Aquaponics Ebb and Flow Mechanisms

ECOLIFE Foundation

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Abstract

In rural parts of Africa, many of the inhabitants resort to hunting bush meat (i.e. monkeys, gorillas, etc) for food. This practice threatens the population of endangered species and poses a serious health risk for those that consume it. To help remedy this problem, The EcoLife Foundation has come up with the solution of implementing aquaponic systems in these areas so that hunters have other options for food. Aquaponics offers an alternative and sustainable food source. Aquaponics is a symbiotic system consisting of a tank of fish and a hydroponic plant grow bed. The byproducts the fish give the water promote growth for the plants. The plants absorb these nutrients, essentially filtering the water, and the cleansed water is then recirculated back to the fish. However, for hydroponic plants to grow, water need to be given intermittently. The plants need time for the roots to dry to prevent rot and maximize root-gas absorption. Thus, water cannot be pumped from the fish tank directly to the grow bed. Instead, the water is pumped into another separate reservoir. In a rural area like Africa, automated timing systems are expensive and complex. What is needed is a low tech device that is reliable, adaptable, adjustable, inexpensive, and simple that creates intermittent flow. In order to achieve the best design, 3 different types of siphons were tested: loop siphon, toilet flapper siphon, and bell siphon. Each design had different advantages and disadvantages, but they all encountered failures at both low and high flow rates into the reservoir when equilibrium flow occurred. At certain points in the siphon at extreme (high and low) flow rates, the rate of water leaving the reservoir would become equal to the rate of water entering from the pump. At this equilibrium, the system would not be able to progress on and intermittent flow could not be achieved. The outflow would just continue at a constant rate. However, we found that the bell siphon could overcome these failures much easier than the other solutions when used with a “tipper”. The “tipper” is what we call a long cylinder affixed at an angle on a pivot that, when the hose is

properly angled, fills with the water flowing into the reservoir. When the cylinder is completely filled, the weight of the water creates a moment around the pivot, causing the “tipper” to tip, and pour its contents into the reservoir. This decoupled the flow rates. The tipper causes the flow rate into the reservoir to be more of a “pulse” rather than a constant linear rate. To avoid tipper failure, the hose outlet from the pump must be angled properly. We built a ‘tipper hanger’ to position the hose. It combines the tipper system and the hose outlet so that they cannot move relative to each other. We designed and optimized the best solution though research, testing, design, and calculations.

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Chapter 1: Project Background

Background

In many third world counties, the availability of protein in the people's diet can be scarce. In order to accommodate for the lack of protein, it is very common for people to hunt and consume primates. The consumption of primates or "bush meat" is a threat to not only the humans that consume them, but to the environment as well. Infectious diseases, such as AIDS, and other pathogens can be transmitted from the animals to humans. Deforestation and dwindling endangered species populations come as a side-effect of harvesting for bush meat. Harmful traps and hunting instruments often lead to orphaned infants or mutilated animals that have survived. This practice is not sustainable; bushmeat animals' reproductive maturity ages are too long to be able to replenish what the hunters take away.

Ecolife Foundation, a non-profit organization, is developing an aquaponics system to be established in Cameroon in hopes of educating the local people about their environment and the dangers of consuming bush meat. Aquaponics is a symbiotic system that cycles water and nutrients between hydroponically grown plants and fish that inhabit the system. Hydroponics is the use of growing plants without dirt. Nutrient rich water is fed directly to exposed plant roots. Because there is no dirt, the only fertilizer the plant receives is absorbed through the water. In the fish tank, the fish produce ammonia and helpful bacteria (Nitrosomonas and Nitrobacter) in the water. Nitrosomonas cause ammonia to turn into nitrate; Nitrobacter transforms into nitrate. The water from the fish is then used to water and fertilize hydroponically grown plants, where the nitrates are absorbed as rich nutrients for plant growth. Nitrate buildup in the fish tank becomes toxic for fish, but it is nutritious for plants. In the last phase, the nitrite-less water is finally circulated back to the fish, and the cycle begins again. This system eliminates the need for chemical fertilizers. The intent of the program is to conserve water (aquaponics systems use about 10% of the water required for dirt farming) and to conserve the environment through recycling and not using chemical fertilizers; while providing sustainable food source, both the fish and plants can be harvested for food in a sustainable endless cycle.

Requirements and Deliverables

Our objective is to build an intermittent water flow siphon for aquaponics system that has to be made of low cost materials, easily built, and most importantly, reliable. Building and testing different siphon mechanisms, we will design and build a final design to be implemented in Ecolife's aquaponics system.

A key concept that the siphon must exhibit is the idea of ebb and flow, or interval water supply. The water from the fish tank cannot constantly flow into the plants because the vegetation roots need air; water flow must stop for a certain time before it can be allowed to hydrate the plants again. This avoids rot and aids in root-gas absorption. The given goal for the siphon is that it should dump a reservoir of about 7-8 gallons of water every 8-10 minutes intermittently.

The final design will have to be highly dependable. If the siphon fails, it will back up the whole aquaponics cycle causing the whole system to fail. Cameroon is subject to many brown-outs (where supply of electrical power is unstable), so our siphon has to work even through situations where inconsistent water flow into the water reservoir is an issue. If our siphon works well, Ecolife foundation will look to implement the system in other countries beyond Cameroon. So this means that it will be subject to different environments and conditions.

It must also be highly adjustable. Because different vegetation will require different amounts of water, adjusting the amount of water coming out of the siphon will depend on the type of vegetation grown. The adjustability factor must be simple enough so that the people using it can easily adjust the out flow at any time with ease.

The materials are another consideration which we must take into account. The parts being used have to be safe for animals and consumption. Because the siphon will be in the water being supplied to the fish and plants, the materials cannot contain any harmful chemicals. Likewise, the materials have to be water-safe and cannot corrode; corrosion particles can be harmful to the fish and plants, and ultimately to the people that eat them. Also, the materials have to be inexpensive to buy and readily available. This is because if something does break when the system is implemented in Cameroon, the natives can easily repair it with parts bought or found there.

Other constraints include the water reservoir tub and a water pump, both of which are to be used into the aquaponics system in Cameroon. The cylindrical tub (14 inch in diameter and 22 inch in height) holds about 18 gallons of water. The siphon has to be either in the tub or attached to it. The water pump is another issue. Depending on how high Ecolife foundation wants the water reservoir tub to be (because the water runs through the aquaponics system by gravity); the flow rate coming out of the pump will vary because of head loss from within the pipes the water has to travel through. The higher the reservoir tub is, the more friction and gravity the water in the pipes have to fight so the flow rate is smaller. Vice versa for when the reservoir tub is closer to ground level. So this means our siphon will have to be functional regardless of whether the flow rate in is slow or fast.

Review of Existing Solutions

There are various types of siphon in the aquaponics world. However, when building, most people do it by trial and error, with no real data or formula.

One of the most popular siphons is called the bell siphon. A bell siphon consists of several components, beginning with a vertical standpipe that projects upward from the outlet opening of the reservoir as shown in the figures below. The height of the standpipe regulates the maximum water level for the siphon to start. An additional pipe, called the "bell pipe", is larger in diameter than the standpipe and fits over the standpipe. Along wall of the bell pipe will be a hole near the bottom of the pipe. This hole will act as a siphon breaker. As the water rises, water occupies the space between the walls of the standpipe and the bell pipe. As the water level exceeds the height of the standpipe, water drains down the standpipe, creating a siphon where the water is dumped out. The siphon will run until the water level reaches the hole on the bell pipe, where air breaks the siphon. Once the siphon is broken, water will fill the reservoir until the siphon reactivates.

Another siphon that is popular in the aquaponics world is called the loop siphon or U-siphon. These siphons are popular because of their simplicity; they have a minimal number of parts. A hose or PVC pipe is attached near the bottom of the reservoir and looped up then down and ends at the dump site that is below the reservoir. When the water level inside the reservoir reaches the highest part of the loop, the water in the tube rises concurrently and begins to fall down the other side of the loop, creating the suction needed to begin the siphon. Once the siphon is engaged, it will run until the water level reaches the hose entrance level where air can enter the hose and break the siphon. The siphon breaks and the reservoir will fill once again.

Another common idea we can across in our research was the use of toilet flappers. The method behind the toilet flapper is the exact same concept used in the toilet. There is a piece of plastic called the flapper, which covers an exit hole in the reservoir tub. The flapper is attached to a chain, which is then pulled by some motion that causes the flapper to open. This allows water to flow out of the hole. Because the water coming out of the hole is flowing at such a high rate, it keeps the flapper open until the flow of the exit water lessens (Same idea in a toilet where you push and release the flush button, causing the whole bowl of water to dump even after the initial motion). The actuation device for pulling the flapper can vary. Some people have simply used a floating device that pulls the flapper through tension once the water level rises in the rub. Others have built side devices that extract water from the tub and into a pulling mechanism.

Chapter 2: Description of Overall Design Solution and Design Considerations

Primary Designs Considered:

Some designs, but not all, that were considered were the original Bell Siphon, the Flapper method, and the Loop Siphon or U-Loop siphon. The final design was difficult to come to. When a solution was found for a method, for example a snorkel to break the bell siphon, that solution would be implemented into other methods. Questions of whether the snorkel could also break the Loop Siphon would be examined. Or different diameters of tubes or pipes were also tested. The combinations of these solutions and the 3 main methods were tested vigorously for consistency.

The justification of the primary design used was founded after the right combination of the bell siphon with different apparatuses. A tipper was added into the barrel where the siphon is to introduce an intermittent flow within. Before adding this tipper the bell siphon had difficulty starting siphons because of a trickle effect that would occur when the water would not be able to cover the stand pipe completely, thus suction of water would not occur.

The Bell Siphon

The bell siphon was implemented in the final design knowing that it had to provide intermittent flow of water to the grow bed. The bell siphon must trigger routinely and reliably so that the crops get their nutrients and grow. The bell siphon also needs to start and stop the siphon with varying flow rates into the barrel. It must reset automatically after each siphon. There should be large room for error. The water must continuously cycle to the plants without supervision. Bell siphon stalling and failure can mean ruined crops. In addition, the volume of water that the bell siphon dumps from the reservoir should be adjustable. Larger systems require higher flow rate, while smaller ones less. The bell siphon should be able to be implemented in any size system and still succeed with minor adjustments. Overall, the bell siphon needs to be easy to manufacture and assemble, because the system is intended for use in a developing country. People with limited education may be assembling the bell siphon system and thus it should be easy to make from cheap and readily available materials. Figure 1 through Figure 8 show how the bell siphon functions.

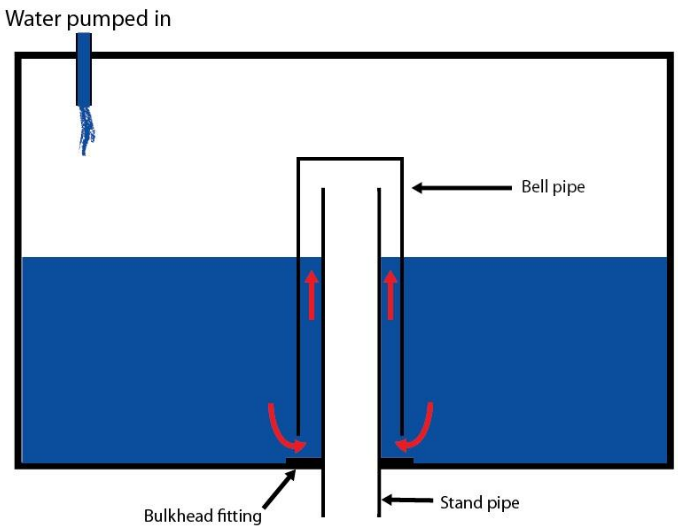


Figure 1: Water level rises in bell pipe as reservoir is filled.

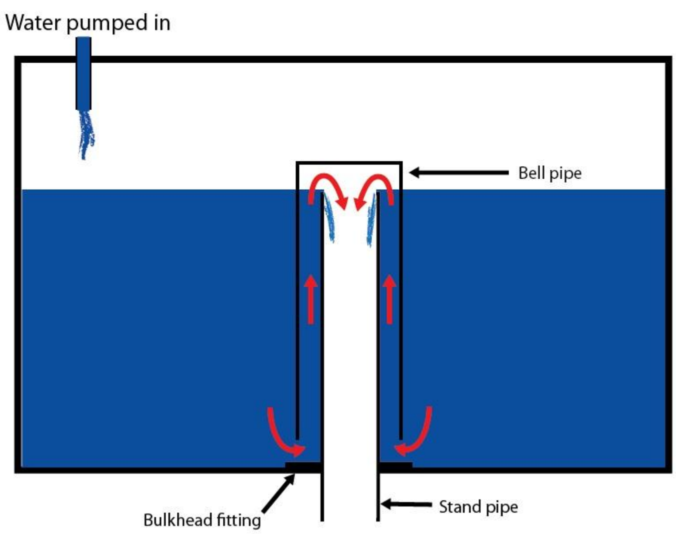


Figure 2: Water trickles over edge of stand pipe with increasing water level.

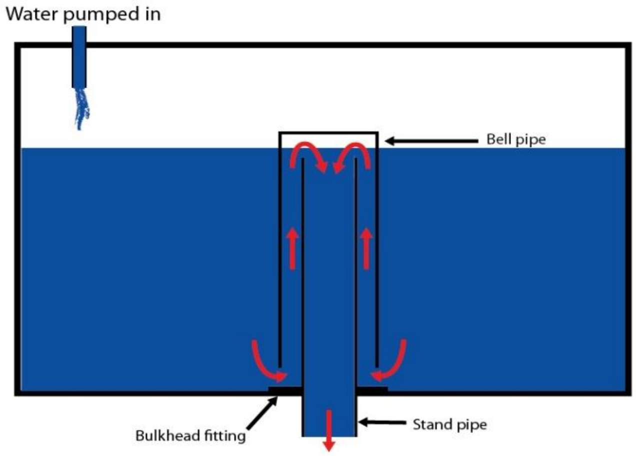


Figure 3: Water level rises past top of stand pipe.

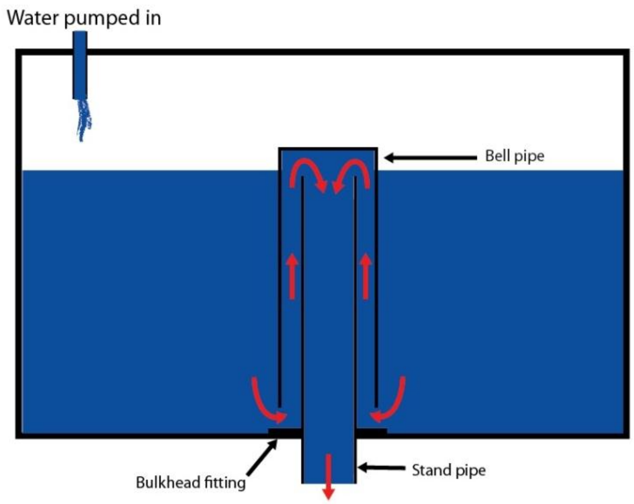


Figure 4: Siphon starts and air in bell pipe is drained out.

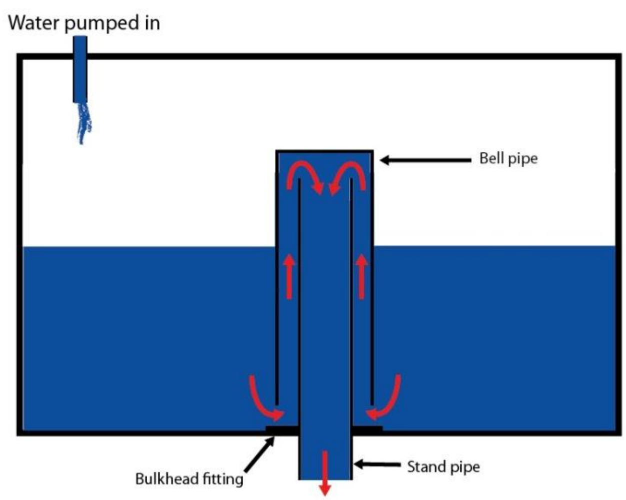


Figure 5: Siphon continues and water level drops.

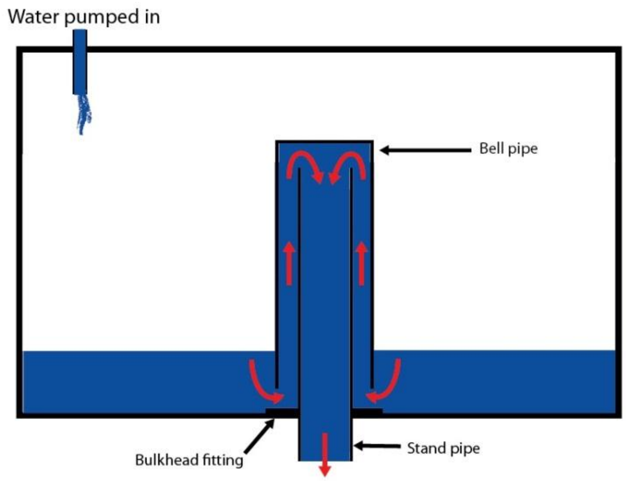


Figure 6: Water level decreases.

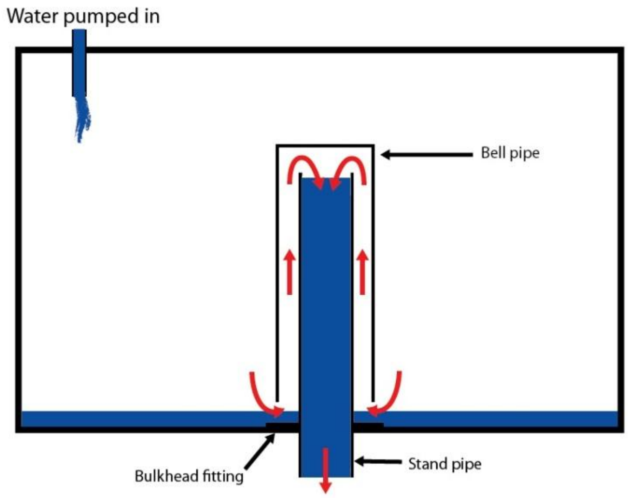


Figure 7: Air enters bell pipe and breaks siphon as water level is below bell pipe.

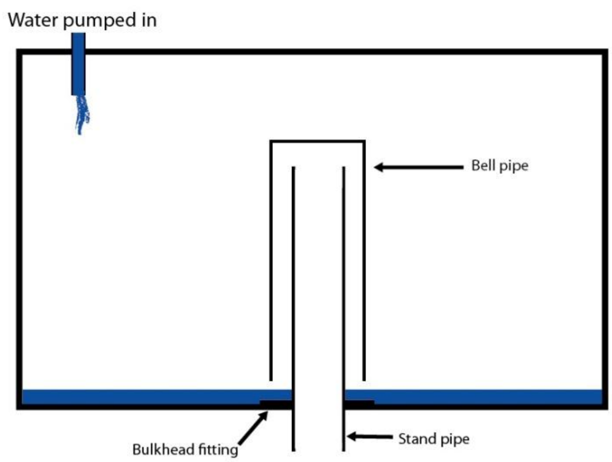


Figure 8: Siphon stops and cycle starts again

To counter the equilibrium flow problem for the Bell Siphon, we used a solution given by Affnan's Aquaponics. Affnan, an aquaponics enthusiast, suggests using a reducer on top of the stand pipe. This allows more water to fall through the stand pipe at a time, pushing out the air and creating the suction needed to engage the siphon. In the same light, adding an extension drop from the outlet of the reservoir aids in starting and stopping the siphon. Adding an outlet pipe gives the water over the stand pipe a longer distance to fall and thus increases the flow rate out. The water exiting pulls the water behind it faster, starting the siphon quickly and subsequently stopping the siphon quickly once air is sucked in.

The first failure mode occurs when the flow rate in is too small. When this occurs, the water level in the reservoir reaches the top of the stand pipe and begins to trickle over the edge, out of the reservoir. The flow in is so low that the water never completely covers the top of the stand pipe and thus the siphon does not start, as shown in Figure 9. The trickle out remains constant, equal to the flow rate in.

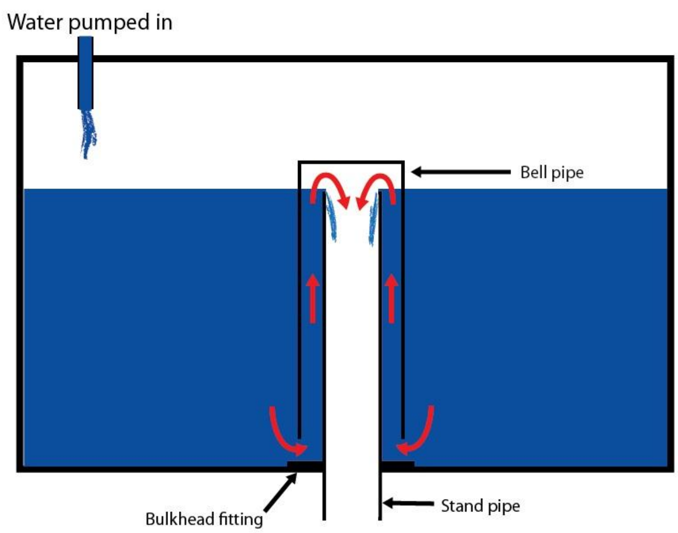


Figure 9: Low flow failure of bell siphon.

The second failure mode occurs when the flow rate in is too large. When this occurs, the siphon starts easily but has trouble stopping. As the reservoir nears empty, air begins to enter the bell pipe, attempting to break the siphon. The flow rate in is so large, however, that not enough air can enter to break the siphon. Again equilibrium is reached as the flow rate in is equal to the flow rate out.

To ensure reliability, we have implemented a Tipper (detailed in the next chapter) that breaks up the continuous flow into the reservoir so that water is entering the reservoir intermittently. Thus, the outflow is independent of the inflow, resolving the problem of equilibrium flows. The tipper works the best with the bell siphon because the bell siphon needs the water in the reservoir to rise just above the edge of the stand tube to start falling and engage the siphon. However, with the loop siphon the water level needs to reach the top edge of the highest point in the loop. This can be nearly impossible as water will begin to trickle out of the hose once the water level reaches the bottom edge of the loop height.

Fabrication of the bell siphon is simple and easy. Two PVC pipes are needed, one with a 0.75 inch diameter and the second with a 2 inch diameter. Depending on the sealant method chosen (explained further in Chapter 6), the relative lengths of the two pipes may differ. The narrower pipe acts as the stand pipe, which will connect to the outlet of the barrel. Most commonly a bulk head fitting is used here; however, there are cheaper versions that can be made. In general, the top of the stand pipe (0.75 inch diameter PVC) should be within half an inch of the top of the bell cap (2 inch diameter PVC) once fitted inside the barrel. A PVC cap should be placed on the top of the bell cap while two holes are drilled/cut into the other end of the pipe. These provide the breakage point of the siphon. The difference in height between the top of the stand pipe and the holes on the bottom of the bell cap dictates the volume of water that will be dumped each time the siphon starts. Once a hole is cut into the base of the barrel, a fitting should secure the stand pipe to the bucket through the hole with a water tight seal. The bell cap is now simply placed onto the stand pipe with the cap pointed upwards.

The Flapper

The flapper design was a method considered when the team was thinking about how a typical toilet worked between flushes. This method seemed promising in theory due to its simplicity and few parts. Figure 10 shows the components of the toilet flapper siphon system. A small force on a chain from the upward buoyant force would pull up on the flapper and start a flow of water out through the hole in the base of the reservoir (Figure 11). The water flow would keep the flapper from closing until the reservoir was drained. The water flow out is dependent on the height of the water level by Bernoulli's principle: when the water level decreased enough, the water flow would be low enough so that the flapper then plugged the hole and the process restarted (Figure 12).

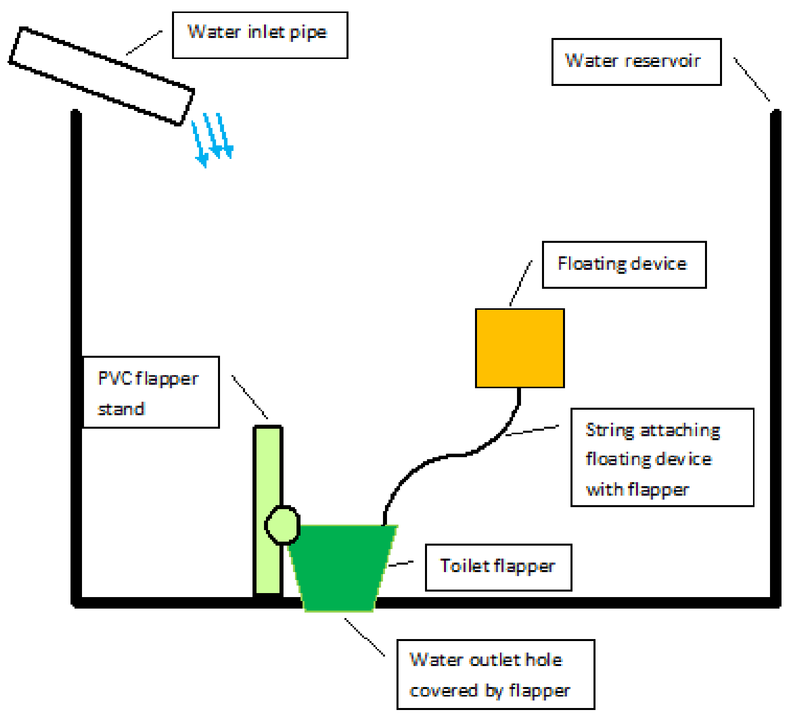


Figure 10: Components for flapper method

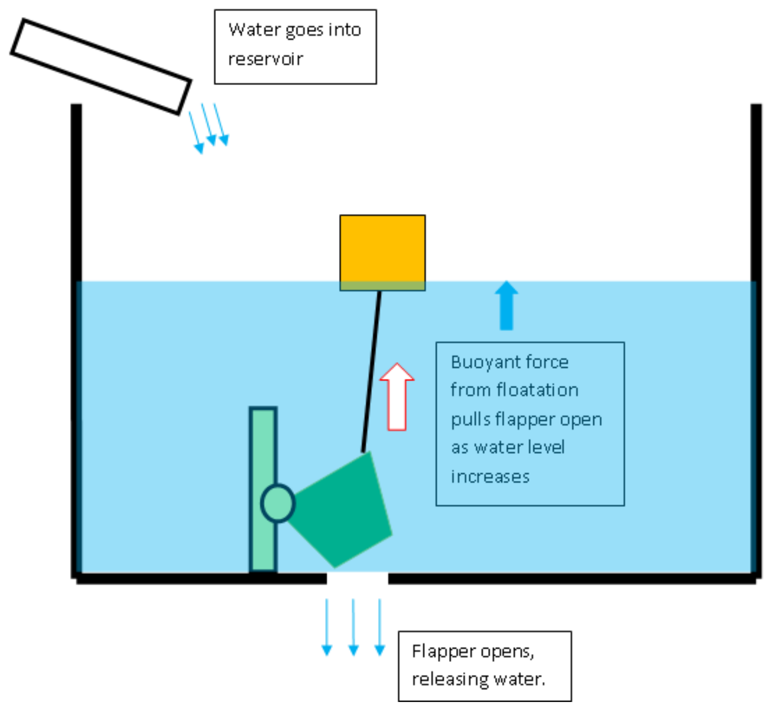


Figure 11: Increasing water causes the flotation device to pull the flapper open.

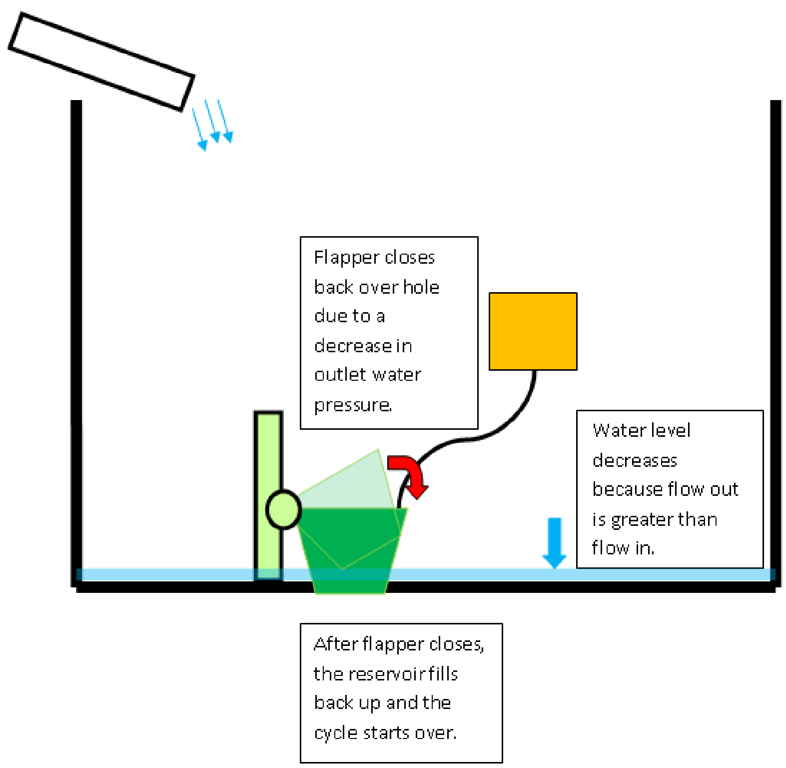


Figure 12: As more water exits through the outlet hole, the flapper closes back down. Once it is closed, the cycle begins again.

The toilet flapper idea posed a lot of problems once we built and tested it. Because we want to limit the amount of parts and complexity of our siphons, we tested the flappers attached to both a Styrofoam block and a balloon. The Styrofoam cube measured four inches in all sides and the balloon we used was just a regular balloon blown to its capacity. In theory, the Styrofoam block and balloon will float as the water fills the reservoir. As the floatation devices rise from the increasing water level, they create a buoyant force that translates into tension force on the chain they are attached to. Once the flotation devices have created enough tension in the chain from the level water rising, it will pull the flapper open, causing water to flow out.

Although in theory, it sounds simple, we encountered a major problem when testing both the Styrofoam prototype and the balloon prototype. The flapper would never fully open; the flapper would only open partially and allow a small stream of water out. If the water going into the reservoir is greater than the water coming out, the reservoir would overflow, causing the system to fail. Thinking that the Styrofoam cube did not generating enough buoyant force, we increased the cube to have sides of 6 inches. The new cube also generated the same problem. Calculations show that a force of 0.8N is required, and buoyant force does not produce that much.

In addition to the lack of force being generated, we also determined that the main reason the flapper worked so well in toilets is because when people push the flushing button, this creates a sudden high force pulling action greater than 0.8N. This sudden pulling force is what allows the flapper to fully open in the first place. In our scenario, we do not have this sudden jolting actuation. Therefore, it is nearly impossible to open the flapper fully open relying solely on flotation devices. Figure 13 shows the failure modes of using the flapper siphon.

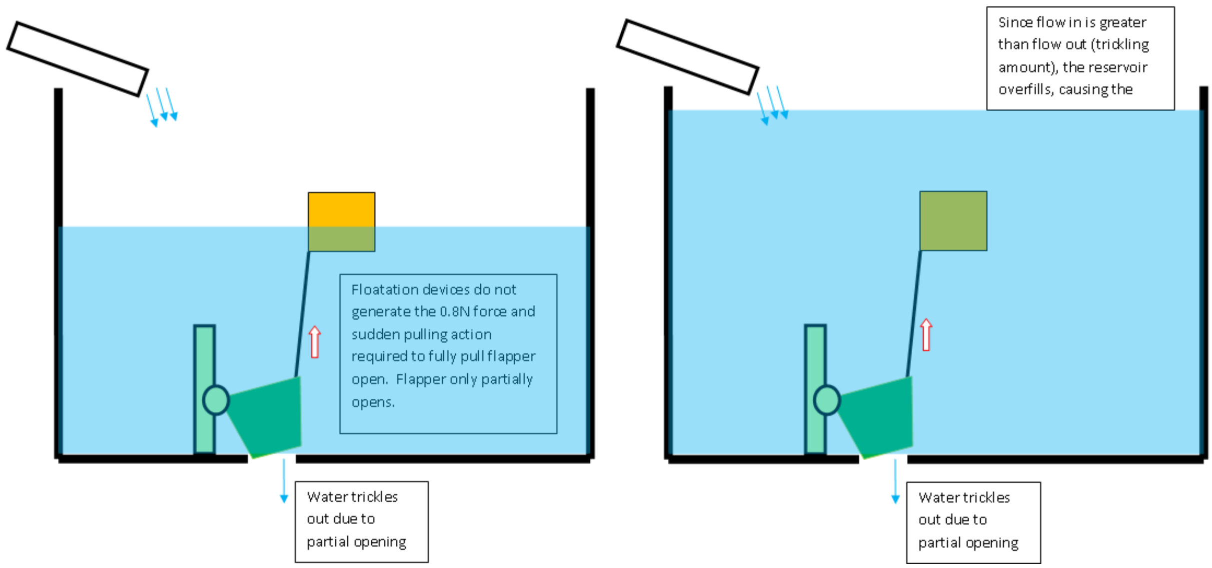


Figure 13: Because flotation device cannot generate enough force to fully pull flapper open, water only trickles out, causing the system to overflow.

The Loop Siphon

The next design choice considered was the loop siphon. Its main appeal is its simplicity, minimal number of parts, and ease of assembly. For the loop siphon only a tube and fitting were required. For the U-loop siphon, PVC pipes were used instead to make an upside down U shape. These siphons work by attaching the tube near the bottom of the reservoir, then looping it up to the desired height. When water fills the reservoir, it flows into the tube as well. Once the water level reaches the height of the top of the loop or U, the water should begin to fall down the other side of the loop. This creates suction, which starts the siphon. The siphon evacuates the water from the reservoir until the water level inside reaches the entrance of the tube. Once air enters the tube, the siphon is broken and the process starts again. Figure 14 through Figure 18 show the process of how the loop siphon works.

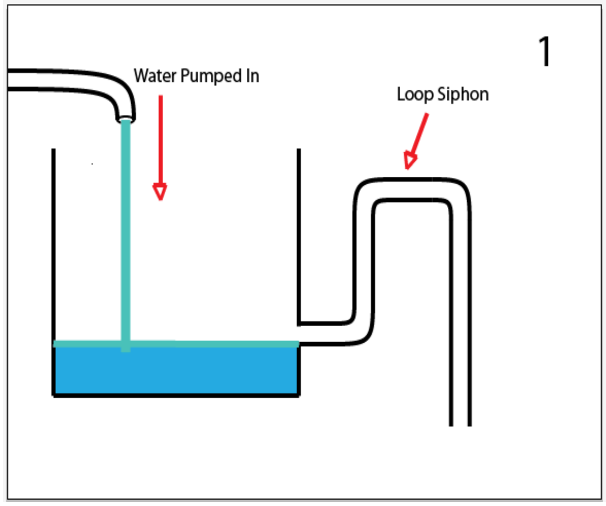


Figure 14: The loop siphon at the beginning of a cycle as water is being pumped in and fills the reservoir

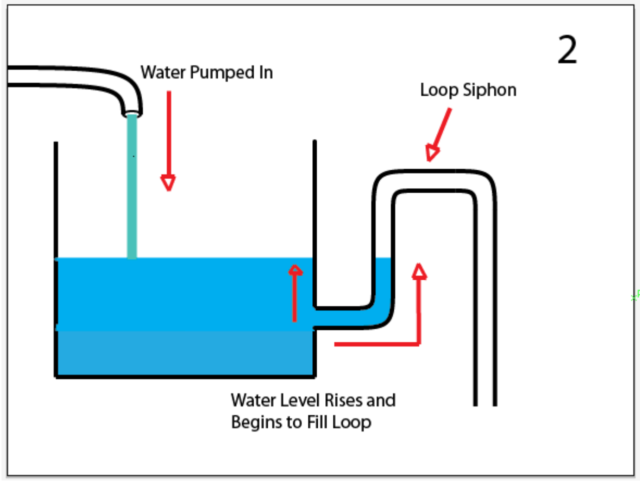


Figure 15: The loop siphon as the reservoir's water level rises

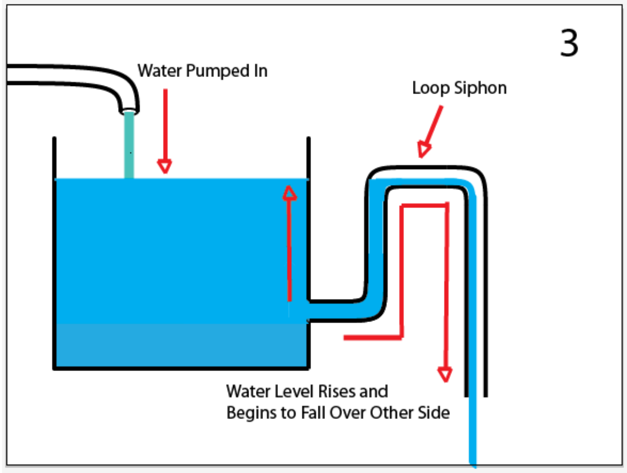


Figure 16: The loop siphon as the water level approaches the top of the loop and water begins to trickle out

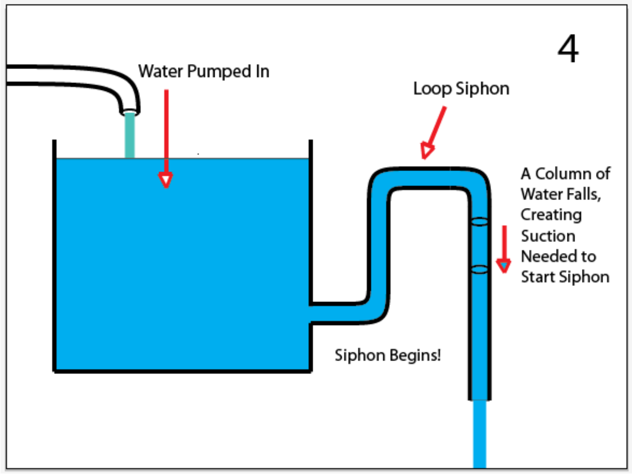


Figure 17: The loop siphon once the siphon has begun

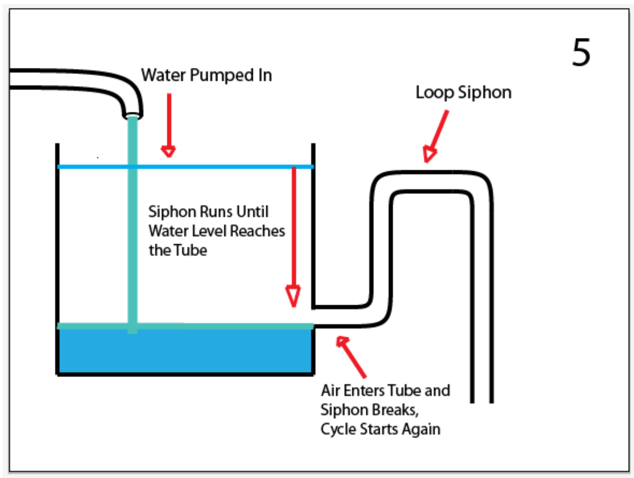


Figure 18: The loop siphon evacuates water from the reservoir until air can enter the tube and break the siphon

We built prototypes and tested two variations of the loop siphon. One design used a flexible hose and the other used PVC pipes that created an upside down U shape with right angled fittings. In out tests, we found that the loop siphon was susceptible to failure in two ways.

The first failure occurs when the hose or PVC pipe diameter is small and/or the flow into the reservoir from the pump is high. The siphon will start, but then become unable to stop. As the water level rises in the reservoir, the loop height is reached and the siphon begins. Initially the outflow from the siphon is strong, but as the water level decreases, there is less pressure difference in the siphon and the outflow rate decreases. At some point, the flow rate in from the pump becomes equal to the flow rate out from the siphon. The system reaches equilibrium where the water leaving the reservoir is immediately being replaced by the same amount of water entering from the pump. The water level inside the reservoir becomes constant and the system is unable to progress and complete the cycle, thus failing to create intermittent flow, as shown as in Figure 19.. This failure occurs when the pump rate is equal to the siphon rate. A way to avoid this problem would appear to be making the tube diameter larger. By making the tube diameter larger to accommodate an outflow rate that will always be larger than the pump rate, equilibrium cannot be achieved. This caused problems of its own.

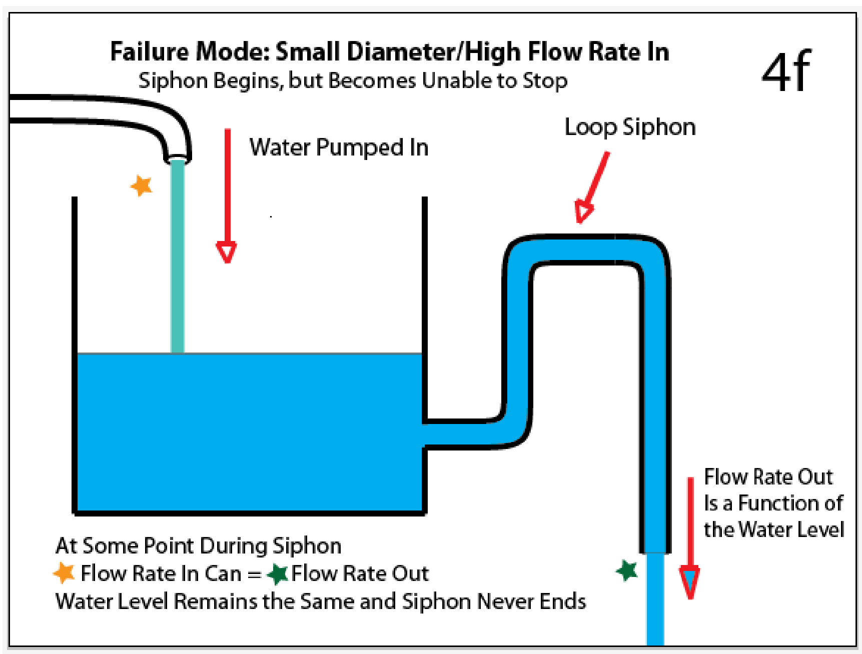


Figure 19: The loop siphon can fail if the tube is of small diameter or there is a high flow rate into the reservoir. The siphon reaches equilibrium with the pump rate and becomes unable to stop.

The second way the loop siphon fails is when the tube diameter is large and/or the flow rate into the reservoir is low. The siphon becomes unable to start. What happens is, as the reservoir fills and the water level approaches the top of the loop, water begins to trickle and fall over the other side. A column of water needs to fall through the tube to create the suction required for the siphon. When the tube diameter is large, it allows the water to slide and trickles down the sides of the hose without creating a suction seal. With low flow rate into the reservoir, the system can reach equilibrium once again. Water can enter and exit the reservoir at the same rate with the siphon never starting and just a constant trickle out. Unlike the bell siphon, where the water level needs to reach just over the edge of a stand tube to initiate the siphon, the loop siphon needs the water level to reach the height of the top of the loop. With a large diameter tube, water begins to trickle out once the water level reaches the bottom edge of the top of the loop. The water level is then needed to raise a height equal to the diameter of the tube in order for the siphon to start. This is nearly impossible as water is only trickling out. This problem is shown in Figure 20.

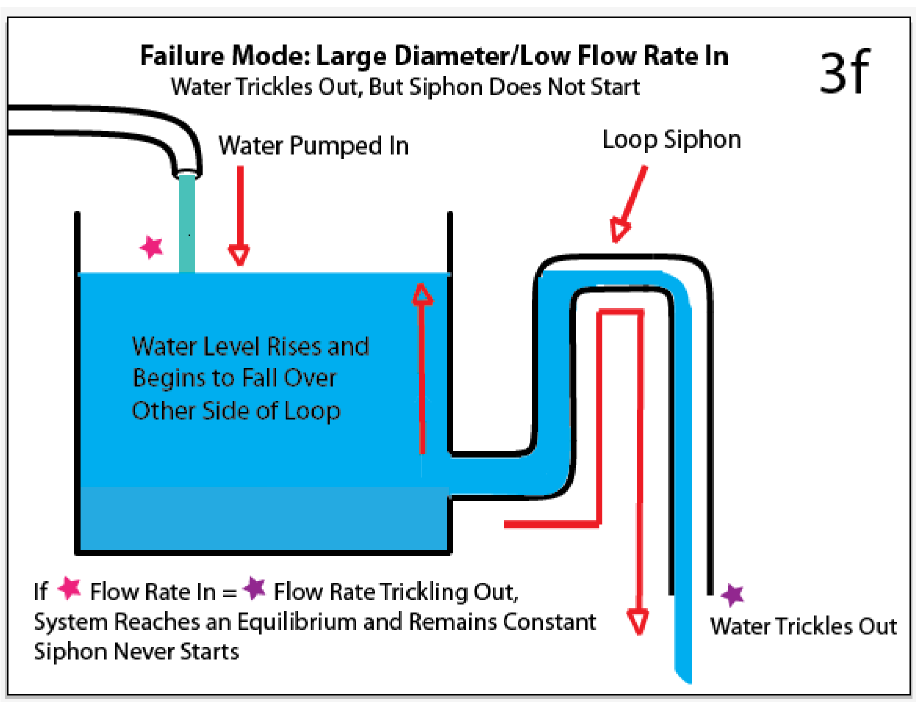


Figure 20: The loop siphon can also fail when the tube is of larger diameter or there is a low pump rate into the reservoir. The loop's trickle out reaches equilibrium with the pump rate and the siphon never starts.

The loop siphon is attractive because of its simplicity, minimal number of parts, and its ease of assembly. However, it is finicky. If we are trying to implement this system in an area where there may be inconsistent pump flow rates, it is susceptible to failure at low and high flow rates.

Figure 21: Loop Siphon (left) and External U-loop Siphon (right) prototypes

The Tipping Bucket

The next iteration of the design cycle was inspired by Professor Delson of the University of California, San Diego. He suggested watching a YouTube video from the Lego Land water park in San Diego. One of the primary features of Lego Land is a water park that has many varieties of water-actuated playground installations: components that spray water in circles, components that create water showers and even components that dump large volumes of water with low constant input. The idea of the “tipping bucket” came from a specific Lego land installation where a bucket gradually filled up with water until it dumped its contents all over the park visitors. It works by a simple center-of-gravity mechanism; because buckets have bottoms and no top, they have a slightly lower center of gravity than the geometric midpoint of a cylinder of the same size. If the pivot of the bucket is placed *slightly* above this point, a very interesting phenomenon occurs when the bucket fills. The bucket naturally rests in the upright position when it is empty; as water fills, it forms a pool on the lower side of the bucket which assists in creating stability. Eventually the bucket fills all the way to the top. At this point, the weight of the water far outweighs the weight of the bucket; this effectively moves the center of gravity of the *system* to *above* the pivot point. Because the center of gravity is then above the main pivot, a large moment is created which tips the center bucket over, effectively emptying its contents and creating a significant "ebb and flow" pattern of water.

Our version of the tipping bucket was very similar but on a smaller scale; we used our 18 gallon food-grade plastic barrels with weights at the bottom to lower the center of gravity. Although the design is simple in concept, there are two main drawbacks. Firstly, the system undergoes a giant shift in mass which produces significant forces of tension and compression on the bucket pivot. If this system is going to perform over thousands of cycles, the pivot would need strong (and expensive) materials and professional water-tight sealing. Secondly, the open bucket system dumps its water in one massive dump to the environment. In order to curb this effect, we installed a top that slowly drains the water out of an adjustable spigot. While this worked in practice, there was no reliable way of injecting air into the bucket to displace the draining water. This created a huge pressure differential and slowed down the draining.

Before we chose to use the bell siphon and tipper as our final design, we researched, built, and tested other intermittent flow system ideas. The primary designs considered and their advantages (and disadvantages) are listed in Table 1.

Table 1: Pros and Cons of Siphon Designs

	Pros	**Cons**
The Bell Siphon	- Siphons quickly - Adjustable volume output - Available materials - Easy to manufacture	- Low flow in: siphon does not start - High flow in: siphon does not stop - Not reliable with inconsistent flow in
The Flapper	- Dumps water quickly - Minimal parts - Easy to assemble	- Flow out not adjustable - Leaks water - Requires impulse force to drain reservoir fully - Hard to adjust frequency of dumps
The Loop Siphon/ U-Loop Siphon	- Minimal parts - Easy to assemble	- Low flow in: siphon does not start when hose is too large - High flow in: siphon does not stop
The Tipping Bucket	- Reliable with inconsistent flow in - Adjustable flow rate out	- Requires a lot of space and manufacturing - High load on bearing of bucket - No adjustable volume output

The Bell Siphon & Tipper: Final Design

The final design was difficult to come to. When a solution was found for a method, for example, an adjustable snorkel to break the bell siphon, that solution would be implemented into other methods we were testing, complicating the number of tests performed. In this sense, questions of whether the snorkel could also be used to break the siphon in the loop siphon design were examined. The combinations of these solutions and the three main methods were tested vigorously for consistency. In one combination, a miniature tipping bucket was added into the barrel containing the siphon. This combination introduced two intermittent flows. Before adding this tipper, the bell siphon had difficulty starting siphons because of a trickle effect that would occur when the water into the barrel from the pump would not cover the stand pipe completely. Suction would not occur in this situation. When the water flow was too fast, the bell siphon was not able to stop siphoning because the bell siphon could not draw in air from the bottom as the water level would constantly be rising too quickly. Figure 22 shows the conceptual idea of the tipper and bell siphon combination.

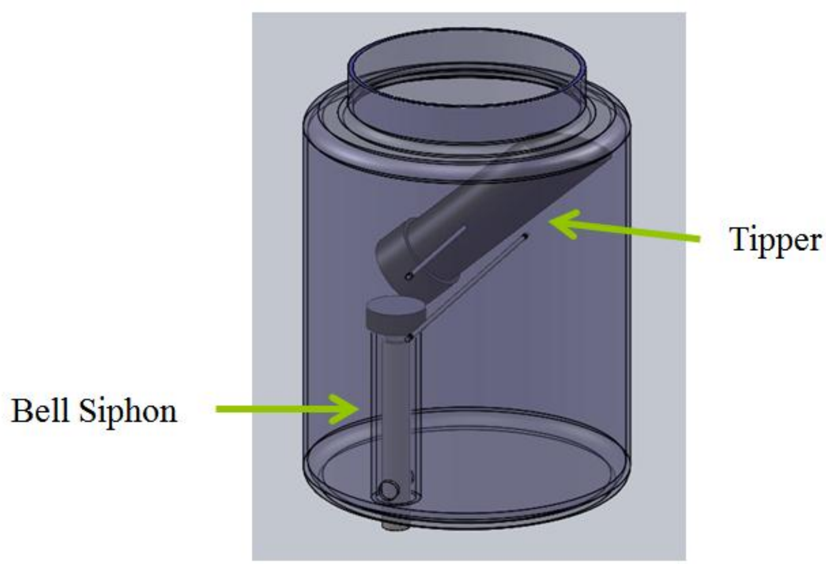


Figure 22: CAD drawing of tipper and bell siphon in reservoir

The tipper solved the two high and low flow problems the original bell siphon had. These problems occurred when the system was at equilibrium. With the tipper, the system could never reach equilibrium because the flow rate into the reservoir was no longer constant. By adding dumps of water, the water level increased in quick pulses rather than at a constant rate. In low flow, this made it easier to cover the stand pipe with water and start the siphon because there wasn’t time for the water to trickle out. In high flow, the siphon was able to stop because there was breathing time where water did not enter the reservoir when the tipper was being filled. This allows the cycle to restart and continue intermittent flow.

Chapter 3: Design of the Bell Siphon

The bell siphon was implemented in the final design knowing that it had to provide intermittent flow of water to the grow bed. The bell siphon must trigger routinely and reliably so that the crops get their nutrients and grow. The bell siphon also needs to start and stop the siphon with varying flow rates into the barrel. It must reset automatically after each siphon. There should be large room for error. The water must continuously cycle to the plants without supervision. Bell siphon stalling and failure can mean ruined crops. In addition, the volume of water that the bell siphon dumps from the reservoir should be adjustable. Larger systems require higher flow rate, while smaller ones less. The bell siphon should be able to be implemented in any size system and still succeed with minor adjustments. Overall, the bell siphon needs to be easy to manufacture and assemble, because the system is intended for use in a developing country. People with limited education may be assembling the bell siphon system and thus it should be easy to make from cheap and readily available materials.

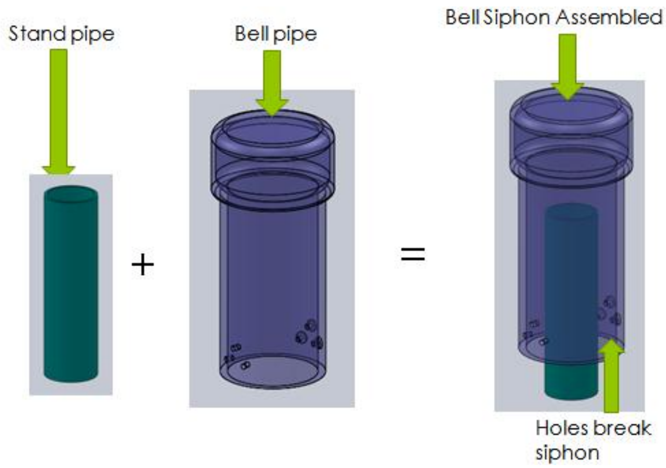


Figure 23: Disassembled CAD of Bell Siphon

We found that the Bell Siphon and Loop Siphon were both prone to failure when equilibrium occurred in the reservoir. That is, the water flow that trickled out of the reservoir became equal to the water flow being pumped in, thus the system would stagnate and the siphon would not engage. The Toilet Flapper and Tipping Bucket avoided this equilibrium problem, but had other problems of their own**.**

To counter the equilibrium flow problem for the Bell Siphon, we used a solution given by Affnan's Aquaponics internet blog. Affnan, an amateur aquaponics enthusiast, suggests using a reducer on top of the stand pipe. This allows more water to fall through the stand pipe at a time, pushing out the air and creating the suction needed to engage the siphon. In the same light, adding an extension drop from the outlet of the reservoir aids in starting and stopping the siphon. Adding an outlet pipe gives the water over the stand pipe a longer distance to fall and thus increases the flow rate out. The water exiting pulls the water behind it faster, starting the siphon quickly and subsequently stopping the siphon quickly once air is sucked in. The Affnan reducer standpipe (inside) and bell cap (outside) is shown below.

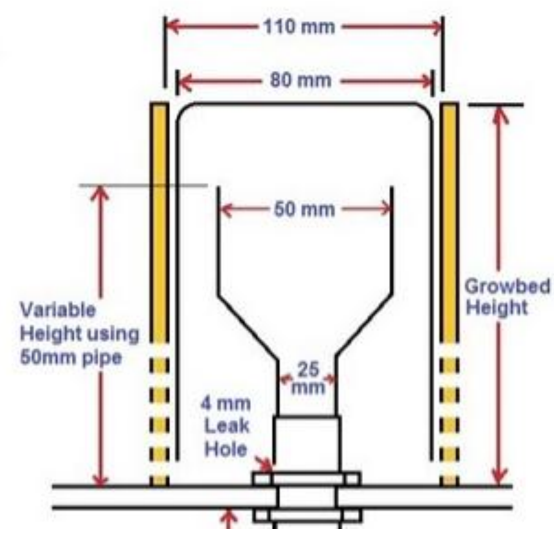


Figure 24: Affnan's Reducer Solution

To ensure reliability, we have implemented a Tipper (detailed in the next chapter) that breaks up the continuous flow into the reservoir so that water is entering the reservoir intermittently. Thus, the outflow is independent of the inflow, resolving the problem of equilibrium flows. The tipper works the best with the bell siphon because the bell siphon needs the water in the reservoir to rise just above the edge of the stand tube to start falling and engage the siphon. However, with the loop siphon the water level needs to reach the top edge of the highest point in the loop. This can be nearly impossible as water will begin to trickle out of the hose once the water level reaches the bottom edge of the loop height.

The first failure mode occurs when the flow rate in is too small. When this occurs, the water level in the reservoir reaches the top of the stand pipe and begins to trickle over the edge, out of the reservoir. The flow in is so low that the water never completely covers the top of the stand pipe and thus the siphon does not start. The trickle out remains constant, equal to the flow rate in.

The second failure mode occurs when the flow rate in is too large. When this occurs, the siphon starts easily but has trouble stopping. As the reservoir nears empty, air begins to enter the bell pipe, attempting to break the siphon. The flow rate in is so large, however, that not enough air can enter to break the siphon. Again equilibrium is reached as the flow rate in is equal to the flow rate out.

Figure 25: Assembling the Bell Siphon and Stand Tube

Fabrication of the bell siphon (shown in Figure 25) is simple and easy. Two PVC pipes are needed, one with a 0.75 inch diameter and the second with a 2 inch diameter. Depending on the sealant method chosen (explained further in Chapter 6), the relative lengths of the two pipes may differ. The narrower pipe acts as the stand pipe, which will connect to the outlet of the barrel. The bulk head fitting is most commonly used in this type of situation; however, there are cheaper versions that can be made. In general, the top of the stand pipe (0.75 inch diameter PVC) should be within half an inch of the top of the bell cap (2 inch diameter PVC) once fitted inside the barrel. A PVC cap should be placed on the top of the bell cap while two holes are drilled or cut into the other end of the pipe. These provide the breakage point of the siphon. The difference in height between the top of the stand pipe and the holes on the bottom of the bell cap dictates the volume of water that will be dumped each time the siphon starts. Once a hole is cut into the base of the barrel, a fitting should secure the stand pipe to the bucket through the hole with a water tight seal. The bell cap is now simply placed onto the stand pipe with the cap pointed upwards.

Chapter 4: Design of the Tipper

The 'bamboo tipper' mechanism was a key component of our final design and was the ultimate key to de-coupling the flow rates of the bell siphon system. The function requirement of the component is to de-couple the flow rate going into the bell siphon from the pump. This could be accomplished in a number of ways, but this component essentially needed to take a constant input of water, store up this water, and effectively discharge it periodically to the bell siphon. This is analogous to a capacitor taking a small current and, upon discharge, releasing a large current at a high voltage to the next component in the circuit. Also, the tipper must accomplish storage, discharging, and resetting without electrical means. Because these rural aquaponics systems perform with no electronic control (only electronic pumps), the component needs to actuate and reset without electronic interaction. Finally, the tipper must be robust and reliable. This component needed to be as reliable as the bell siphon and perform under even more cycles than the bell siphon. If this component failed, the bell siphon would receive constant input and the prototype would be subjected to the same design flaws as the original design. Figure 26 shows how the center of mass changes as water fills the tipper, causing the tipper to dump.

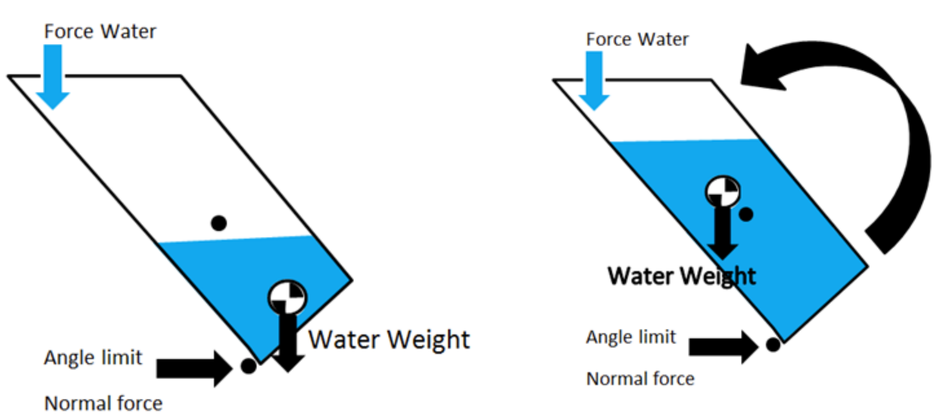


Figure 26: Free Body Diagram of Tipper Mechanism

Primary Designs considered:

Only two primary designs were considered for this component: one was a miniature "tipping bucket" inspired by Lego Land, and the other was a popular Asian bamboo garden decoration that was featured in Kill Bill. The miniature tipping bucket worked on the same principle as the large tipping bucket, but just at a far smaller scale. The issues with this design were that it required careful manufacturing (the pivot relative to the center of gravity has to be almost perfectly placed) and that it required exotic materials; it could not be made out of normal-diameter PVC pipes, so it would have required either independent metal manufacturing (with a coating to prevent leeching into the water) or some kind of plastic molding.

The bamboo tipper design could be easily replicated with PVC pipe and required less precise manufacturing. Because it's natural position is already tipped to the side, the center of gravity needs to simply shift up (and to the side) in order to create a moment to tip the entire piece. This effectively allows the pivot to be placed in a number of locations (rather than in a precise location), making rural manufacturing even more accessible.

When we finally prototyped the PVC tipper, it performed amazingly well. It stored, discharged, and reset with mechanical ease and performed under a wide range of input flows. It also was able to discharge a significant amount of water in the 3-inch diameter design, a feature that would end up being key to starting and stopping the bell siphon.

Table 2: Pros and Cons of Tipper Design

	Pros	Cons
The Tipper	• Solves equilibrium problems with the bell siphon • Simple • Automatic • Made of inexpensive parts	• Requires more parts • Requires more assembly

Chapter 5: Design of the Hose Clamp

The hose positioning system must allow for the water flow at any rate to flow into the tipper and successfully keep the tipper working. This is more imperative for low flow situations. The hose position must also be stable, so that it does not move and cause the tipper to stall due to hose water pressure, tipper movement, or outside factors.

When testing the tipper in different flow rates, we found that the tipper can fail at different angles for different flow rates. The hose needs to be positioned because the angle and flow rate of the incoming water can cause the tipper from working properly. If the tipper does not work successfully, the bell siphon may not work in high or low flows. The system can still be successful with incorrect hose placement, but in extreme flow cases, the bell siphon may fail.

We conducted some tests to see where the failure occurred. Failure occurs when the water flow hits the tipper when it's upside down just after it has dumped and is trying to come back up to reset. The water kept the tipper pushed down and unable to come up. The force of water pushing down is equal to the moment of the tipper's weight pushing up. The forces on the tipper are at equilibrium, so it stays stalled in one place.

The bell siphon may function, but at high or low flow rates in, it can fail. The grow bed will still receive water, but not intermittently. If unchecked, this can be disastrous to the aquaponic system. To avoid this, the hose should be angled so that incoming water hits the side of the inner wall of the tipper. This way, the water hitting the tipper is not a downwards force, but rather, a horizontal force. A cut on the opposite side of the tipper maximizes the water's access to the inner wall.

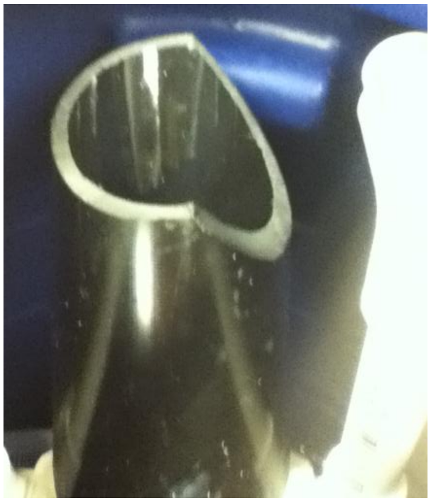


Figure 27: Tipper with side cut to maximize in flow's access to inner tipper wall

Primary Design Considered

The first solution we tried was to cut a hole in the lid of the reservoir and secure the hose with a PVC outlet fitting and hose adapter on the end through the hole as shown in the Figure 28. The outlet fitting is attached to the reservoir lid and pointed so that the water flow was aimed into the tipper, as shown in Figure 29.

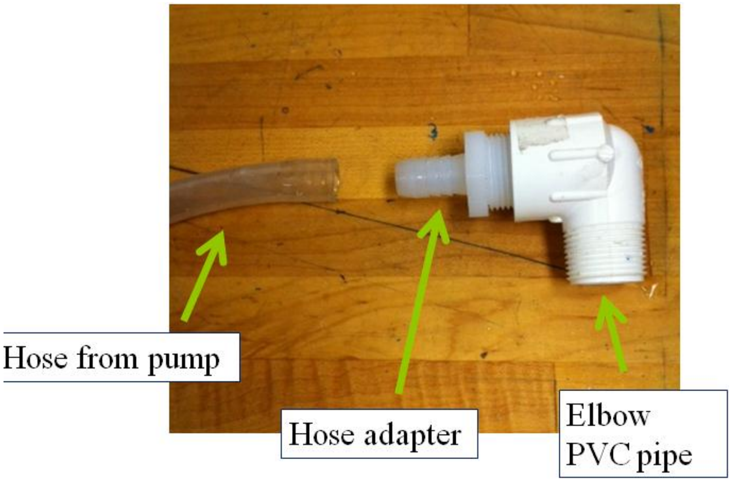


Figure 28: Hose position lid design solution

This arrangement held the hose, but the water pressure and tipping vibrations could slightly change the hose angle. The tipper was known to stall after several cycles due to the hose's position. The hose was attached to the reservoir lid and had to be repositioned every time we took the lid off the reservoir. Checking on the hose position, tipper, and bell siphon required taking the lid off. We needed the hose to be secured to the tipper mechanism so that it didn't move relative to the tipper.

Figure 29: Hose positioner lid design solution

We considered several solutions, including attaching the hose to the tipper itself. This was unrealistic because the hose would contribute to the moment of the tipper's tipping and resetting. Another solution we tried was the 'tipper hanger'.

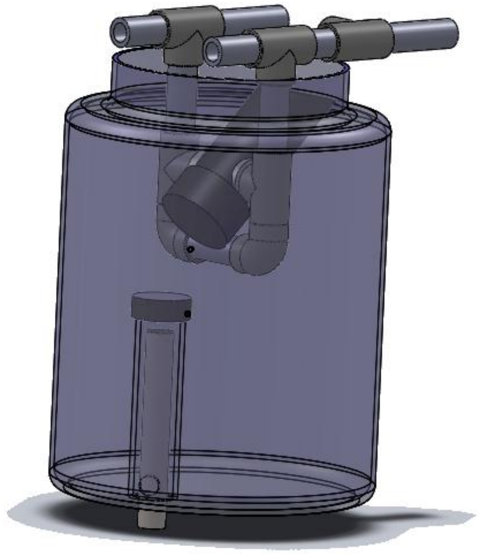


Figure 30: CAD model of our new tipper hanger with tipper and bell siphon.

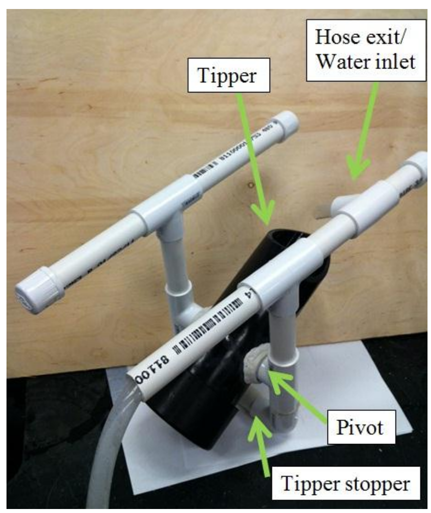


Figure 31: CAD model of our new tipper hanger with tipper and bell siphon.

It is essentially a frame built of pvc tubes, L-joints, and T-joints that combines the tipper's pivot and stop with a hose positioner and horizontal bars that rest outside on the reservoir's lip. The horizontal bars suspend the tipper mechanism in the reservoir, so drilling and inserting rods for the tipper's pivot and stop are not needed. Drilling holes in the side of the reservoir can cause stress concentrations that may be detrimental to the long term life of the reservoir. The horizontal bars have notches cut in them that correspond to the correct position on the lip of the reservoir. This way, if the system is bumped or moved, the tipper does not move so that it hits or stalls on the sides of the reservoir. The pump hose can be strung though the PVC tubes and directed out of the hose angler. The CAD model of our system is shown in Figure 30 and the final built prototype is shown in Figure 31.

Figure 32: Tipper hanger positioned in reservoir

The tipper hanger, as shown in Figure 32, mechanically links the water inlet with the tipper, thus constant adjusting of the hose position is not needed. The tipper hanger decreases the precision factor for the person assembling the system because they do not need to correct or align the inlet angle. The hose position is set at an angle that accommodates both high and low flow situations so that the tipper will work with any flow. Once the hose is angled, it does not need to be moved again. Only simple materials were used. PVC tubes and fittings were used for consumption safety as well as affordability.

Table 3: Pros and Cons of Hose Positioning Designs

	Pros	Cons
Hose Inlet Through Lid	• Does not add much more assembly or parts to the system	• Unstable, easily misaligned • Needs to be adjusted every time lid is taken off or moved • Angles can be changed easily, difficult to test for different flow rates
Tipper Hanger	• No need to drill holes in the sides of the reservoir • Couples the position of the tipper with the hose, so that they cannot move relative to the other • Stable, jostling the hose or tipper hanger will not cause failure • Can account for both high and low flow situations • Easy to see and test for different flow rates	• Adds more parts (5 T-joints, 2 L-joints, 1 cap, pvc rods) • Adds more assembly (cutting and gluing) • Lid cannot fit on top

Assembly of the tipper hanger is relatively easy. (Details are shown in the assembly guide.) Cut PVC tubes so that the tipper pivot and stop cause the tipper to rest at an angle. The height from the pivot to the T-joints of the support structure should be minimal. The closer the hose position is to the tipper, the better. The hose should be angled to hit the side wall of the inside of the tipper.

Chapter 6: Design of the Outlet Fitting

The outlet fitting used in the design needs to fulfill several functional requirements. The outlet fitting is used to hold the bell siphon in place against the bottom of the reservoir. It connects the siphon inside the reservoir with the corresponding equipment outside it while keeping all the water inside the reservoir. The outlet fitting must be reliable. Ecolife is looking for a design that will not need constant attention. An outlet fitting that works well for a long time is desirable. The fitting must also be water tight. The outlet fitting must not be prone to leaks. Leaky fittings cause unwanted puddles and waste water. In a location like Africa where water is a scarce commodity, this should be avoided. The fitting should be safe for the plants, fish, and humans. The outlet fitting should be made of a material that does not leech or release toxins into the water. The water must remain habitable and nutritious for the plants and fish, so non-corrosive metals and non-food grade plastics should be avoided. It is ideal for the fitting to be adaptable: The outlet fitting should be easily compatible and water tight with whatever hose or pipe configuration the design uses. Some secondary requirements for the outlet fitting are for it to be cost effective and made of readily available parts. If the parts are expensive, doing aquaponics is expensive and becomes an ineffective way to get food. The outlet fitting should ideally be made of parts that are easy to find. Having to send over a rare special part just to make it is not cost effective or ideal. The outlet fitting should ideally be made of parts that are readily available to workers in Cameroon.

We have used several options for the outlet fitting with varying results. We tried bulkhead fittings and a locknut with PVC configuration in combination with O-rings and with gasket material.

We bought several sizes of bulkhead fittings from Marshalls Hardware after being unable to find them at Home Depot. These fittings are proven to be effective and routinely used in applications where an attachment needs to be water tight. A bulkhead fitting is essentially a wide plastic screw with the outlet hole cut out along the axis. There is a rubber gasket and a threaded plastic nut that attaches the screw to the reservoir. Bulkhead fittings, shown in Figure 33, are expensive (~$20) and hard to find. However, they worked well and do not leak much.

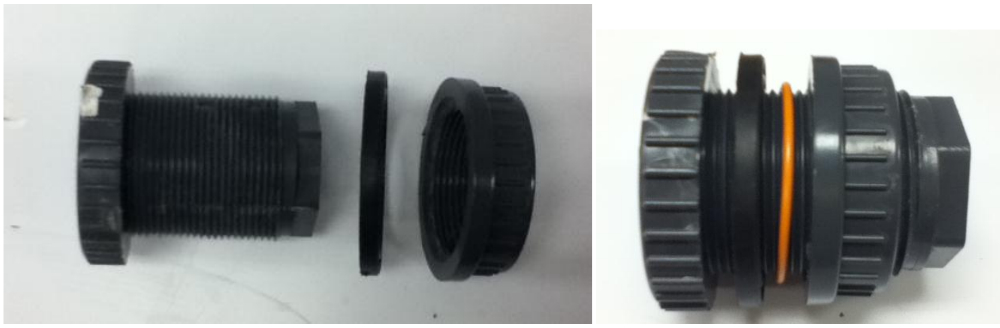


Figure 33: On the left, bulkhead Fitting exploded view. From left to right: Bulkhead screw, rubber gasket, and bulkhead threaded nut. On the right, the assembled view of bulkhead fitting. Lighter band represents the reservoir wall.

Figure 34: Bulkhead fitting attached to reservoir bottom

After inquiring a Home Depot worker about bulkhead fittings, he led us to a cheaper option of using O-rings and electrical locknuts to fit threaded PVC joints as outlets. Sandwiching the reservoir wall between locknuts and o-rings was very messy. Water leaked out in streams as the o-ring was prone slip out around the fitting when subjected to pressure. Another concern was the metal locknut, which may rust or contaminate the water.

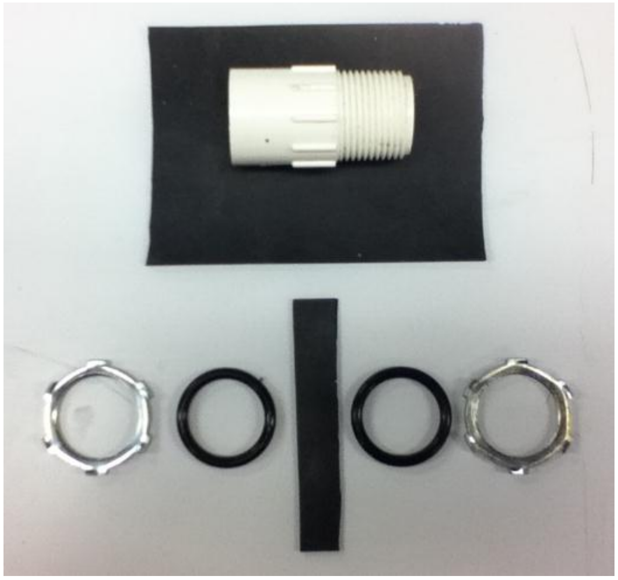



Figure 35: O-ring/locknut fitting is screwed onto the pvc fitting (top). Exploded view from left to right in order on the fitting: locknut, o-ring, reservoir wall (represented in black), o-ring, locknut. Shown on the right assembled.

After some experimentation with the O-ring/Locknut configuration (shown in Figure 34), machine shop engineer Dave Lisher suggested cutting gasket material to size and using it instead of the O-ring. He had many types of gasket material to experiment with. This configuration is shown in Figure 35. Functional requirements for the gasket are that it must be water resistant and also conform to the walls of the reservoir. At the time, we were considering other options besides the bell siphon, so conforming to the reservoir wall was desirable. With a material that can conform to the wall, a tighter seal is created. The reservoir buckets supplied by Ecolife had minor surface irregularities that could be potentially leaky as well. Several materials were tested, but the best results came from a combination of 1mm thick black rubber and 2mm spongy [will find out what it is] material. The two materials created a decent seal. Leaking was minimal, even when the reservoir was full. This solution is cost effective, but the metal locknut remains a problem.

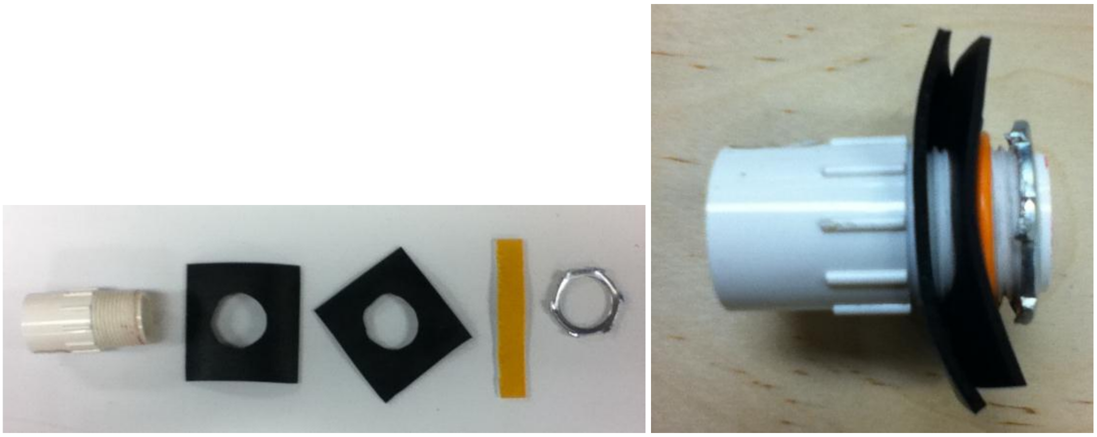


Figure 36: Gasket material/locknut fitting. On the left from left to right: pvc fitting, spongy gasket material, rubber gasket material, reservoir wall (represented by colored bar), locknut. On the right is the assembled view.

Currently we have continued to use the bulkhead fittings for the bell siphon. They are reliable and specifically made for this application. Each part of the bulkhead fitting is perfectly tailored to attach to the other parts. There is little to no leaking from the bulkhead fitting when attached properly. It is reliable, water tight, food safe, and adaptable to a stand tube. However, it does not satisfy secondary functional requirements, as it is expensive and must be specially ordered.

To attach a bulkhead fitting, simply measure the diameter of the threaded portion and drill a corresponding hole though the bottom of the reservoir container. Push the threaded outlet pin through the hole, then place the gasket and screw on the plastic ring until it is tight. The outlet hole it creates can come in various diameters that correspond to PVC sizes.

Table 4: Pros and Cons of Outlet Fitting Options

	Pros	Cons
Bulkhead fitting	• Reliable • Simple • Requires no assembly	• Expensive
O-ring & Locknut	• Cheap	• Prone to leaks • Not food safe
Gasket Material & Locknut	• Inexpensive • Pretty water tight	• Not proven to last a long time • Not food sage • Requires assembly

Chapter 7: Analysis of Performance

Assumptions

All of our tests are performed with the pump at ground level and the system placed on top of a counter three feet above ground level. This height difference is essential as the pump flow rate will be different depending on how high it has to pump. The water coming out of the hose attached to the pump will be small at higher heights because of frictional headloss that occurs as water travels further within a hose. The opposite effect will happen when the system is closer to the pump and the water has to travel less in the hose. Because Ecolife Foundation does not know the exact height at which the system implemented in Cameroon will sit, calculations and data collection are done with an assumption of three feet difference. Three feet was chosen to replicate their aquaponics system setup.

Analytical Methods Used

It is important to test the bounds of our system to know at what point our system will fail. We first test if the system will work under low water inflow rate by manually adjusting a faucet connected to a hose. The hose is placed over the tipper and then system is tested with different flow rates. The water flow rate is decreased after each successful siphon dump until the system fails. Once the system fails, we place the hose over a marked bucket, and using the bucket and stopwatch method, we record the flow rate.After recording the observation and data, the water flow rate is then increased to test the upper bound of our system. Similar to testing the lower bounds of the system, the water flow rate is increased after each successful siphon dump. Water flow rate is continuously increased until the system fails. Once the system fails, we use the same method as in the low flow method to measure the flow rate. Observation as to why it failed and the flow rate are recorded.

Experimental Results

Our system was successful in working at a low flow rate of 0.155 gal/min. Although the pump will never create such low flow, we are able to prove that our system will work with even trickles of water coming out of the pump. This means our system is able to work as long as some water is being supplied.

After measuring the lower bound of our system, we had to measure the maximum flow at which our system would work before failure. Our siphon system works at a flow rate of 4.752 gal/min before it fails with a higher in flow. At this rate, the tipper is dumping ever second or two, which does not provide the bell siphon will enough air time to break the siphoning action. However, the maximum flow rate achieved by our system is higher than the flow rate of which the pump pushes out (3.402 gal/min). This proves that our system has no trouble working with the pump given to us by Ecolife and will work with the given constraints.

Component Selection

We are still optimizing our design, but the components we are currently using are the bell siphon (which is comprised of the inner stand pipe and bell pipe), bulkhead fitting, a tipper, and the tipper hanger that acts both as a pivot and stop for the tipper but also has a placement for the hose. All components are made of PVC. Portions of the hanger are held together with waterweld. All components are non-corrosive and will not leech harmful chemicals into water.

Chapter 8: Design Recommendations and Conclusion

Description of Fabrication Process: The Fabrication Manual

Part One: Tipper and hanger construction

The required tools include:

- Hand drill
- Circular saw attachment – 44mm (or 1.75 “) diameter
- Hand saw or band saw

The required materials:

- Assorted PVC pipes:
    - 3 inch diameter
    - 1 ¼ “
    - ¾ “
- Silicon Epoxy Glue
- Waterweld ® Potable Water-proof glue (not pictured)

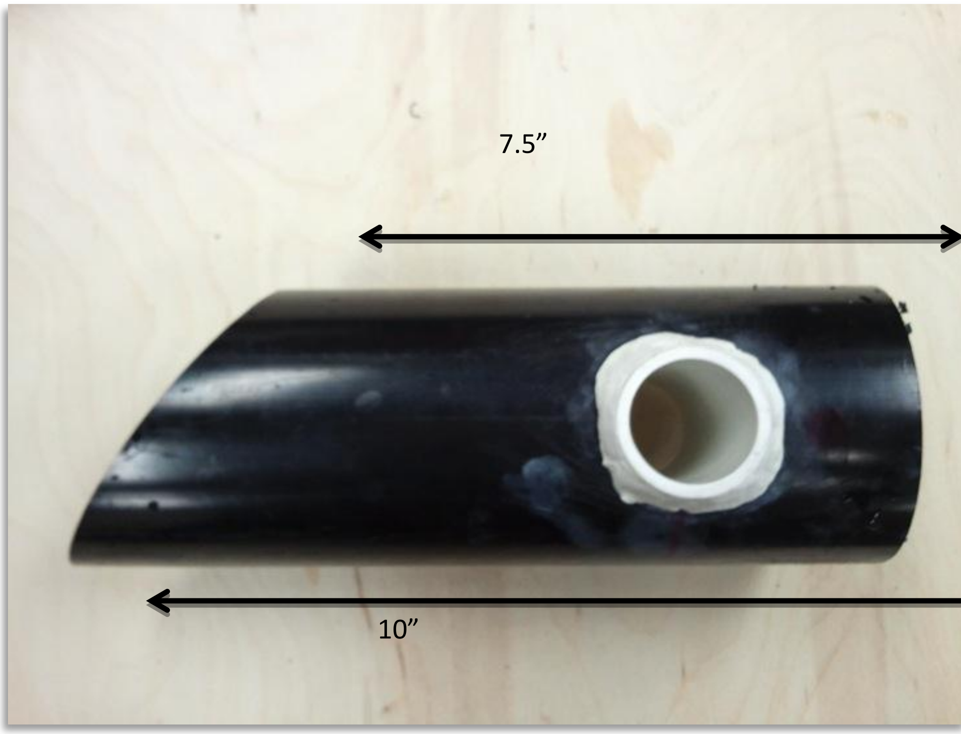
- ¾" PVC fittings:
    - 5 T joints, slip fit
    - 2 Elbow joints, slip fit (three pictured)
    - Bell cap (optional)
- 3" PVC fittings:
    - Bell cap

Step 1: Constructing the Tipper:

Drill a hole into the 3" PVC pipe with the circular saw attachment precisely **2.835** inches from the edge of the pipe. Drill another hole exactly opposite this one on the other side of the pipe (located at the same distance away from the edge). This set of holes will become the pivot for the tipper; since the tipper relies on precise center-of-gravity positioning, it is highly advised that this step is done carefully.

Cut approximately **3.75”** of the 1 ¼” PVC pipe and insert into this drilled hole. This PVC pipe should be centered inside the 3” tipper and have a small amount of pipe protruding from the tipper. Secure in place with generous amounts of water weld to ensure a water-tight seal (allow 30 minutes for waterweld to set).

Next, cut the top of the tipper at an angle to ensure proper tipping. Make a small mark exactly **7.5”** from the bottom of the tipper pipe. Make another mark on the exact opposite side exactly **10”** from the bottom of the tipper. If a planar cut is made between these two marks, the tipper look like the photo below:



Finally, insert the bell cap securely on the end of the tipper, making sure to press the bell cap **all** the way down until it is flush against the 3” pipe. Congratulations, your tipper is now complete.

Step 2: Construct the hanger

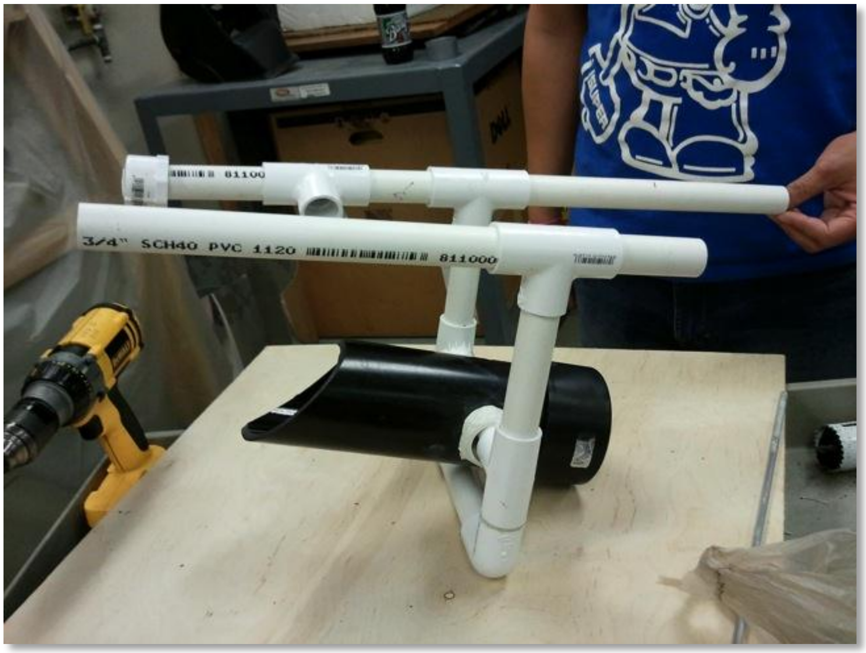
Insert a small (1") length of ¾ " PVC pipe in between both elbow joints and T junctions. Add epoxy glue at this seam for extra structural integrity.

Cut two lengths of ¾ " PVC pipe, approximately 5" in length. Insert these between the T junction and elbow fittings as depicted below. **Note:** Our initial prototype used ½ " pipe between threaded T junctions; this design is inferior and using slip-it T junctions and ¾ " pipe is recommended. Our initial prototype is shown in the figures.

Insert the completed tipper over the length of PVC pipe between the T joints.

Next, cut two sections of ¾ " PVC pipe, approximately 5.5" in length. Add these to the open ends of the T-junction and insert two T-junctions over these sections of pipe.

Cut three sections of ¾ " PVC pipe, approximately 3.5" in length. Cut an additional two sections of the same pipe, approximately 4.5" in length. Arrange these with the final T joint as depicted in the figure below:



This should allow the tipper hanger to span the diameter of the water reservoir barrel.

Note: The end cap on the PVC pipe is optional. Either the hose can be routed through the PVC pipe and out the T junction to spray into the tipper, or the pump can pump directly into the hanger PVC structure. If all open ends of the PVC hanger structure are secured with caps, the water will spray out the remaining T junction open end and into the tipper. This allows for different types of pumps to be used with the tipper hanger.

Insert the hanger into the Aquaponics water reservoir barrel. **Note:** An additional planar cut was performed on this initial prototype tipper. This is considered an optional step in the construction of the tipper hanger.

Next, thread the hose from the pump through the PVC fittings and into the open end of the T junction:

Finally, adjust the T junction angle to account for flow speed of the pump to ensure the water stream enters the tipper opening. Congratulations, your tipper hangar is complete.

Part Two: Constructing the Bell Siphon:

Required tools:

- Hand drill and circular saw attachment (½ “ and 1.5 “)
- Band saw or hand saw

Required materials:

- Assorted PVC pipes:
    - 2 " diameter
    - ¾ " diameter

- PVC fittings:
    - 2" diameter bell cap
- Bulk Head fitting – inner opening for ¾ " PVC pipe attachment (1.05 " diameter), not shown

Step one: Drill two holes into the bottom of the 2" PVC pipe to allow for "burping" during the siphoning process. These can should be approximately 0.5 " from the end of the bell pipe, but precision is not required. If more frequent and lower-volume dumping is desired, these holes can be moved further away to ensure earlier burping.

Cut the bell pipe (2” diameter pipe) to be approximately 7 inches in length. **Note:** The actual length of the bell pipe and stand pipe are not a precise requirement and can vary greatly depending on the height or desired volume output of the water reservoir. The main objective is to obtain a bell cap and stand pipe that are approximately the same height *once assembled* in the barrel. Because the bulk head fitting as a recess of approximately 1.5 inches, our stand pipe was approximately 8.5 inches in length so both pipes were equal in height once assembled. Ideally a small air gap exists between the bell pipe and stand pipe, but if the fitting is flush, the bell pipe will rise with a rising level water and allow the siphon to start.

Insert the bell cap over the 2” diameter bell pipe.

Next, cut the stand pipe (¾ “ diameter) to approximately 8.5 inches in length (or whichever length is desired by the project requirements).

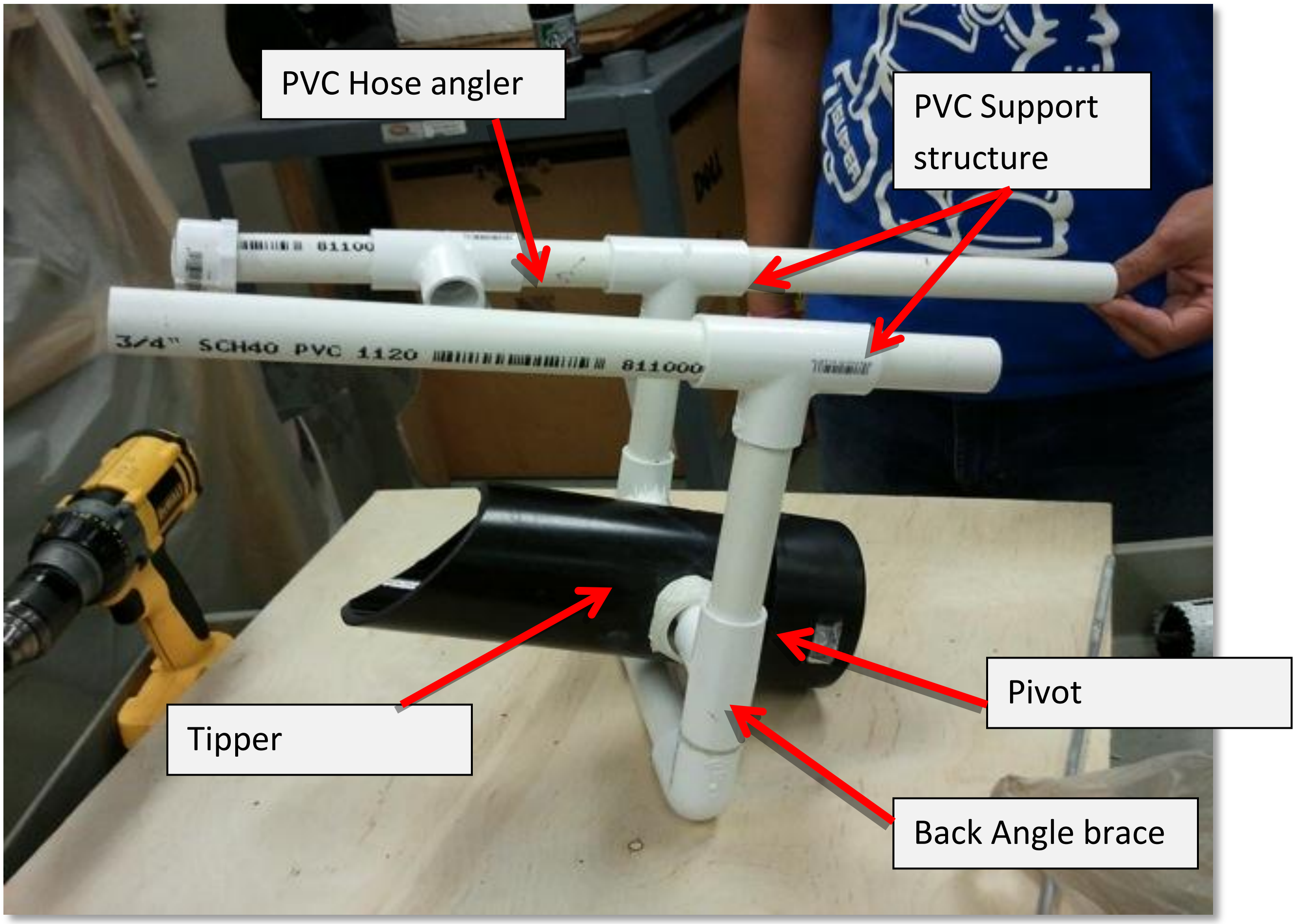
Next, drill the opening for the bulk head fitting at the bottom of the water reservoir barrel. A variety of diameter circular saw attachments will do here, as long as they are smaller than the outside diameter of the rubber O ring and larger than the bulk head exterior threading.

Insert and secure the bulk head fitting

Assemble the bell siphon into the bulk head fitting as shown below (barrel not pictured).

Congratulations, your Aquaponics Tipper Hanger and Bell Siphon is complete! This construction guide is also in our Project website.

The final product:



Testing and Evaluation

Our prototype has been tested at the extreme levels of flow rate in. The goal of our design was to accommodate varying flow rates and thus we have tested our prototype throughout the process of designing and assembling. We have created a design that allows for function in very low flow rates, near to a trickle, and high flow rates. These conditions should resemble those experienced in rural African villages where power supply (which affects how much the pump dispenses) will vary. If brown outs occur, power can be lost and the pump will stop working. Our design can tolerate inconsistent flow rates of which we have tested vigorously for reliability. Reliability is the largest concern for the project and our system successfully exhibits that.

Comparison of Prototype to Production Design

Our tipper hanger prototype could serve as an initial production design. Because it is comprised of cheap off-the-shelf parts that are widely available, acquiring the necessary materials is not an obstacle. Although a reasonable amount of assembly is required, these tippers will most likely be used on large aquaponics systems that can serve entire villages. Spending an hour on assembly of a component that will have a large lifetime and serve a large amount of people is not considered too high of a cost.

However if this tipper hanger was re-designed for wide-scale production and use, several advantages could be made. The entire tipper itself most likely could be plastic-mould injected (or comprised of two different parts), and the PVC hanger structure could be plastic mould injected as well. This would eliminate the need for all the PVC fittings and parts. The assembler would not be responsible for accurate measurements to cut for the correct hanging height, pivot point, tipper stop, and hose positioner. Also, the consumer would not have to find the perfect pivot point on the tipper to place the pivot hole. A regulated plastic mould would hopefully reduce the overall cost of the part and the time it takes to assemble. If these changes were made, ECOLIFE could begin to produce a very cheap and highly reliable aquaponics device.

Cost Analysis and Projection

So far we've spent 196.63 on parts (fiscal breakdown can be found in **appendix #**), not including travels to Ecolife Foundation's head quarters (111 miles) and numerous drives to Home Depot and Marshals hardware store (80 miles). At $0.55 per mile the expenses for travels come to be $83.16. On a total budget of $1600 that the sponsor had put it, we are in great shape for being more that 70% through the quarter.

Safety and Impact on Society

For all materials chosen for building the aquaponics system, potable-safe and noncorrosive materials must be used. For our prototype, PVC and safe sealants were used to ensure that the plants and fish consumed from the system are not toxic. This condition must be upheld at all costs; metal of any kind should not be used to replace the components.

Aquaponics systems have great potential to help both third world communities and developed countries alike. Because aquaponics systems give both protein (in the form of fish) and vitamins (in the form of plants), they can deliver a balanced form of nutrition that is self-sustainable and ecologically friendly.

Many rural communities in Africa are forced to resort to hunting bush meat for their protein intake due to the scarcity of natural protein sources. Bush meat can bring disease and illness into communities as well as endanger animal species in the jungle. If rural communities adopt aquaponics systems instead, they can produce their own protein. Doing this saves them from disease and restores the ecosystem to its natural balance.

Developed countries can benefit from aquaponics systems in a similar way; by producing local vegetables and fish, normal members of society can gain independence in their food source and improve the environment at the same time.

Our production of a reliable and robust bell-siphon will improve the yield of aquaponics systems, furthering the goal of sustainable and ecologically-friendly food production.

Users Manual for Maintenance and Operation

After the initial assembly, minimal maintenance is required on the tipper hanger, although routine periodic check-ups are advised. The PVC T junction that guides the hose is the only variable in the tipper hanger operation; its radial angle adjusts the direction of the inlet flow. If the pump being used is changed, this angle may require adjustment by hand to correctly direct the inlet flow into the tipper.

If the tipper hanger is being used on outdoor non-covered aquaponics systems, routine maintenance and cleaning of the PVC pivot on which the tipper rotates should be performed. The tipper can be disassembled easily by separating the two sides of the hanger; the upper PVC pipe that serves as a pivot should be cleaned of debris and (optionally) sanded to a smooth surface. Reinstallation is then performed. Application of lubricant is not advised due to water potability concerns.

Lessons Learned

Our project objective description was to design a better bell siphon that is reliable, adjustable, and inexpensive. In the very beginning of this project, we reached out to the internet community for information and advice. Two of the three authors of *Construction of Automatic Bell Siphons for Backyard Aquaponics Systems*, Bradley Fox and Clyde Tamaru responded to our email. They gave us a little information about the pitfalls of the bell siphon, but also encouraged us to look at the big picture. There were other viable solutions other than the bell siphon that we did not consider because our project statement was specifically about it. Although we ended up choosing the bell siphon as our solution, we learned to consider all solutions that most successfully completed a task rather than just the solution provided.

When encountering a problem it is most beneficial to try to find the cause of the problem rather than automatically work toward a new design. Ecolife Foundation had their prototype bell siphon design that had failed every two weeks. In order to successfully build a new prototype, we have to figure out what was wrong with their system before starting our own design. The difficulty with working with the bell siphon was the lack of information available on the subject. The many forums online have trivial answers for problems with the bell siphon but no theory or data; most people building an aquaponics siphon rely on trial and error. In order to fully understand the component of not just the various siphon ideas but the pump also, we played with them to find what variables were most important. After testing different setups and inflow rates, we learned about how and why each of our test siphons failed. We would constantly come up with other solutions, and then test them to see their effectiveness, until we found a design that wouldn’t fail.

Conclusions and Recommendations

We recommend that for aquaponics systems that need to function under the condition of inconsistent flow rates, utilizing a bell siphon with a tipper and tipper hanger will be the most reliable and inexpensive solution.

Acknowledgements

We would like to thank ECOLIFE, specifically Bill Toone and Michael Ready. They have been excited on this project from the beginning and allowed us to experiment freely.

Additionally, Nathan Delson and Greg Mills have given us encouragement and advice throughout the process. We would like to thank Bradley K. Fox, and Clyde S. Tamaru from the College of Tropical Agriculture and Human Resources (CTAHR) University of Hawaii, Manoa for offering forth their knowledge. We could also like to thank the aquaponics community: many members have responded to emails and given us advice in confusing areas of aquaponics that have been very valuable.

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Appendix

Task Distribution

All members of the team aided in the design and assembly of the final prototype. In addition we experimented with many popular designs to test their feasibility and to determine their failure modes. Wesley was in charge of the flapper design, Vanessa was in charge of the loop siphon design, Peter was in charge of the dumping bucket, and Henry and Rachel were in charge of the original bell siphon design. Independently we tested these various designs and brought our knowledge together into a broader understanding of automated siphons.

Risk Reduction Effort (list high risk issues identified, and how risk was reduced)

Our high risk issues were if the siphon did not start or stop. With the original bell siphon design we found that varying the flow rate in drastically augmented the bell siphon's performance. We thus added the tipper in order to decouple the flow in and out. By doing so, the flow rate in did not affect how well the siphon started and stopped. Rather, the flow rate in only affected the time intervals between dumps of water.

Intermediate deadlines

- Understand the bell siphon (week 1)
- Understand other design options: loop siphon, dumping bucket, flapper method (week 2)
- Test variables including hose/pipe diameters, flow rates in, etc. (week 3)
- Implement two intermittent flow devices at the same time (week 4)
- Build a clear model for visualization (week 7)
- Create a way to couple the hose inlet with the tipper (week 6)
- Create a clear assembly guide (week 8)
- Make 2D step-by-step images of how the various designs work (week 9)

- Make a clear video showing the importance of our prototype in relieving previous problems (week 9)

Drawings / layouts / parts listing

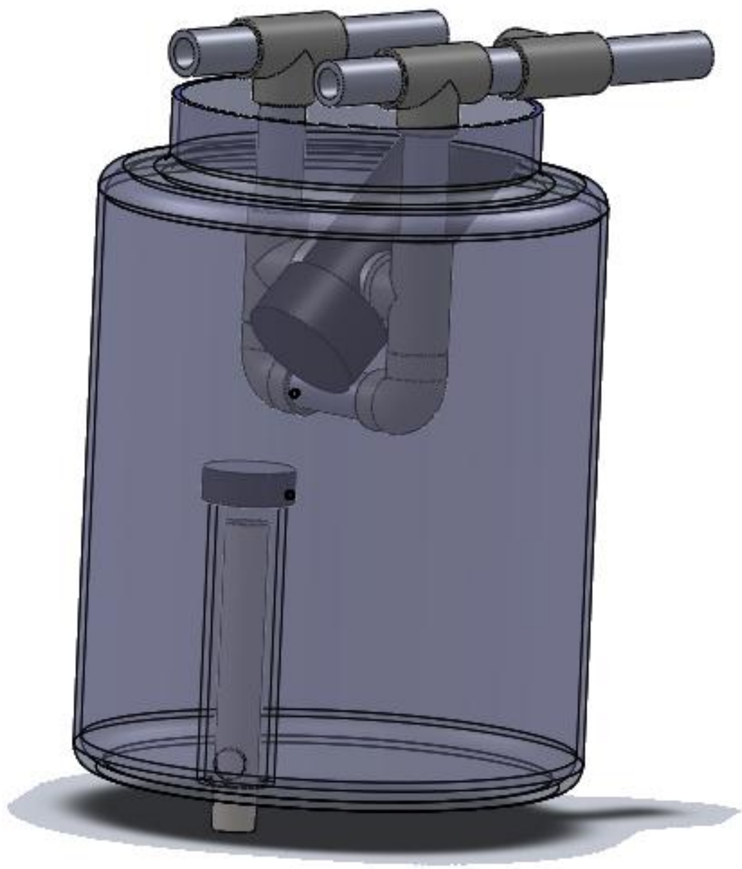

Figure 37: CAD drawing of all parts in reservoir

Materials Needed for final design:

- PVC pipes (1/2, 1, 2, 3 inch diameters)
- Bulkhead fitting
- 2 PVC caps (1 for bell cap, 1 for tipper)
- 5 x 1 in PVC T-joints
- 2 x 1in PVC L-joints
- Glue

List of Suppliers / Purchased Part Information

All parts were bought at Home Depot or Marshals.

Designs Considered

We originally studied four designs. The bell siphon and loop siphon were the first two solutions that we considered because they are the most commonly used in aquaponics systems. We next considered variations of other designs, including the toilet flapper and dumping bucket methods. The flapper design was based off of Travis Hughey's design, while the dumping bucket was an idea taken from the Lego Land water dumper. After studying these designs we decided to add the tipper design which was based off a garden fountain design. The goal of adding this component was to break up the constant flow into the reservoir and allow for the various siphons to start and stop more easily. We implemented this tipper with our various original designs, including the bell siphon and flapper. Using the tipper with the flapper would allow the flapper to be pulled open suddenly when the tipper rotated. The tipper, however, did not provide the necessary force for this design to be feasible. Instead, we decided to add the tipper to the bell siphon to alleviate the current failure modes of the bell siphon. Once this was completed we considered various designs for the ideal placement of the inlet hose so that the flow in would not affect the functionality of the tipper. Our first design included a hose clamp through the lid of the reservoir barrel, but found that it was difficult to be precise with this design and the water oftentimes missed the tipper completely. This led to our final design which includes the tipper hanger, a structure that keeps the tipper and hose inlet coupled together.

Equations and Formulas Used

In order to optimize the design of the tipper, an extensive Matlab-powered numerical analysis was performed on the particular dynamics of the tipper. Our group had a large qualitative knowledge base on the performance of the tipper depending on the vertical height of the pivot, but actual quantitative analysis was never performed. Thus, Peter decided to write a Matlab script that both simulated the weight-shifting dynamics of the tipper (via an Euler-based numerical solution) and also rendered the graphics on screen with Matlab's built-in polygon filling tools:

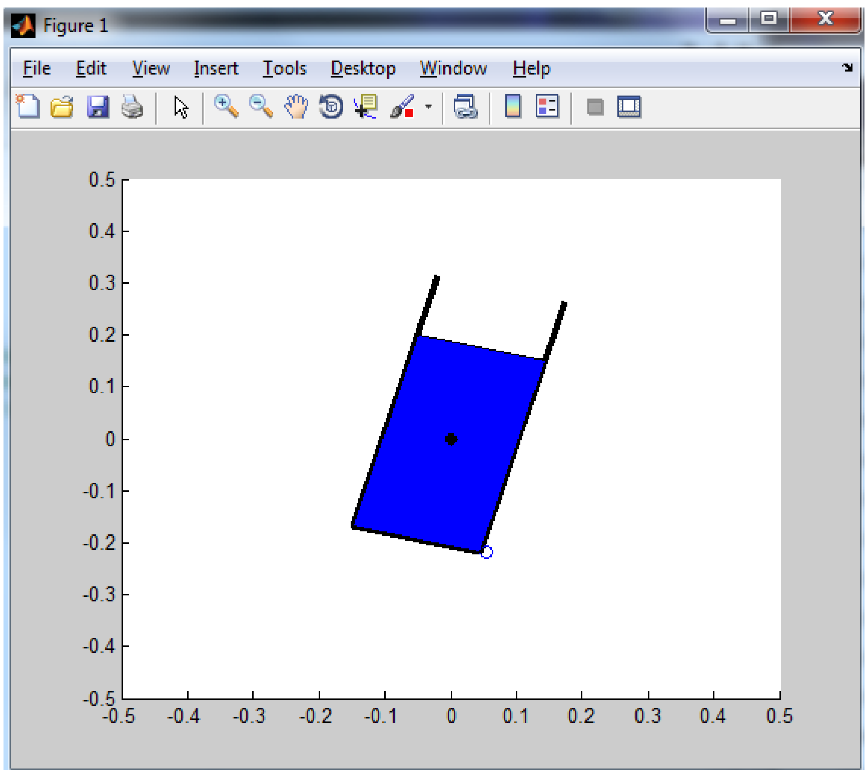

Figure 38: Matlab rendering of tipper

With this script running, our group could then alter the maximum back-angle, the pivot height, the pivot lateral positioning, flow rate, and tipper radius. This allowed us to perform many different simulations and see which variables truly affected the performance of the tipper. After doing an extensive analysis, we determined that increasing the radius of the tipper would not sacrifice performance requirements but improve the performance of the bell siphon. This decision to increase the tipper radius from 2 inch to 3 inch PVC pipe was one of the key factors in our initial prototype design.

We also programmed a loop siphon simulation that was used in the early design stage.

Calculations

Using the formula for buoyant force (BF):

$$BF = \rho V g - mg$$

$$BF = \rho(w * l * h)g - mg$$

Where we assume ρ is the density of water at 70°F (977.8 kg/m^3), V is the volume of the block being submerged in the water, g is gravity on earth (9.81 m/s^2), and m is the mass of the Styrofoam block (0.145 kg). Because the volume submerged is constantly changing due to constant water being pumped in (assumed a flow in rate of 0.25 in/s), we have to adjust the equation to account for the change in height in the volume (change in height increases by 0.1in/s taking into account the size of the reservoir), giving us:

$$BF = \rho\left(w * l * \frac{0.05\ in}{s} t\right)g - mg$$

Plugging in all the numbers, we get a final equation:

$$BF = (\frac{0.566N}{s} * t) - \ 1.422N$$

We want to see how much time it takes for the flapper to open fully, we can use this equation:

$$BF = \left(\frac{0.566N}{s} * t \right) - \ 1.422N > 0.8N$$

Where we can solve for buoyant force for any time, t (in seconds), given the assumptions. Solving for time, t, we get 3.926 seconds. The Styrofoam block should be able to pull the flapper fully open because it generates enough force from buoyancy, but it still does not. This is because we have not taken into account the water coming out of the flapper when it is slightly ajar. As the flapper rises, the Styrofoam block pulls the flapper slightly open allowing water to come out the same time water is going in to the reservoir. Therefore we have to subtract the leakage outflow from the inflow. With the new smaller inflow, it took about 2 minutes for the height of the water to raise 1 inch on the block. The new buoyant force equation with the new change in height becomes:

$$BF = \left(\frac{0.000212N}{s} * t \right) - \ 1.422N > 0.8N$$

Theoretically, it would take 10481.13 seconds for the Styrofoam block to generate the 0.8N required to open the flapper fully open. Somehow, the system seemed to be reaching close to equilibrium; the outflow leakage rate almost matched that of the inflow rate, which is why the increase of water level on the block was so slow. By the time it reaches 10481.13 seconds, the water level would have already reached the top of the block. It takes 720 seconds for the current water rate to reach the top of the block. The buoyancy force cannot increase anymore once the water level reaches the top of the block because there is nothing to increase the buoyancy more. The buoyancy force will stall at some point below the 0.8N required, which is why we always see the flapper ajar but never fully opened.

Budget

From Marshalls 11/30/2010

½" BULKHEAD FITTING PVC SCH	
	1 EA 22.89 EA
¾" BULKHEAD FITTING PVC SCH	
	1 EA 21.69
1" BULKHEAD FITTING PVC SCH	
	1 EA 23.29

SUB-TOTAL: 67.87 TAX: 5.94

TOTAL: 73.81

FROM HOME DEPOT 11/30/2010

2 PVC CAP	7.70
ABS CAP	5.96
2 FT ABS	7.75
½" CAP	0.56
1- 1/4" CAP	0.92
1" CAP	
2 @ 0.74 EACH	1.48
CONDIUT LCKN	0.73
CON LOCKNET	0.50
SPTORNGDL/PL	1.98
CONDUIT LCKN	0.91
LOCKNUT	3.10
O-RING	1.97
AQUARIUMSEAL	4.57
2FT ABS	2.95
1 PVC EL45	0.98
1INX2FT PVC	
2 @ 1.67 EA	3.34
2 PVC EL90	1.98
½ PVC EL90	0.46
½INX2FT PV	0.94
¾ PVC EL45	0.68
¾ M ADAPTR	0.33
3/4INX2FT PV	1.15
1" M ADAPTER	
2 @ 0.68 EA	1.36
WATER WELD	5.77
PVC CEMENT	3.95
LOCKNUT	2.20
#15 O-RING	1.97
SEALKNUT	1.55
PTFE TAPE	1.18
HOMER BUCKET	

2 @ 2.54 EA 5.08
SUBTOTAL 78.56 SALES TAX: 6.87
TOTAL: 85.43

FROM HOME DEPO 1/20/11

PVC BUSHING	0.94
PVC PLUG	0.95
1-1/4 ADAPTR	0.76
CON LOCKNET	0.58

SUBTOTAL 3.23 SALES TAX: 0.28
TOTAL: 3.51

FROM HOME DEPO 02/09/2011

BEV+DECDEP	1.53
ABS CAP	6.25
KO TEST CAP	0.30
2FT ABS	7.75
½ TEE SSS	
5 @ 0.34 EA	1.70
¾ PVE TEE	
2 @ 0.74	1.48
3/4INX2FT	1.15
¾ TEE SSS	
3 @ 0.33	0.99

SUBTOTAL 21.15 SALES TAX: 1.85
TOTAL: 23.00

FROM HOME DEPO 01/18/2011

PEPIPE	3.94
1-1/4 TEE	1.22
1-1/4 ELBOW	
4 @ 1.12 EA	4.84

SUBTOTAL 10.00 SALES TAX: 0.88
TOTAL: 10.88

FROM HOME DEPO 03/10/2011
INDUSTRIAL RAIN GUTTERS
1IN TUBING
SUBTOTAL 28.40 SALES TAX: 2.41
TOTAL: 30.81

FROM AQUA SD
10GALTANK 20.00
SUBTOTAL 20.00 SALES TAX: 1.75
TOTAL: 21.75