frame as shown in Figure 8. The strips are taken from the top portion of the bamboo culm (i.e. no more than 1 cm wall thickness) and split into six pieces. If the strips are too thick they will not have the flexibility to match the diameter of the tank wall. After being split, the bamboo strips are cleaned of their internodes and given an even profile using a knife, as shown in Figure 14.



Figure 14: Fitting bamboo boards



Figure 15: Cutting bamboo strips

The bamboo boards are pulled tightly against the metal band using binding wire between each of the boards as they are put into place. It is recommended to attach the first bamboo boards in the middle of the strip working outward until the full length of the strip is secured to the metal band. Figure 16 shows half of the tank wall completed, with three of the four bamboo strips secured in place.

Before continuing with the wall construction, it is crucial to establish an entrance to the tank before the other half of the wall is completed. For the demonstration tank featured in this manual, a simple standing ladder was constructed from bamboo to enter and exit the tank. The second half of the wall goes together exactly like the first, pinning the bamboo boards to the metal frame by using bamboo strips and binding wire. It is important to keep the boards as flat as possible against the surface of the metal strips, as this limits the overall thickness of the tank wall and ensures a stronger wall. The internodes of the bamboo boards are removed as necessary to eliminate conflict with the strips and ensure a flat and even connection to the metal bands. Figure 17 shows the tank with all of the bamboo boards attached to the metal bands.



Figure 16: Fitting bamboo board with half the wall finished



Figure 17: Finished wall with all bamboo boards attached



Figure 18: Stapling bamboo strips



Figure 19: Attaching bamboo strips

At this point, it is necessary to remove the bamboo posts from the outside of the tank. However, before doing so, the metal bands must be fixed to the bamboo boards to create an independent structure. This is done by nailing the bamboo strips to the bamboo boards on the inside of the tank using a nail gun, as seen in Figure 18. This prevents the metal bands from slipping laterally down the boards.

At the point of stapling, the wall becomes a structurally independent object. Under loaded conditions all of the hoop stress will be carried by the four circumferential metal bands. Further bamboo strips are attached around the tank wall to increase its rigidity and hoop stress. Six continuous bands are placed on the tank as shown in Figure 19. Each of these bands consists of four bamboo strips; two on the outside of the tank wall and two on the inside. When attaching the strips, it is important to establish an offset between the inside band and the outside band. This offset ensures a continuous circumferential band around the tank wall, and the seam of the bamboo strips does not coincide at a single point.

The bands on the outside are secured to those on the inside using binding wire, which are then nailed to the bamboo boards on the inside and the outside of the tank wall. The bamboo strips are connected using quarter inch steel bolts on either side of the seam where the bamboo strips meet. Figure 20 shows one band with the bolts attached; two for the outside seam and two for the inside seam. It is important that the bamboo used for these bands have a slightly higher moisture level to allow for additional flexibility. If they are too dry, then cracking and splitting will tend to occur as the strips are put into place. If possible, it is important to use strips which have nodes at their end, as this helps ensure that the bolt does not shear through the end of the strip. The internodes are much stronger in stopping any lateral shearing as the orientation of the fibres are perpendicular to the load.



Figure 20: Bolting the bamboo strips

After attaching all of the circumferential bamboo bands the wall is complete. Once complete, a few final adjustments may be required. Firstly, make sure all the bolts are tightened and all the bamboo strips lay flat against the surface of the boards. If there are gaps between the strips and the boards, pull the strips closer to the wall using binding wire. Be sure to check that any protrusions, such as excess bolt lengths on the inside of the tank, are cut off. This is important prior to plastering to ensure that the plaster layer is uniform and of a limited thickness.

DOME ROOF

It is critical to ensure that the tank has a closed roof to protect stored water from contamination. In the design featured in this manual we have chosen a dome roof because of its adaptability to the circular tank. The dome shape can be very strong with the right construction and dimensions chosen. As seen in Figure 21, this structure easily holds the weight of a 90 kg individual. The most important thing to remember when building the dome shape is that the load is distributed evenly across the structure and walls of the tank.



Figure 21: Dome roof with a 90kg load

PREPARATION

Preparation of the roof should be undertaken in a similar manner as for the walls of the tank. Start by cleaning out the inner nodes and making the pieces uniform in cross section from one end of the strip to the other. A uniform cross section is especially important for maintaining a circular shape when the strips are placed on the tank, giving an even load distribution to the tank walls. Depending on the size of the tank required, the roof should have a rise of 30cm from the top of the tank walls to the maximum height at the top of the dome, while a grid spacing of 15cm is ideal for the spacing between bamboo strips. A height of 30cm is considered as optimal in terms of load distribution to the walls.

After determining the rise of the roof and the grid spacing, a simple geometrical model will be required to determine the exact number and flat length of the strips required. It is important to take into account a few points when calculating the strip lengths, one being the square profile of the strips meeting the round tank wall. This will shorten the calculated length of the strips. The other is that the strips placed on the bottom will be slightly shorter than the ones on top. These points can be accounted for, but for some it is better just to fit them into the field as the strips are put into place. It is recommended to estimate the length for the first set of strips on the top half of the dome and fit the rest of the strips as needed. The more preparation you can do the smoother the process will be.

THE BUILDING PROCESS

The first step is to find the middle of the tank and place the two centre pieces of the arc perpendicular to each other. These pieces should be drilled and fixed together in the middle to ensure a near perfect arc shape (see Figure 22). Setting these two pieces correctly will tell you how well the following strips follow the arc.

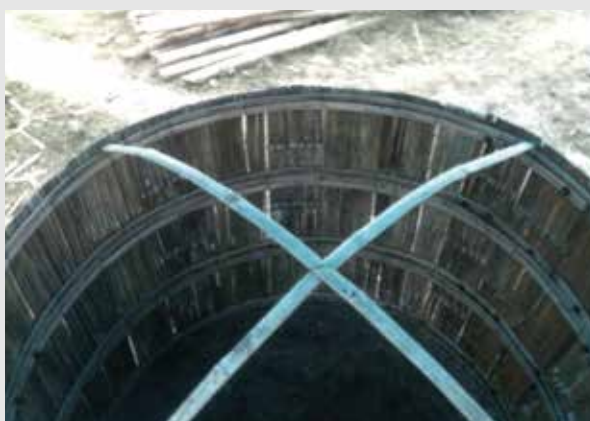


Figure 22: Beginning to construct the dome roof



Figure 23: Half dome roof

The next step is to attach the first six strips covering half of the dome as shown in Figure 23. Setting these strips will indicate how accurate the estimates of their length and how circular the tank is. If the strips are measured correctly they will just make contact with the tank underneath when set in place. Laying the strips is a delicate process; erring by a few centimetres makes a big difference. Therefore, it is worth taking some time at the beginning of the layout process to get the space as near perfect as possible. When all the strips are put into place, they should be attached to the walls using binding wire, with the centre strip being used in a criss-cross pattern to ensure the strips do not move later on.

Next, attach the strips laying on the underneath of the dome to all parts of the tank, as shown in Figure 24. This can be achieved using binding wire or bamboo pegs to secure each strip as it is fixed to the next. You should ensure that the dome maintains a symmetrical shape during construction. If one side is flatter than another, the sides will bulge. This is an indication that your strips are not sized correctly, with one piece overworking another and pulling it out of symmetry. Making any necessary corrections before all strips are secured is therefore highly important, and will help to complete the grid on one half of the dome. After completing this half of the dome, you will feel the strength and rigidity of the dome increase dramatically as the load is distributed to all sides of the tank. For this type of structure, rigidity is of the utmost importance. Prior to plastering the tank there should be little or no bulging when load is applied to it.



Figure 24: Attaching a grid network for dome roof

As the grid network is completed, all access to the inside of the tank will be blocked, so refrain from dropping valuable tools inside until the entry port has been cut. After finishing all structural members of the grid, other non-structural members should be attached to fill the gaps as shown in Figure 25. The gap should be small enough to support the cement plaster so it does not fall through. For this tank a final spacing of 7cm proved to be too large. Support is likely to be needed when plastering the roof. This extra step can be easily avoided by attaching more strips and making the grid spacing smaller.



Figure 25: Attaching additional bamboo strips

The next step is to cut a hole in the roof of the tank for the lid. Many different lid designs can be used, but it is important to keep a few things in mind. The opening should be big enough to allow easy access into the tank and should be easily sealable to ensure no outside debris can enter the tank. A minimum width of 56cm is suggested. The lid should also be resistant to the elements and should have a lip of at least 1 inch to allow space for the plaster that will be applied around it. For this tank, a square lid was prepared of 53cm width with stainless steel on the top. Hinges and a lock also allowed ease of opening and security. The lid was attached using binding wire and eight bolts around the outside. Figure 26 shows the opening being cut into the bamboos and the application of the lid.



Figure 26: Cutting an opening and attaching the lid

MOISTURE PROTECTION

One of the problems with bamboo cement construction is the adherence between the bamboo and the concrete. This is due to the moisture exchange between the bamboo and the cement. Often the bamboos used in construction will shrink as the moisture is sucked out of them into wall. This decreases the adherence of the concrete to the bamboo and can cause significant reductions in strength and structural failure. To limit these effects, bitumen was applied to all surfaces of the tank prior to plastering. Easy application can be done using an air compressor and spray nozzle. Three quarts of bitumen were applied to the tank, as well as two quarts of turpentine, lowering its viscosity and allowing for an even coating. The completed tank, with a full coat of bitumen is shown in Figure 27.



Figure 27: Application of bitumen coating

FOUNDATION AND PLASTERING

In our original demonstration tank in Nepal, the foundation and the tank plaster were completed at a different site than the building of the bamboo frame. The bamboo frame was transported by tractor to a site in Madi, Nepal. The foundation and the plaster were completed in two weeks with a team of two individuals. More delicate procedures, such as plastering the tank edges, take a longer time. A rubble and trench foundation was used for this tank using large river rocks as the base and pouring concrete over a simple rebar reinforcement structure. The main drain and flush were built into the foundation and an access panel was created for access and protection of the piping. The plastering was done layer by layer in a total of six days; including a scratch coat and a final coat for the inside and outside, plus a single coat for the top inside and outside.

PREPARATION

The foundation and plastering requires a total of twelve 50kg bags of cement, one load of sand and a load of small and large river rock for the foundation. Water proofing compound was also used for the foundation and wall plaster. One roll of standard chicken mesh was used to cover all of the tank's surfaces. Much planning and consideration as to the purposes and requirements of the tank should be given before choosing a location. For this tank we chose a location which could be used for irrigation of some crop. In Madi the water level is less than ten feet in most places so a well was dug and an eighty watt solar pump was employed as the water source to fill the tank.

THE BUILDING PROCESS

Figure 28 shows the site chosen to build the tank. A compass can be used to mark the correct diameter for the tank and to dig a 1 foot hole in the ground. A piece of rebar should mark the exact centre of the tank foundation. For the foundation and the floor of the tank it is important to maintain a small bowl shape for the water to drain and for maximising the strength of the tank floor. The diameter of the foundation should be made one foot wider than that of the tank to allow a solid platform to build on. In addition, a space should be provided for the access panel for the plumbing at the edge of the circle.



Figure 28: Site and foundation preparation



Figure 29: Fitting pipe and laying river rocks

Next, the piping can be set in place, including river rocks positioned as shown in Figure 29. One pipe should be set in the exact centre of the tank for the complete flush and another offset by four inches to act as the main access drain.

The beginnings of the access port can now be plastered, establishing its dimensions and securing the piping that drains into it. Figure 30 shows the access port with concrete on the floor and the piping secured. It is important to note when building the access port, to allow sufficient space round the pipes for maintenance and any additional hardware.



Figure 30: Access port



Figure 31: Pouring a concrete foundation

Metal reinforcement should be carefully positioned prior to pouring the first layer of concrete over the foundation. It is important to maintain the bowl shape during this entire process. Figure 31 shows the rebar mesh laid for reinforcement after the application of the cement. For these layers of concrete, smaller stones were used to fill gaps between the base layer of rock, as well as to increase the strength of the concrete in the foundation.

It is important to include a drain and a space for future plumbing in the bottom of the access port (see Figure 32). The opening should be filled with sand and the drain used can be a plastic piece of pipe protruding a few inches into the earth. At all times, the threads and the openings of the piping should be protected from being filled with concrete. A simple plastic bag works for this purpose.



Figure 32: Access port



Figure 33: Drain and future pipe accommodation

At this point, the foundation can be left to cure for one day and the tank frame can be set in place to begin plastering. Before plastering, chicken mesh should be applied to all surfaces of the tank, both the inside and the outside. It is important to make sure that the chicken mesh is tight against the surface of the tank walls. If the chicken mesh hangs loosely on the tank then so will the plaster that is applied to it. It is easiest to apply the chicken mesh with a team of two. One person works on the inside and the other works on the outside of the tank walls. At this point, it is of the utmost importance to ensure the tank is level prior to plastering. This can be done using a level pipe and a plumb line. Tilt the tank and push it until it sits level and secure to the rebar attached to the foundation (see Figure 34).



Figure 34: Tank ready for plastering



Figure 35: Concrete reinforcement at the tank base

Fill the bottom edge of the tank is plastered and any gap between the foundation and the tank with concrete, as shown in Figure 35. It is important to apply a thicker layer of concrete around the bottom of the tank, as it will carry the maximum hoop tension when loaded.

Apply the first scratch coat of plaster to the outside wall of the tank. The surface should first be splashed with a mixture of water and pure concrete before the plaster is applied (see Figure 36). The finished scratch coat on the outside of the tank is seen in Figure 37.



Figure 36: Application of the plaster scratch coat



Figure 37: finished scratch coat

The final coat of plaster can be applied the day after the scratch coat, with the second coat applied in much the same way as the first. Always remember to begin by applying the water and cement mixture. Figure 38 shows the application of the final layer of plaster on the outside of the tank. The wall is made plum and as flat as possible during plastering.



Figure 38: Final exterior coat



Figure 39: shows the tank with the completed outside layer of plaster. Finished exterior coat

The next step in coating is to do the same procedure on the inside wall of the tank. It is best to wait at least one day after plastering the outside before beginning on the inside plaster. The procedure is exactly the same as for the outside, beginning with a scratch coat, waiting one day for it to cure, and finishing with a final coat of plaster. Figure 40 shows the inside wall plaster.



Figure 40: Interior plastering



Figure 41: Floor plastering



Figure 42: Access port final plastering

Along with the final layer of plaster on the inside of the tank wall, a final layer of plaster is applied to the tank floor. Once again it is important to maintain a bowl shape when plastering the floor. At this stage, it is also of utmost importance to make sure that the plaster meets exactly with the mouth of the flush pipe at the centre of the tank. This will allow the water to be completely flushed from the tank. The adjacent pipe should have a few free inches above the bottom of the tank floor. The final layer of plaster on the floor can be seen in Figure 41.

A final layer of plaster is applied to the access port before adding the lid. This will mark the final dimensions of the access port. For this tank, the access port was approximately 21x22 inches and 24 inches deep. This dimension was chosen to allow ease of access to the pipes and valves inside. For the finished plaster for the access port (see Figure 42).

After finishing two coats on the inside and outside of the tank and the access port, the roof plastering can begin. For the demonstration tank pictured in this manual, the spacing of the bamboo strips was too wide to support plaster, so we used additional cardboard and bamboo supports on the inside of the roof to fill the gaps. This allowed for easy application of the plaster to the roof, which was done using one coat (see Figure 43).

Figure 44 shows finishing touches to the roof plaster taking. Special care should be taken on the roof edges



Figure 44: Roof plaster finishing and overflow pipe

For this section, it is important to take a step back every now and again to make sure the proportion of concrete is even over the surface of the tank. Figure 44 also shows the addition of an overflow pipe.

The last step for the access port is to create a final slab a few inches above ground and secure the lid on the top. This is seen in figure 46. A final layer of plaster is also applied to the edges of the slab and around the base.



Figure 45: Completing the roof plaster

Figure 46: Finished access port

Figure 47: Finishing inside roof plastering

After removing the cardboard supports from the inside of the tank, plaster can be applied to the inside of the tank roof. Figure 47 shows the finishing touches of the plaster around the entry port of the tank. Special care should be taken in this section as gravity is working against you. If needs be, this section should be done in two days. It is better to take the extra time and allow time for the concrete to set rather than do it all at once.

Finally, a layer of cement and water should be brushed over the entire inside surface of the tank to seal it and protect the concrete from moisture penetration. Figure 48 shows the application of the cement water mixture over all inside surfaces of the water tank Figure 49 shows the finished tank with all coats of plaster.



Figure 48: Cement water mixture interior application

Figure 49: Finished water tank

FUTURE IMPROVEMENTS

Improvements and changes to the tank design are dependent on the location of the tank and customer requirements. It may be necessary to make changes to reduce cost as the availability of certain materials will change from location to location.

The largest cost for this tank was the concrete. Reducing the use of concrete should always be thought about during the construction of the tank. Some future variations to this tank may be employed such as an un-plastered tank. For a more temporary structure one could simply use the structural bamboo frame and seal the inside with a plastic tarp or another water proof material. However, this has yet to be tested.

OVERFLOW

If possible, all the hardware and plumbing should be protected from the elements and put in a place that is easily accessible. For future tanks, the access port could run the entire height of the wall. The overflow and all other hardware would then be placed inside of the protected area in a similar manner to the flush and main drain pipes.

INFILL

The infill for this tank was assumed to be through the main entry door of the tank, but for all practical purposes this is not an easy place to access as it sits on the top of the tank – nearly two meters high. It is therefore recommended that future tanks have a separate infill port next to the overflow with its own shut-off valve. This would also be encased inside an access port protected from the elements.

LID PLACEMENT AND ACCESSIBILITY

The placement of the entry port into the tank is also very important for a number of reasons. The entry port for this tank was put on the very centre and at the top of the roof, where it is only accessible with a ladder. Future tanks should have the entry port on the outer edge of the tank next to all the other hardware and pipes.

SPACING OF BAMBOO BOARDS

To increase cohesion between the inside and outside layers of plaster on the tank walls, small gaps should be left between bamboo boards when building the tank walls. This will allow for contact between the plaster on the outside and inside of the tank and an overall stronger wall.

CHAPTER 2

TRANSPORTING WATER USING A MECHANICAL PUMP

For the water tanks developed in Chapter 1, two sources of water were considered for storage: rainwater, which can be collected from roofs provided the tanks are appropriately sited, and ground water. For ground water, the team looked to develop mechanical hand powered pump systems that can be built using off-the-shelf components.



THE PUMP SYSTEM

A Bicycle is the most readily and widely available off-the-shelf tool – with more than a billion bicycles in use around the world today – to convert human muscle power to useful mechanical energy. To build a mechanism that is easy to operate and maintain, even in remote locations, off-the-shelf components give a fair advantage. All the components used in the mechanism detailed in this manual are available off-the-shelf, which makes it installable in any remote location, requiring minimum expertise to maintain the equipment. Furthermore, this device allows for lateral transport of water; at present, there are very few cheap systems for pumping water laterally that can replace carrying water from a well.

In this particular endeavour, an off-the-shelf centrifugal pump is driven with the help of a bicycle; by employing a frictional drive mechanism. An arrangement is made to drive the prime mover of the pump with the help of the rotating rear wheel of a stationary bicycle. During the operation, the bicycle is stationed on its stand and the rear wheel is free to rotate upon pedalling. A contact is made between the roller of the centrifugal pump assembly and the rear bicycle wheel to transfer rotational kinetic energy from the wheel to the pump.

The impellers of the off-the-shelf centrifugal pumps available in the market typically operate on two speeds – 1500-3000rpm. Therefore, the frictional roller extension to the impeller shaft needs to be driven to 1500-3000rpm, accordingly, for optimal performance at the pump. Both pumps were considered in the proof-of-the-concept experiments and a ¼ kW pump that operates at 1500rpm is used to build this system.

Now, to achieve the desired speed in the impeller of the pump, the constraints here are the speed with which the bicycle wheel can be driven and the diametric ratio of the two rotating members in the picture – the bicycle tire and the friction roller. The two parameters need to be fixed to practically feasible values in order to achieve a speed of 1500rpm in the roller while driving the rear bicycle tire with practical speeds doable by an average human being.

Considering a diameter of 6cm for the roller, for practical purposes, with the diameter of the bicycle tire around 60cm, to achieve a speed of 1500rpm in the roller, the bicycle tire needs to be driven at 150rpm. This means a linear speed of 18 km/ph, if the rider were to commute on the road to clock the same 150rpm on the wheels. As the speed with which the bicycle wheel needs to be driven is within the practical limitations, the next task at hand is to build the physical system according to the above specifications.

$$\text{Speed of the roller} = \text{Speed of the tire} \times \left(\frac{\text{diameter of the tire}}{\text{diameter of the roller}} \right)$$

PREPARATION

To build this system, the following components are needed:

- Centrifugal pump assembly 2800rpm
- ¼ HP Centrifugal pump with pulley and base
- Pedestal bearings
- Roller ball bearings
- Nipples and nozzles
- Aluminum roller shaft
- M.S. L-angles
- M.S. Plate
- M.S. Block base
- High tension nuts and bolts (M12 and M16)

THE BUILDING PROCESS

The centrifugal pump is arranged on a platform to have an extension to accommodate the friction roller. This friction roller extension is made of aluminum to keep it light in weight, and also to ensure minimum loading on the bearings during the operation. The impeller shaft is supported by a roller ball bearing on the outer end, just after which there is a provision made to attach the roller. The other end of the roller is appropriately positioned on a pedestal bearing. This whole pump, roller, bearing setup is mounted on a flat plate to avoid misalignment issues. In order to improve the coefficient of friction between the roller and the bicycle tire, the roller is wrapped with a sheet of rubber. This is done by using a special metal-rubber adhesive to hold the rubber firmly on the roller.

Now that the whole arrangement is on one plate, the friction roller needs to be properly positioned so that it aligns perfectly with the rear bicycle tire to drive the pump. For this, the plate is in turn placed on an angular frame and is provisioned to move to and fro on this frame, so that the roller can be adjusted to touch the bicycle tire as required. A screw mechanism is provided between the plate and the frame to facilitate this movement.

All the components of the system are painted after being verified for any possible misalignment issues. To operate, this newly built system is placed on the ground, just behind the rear bicycle tire, such that there is a gap of 5-8mm between the tire and the friction roller. This gap is provided to allow the bicycle wheel to move backwards and touch the periphery of the roller after the rider gets on the stationary bicycle positioned on its stand. The system is now ready to be tested.

TRIAL TESTS

In our project, a total of three trial runs were carried out using the newly built pump. It was tested to pump water to different heights and to operate on the pedalling capacity of three individuals aged 18, 25 and 40 years old, respectively. The results of the tests are provided below.

Trail Run 1

| Age of rider: 18 years | | Water pumping head: 25ft | |
|------------------------|--|--------------------------|--|
| No. of litres (n) | Cumulative time taken to pump 'n' litres (seconds) | | |
| 1 | 8.1 | | |
| 2 | 16.9 | | |
| 3 | 25.6 | | |
| 4 | 35.6 | | |
| 5 | 45 | | |
| 6 | 54.7 | | |
| 7 | 65.2 | | |
| 8 | 74.2 | | |
| 9 | 82.8 | | |
| 10 | 91.5 | | |

Average Pumping Rate = 9.15 seconds per litre => 393 litres per hour

Trail Run 2

| Age of rider: 25 years | | Water pumping head: 20ft | |
|------------------------|--|--------------------------|--|
| No. of litres (n) | Cumulative time taken to pump 'n' litres (seconds) | | |
| 1 | 26 | | |
| 2 | 41.6 | | |
| 3 | 56.6 | | |
| 4 | 76.4 | | |
| 5 | 96.5 | | |
| 6 | 108.1 | | |
| 7 | 122.7 | | |
| 8 | 135.4 | | |
| 9 | 154.8 | | |
| 10 | 165.3 | | |

Average Pumping Rate = 16.53 seconds per litre => 217 litres per hour

Trail Run 3

Age of rider: 40 years

Water pumping head: 15ft

| No. of litres (n) | Cumulative time taken to pump 'n' litres (seconds) |
|-------------------|--|
| 1 | 25 |
| 2 | 49 |
| 3 | 74 |
| 4 | 94 |
| 5 | 124 |
| 6 | 149 |
| 7 | 175 |
| 8 | 205 |
| 9 | 230 |
| 10 | 255 |

Average Pumping Rate = 25.5 Seconds per litre => 141.1 litres per hour

FUTURE IMPROVEMENTS

The flow rates at various heads of pumping are mentioned in the above tables. As the off-the-shelf centrifugal pump used in this system has an impeller that is designed to pump efficiently at a specific head and flow rate, its performance fluctuates depending on varying heads. Though more expensive than an off-the-shelf solution, a custom made impeller to suit the specific application here would result in better performance in terms of flow rates at greater heights, even with just as much power supplied to the pump from pedalling in the above mentioned trials. Also, higher speeds to aid pumping to higher heads can be achieved with an additional gear mechanism such as a pulley drive.



Figure 50: A working prototype of a bicycle driven water pump

CHAPTER 3

HOW TO MAKE AND OPERATE A BIOSAND FILTER

To treat the water stored in our bamboo tanks, a biosand filter was used. A biosand filter is a household water treatment system that uses fine sand to filter out a large portion of microorganisms, such as bacteria, protozoa, worms and some viruses. If properly built and operated, over 90% of bacteria can easily be removed.



PREPARATION

To construct a biosand filter the following materials are needed:

Fine sand, washed and less than 0.5 mm in grain size (ideally between 0.15 to 0.35 mm).

Separation gravel 6mm in diameter, completely washed.

Drain gravel 12 mm in diameter, completely washed.

Half-inch or 13mm inner diameter PVC pipe; three 90-degree elbows, glue.

A 70-100 litre tank with a minimum of 60 cm height (taller tanks are more desirable).

Screens to sift the gravel and sand to obtain the appropriate sizes.

Wood and a hammer and nails to make a frame for the screens for sifting.

Basic carpentry tools, such as a saw, measuring tape, hand drill, and knife.

Exact volumes required depend on tank size. Therefore, it is best to calculate the required volumes after you purchase the tank. Calculations will be shown below.

SAND AND GRAVEL PREPARATION

Build a wooden frame, approximately 60 by 90cm. Attach screen using nails or staples; Sift the gravel and sand through the screens to obtain the appropriate sizes for the sand and two sets of gravel. The best sand and gravel come from a construction site or crushed rock. If that is not available, river sand may be used. Ocean beach sand is not ideal because it may contain dissolved salts from the ocean.

Wash the gravel, but be sure to keep each size separate so as not to get them mixed up. The gravel must be washed thoroughly until the water rinses away completely clean so that no sediment or dirt remains on the gravel at all. The number of washings depends on how dirty the sand is. Figure 51 shows the picture of a jar test. After swirling the sand and water, let it sit for 3 to 4 seconds then observe the jar. If the water above the sand is only a bit cloudy, it is good. If it is very cloudy and you can't see the top of the sand when it settles, you must wash it more. Dry the sand and gravel in the sun in a clean place. This further helps to kill any residual microorganisms.



Figure 51: Sieves used for sifting and washing sand and gravel (Source: CAWST, 2008)

PREPARE TANK AND PVC PIPE

First cut a piece of PVC pipe to fit the entire diameter of the inside of the bottom of the tank, as shown in Figure 52. Make tiny holes in this PVC pipe so that water can get through. The holes should be tiny enough so that the gravel cannot get in. Then cut a piece of PVC pipe for the vertical part of the tank. If the tank is only 60cm high, then the overall height (including the elbow to turn it 90 degrees) should be 55cm. Another elbow and piece of horizontal pipe are required to now bring the PVC pipe out of the tank;

Make a hole in the side of the tank to bring the PVC pipe out of the tank. The third elbow can now be used on the outside of the tank to direct the flow of water down, and into a clean water storage tank (see Figure 53). Use glue to ensure the pipes are well connected together, and seal the hole in the tank where the PVC pipe protrudes from.



Figure 52: PVC pipe fit to the diameter of the bottom of the biosand filter tank



Figure 53: PVC pipe third elbow directs water outside of the tank for clean water storage

INSTALL THE FILTER

Add large (12mm) gravel to the bottom of the tank. The height of this gravel should be 4cm to 5cm, or 0.04m to 0.05m (not more). If the tank has a diameter of 40cm, then the radius (r) is 20cm = 0.2m. To calculate the volume (V) of large gravel required we use the following equation:

$$V = \pi r^2 h$$

Note that $\pi \approx 3.14$

Therefore, in our example tank above the volume required is:

$$V = 3.14 * 0.2^2 * 0.05 = 0.0063 \text{ m}^3 = 6.3 \text{ L.} \quad \text{Note that } 1000 \text{ L} = 1 \text{ m}^3.$$

Next, add the smaller (6mm) gravel on top of the larger gravel. The height and volume required are identical to those used for the larger gravel (i.e. 5cm height, and about 6.3 litres total volume of small gravel). Water must then be added prior to placing the sand in the container. The height of the water must always exceed the height of the sand while adding the sand. Never add the sand dry.

After water is in the tank, add sand. You may alternate between adding water and sand. The height of the sand in the tank should be a minimum of 40cm. The sand level should be about 5cm below the elbow at the top. Keep adding more water to see where the standing water level is (where the water stops flowing). It should be somewhere around the PVC elbow that leads out of the tank. After water stops flowing, measure the height of standing water that is above the top of the sand (make sure there are no peaks or valleys in the sand, it should be completely flat).

The height of the standing water MUST be 5cm. If it is more, then add more sand. If it is less, then remove some sand (and make the sand flat again!). When you alter the sand height, the standing water level will also change. Therefore, you must, again, wait for the water to stop flowing, and measure the water height above the sand again. This is often a time consuming process, but it is crucial in order for the filter to work.

After the correct amount of sand is in the filter, add a diffuser plate to the top. This is a plate or bucket with tiny holes in the bottom. The water must be poured through this diffuser plate so that it doesn't splash down quickly onto the sand and destroy the biolayer. A small plastic container sitting on the top of the tank will suffice. It is important to protect the filter – use a lid to reduce the chance of anything entering.

DEVELOP THE BIOLAYER AND POUR IN WATER

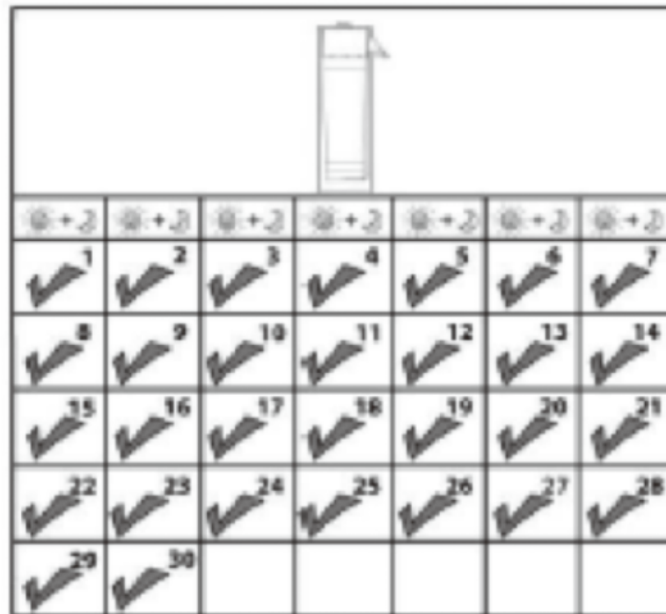


Figure 54: Using a calendar may help users remember to pour water into the filter every day; do not drink for the first 30 days (Source: CAWST, 2012)

On the top of the sand, a community of microorganisms will develop. This is desirable and improves the filter's performance. Therefore, care must be taken with the biolayer.

First, choose the source water that you will be using to put in the filter. Try not to change where you get the water from because that will change the biolayer. Be sure to add water every day to the filter (see Figure 54). You can add water more than once per day, such as morning, noon, and night. But, you must pour water in at least once per day. The volume of water you can add is equal to $1/3$ of the volume of sand used. In this case, the volume of sand is approximately $0.4\text{m} \times 3.14 \times 0.2\text{m}^2 = 0.05\text{m}^3 = 50\text{ L}$ for a tank that has a 40cm diameter. Therefore, the water that can be poured into the filter at any one time is $50\text{ L}/3 = 16\text{ L}$.

Do not use the water for the first 30 days. But during these 30 days, you must still pour water in it every day, from the same water source.

CALCULATIONS

Surface Area

Assuming a tank diameter of 40 cm, and a radius of 0.2m, the surface area is calculated using the following equation:

$$SA = \pi r^2 = 3.14 * 0.2m^2 = 0.1256m^2$$

Sand Bed Volume

Assuming a sand bed height (h) of 0.4m, the sand bed volume is calculated using the following equation

Sand Bed Volume = $h * SA = 0.4m * 0.1256m^2 = 0.05m^3 = 50L$ of sifted and washed sand, packed down, per filter

Gravel Volume

Assuming a gravel height (h) of 5cm (0.05m), the gravel volume (for each type of gravel size) can be calculated using the following equation:

$$\text{Gravel Volume (for each type of gravel size)} = h * SA = 0.05m * 0.1256m^2 = 0.0063m^3 = 6.3 L$$

Total PVC Pipe Length

The length of PVC pipe (L) required is calculated using the following equation:

$L = \text{diameter of tank} + \text{vertical height of water} + \text{horizontal outlet (but this may be longer if required to reach a storage tank)}$

$$L = 0.4 + 0.55 + 0.05 = \text{at least } 1m, \text{ as well as three } 90^\circ \text{ elbows}$$

Approximate Capacity

The sand bed holds water of roughly one-third of the volume of sand:

$$50 L / 3 = 16L$$

This is how much water should be poured into the filter, with pause periods in between.

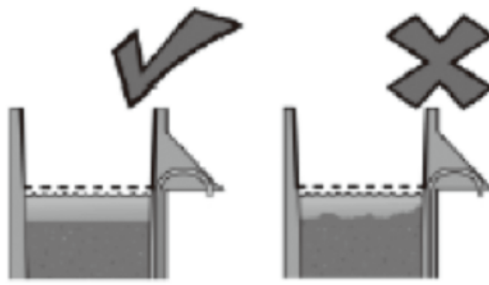


Figure 55: The sand should be completely level, with a standing water height of 5cm above it. A diffuser plate (see dotted line) should always be used (Source: CAWST, 2012)

When operating the system, users should take note of the following points:

Water that has had a disinfectant added to it (such as chlorine, or sodium hypochlorite) should never be poured into the filter; this will destroy the biolayer.

The filter must be used every day to ensure nutrients are being fed to the microorganisms in the biolayer.

Never let the top of the sand dry out or be exposed to air. It should always be covered by 5 cm of water.

The source water should not be changed. The biolayer in the filter eventually adapts to the type and level of contamination found in the source water. If the source water is changed, it can take several days (or even weeks) for the biolayer to adapt to the new source water. During this time, the water coming out of the filter may not be safe to drink, and another method to kill microorganisms (such as SODIS, boiling water, or adding chlorine) should be employed.

A diffuser plate should be used at all times to prevent the top of the sand from being disturbed by the incoming water. A lid should be used at all times to protect the filter and prevent additional contamination.

The top of the sand should be flat and level – without any valleys or hills in it (see Figure 55).

When water stops coming out of the filter, the water depth above the sand should be 5 cm.

A pause period of a minimum of one hour and a maximum of 24 hours should be provided in between pouring unfiltered raw water into the filter.

An initial flush of the filter should be performed, where 40-80 litres of water are poured through it to remove any dirt and fine sediment that might still be in the sand and gravel. Water should be poured through until it comes out clear. If, after pouring over 120 litres of water through the filter, the water does not become clear, it means that the gravel was not washed enough. In this case, there is no option other than to remove the sand and gravel, sort it, and then wash the gravel more, until it is completely clean. Then, reinstall the filter using the clean gravel.

Clean the outside components of the filter periodically by washing with soap and in clean water, the diffuser plate and the lid. The water used for washing does not have to be filtered water, but it should at least be clear. Wash the outlet tube with filtered water.

It is always recommended to use some sort of disinfectant technique after the filter, since the filter does not remove 100% of the bacteria. This disinfection can be in the form of SODIS, boiling, or adding a chemical disinfectant such as chlorine.

Clean the inside of the filter using the swirl and dump method. This is done when the flow rate slows down too much to be useful. For this technique, it is similar to the raking method described for larger filters. First, take off the lid and diffuser plate. Second, using the flat side of your hand, touch the sand and swirl your hand around in a circle a few times to stir up the very top layer of the sand. Third, quickly scoop out the water above the sand using a small cup. Be careful not to dig into the sand with the cup. Fourth, dispose of this water somewhere safe, such as in the bushes. Finally, make sure the sand is still flat at the top, and replace the lid and diffuser plate (after cleaning it). Wash your hands and pour a fresh bucket of water into the filter.

The cleanest water available should always be used for the filter.

The flow rate will vary based on the filter dimensions. However, the filtration rate of 0.1 to 0.3m per hour should always be followed. That means that water should pass through a vertical column of sand, only 10-30cm high, in one hour and no faster. This allows enough time to filter, adsorb, digest, and break down contaminants.

Do not move the filter once it is installed. This would shift the sand and gravel, and compromise filter's performance.

CHAPTER 4

MAKING A REED BED FILTER

In this project, we also developed a reed bed filter system for grey water recycling. At the time of publication, the research team was also evaluating the use of bamboo to filter grey water. Grey water is the water that has come in contact with soap and detergents from laundry, bathroom sinks, showers, and bath tubs. However, it does not include water that has come in contact with faeces. Grey water may contain traces of dirt, soap, detergent, hair, and oil. It can pollute rivers and pond if released without treatment but it has also been identified as a potential source of irrigation or for cleaning purposes.

In a field study undertaken in Nepal for example, 60% of the daily water usage was found to be used for cleaning purposes. By cleaning and reusing this water, grey water recycling can minimise fresh water usage, and prevent soil, water and environment pollution. It is a sustainable household solution that is capable of addressing the issue of water shortages.



REED BED FILTER TREATMENT

For the treatment of grey water, a wetland that has mediums like sand, gravel, bones, iron and live plants is constructed. Waste water is distributed evenly on the bed of the wetland and the water flows through reed and sand mixed with bones and calcium (see Figure 56 1). Like bio-sand filters, dirty water goes through various stages of biological, physical and chemical processes of purification as it passes through the layers of the filter.

The most commonly used plants for this application are reeds. The roots of reed plants have aerobic and anaerobic microorganisms that facilitate the decomposition of organic matter present in waste water. While reeds collect phosphates out of grey water, bone chars remove fluoride, sand and gravel help in the filtration and sedimentation of solid particles present in the water. Phosphorus is co-precipitated with iron and calcium compounds (placed in the form of bones) located in the medium.

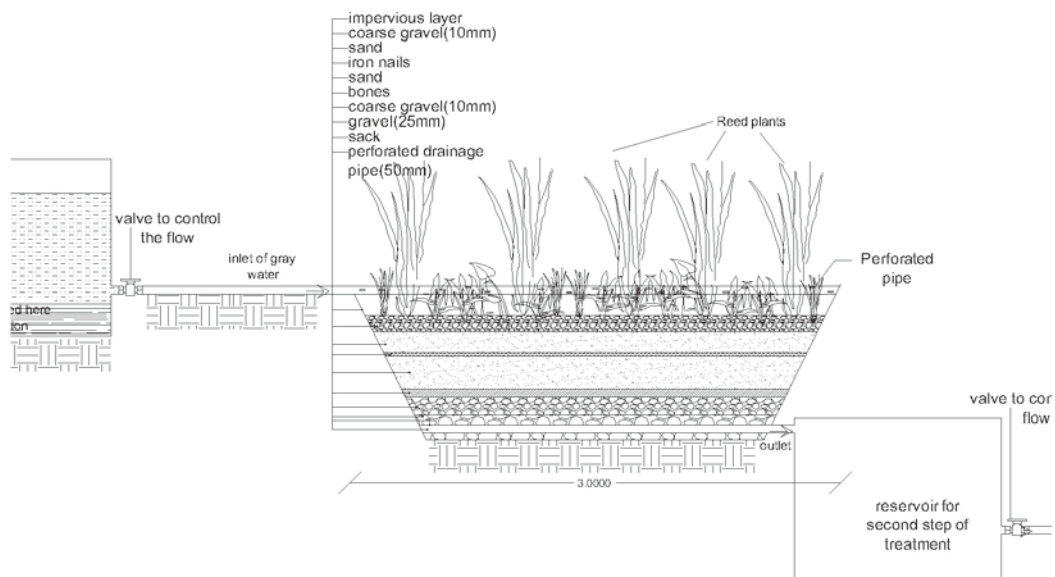


Figure 56: Details of a reed bed water treatment system

THE BUILDING PROCESS

The following steps can be followed to make reed bed:

First, a 500 litre tank has to be dug to collect grey water directly from the kitchen and/or bathroom. This is because any solid particle present in the water will settle down in this tank instead of directly sending it to reed bed. Do not connect sewage to this system. Make an outlet using a 10cm pipe with a valve right above the bottom of the tank.

Dig two pits of 3m long, 1m wide and 1m deep. The first pit should be 1 m higher than the next one. These 2 pits are the two different stages of reed beds where the water will be treated. In both trenches, apply a thick plastic sheet in order to prevent water from leeching. Fit a 5cm perforated pipe at the bottom of the 1st trench as shown in Figure 57, then cover it with jute cloth so that it prevents sand from entering into the pipe.

From the bottom, use 25-36mm of coarse gravel as the first layer, up to a height of 25cm, then add a layer of sand and bone char for the next 25cm layer of the pit. Another layer of fine sand should be added covering a further 25cm in height. Meanwhile, after this layer comes a layer of iron nails and sand, which should occupy the top portion of the tank.

The topmost surface of the pit is then covered with coarse gravel again. This is because the gravel helps to prevent sand from going down and maintains its level. Do not forget that the reed has to be planted in such a way that the root of the reed reaches the bone char level. These steps are same for both the reed beds.

Fit a 5cm perforated pipe, distributed into five outlets to dispense grey water to the first reed bed. Now make another tank of 500 litres that links to the outlet of first reed bed as shown in Figure 58. The water collected is the treated water from the first stage. This water is then passed on to the second reed bed through the connecting pipe at the bottom of the tank. The water goes through the same process in the second stage reed bed.

The treated water is now collected in another tank right below the second reed bed. This water can be pumped and used for washing, bathing, cleaning, and toilet flushing.

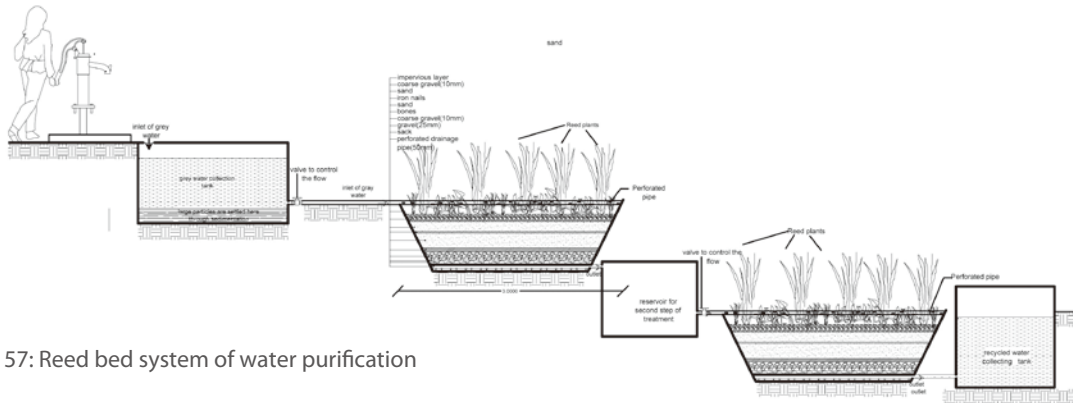


Figure 57: Reed bed system of water purification

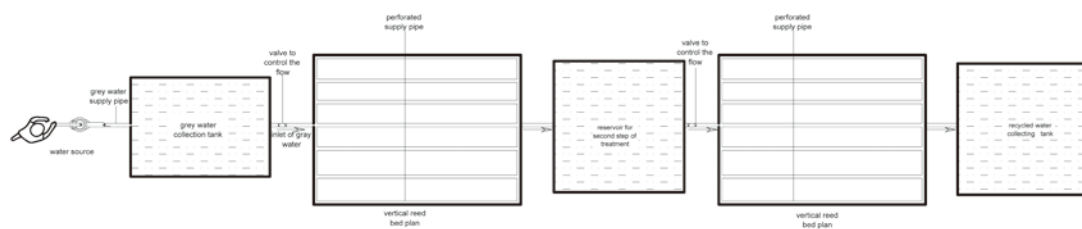


Figure 58: Plan of the reed bed system

OPERATION AND MAINTENANCE

Constructed wetlands require more maintenance than conventional septic-tank-drain field systems. Maintenance includes inspecting all components and cleaning and repairing the system when needed. Visual inspection of the effluent is required and often a lab analysis is necessary. Plants should be inspected and, if a good stand does not exist, replanted. The user can also consider introducing a different species mix.

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INBAR is an intergovernmental organisation established in 1997 to improve the social, economic, and environmental benefits of bamboo and rattan among some of the world's poorest communities. With regional offices in Asia, Africa and Latin America, INBAR draws on expertise from around the globe in assisting government, business and local communities in over 50 countries, to identify new and innovative uses for bamboo and rattan.



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