Grey Water Capture
Final Design Review

ME 430-06
Senior Project III
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Statement of Disclaimer

1 – Introduction

Grey water is relatively clean water that is produced when potable (drinkable) water is used for tasks such as washing hands in households. Grey water can be reused for things like irrigation, washing cars, and toilet flushing.

Many households today do not implement any kind of grey water recycling system. People do not get a grey water system for a variety of reasons; the benefits could be unknown, the uses for grey water could be limited in their specific home, or the economic gain is too minimal to constitute a modification to the house.

For our project, we are going to design an easy to install product that enables the reuse of grey water from household sources. Examples of our final product could be something that lets the customer use grey water from the bathroom sink to the toilet or from the shower to the toilet in an easy manner.

With guidance from our sponsor Michael Allwein, we will make the benefits of grey water recycling accessible to the average homeowner, reducing their household water usage and saving them money.

2 – Background

Grey water is defined as gently used water that comes from devices like sinks and showers that has not come into contact with sewage. Because grey water is almost as clean as potable water in many cases, possibilities of reusing grey water have been explored by environmentalists and homeowners to help the environment and cut down their water bill.

Grey water can be used for things such as irrigation, toilet flushing, heat reclamation, washing the car, and watering plants. Capturing the water that flows out of the shower head while it warms up and then using the water to fill the reservoir in a toilet is just one of many examples of how grey water can be used. Saving freshwater is beneficial to the user by decreasing their water bill and also helps the community conserve, which is especially important in times of drought. An additional environmental benefit is that recycling water limits the amount of sewage your house produces, as grey water ends up mixing with sewage water.

Grey water is usually harmless, but there are cases where the application can warrant the need to treat and filter the water. An example can include reusing kitchen sink water, which can hold toxic materials like those found in detergents, which need to be avoided if the water will be used on plants. The storage of grey water also needs consideration, as the

bacteria in grey water can colonize as quickly as 24 hours causing strong odors and rendering it unusable in some cases.
Grey water codes in the United States differ from state to state. West Virginia and Massachusetts allow grey water systems only in houses with a composting toilet. Florida bans outdoor grey water use but allows it for flushing toilets. Georgia allows residents to carry grey water in buckets to the plants, but they cannot get a permit to build a simple grey water irrigation system. Washington state's code allows very small systems built without a permit (following performance guidelines), but all other systems have quite stringent requirements [1].

Since then, many areas are reconsidering the regulations and making them less strict. The laws are dependent on the area and many are about irrigation use, as this has potential to affect other people by spreading disease in the soil or air. As grey water becomes more valuable as the benefit of saving water increases and as the risks (or lack thereof) are understood better, laws and regulations are becoming less strict. This opens opportunity to expand the use of grey water in the home.

According to the Universal Environmental Protection Agency, the average American family of four uses around 400 gallons of water per day. Figure 1 shows toilets alone can make up around 25%, or 100 gallons, of home water usage. This proves that there is potential to make a substantial impact on home water usage by using gray water.

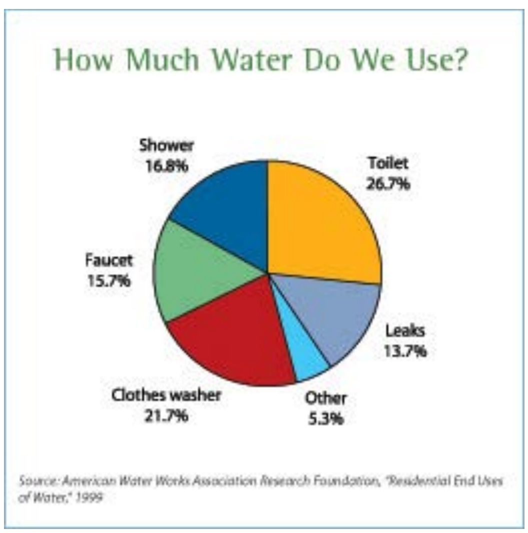

Figure 1: Percent of home water usage by appliance

Why are grey water systems not popular in homes if they could potential reduce water usage by a fourth? The main reasons are that water is cheap, aesthetics of the home are important, it takes time and money to implement a system, and there are risks such as damaging plumping. There is evidence that grey water systems often come short of their goals. Art Ludwig, a renowned environmentalist and grey water activist, shares from his experience that "most complex grey water reuse systems are abandoned within five years" and "most simple grey water systems achieve less than 10% irrigation efficiency within five years”. While a significant percentage of grey water projects fail, there are also ones that do have a positive impact. A handful of these successful systems are listed below.

2.1 Benchmarking

Grey water systems come in all shapes and sizes. While there are some off-the-shelf systems available, there are also other systems being pioneered by DIY'ers. During the benchmarking process, we researched both off-the-shelf and home built systems.

If implemented correctly, reusing washing machine grey water for yards can save a substantial amount of water. As shown in Figure 1, the washing machine uses 80 gallons of water a day which could easily be used for irrigation in a home with a large yard. The water could either be gravity fed or pumped to the irrigation. However, depending on the layout of the home and the skill of the installer, this system might not be appealing to the majority of homes. [1]

A commercially sold existing product is the Sink Positive toilet cover, shown in Figure 2. This product is a sink that is put over the toilet allowing the sink water to flow directly into the toilet tank. Some benefits of Sink Positive are easy installation, no extra energy is needed, and no extra space is taken up. There is little maintenance and all of the sink's grey water has potential to be reused.

Figure 2: Sink Positive

Wetlands consists of plants that can feed and purify grey water. The main benefit of purifying grey water is if the grey water is going to be discharged into a water source. While purified grey water is better to discharge than non-purified grey water, both are not recommended and potentially not legal. The main value for having wetlands would then be the same as having other plants.

A product that was once commercially sold but currently out of commission is called The AQUS Sloan system. Shown in Figure 3, this system has a tank and pump under the bathroom sink which moves the sink's grey water to the toilet when water is needed. The AQUS Sloan system is similar to Sink Positive but allows the homeowner to keep the bathroom layout more conventional while paying the price of extra energy inputted. It also includes a filter which clears objects like hair from entering the toilet tank. The pump knows when to pump the water by observing a sensor on the tank.

Figure 3: Sloan AQUS Grey Water System

Patents that could be infringed upon by our solution were researched and documented. Patents generally last for around 20 years, which is important because we found some 20+ old patents are very relatable to our project. A patent filed in 1992 has the description "Gray water is collected from a tub, shower, or sink, by a drain fixture module, and is stored in a storage tank module for reuse in flushing a toilet" [14]. This patent sound similar to the Sloan AQUS system. Another patent filed in 1992 claims "the present invention provides a gray water recycling system that can conveniently direct gray water from a fixture such as a wash basin, sink, tub, or shower to a holding tank or the like by replacing the fixture's existing drain pipe with a drain pipe valve assembly that is operable between a drain condition, in which water from the fixture is allowed to flow down the drain pipe into the sewer line, and a recycle condition, in which the water is blocked from flowing into the sewer line and instead is allowed to flow into a holding tank line and ultimately to the holding tank" [15]. This patent is very broad and seems to claim any kind of system that stores shower/bath water in a tank. If our ideas infringe on either of these patents, then more research will be done to see if they are still active.

3 - Objectives

Our overall goal is to design and build a grey water capture system to answer the demands of those homeowners who wish to save water. During our group meetings we developed certain requirements that we felt would be important in a successful grey water system. In addition, we surveyed homeowners (family, friends and teachers) to get other insights and feedback about our goals. Homeowners surveyed ranged from those living in municipalities with very expensive water, to those who simply wanted to decrease their environmental footprint. The opinions we gathered allowed us to develop a reasonable list of customer requirements in no particular order.

3.1 Customer Requirements

The customer requirements for our system are shown below. These are all qualities of our system that need to be met for our product to be appealing to someone looking to reuse grey water.

1. Grey water must be filtered and treated properly
2. The system must be safe for the user and environment
3. The system must be an economically positive product
4. Grey water must be recycled at least every 24 hours [8]
5. Deodorize any foul odors present in system
6. Easy to install and maintain
7. Aesthetically pleasing
8. The system must not leak
9. Divert excess water in storage unit to sewage
10. Minimal manual labor

In addition to these requirements, we also need to be aware of proper grey water usage. Following state regulations is one of our biggest priorities when it comes to our product. Summarizing where most states stand on grey water, our system shall be prohibited from the following uses: [9]

1. Consumed by humans or animals
2. Used for bathing or showering
3. Used to top-up swimming pools or spas
4. Used for food preparation or washing dishes or kitchen appliances
5. Used for irrigating in a way that will contact edible parts of herbs, fruit, or vegetables
6. Piped to hot water services

3.2 Scope

These are several different ways that grey water can be reused once the water has been treated properly. Table 1 shows some potential grey water sources and destinations. Any of the sources can be combined with any of the destinations to arrive at a potential grey water capture system. As you can see, irrigation, toilet flushing and car washing are reasonable uses for recycled grey water.

Table 1: Grey Water Sources and Uses

Grey Water Source	Grey Water Destination
Sink	Irrigation
Shower	Toilet Flushing
Washing Machines	Car Washing

3.3 Boundary Sketch

We would like to further discuss the scope of our project and what we will deliver as a finished product to our sponsor. There are certain elements of our project that we will not be able to provide for the system to fully function. Our non-portable system will have mechanical components that require utilities such as electricity and water which we will not provide. The system will be designed to store and reuse water. Our boundary sketch in Figure 4 shows our vision of the entire system. Indicated by the dashed lines are the components of the system that we are responsible for. Some of these components include a container to capture grey water (on top of toilet), an electrical pump, non-rigid piping system, valves and fittings which are designed to safely fit into your home plumbing. The source of grey water will be the shower as shown in Figure 4, while the destination is the toilet that allows for a maximum savings of water.

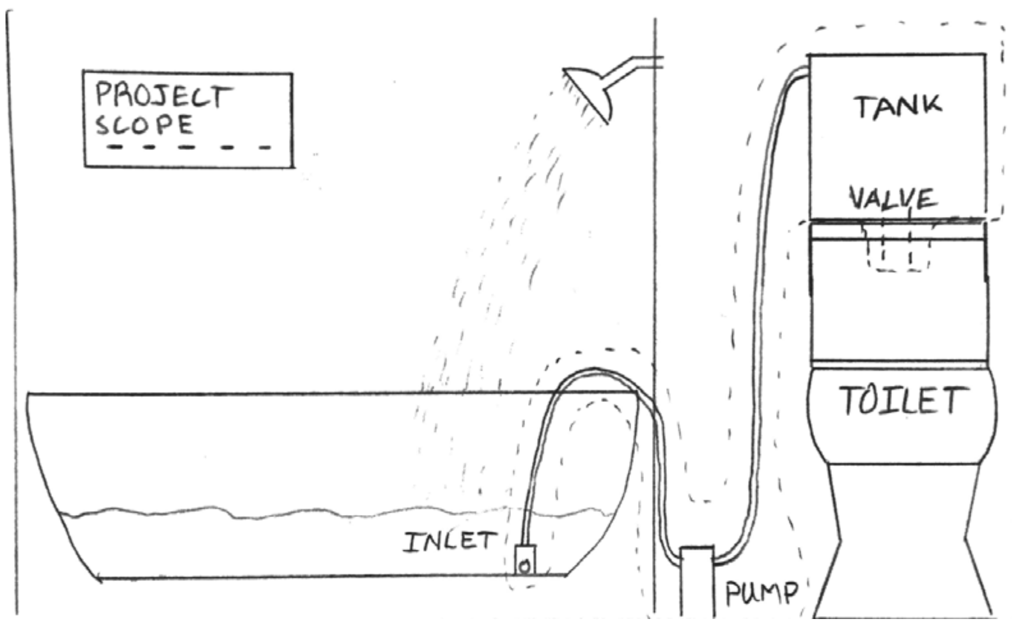

Figure 4: Boundary sketch of our system and different ways grey water can be reused.

3.4 Quality Function Deployment

We used a Quality Function Deployment (QFD) exercise which can be found in Appendix A to identify and quantify customer requirements, wishes, expectations and demands. The QFD allowed us to measure our product versus existing products which gave us certain benchmarks to build upon and help drive our engineering specifications. Once we completed our QFD we were able to see the shortcomings of the products currently on the market. We found that while some of the systems are easy to install, they are inconvenient to use and don't save much water. Additionally, we found that some which do save a good amount of water are too difficult to install for the average homeowner. Both the QFD and customer requirements allowed us to develop a set of design specifications which are listed in the table below.

3.5 Specification Development

Engineering specifications provide measurable and quantitative criteria for satisfying the customer's needs and requirements. The engineering specifications we chose were based on the results of the interviews we conducted with our sponsor Michael Allwein along with potential customers. While conducting these interviews, we were able to determine exactly what they're looking for in a grey water capture system. The engineering design specifications we developed are listed in Table 2 followed by an overview for each specification. Under the compliance column, "A" refers to analysis, "T" refers to testing, "I" refers to inspection, and "S" refers to similarity existing designs.

Table 2: Engineering Specifications

Spec #	Specification Description	Target (units)	Tolerance	Risk	Compliance
1	Water Captured	20 gal/day	Average	M	A, T
2	Installation Time	1 hour	Max	M	S, T
3	Maintenance Frequency	1 time per 3 months	Min	M	S
4	Leakage	None	Max	M	I
5	Manual Labor	None	Max	M	I

3.6 Water Reused

Water is a scarce resource that is often used in a wasteful manner. The amount of water to be reused is a specification that was chosen based on our goal to save the most water. The plan is to save five gallons of water per day on average. Since our bathrooms are one of the largest consumers of water in our household; this would be an ideal place to reuse water. Specifically, the water to be reused is that from the shower head, due to its higher flowrate when compared to that of the sink. The water will then be diverted to the toilet which can be used for flushing. This will allow us to save the maximum amount of water while using only one source of grey water. We can achieve this by testing and being actively aware of potential drawbacks that need to be prevented in order to reach this standard.

3.7 Installation Time

Whenever a product is too difficult to install it can cause a "loss of interest" for the user. A simple to install system is ideal for most people. The installation time of our product will take the average person one-hour maximum. We plan to achieve this by designing a system that is easy to install, while at the same time meeting all of the requirements needed to capture grey water. In order to achieve a simple to install system, we will minimize the number of components that are needed to be assembled and have a standard size that can fit the average home toilet tank.

3.8 Maintenance Frequency

Maintenance frequency is a specification that was developed through research on existing systems and seeing what ideas that we can incorporate into our own system. There will be components to our system that require maintenance to keep the system working at its optimal level. Maintenance will be required approximately four times per year or once every three months. Maintenance includes inspection and cleaning of critical components like the filter and the tank itself. This specification is a key quality in the performance of our system in order to maintain its efficiency.

3.9 Leakage

A closed system that will not leak in any way is a very important specification that was considered in order to keep our system performing properly and reducing potential hazards that come with leaking water. If any leakage occurs, it can affect the amount of water we save in our homes and cause potential dangers like the user slipping and possible electrical hazards that can come from the electric pump. A durable watertight system will be implemented to reduce any leakage and potential hazards.

3.10 Manual Labor

Initially a transportable system was going to be designed. However, after research and ideation, we developed the specification that no manual labor would be required once the system is installed. The idea will be to create a cycle that does the work for you. Rather than transporting a container, the water will be siphoned from the shower and into the toilet through a piping system. A pump will perform the work required to siphon the water from the shower.

3.11 Capacity

Ideally, we want to have a large enough container so that we can save a minimum of one flush per day. Rather than using fresh water with our system, we would like to have a large enough tank to be placed on top of the toilet tank itself to where every flush is grey water that has been reused. This specification will meet all requirements necessary to capture, deliver and transport grey water in a non-portable way.

4– Design Development

There are several major phases which we will move through during this design process. First, we spent the first few weeks researching and defining the problem. This included interviewing our customers or end users and what their needs might be. Once our problem and customer needs have been clearly defined, we will then move forward into the ideation phase. The ideation phase is when we developed some conceptual solutions to solve the problem as we've defined it. Once we came up with a range of possible solutions, the next step was to use Pugh Matrices in combination with a decision matrix to converge on the best possible solution. This process is detailed below and that "best solution" will be revealed. Pending approval from our sponsor, we will move forward with that concept design solution.

Following the New Year, we will enter into the next few phases of the design process. During the next five weeks, we will develop the detailed design of our chosen concept. Once we have a detailed design, we'll present that to you in the form of a Critical Design Review in the first few weeks of February. Following your approval of the design, we will then begin obtaining materials and building a prototype.

Once we have built a working prototype, the next phase will be testing. This is when we'll find out how effective our design is and how well we've achieved the objectives we set for ourselves at the beginning of the design process. Finally, the last item on the agenda is to present our project at the "Project Expo" on June 2nd. Completing this, we will also present our final report and the hardware we have developed to you.

In Figure 5, you will see the general design process our Senior Project class will follow, along with certain dates for deliverables.

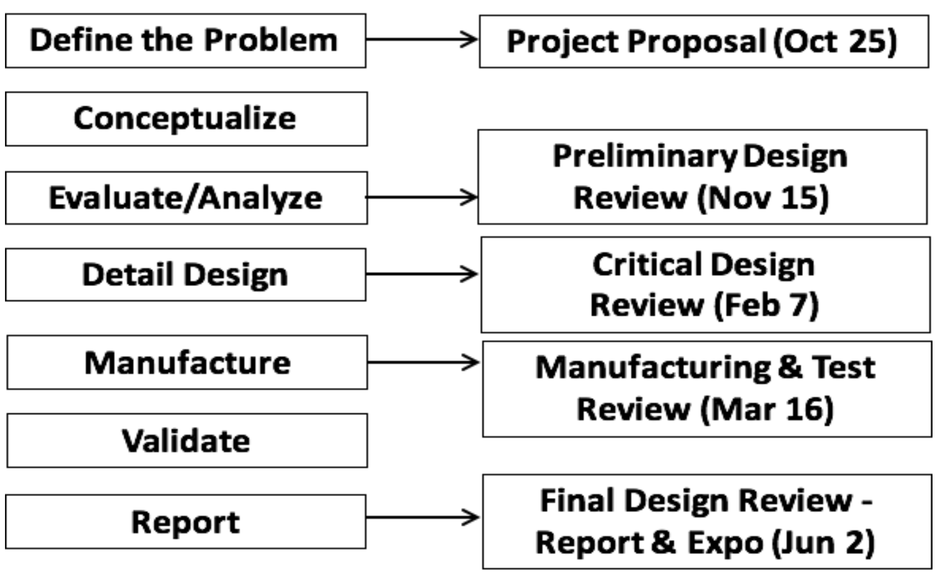

Figure 5: Design process flowchart

4.1 Concept Generation

Concepts for our grey water system were created after our specifications were made. The goal for this section is to come up with many ideas that will later be evaluated in the idea selection part of the process. Focusing on the functions that our system needs will lead us to many possible system configurations. These functions include capturing, transporting, and delivering grey water.

4.2 Idea Generation Strategies

In order to come up with solutions we used many well-known idea generation strategies including brain-writing, brainstorming, and the SCAMPER method. Brain-writing is when each team member writes down individual ideas on a sheet of paper. The paper is then passed around to other team members where each idea is built upon. Brainstorming is when idea generation is done as a team all at once with a whiteboard and posted notes. The SCAMPER method is used at the end when new ideas are created my combining and modifying ideas that have already been created. Attached in the Appendix B are pages that show sketches that were created through these strategies.
When involved in the idea generation strategies we stayed focused on the functions needed for the system. Focusing on functions allows us to come up with partial solutions that can then be combined into a complete solution. The individual functions and potential ideas are shown below. For each function, a Pugh matrix was generated in order to weigh the various options against each other and rate how well they accomplished the function. A Pugh matrix is a commonly used tool which helps facilitate disciplined, team-based concept generation and selection. In a Pugh matrix, multiple concepts are evaluated against a reference concept which helps illustrate the strengths and weaknesses of each. The Pugh matrix associated with each function is given in the appendices.

Function 1: Capturing Grey Water

Our system will need to capture grey water from a source. The main sources of grey water in a home are sinks, showers, and washing machines. For sinks, installing a T-flange in the existing piping under the sink is the easiest way to gain access to the grey water. For showers, capturing grey water is more difficult because the drain piping is buried under the shower basin, making it much harder to access. To come up with solutions, we looked at different points in the shower grey water can be captured. Points of capture include before the water has flown out of the showerhead, before the water goes down the drain, or after the water has flown down the drain. If the water is allowed to flow out of the showerhead (allowing someone to bathe with it) the water can then be captured in a container like a bucket. An alternative to this is to let the water pool on the shower floor and then be siphoned by a vacuum like pipe. Capturing the water after the water goes down the drain could be accomplished by tapping into the plumbing and installing a T-flange, but as discussed earlier this would be much more difficult. For washing machines, installing a T-flange where the water exits the machine would be an easy solution. For all of these ideas, the grey water can be sent directly into a tank or left in the piping.

Function 2: Transporting Grey Water

After the grey water is captured, the next need of the system is to transport the grey water to the destination. This can be accomplished by human power, either by carrying or rolling the tank. The alternative way to transport the water is by using an electric or hydraulic pump in combination with a pipe system.

Function 3: Delivering Grey Water

The destinations to reuse grey water include toilets and irrigation. For toilets, modifying the top of the toilet tank would allow incoming grey water to be used. When a toilet tank needs to be refilled the grey water would be used in place of the freshwater normally used. To do this we would need to modify the float valve in the toilet to ask for grey water first. For irrigation, the delivery of the water depends on the format of the yard. Having drip piping can be used through the areas that need watering if a large area needs to be covered. Another way to deliver the water is a sprinkler system.

4.3 Top Concepts

The following will be a discussion of the top concepts that were generated in the design development process. Each concept was chosen because it meets the customer requirements, but which one is the optimal solution?

Concept #1:
One potential solution that we considered was a grey water system underneath the sink. For this concept, the water will be stored into a container underneath the sink. This particular concept met all the requirements that we have developed. In order to capture grey water, the tank is connected to the existing piping through a T– flange where a grey water tank resides as shown below in Figure 6.

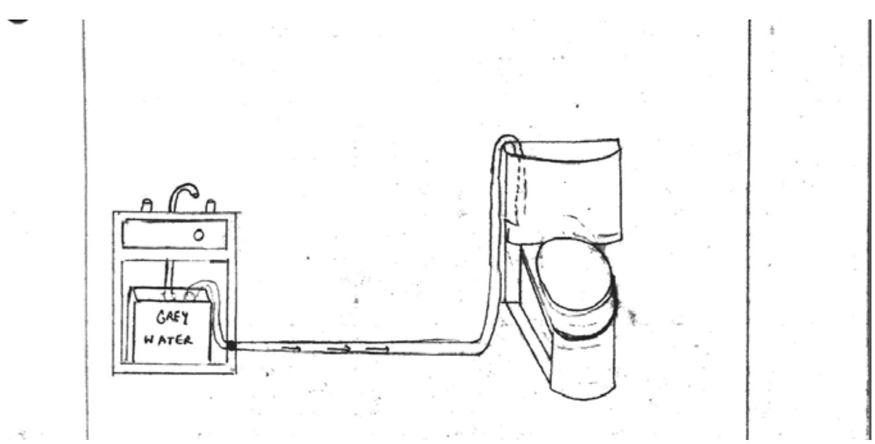

Figure 6: A sketch of our Sink to Toilet concept.

In order to route the water from underneath the sink to the toilet, it is required to drill a hole in the vanity which will be used to route the piping through and directly to the toilet as shown in the figure above. Gravity and a pump will allow the water to be transported from under the sink and directly to the toilet. Where the piping meets the tank of the toilet, there will be a leveling clip that will stabilize the toilet lid. This concept allows for the re use of water in a non-intrusive way since the grey water tank is stored inside the vanity at all times.

Concept #2:
Another concept was to capture water from a different source such as the shower and deliver the water to the toilet. For this particular concept, water is siphoned from the bathtub as you are warming up the shower. As you warm up the shower, all the water is captured from the shower and diverted to the toilet as shown in the figure below. The means of transporting this water will be through an electric pump that is connected to a non-rigid piping system in your shower. This non rigid piping system will be installed from the shower to a small electric pump that will pump the water up to our tank which can be used for flushing.

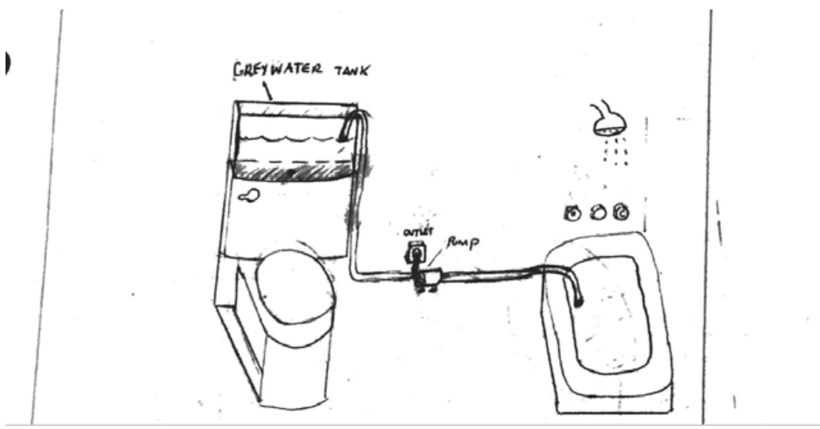

Figure 7: Grey water system from shower to toilet with tank on top of the toilet

The means of transporting this water will be through an electric pump that is connected to a non-rigid piping system in your shower. This non rigid piping system will be installed from the shower to a small electric pump that will pump the water up to our tank which can be used for flushing.

Concept #3:
Furthermore, another concept that was considered was to use the grey water from the washing machine which can then be diverted to the irrigation. We thought of this concept as a system that will go from laundry to your landscape as shown in Figure 8.

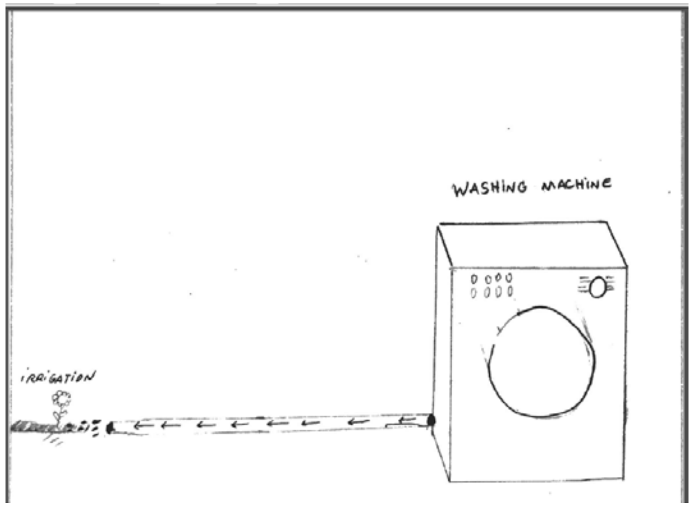

Figure 8: A sketch of a washing machine to irrigation system.

For this particular concept, we were not actually storing grey water, but we are diverting the grey water directly to the landscape. To accomplish this, the system captures grey water from the drain hose and sends it out to the plants, grass or any other landscape where grey water can be used. To transport the grey water, the system relies on a sloped surface along with gravity. Benefits to this concept include a system that does not rely on an external pump to transport the water.

Concept #4:
A similar concept that was generated is a grey water system that captures water from the shower and delivers the water to the toilet. However, instead of using an electric pump, this system uses a hydraulic pump to send the water to the toilet.

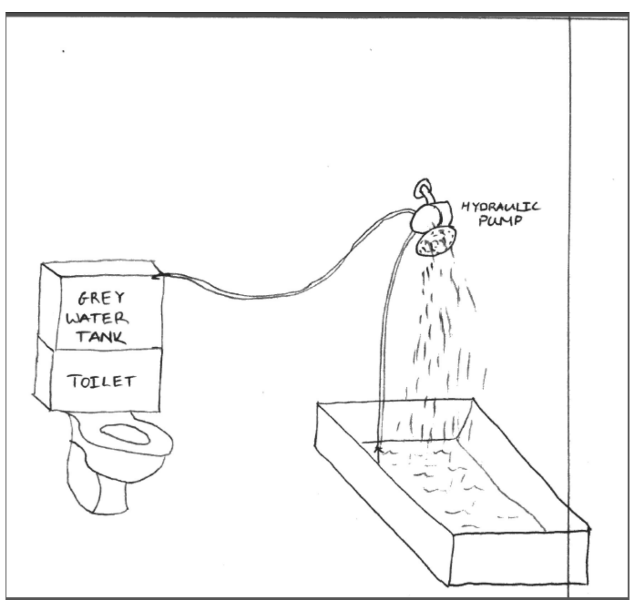

Figure 9: Sketch of shower to toilet grey water system by way of hydraulic pump

The way it works is there will be an impeller / propeller connected to the existing piping before the shower head. So as long as the shower is running, the pump is receiving hydraulic power. This system will have an automatic on/off feature which automatically turns on when the shower is running and turns off when the shower is not running. One distinct advantage is that this system avoids electricity thus avoiding potential dangers and motor costs that arise while using electricity.

Concept #5:

The last concept that was generated involved two electrical pumps and a grey water storage tank that is placed on the ground beside the toilet as shown in Figure 10.

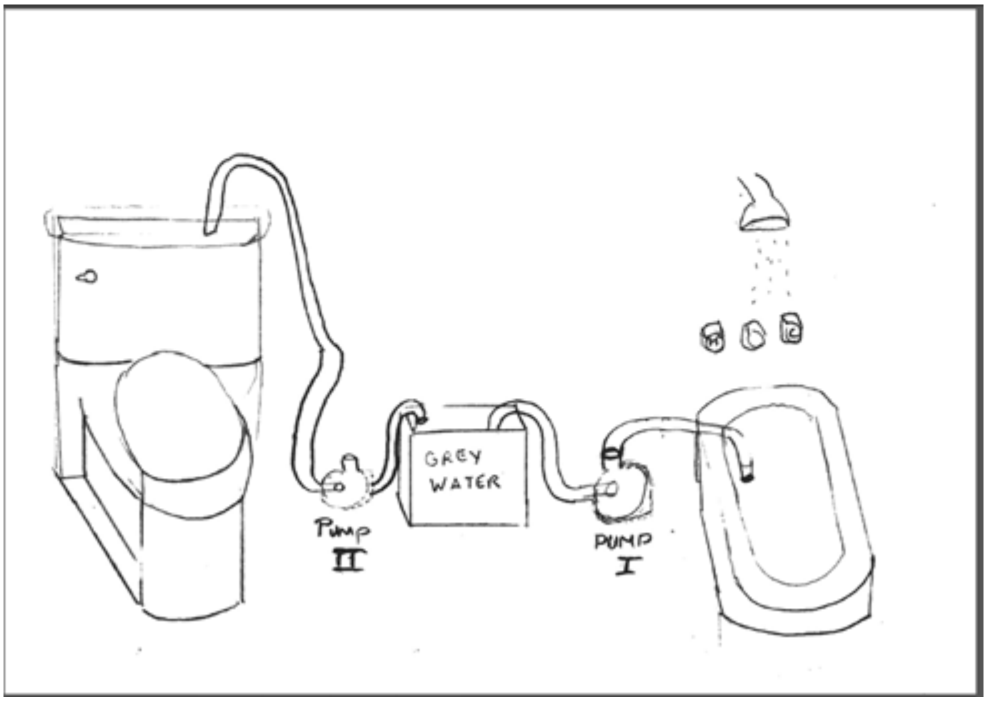

Figure 10: This system is a tank that is beside the toilet which involves an electric pump to transport the water.

This concept meets the requirements to capture, transport and deliver grey water. The water is siphoned from the bottom of the shower by one pump which then transports the water to the grey water tank. After, the water is pumped by the second pump and into the toilet tank which can be used for flushing. A benefit to this concept includes the safety of not having a large tank on top of the toilet that can potentially fall off the toilet. However, a disadvantage for this system is its reliance of two pumps; one to pump the water from the shower and into the grey water tank while the other pump is sends the grey water from the tank directly to the toilet.

4.4 Decision Matrix

The top concepts are a few of the many concepts that were placed in a decision matrix in order to systematically converge on the best solution. In the decision matrix, requirements were weighted against each other according to their respective priorities we gathered from interviewing potential users and our project sponsor. Concepts were than graded on how well they met those specific requirements and each concept was given a point total. By comparing those point totals, we were able to select the concept which best satisfied all of our design requirements. The decision matrix can be found in Appendix C**.**

Concept #1, capturing water from a bathroom sink, storing it in a tank inside the vanity, and pumping it to the toilet as needed; lost points for a tricky installation, the necessity of having a vanity big enough for the tank, and not saving as much water as other solutions.

Concept #2, capturing water from the shower and using an electric pump to pipe the water to a holding tank placed on top of the toilet reservoir tank; held up well in the decision matrix. It will be one of the easiest systems to install, works in most homes, saves a large amount of water, shouldn't leak and is very safe. Also, the water is constantly being used so it won't be stagnant enough to culture into black water and is aesthetically pleasing while still being very easy to use. Despite the installation process being one of the easier ones among our concepts, it lost points for the potential that the shower and toilet could be fairly far apart. It also lost a few points in the "works in most homes" category as well for this same reason. The projected cost of this system will be on par with the other concepts generated, but more expensive than a simple container.

Concept #3, washing machine to irrigation. While this concept will be very safe and easy to use, it did not fare well with the other requirements. Its installation, costs, and aesthetics were not worse than other designs, but not all homes have washing machines near their landscaping. Additionally, the water from the washing machine will not be very clean at all - most likely containing strong degreasers.

Concept #4, capturing water from the shower and using a hydraulic pump to deliver it to a holding tank placed above toilet reservoir. This concept is nearly identical to Concept #2, except a hydraulic pump will be used instead of an electric pump. A hydraulic pump would eliminate the need for electricity, but we found the hydraulic pump had some strong disadvantages as well. First, it would need to be placed between the wall and the shower head. Unless it is to be anchored to the wall, this configuration will put shear and bending stress on the fresh water pipe going into the wall. These pipes can be made of a brittle plastic, and are not designed to sustain heavy loads. Should the pipe fail, water will flood into the wall and quickly do massive damage? Water damage is some of the worst that a house can sustain, and requires lengthy and costly repairs. For this reason alone, the hydraulic pump was considered too much of a liability. Additionally, placing a hydraulic pump in line with the shower head will reduce the shower water pressure – making showers less enjoyable. Finally, there are many users who enjoy taking baths in their combination shower / bath units. With a hydraulic pump, the system would not be able to capture any of the bathwater because there would not be any flow coming through the shower head to provide pump power. The only way to capture bath water would be to add an electric pump to the system. But if you're going to do that, then what is the point of the hydraulic pump? As will be discussed later, small waterproof electric pumps only cost around $10-15 and use less than 10 watts of power – a nearly miniscule amount. While it's a clever solution, we concluded the benefits of using a hydraulic pump simply did not outweigh its many disadvantages.

Concept #5, capturing water from the shower and storing it in a tank on the bathroom floor before it is pumped to the toilet. While this concept saved a good amount of water, shouldn't leak, was very safe, clean, and easy to use; there were a few distinct disadvantages. First, not all bathrooms have floor space for a large water tank. Second, this concept would be unsightly – it is not attractive to most potential users to have a large tank on their bathroom floor. Finally, we realized this concept would require two pumps for it to work properly. This is because water first needs to be pumped from the shower to the holding tank. Than once it is needed in the toilet reservoir, the water needs to be pumped yet again. Two pumps would add considerable cost to this system and is an inefficient way to re-use the water when comparing to Concept #2 (only one pump required). For these various reasons, it was determined this concept did not perform as well as other's we considered.

4.5 The Optimal Solution

The results from our decision matrix were that Concept #2 was determined to be the optimal solution. It is the best answer to the customer requirements we have gathered from potential users and our sponsor.

In order to get a more detailed idea of how our grey water capture system would be arranged, a solid model layout was done. As you can see from the front and top views given in Figures 11 and 12, the plan is to pipe water from a shower to a tank located on top of the toilet reservoir using a small pump.

Figure 11: Front view

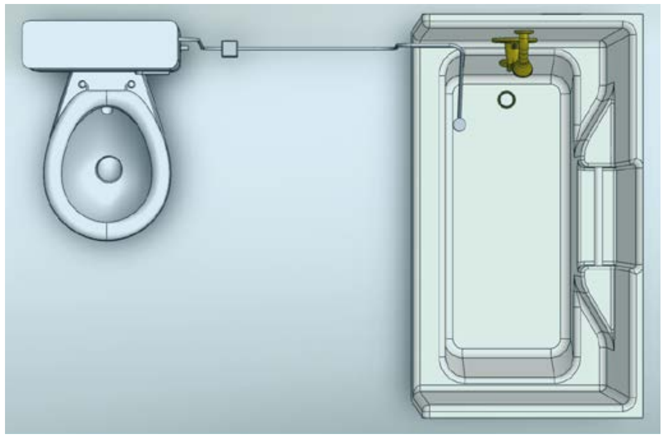

Figure 12: Top view

What was emphasized going through the process of building a solid model layout is this system is best suited for bathrooms where the shower is located near to the toilet.

At this stage in the design process, exact dimensions have not yet been determined. The tank will need to fit on top of a toilet revoir so that requirement inherently drives the length and width of the tank we will be designing. Likewise, the exact height of the tank is not yet determined. All we have at this stage is that the tank should contain enough volume to match the volume of water associated with at least one flush of the toilet. So in that sense, we know the tank size will be a function of that volume requirement. Together with the length and width requirement discussed earlier, these two requirements will drive the tank geometry. We also have some idea for the internals of the tank but no specifics yet. We know there will need to be a system of valves which will ensure the filling of the toilet reservoir will bias to our grey water tank, but will also pull water from the fresh water line should the tank run empty. We know that the tank will likely be made out of plastic, but we have not decided upon this material at this time. We are still considering other materials such as fiber glass and metal as potential alternatives. If possible, it would be best if the tank could be purchased instead of needing to be manufactured – at least for the first prototype.

Since this system is designed to be configurable by the DIY installer, the tubing connecting the inlet to the pump and the pump to the tank will likely be cut to fit. We are envisioning that when this system is sold as a product, included in the kit will be a length of tubing which the DIY installer will simply cut to the length needed for their specific bathroom layout. The exact length of the tubing included in the final kit which would cater to most bathroom layouts has yet to be determined. The Bernoulli analysis was conducted with ½ inch tubing which yielded a relatively low required pump head of just 4.75 ft. Pump head required is highly dependent on the diameter and length of the tubing, so further analysis will be required before we are able to determine the optimal tube diameter. Likewise, the specific material selected for the tubing has not yet been decided. We know it is important for the tubing to be flexible so that it can easily conform to varying bathroom layouts and be easy to install. We also know that the required pump head is a function of the friction factor, which depends on the tubing material; so that will serve to help determine tubing material as well. That being said, no specific material has been selected. This will most likely be something which we purchase instead of manufacture ourselves.

The selection of the pump to pipe the water from the shower to the tank has likewise not yet been selected. We have however done some preliminary calculations using the modified Bernoulli's equation and have an idea for what sort of pump head will be required, we know it should be around 4.75 ft. So while we don't have a specific pump selected, we do know that the sort of pump head required will likely be achievable by a small fish tank or pond pump. Either way, this is a component we will be purchasing and not manufacturing ourselves.

The exact geometry of the inlet which is to collect the water from the shower basin has also not yet been determined. An idea we're considering at this time is that there will be a suction cup on the bottom of the inlet housing which will affix it to the floor of the shower to keep it from moving. But as was stated, the geometry of this component has not yet been determined. It is very possible this is a component we will be needing to manufacture ourselves due to the uniqueness of this system. Therefore, the material choice will most likely depend on our ability to manufacture it. 3D printing out of ABS could prove to be a very good option here for the first prototype, or maybe we'll choose to machine it out of Delrin. Either way, we are fairly certain it will be made of some sort of plastic as it is difficult to see any benefit to choosing metal or a composite.

As you can see there are still more than a few unknown in our design, but we feel that we are very much on the right track. We are eager to overcome each of these challenges.

4.6 Preliminary Safety and Testing Plan

Both the water reused and installation time specifications will require testing. Once we have a working prototype, it will be installed in one of the team-member's bathrooms. This install process will allow us to put to the test our specification of an installation time less than 1 hour. Once the system is in place, we will be able to test our first engineering specification; if it will recycle more than 5 gallons of grey water per day.

In order to ensure safety, a preliminary design hazard checklist has been completed. The checklist is given in Appendix D**.** In summary, there will be a spinning pump which could be harmful. There is the hazard that the tank could fall from its location on top of the toilet reservoir tank. The system will most likely have sharp edges which could be dangerous. The system will be exposed to high temperatures and high humidity in the bathroom, as bathrooms tend to fog up during hot showers. Finally, there is the possibility that the system could be used in an unsafe manor. Table 2 below shows the relationship between our tests and specifications.

Table 2: Engineering Specifications

Spec #	Specification Description	Target (units)	Tolerance	Risk	Compliance
1	Water reused	20 gal/day	Average	M	A, T
2	Installation Time	1 hour	Max	M	S, T
4	Maintenance Frequency	3 months	Min	M	S
5	Leakage	None	Max	M	I
6	Manual Labor	None	Max	M	I

In light of these potential hazards, we plan to answer them with a combination of good engineering design as well as warning labels and disclaimers. We will place warning labels and clear instructions in the instruction manual in order to warn users against inserting their fingers into the pump while spinning. In order to address the heavy water tank, there will be a warning given in the instruction manual and the tank may potentially be attached rigidly to the toilet reservoir tank. To address sharp edges, there will be a warning in the instruction manual and edges will be rounded where possible so that we can reduce potential stress concentrations that may be present in the system. To address the hot/ humid environment the electric pump will be a waterproof variety, potentially battery powered if that proves to be better and safer. Finally, in order to address the possibility for unsafe use; we plan on including a warning and disclaimer in the instruction manual.

5- Management Plan

In general, our team seeks to work on stages of the design process together as a group. We believe that the ideal way to incorporate both individual ideas and team consensus is to work on tasks individually and then come together and share what we have done and what we have found. From there we will share and understand our different points of view to ultimately arrive at an agreement on how best to proceed. This process means that we will rarely ever have just one person working on any one task, all members of the team will be working together to ensure each task is completed to the best of our ability. We will approach each step of the process as a team. Should we arrive at a stage which does not require all team members to be dedicating time to it; we will decide at that time who is best to take charge of that task.

That being said, each team member will have certain specialties - things they are constantly doing which the team relies on to stay on track. Paul has elected to keep the team on track and maintain communication with our project sponsor. Kevin will maintain our travel and material budget. Vicente will maintain our information repository. Together, the team has the analytical skills, engineering intuition, and prototyping skills needed to take this project from conception to prototype.

Our project Gantt chart for the first phase of the design process is included in the appendices which details each step in the process. The major milestones will be design reviews, reports, prototype testing, and the design expo. These are stages of the process where we would very much appreciate involvement from our sponsor.

6- Final Design Details

6.1 Design Description

Our final grey water capture system design allows homeowners to conveniently reuse their shower water to fill their toilet. This is accomplished by pumping water from the shower to a tank which sits on a stand directly above the toilet. This final design is very similar to the optimal solution in the design development section above with a few changes, most notable a shelving unit that will now support the tank instead of the tank resting on the toilet. The CAD drawings showing our final design can be referenced in Appendix H. CAD drawing 0001 shows the full assembly of the design.

The pump, shown as item 5 in the main assembly, will be turned on when the shower is being used and will be responsible for the power required to send grey water from the shower to the tank. The pump chosen is the SHURflo 2088-59-154, which is self-priming and provides a maximum 100 feet of head at a flowrate of 3 gallons per minute. Self-priming was a critical attribute for us because the flow of water will not be constant and the pump will need to function when there is only air in the pipes. Two male brass barbed fittings will be threaded into the inlet and outlet of the pump so that it can be connected with the PVC tubing. The PVC tubing on the inlet side will go to the shower floor and the outlet side will go to the tank. It is important to note that the water level on the shower floor must be over ½” high to allow the inlet pipe to be able to collect water.

The end of the tube which collects the grey water will be attached to the shower floor by a suction cup in order to stay below the water line, as shown in the sub-assembly CAD drawing 0004. Item 2 in the sub-assembly is a suction cup that will be attached to the PVC pipe via a zip-tie. Item 4 in the sub-assembly is a carbon impregnated felt filter sheet which will cover the opening of the inlet pipe to deny hair and other follicles from entering our piping system and getting tangled in the pump or causing other adverse effects. The felt sheet will also be attached with a zip tie. During assembly, the inlet pipe should be placed where the water level will be highest; near the drain in most cases. The drain of the shower will need to be disabled by either closing the drain or installing a plug in order to collect the water so it may be captured.

The piping layout, shown as item 7 in the main assembly, will depend on the bathroom and will need to be assembled by the individual. We envision the end product to come with approximately 25 feet of PVC flexible tubing; up to approximately 20 feet will be used to traverse from the shower to the tank and the remainder will be used to connect the tank to the toilet. In order to minimize head loss, the minimum amount of tubing required should be used; however, the pump specified can supply enough head should the user need the full 25 feet.

The PVC tubes will be connected to the tank with the barbed-fittings as shown in CAD drawing 0003. The sub-assembly shows two parts: the piping (item 1) and the plastic barbed fitting (item 2). The inlet and outlet holes from the tank will feature this attachment method.

The tank to toilet sub-assembly, detailed in CAD drawing 0005, shows how to connect the tank to the toilet while also keeping the main water line connected. A brass tee joint will be utilized for this purpose along with the proper barbed-fittings. Our product is designed to collect enough shower water to meet the toilet water demand; so the main water line should remain shut off. However, in the event the tank runs empty, the main water line may be turned on to supply water until the user can collect more grey water.

The shelving unit, part 8 in the main assembly, is used to support the tank above the toilet. The shelving unit will be purchased from Home Depot and comes at a height of 60" with 6 shelves, each with a capacity to hold 250 pounds. This weight capacity is able to hold 20 gallons of water with a 1.5 factor of safety. Only the top shelf will be used in our design, and the height will be cut to the length specified (33") using a chop saw in the manufacturing phase by the team.

The tank, part 2 in the main assembly, will be used to hold the grey water and is attached to the shelving unit with four sealed bolts. The tank has a capacity 25 gallons of volume but will only be filled to 20 gallons. The reason for choosing the 25-gallon tank was because the proportions and cost of the tank specified best suited the design. The proportions for the 20-gallon tank were not conducive for our design. A float switch will be installed within the tank and will be used to shut off the pump when the tank gets to our desired max water volume of 20 gallons. A 5" access hole on the top of the tank will be needed in order to allow installation of the float switch. Additionally, there will be five other holes drilled in the tank at the locations specified in CAD drawing 0002. Two of these holes (.19" diameter) are used to mount the float valve, one (.50" diameter) is for the wiring of the float valve, one (.54" diameter) is the inlet from the shower, and one (.38" diameter) is the outlet to the toilet.

The float switch assembly, which will be attached on the inside of the tank, can be seen in CAD sub-assembly 0006. The float switch bracket will be mounted with the holes that were drilled in the tank, shown as item 1 in the sub-assembly. The float switch (item 2) will rise when the water volume is near 20 gallons and physically interrupt the circuit powering the pump. Proper operation of the float valve is critical because if more than 20 gallons is allowed into the tank, the factor of safety for the shelving unit will drop below 1.5.

6.2 Material Selection

For many of the components in our design, material was a primary factor in choosing which to purchase. The reasons for these choices are enumerated below in Table 4.

Table 4: Materials selected for system

Part	Material	Reason material Selected
Pipe	PVC	Flexible, cheap, light
Suction Cup	Zinc-Plated Steel	Corrosion inhibition Durable
Pump	(Various)	Water Proof
Filter	Carbon impregnated	Removes odor/follicles Minimal head loss
Tank	Plastic	Light Corrosion inhibition
Float Switch	(Various)	Floats in water Corrosion inhibition
T-Joint	Brass	Strength
Stand	Steel	Strength, Durability

6.3 Safety Considerations

In order to brainstorm some of the potential safety considerations associated with our design, a Design Failure Mode and Effects Analysis (DFMEA) was created as seen in Appendix I. The resulting safety considerations and corresponding precautions are summarized in Table 5 below.

Table 5: Safety Considerations

Failure Mode	Effect	Precaution
Stand Collapse	Possible human injury Tank breaks/spills on floor Damage the toilet	Do not load the stand with more than 250 pounds (20 gallons of water).
Tank Overflow	Water spillage	Float valve to close tank from shower water works correctly.
Electrocution	Human injury Damage to pump	Pump is waterproof
Tripping over Pipe	Human injury Possibly pull tank over	Assemble piping system so the risk of tripping is minimal

Slipping from water in shower	Human injury	Place mat in shower
Water level is not high enough	No grey water captured	Plug shower drain
Filter Clogged	No grey water captured	Check for items blocking filter before each shower
Pump cannot provide enough head	No grey water captured	Assemble piping system for least head loss
Odor from Tank	Bathroom smells	Clean tank at the maintenance frequency suggested
Tube Disconnects	Leakage	Attach pipes using the barbed fitting assembly

6.4 Maintenance Issues

The maintenance plan provided will allow the system to run successfully for a long period of time. The filter should be inspected and cleaned as this will allow more water to pass through while minimizing head loss. The tank should be cleaned to kill bacteria and prevent odors from lingering in the bathroom. The suction cup should be cleaned when the suction is loss. The pump, stand, float switch, and pipes have no maintenance plan as they should work for a long period of time on their own. A more detailed look at the maintenance plan is shown in Table 7 below.

Table 7: Maintenance Plan

Part	Maintenance Plan
Filter	Replace once per three months
Suction Cup	Clean when suction is loss
Tank	Clean once per three month

6.5 Justification/Evidence

In order to reach our target of reusing 20 gallons of water per day, it was necessary to determine the potential volume of water that could be captured. By doing research on the average household size, average elapsed shower duration, and average shower flowrate, we were able to conduct this analysis. Table 8 shows the information used.

Table 8: Research data used to determine potential water reuse.

Average Household Size	Average Elapsed Time Per Shower	Average Shower Flowrate	Average Number of Showers per Day
2.54 People	8 minutes	2.1 gallons per minute	1

By conservatively assuming only 50% of the available water is captured, we would still capture over 20 gallons of water; satisfying our specification. In reality, we expect to be able to capture much more than 50% of the available water; although some will be lost as steam.

Another important design decision was the size of the pump that would be required to pump water from the shower to the storage. To aid our decision in what pump would be required, we first designed our CAD model to the appropriate scale. While designing the model, we determined the water would need to travel a maximum height of 5.5 feet. From this point we conducted a modified Bernoulli analysis to find pump head required. The following shows the assumptions in order to calculate for the pump head required:

Assumptions:

- Incompressible fluid (fluid being analyzed is water)
- Constant properties at the inlet and outlet control surface
- Velocity at the inlet will be considered equal to the velocity at the outlet
- Shower head flow rate of 2.1 gallons per minute.
- Smooth pipe tubing system

Modified Bernoulli Equation:	$\frac{P_1}{\rho}+\frac{V_1^{\,2}}{2g}+z_1+h_{pump}=\frac{P_2}{\rho}+\frac{V_2^{\,2}}{2g}+z_2+h_l$	(1)

Where the pump head is $h_{pump} = h_2 + h_l$, the total head is $h_l = h_{l,minor} + h_{l,major}$, and $z_2$is the maximum height of our apparatus. After simplification, the following equations resulted:

Head Loss:	$h_l = f\left(\frac{L}{D}\right) * \frac{V^{\,2}}{2g}$	(2)
Velocity :	$V = \frac{Q}{A_{tube}}$	(3)
Reynolds Number:	$Re = \frac{\rho * V * D_{tube}}{\mu}$	(4)

While making relevant assumptions and using the equations, we obtained data from the moody diagram (for round pipes) and fluid property tables. Looking up the kinematic viscosity at ambient temperature (70 ° F) we were able to calculate Reynold's number. Also, using the assumption that our system will be similar to that of a smooth pipe system. After obtaining Reynolds number and the relative roughness of our system, we were able to use the Moody diagram (Figure 13) to find the friction factor.

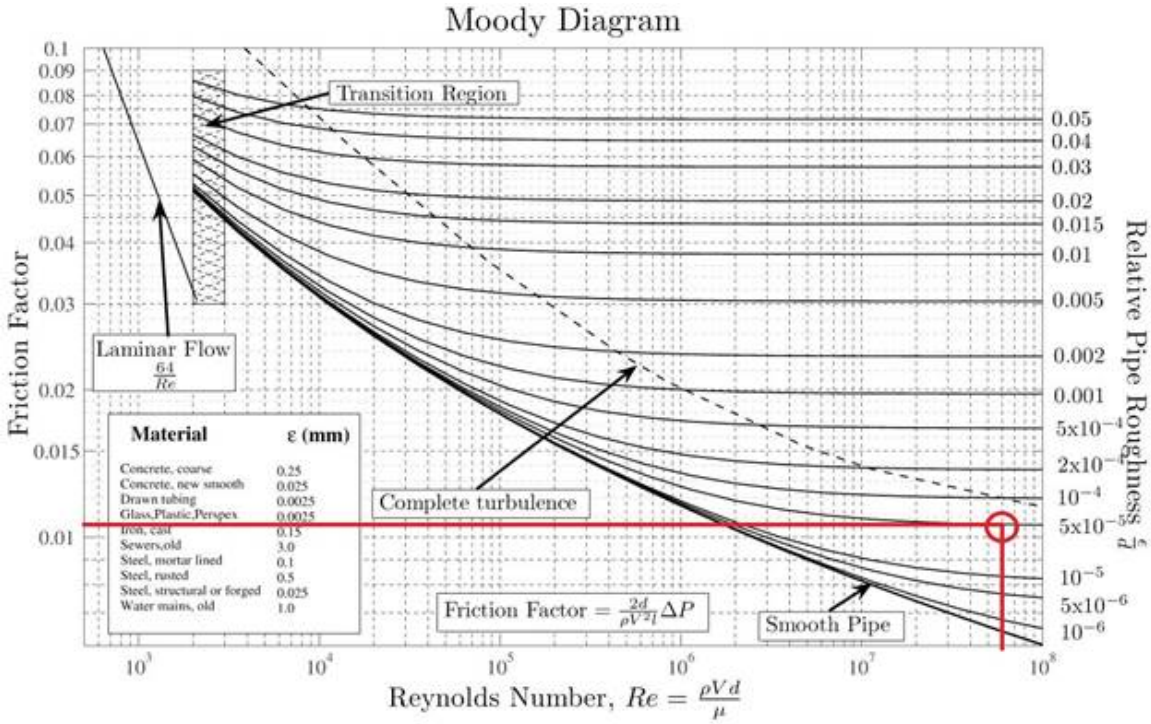

Figure 13: Moody diagram used to calculate the friction factor.

Based on Reynolds number and relative pipe roughness, we used the Moody diagram shown in Figure 13 to obtain a friction factor of 0.04 which allowed us to calculate the pump head required using equation (2). Figure 14 contains a suitable pump that meets our requirements.

Figure 14: SHURflo 115 VAC diaphragm industrial pump.

The SHURflo pump specified in our design can provide 100 ft of head, far exceeding the calculated required head. This pump was chosen primarily because it is self-priming up to

9 vertical feet. This was a critical requirement because the system will need to be primed every time water is collected from the shower and the pump will need to pull water up and over the side of a tub in some instances. It was for these reasons this particular pump was chosen, despite the fact that it can supply a pump head far exceeding the requirement.

6.6 Installation Time

Installation time will be justified based on similitude. We do this by considering other systems of similar size and scale. Components that will need to be assembled include: tubing, pump, storage tank, float switch and shelving unit. Please note that the pump and the float switch will need to be connected to allow for proper control of the pump. The system is designed to be assembled and installed with minimal tools. Tools necessary would include screwdrivers, scissors, and hex keys. To reliably and conveniently connect the tubing and the storage tank, barbed fittings will be used. Barbed fittings will allow the user to easily slip the tube onto one side of the barbed fitting while the other threaded side will be screwed into the tank.

6.7 Maintenance Frequency

Maintenance details are given in the maintenance plan section. only maintenance that would be required will be to replace the filter every three months. This is based on similitude of other filters that are of a similar nature to the filter we are incorporating into our system. Based on research, we found that that the lifetime of a standard filter is at least 3 months. Also due to wear and tear on the system, other components might need to be replaced every so often. To account for this, our system is composed of standard parts that can be obtained at most hardware stores. Also, the user will have additional tubing that can be used to replace any worn tubing.

6.8 Leakage

Understanding that testing for leakage is important because leakage can waste water, cause damage, and be a safety hazard; it is a priority to ensure our system is properly sealed and take every precaution necessary to ensure a watertight system. To accomplish this task, every inlet and outlet of our system will be sealed. Furthermore, if any leakage occurs from faulty tubes, additional PVC tubing will be readily available as it is a standard component. Any leakages that might occur within our system can be easily detected through a quick and simple inspection.

6.9 Manual Labor

Manual labor will not be required for this system since our system is an assemble, install and run type of system. The only “manual” requirement for the user would be to activate the system through a 3 wire grounded switch tap as shown in Figure 15 which is then plugged into the outlet.

Figure 15: Leviton 3-Wire Grounded Switch Tap.

The switch is a safe alternative which only requires the user to simply press the switch to activate the system. Thus, through our design no manual labor is required.

6.10 Stand for Storage Tank

Since there are building codes that state a centerline of the toilet has to be at least 15 inches from the outer edge of the shower (nearest to the toilet) we were finding difficulties on where to place the storage tank. If we had chosen to place the storage tank on the ground next to the toilet, we would have to get a very slim and tall tank which would likely not allow room for the pump and tubing. After strategizing, we decided to have a shelving unit that the tank would reside on while being kept in place and preventing any tipping from occurring. The stand we chose is one that we can purchase and holds a maximum load of 250 lbs. This is more than enough, even if our storage tank is full to the 20 gallon limit it will only weigh approximately 167 lbs. Due to this, we calculated a factor of safety.

$$F.S = \frac{Ultimate\ Stress}{Actual\ Stress} \quad \textbf{(5)}$$

The factor of safety that was calculated was 1.5. Not to mention, the stand itself has a factor of safety associated with it, so our calculated factor of safety is likely very conservative.

6.11 Supporting Data

The total cost of our system including shipping and tax is $452.25. Our sponsor has been involved throughout the design process; so, while he did not give us a hard budget, he is informed about how much the system will cost. A summary of the bill of materials is shown in Table 9 below (the complete BOM can be seen in Appendix J).

Table 9: Parts and Costs

Part	Total Cost
30 Gallon Tank	$94.45
SHURflow Pump	$85.31
Shelf	$43.17
Float Switch	$39.94
Backflow Prevention Valve	$36.54

Nylon Barbed Fitting	$16.05
Brass Barbed Fitting (Male)	$14.90
PVC Tubing	$14.58
Suction Cup	$13.69
Socket Head Screw	$11.42
Tee Joint (Pipe Fitting)	$10.77
Steel Flange Nut	$10.37
Filter Sheet	$10.10
Steel Washer	$9.85
Switch Tap	$8.10
Steel Hex Nut	$7.87
Brass Barbed Fitting (Female)	$6.44
Zip Tie	$6.26
Hex Panel Nut	$5.18
Steel Rectangular Bar	$3.72
Brass Pipe Nipples	$3.55
Total Cost	$452.25

The bill of materials ordered in descending price shows the tank and the pump are the two most expensive items at $94 and $85 respectively. The shelving unit, float switch, and backflow prevention valve are next at around $40 each. All other parts are under $20. The Gantt chart in Appendix F shows the appropriate timing to receive all components.

7- Project Plan

7.1 Manufacturing Plan

One of the strongest aspects of our chosen design is its simplicity. Because of this simplicity, we were able to specify standard components, which serves to ease time spent manufacturing and ultimately reduce cost. The two manufacturing tasks to be completed are cutting the shelving unit to the desired height, specified on drawing number 0001 in Appendix H, and drilling the holes in the water storage tank needed to mount tank fittings and the float switch. We plan to complete both tasks in the machine shops on campus in order to maximize safety.

The steel shelving unit will function to support the weight of the tank and position it above the toilet. The dimensions of the shelving unit are 60 in. x 23.23 in. x 13.39 in. as shown in Figure 16.

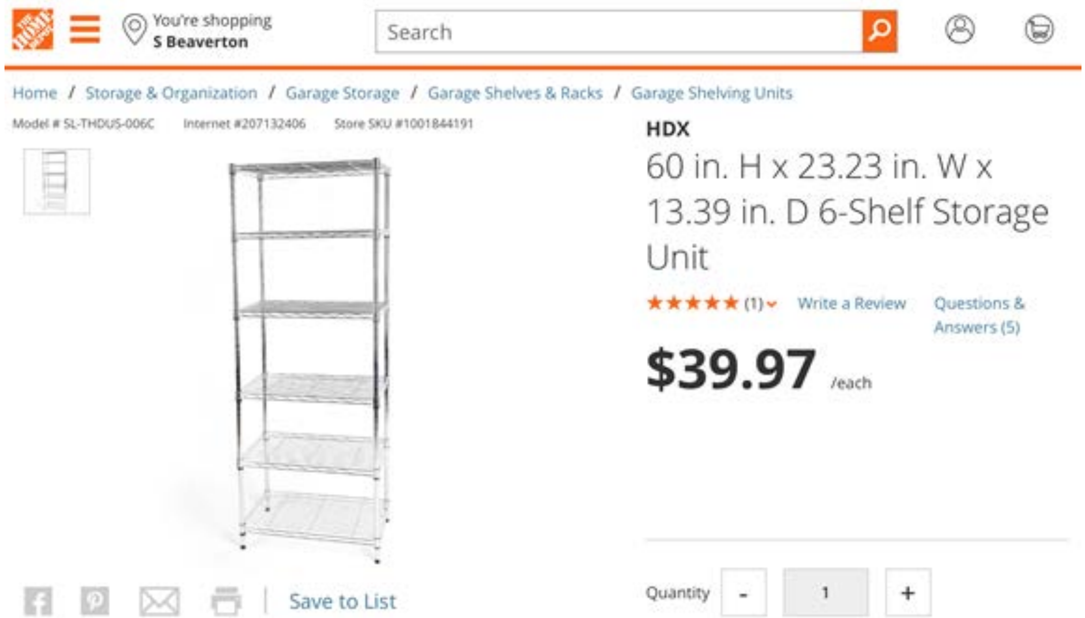

Figure 16: Shelf Storage Unit

60 inches is too tall for our purposes, so the four legs will need to be shortened. The shelving unit is of steel construction, so the legs will be cut on a chop saw with a blade designed to cut steel. The tolerance on the length is ± .25 inch, as can be seen on drawing 0001. The precision we can expect from a chop saw will be more than good enough to achieve such a wide tolerance.

The second manufacturing operation we will need to conduct will be to drill the holes in the 30-gallon water storage tank. These holes will be necessary for the mounting of the barbed fittings, which will be used to connect the ½ in. PVC tubes to the tank, as well as mounting the float switch bracket. As can be seen on drawing 0002, the dimensional tolerance on the hole locations are ± .25 in. for everything except the mounting bracket holes. The mounting bracket holes must be located with greater precision relative to each other, but the location of the mounting bracket relative to the edges of the tank is non-critical. This information is conveyed with the ±.25in position tolerance to one of the mounting bracket holes, and the ±.025 in. tolerance on the spacing between the holes. The size tolerance on all holes was specified to be ±.015 in. The precision required for both the position and size of the holes is not beyond what is reasonably achievable with just a hand drill and a set of drill bits.

The components specified for this design are readily available and we expect no trouble in procuring them in a timely manner. There are a wide range of suppliers from which we could acquire them from should we run into problems. The shop tools required to complete these manufacturing processes are likewise widely available and the processes themselves are not time consuming. For both these reasons, we do not expect problems with determining a time to complete the necessary manufacturing processes in the on-campus machine shops. Both processes are also within the capabilities of the team members to complete without the assistance of shop techs, so we will not need to plan for their time availability.

We expect the completion of the two manufacturing processes to take only about an hour or two of shop time, but have planned a week in order to accommodate potential setbacks.

8– Manufacturing

Following a meeting with our sponsor, it was decided that while the proposed design was very good; some cost saving decisions could be made in order to build the most economical proof-of-concept prototype. Some of the elements in the proposed design were deemed to be not totally necessary to being able to conduct testing and design verification. This was decided because many of the components in the proposed design would be used as they were intended, it was decided that there is little purpose in conducting what would essentially be product testing of those components. This decision resulted in the elimination of the suction cup, filter, and components which would connect the 25-gallon tank to the toilet. Additionally, the steel stand which we planned to purchase from Home Depot was substituted for one of wood construction, again this was done in order to save cost and avoid just doing product testing of existing things on the market. This decision to omit certain components during testing and substitute the steel stand for a wooden one does not constitute a design change and are instead simply cost saving measures to lower the cost of the proof-of-concept prototype intended to just prove the validity of the proposed design.

8.1 Grey Water Stand Construction

The wooden stand substitute was constructed using 3-inch deck screws, 2 x 4 in. Pine lumber, and ¾ in. Plywood. A quick finite element analysis was conducted in Solid Works in order to verify the design would be capable of bearing the weight of the 25-gallon water tank.

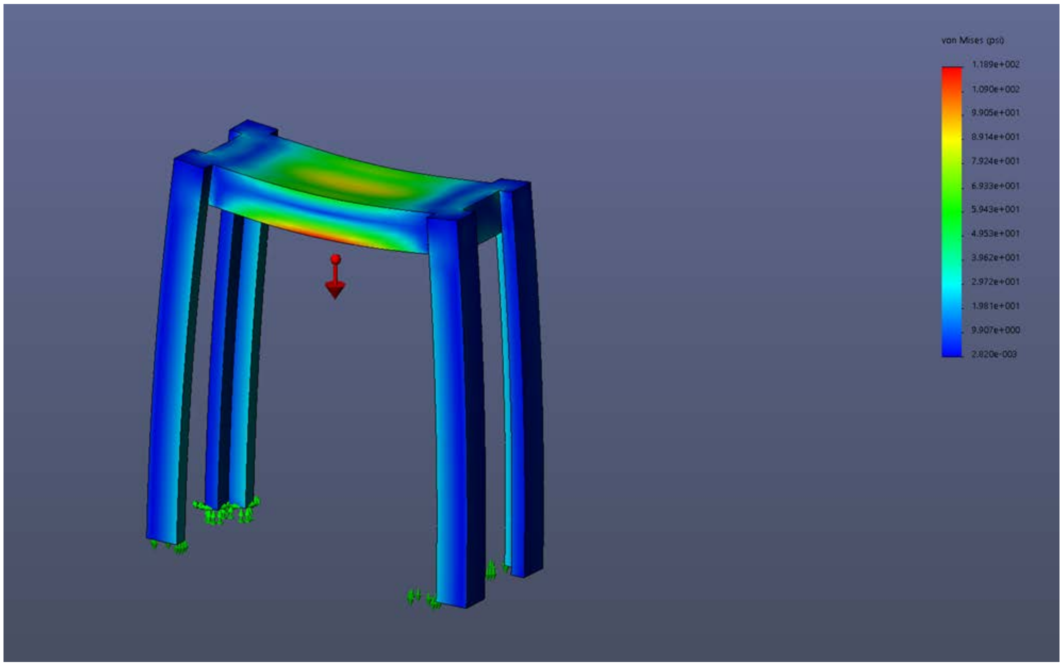

Figure 17: Finite Element Analysis of Stand

It is important to note the limitations of this finite element analysis due to the fact that it was assumed to just look at the strength of the wood and disregard the fasteners. Friction between the stand legs and the ground was also neglected in order to make the analysis as conservative as possible. The analysis resulted in a factor of safety of approximately 6 which is high enough to conclude that even with the prior assumptions, the stand would be more than strong enough for our purposes.

In order to construct the stand, the 2 x 4 in. Lumber was first cut to length on a Miter Saw and the plywood top was cut using a Skill Saw. Clamps were used to hold the pieces in place so they could be screwed together.

Figure 18: Clamping for Stand Construction

8.2 Grey Water Tank

There were several modifications that needed to be made to the 25-gallon water tank so it can be used in the system. First, an access hole was cut in the top of the tank so the team could reach inside. This was completed using a router bit in a Dremel.

Figure 19: Cutting the Access Hole

Next, the holes for the inlet and outlet barbed fittings were drilled with a hand drill along with the four bolt holes in the bottom of the tank which would be used to rigidly connect the tank to the stand using sealed bolts.


Figure 20: Bolting the Tank to the Stand (only 2 of 4 bolts shown)

Finally, the float switch bracket was attached to the tank using socket head cap screws. The required holes were drilled using a hand drill.

8.3 Installing Pump Fittings

Adapter fittings were installed into the SHURflo pump so that it could be connected to the ½ in. PVC tubing. The only combination of adapter fittings which would work required some minor PVC cementing along with proper application of teflon tape on threads. Ultimately the pump was successfully connected to the ½ in. PVC tubing.

8.4 PVC Tubing

The PVC tubing was cut according to how the team decided to the system should be laid out. Cutting of the tubing was completed using scissors, before the tubing was attached to the barbed fittings and secured in place with Zip-Ties.

9 – Testing

9.1 Design Verification Plan

During the assembly portion of our design process, we will be testing our product in a bathroom to confirm that we meet all design specifications. Table 10 shows a subsection of the design verification plan (see Appendix K) and a total of nine tests to evaluate how our design meets our specifications.

Table 10: Design Verification Plan

Test No.	Specification	Test Type	Acceptance Criteria
1	Pump flowrate > shower flowrate	Testing	Must be greater than 2.1 gpm
2	Installation Time	Similitude	Install system in 1 hour or less
3	Maintenance Frequency	Similitude	Every 3 months maintenance is required
4	Leakage Test	Inspection	No leaks
5	Manual Labor	Inspection	No Manual Labor once installed
6	Tank Tipping	Testing	Tank does not tip when bumped
7	Minimum Water Height of Source	Testing	Pumping works when water is ½ inches high
8	Float Switch	Testing	Float switch turns of pump when water in tank reaches 20 gallons

Test 1 is to ensure the pump can transfer water faster than the shower will be putting it out. To test for this, we will simply run our system from empty until the float switch turns off the pump to indicate 25 gallons of water has been delivered to the tank. We will than take the 25 gallons of water now in the tank and divide it by the time it took to fill to calculate the flowrate of the pump. This must be greater than 2.1 gpm, the average flowrate from a shower head.

Test 2 is to be able to install the system in an hour or less. We will time ourselves assembling some tasks and the rest will be estimates based on our experience.

Test 3 is that the maintenance frequency required by the system is no more than once every three months. The main items to maintain are the tank (odors, cleanliness), the filter, and the suction cup. We will be using data based on researching similar products to get an accurate estimate that these three items will fit this specification as our project timeline does not allow for a 3-month test.

Test 4 is to check the system for leakage in our tubing system. After the system is assembled, we will run the system and investigate each assembly for leakage. Since our system is relatively small, we can easily inspect our system to see if any leakage occurs within the system.

Test 5 is that there is no manual labor after the product is assembled. This will be done by inspection.

Test 6 is to make sure the tank does not tip when a force is applied. This test will be done by simulating someone bumping into the stand and by yanking on the tubes attached to the tank.

Test 7 is to test how high the water has to be in the shower for the water to circulate to the tank. This will determine how long the shower needs to be on before the system can start and if this is feasible.

Test 8 is to check that the float switch turns the pump off when the water in the tank reaches 20 gallons. This will ensure the tank does not overfill when there is an excess amount of grey water.

9.2 – Tests Carried Out

The results for the tests carried out are shown in Table 11 below. How each test was carried out is discussed in the following sections.

Table 11: Tests to ensure specifications were met

Test No.	Specification	Pass/Fail
1	Pump flowrate > shower flowrate	Pass
2	Installation Time	Pass
3	Maintenance Frequency	Pass
4	Leakage Test	Pass
5	Manual Labor	Pass
6	Tank Tipping	Pass
7	Minimum Water Height of Source	Pass
8	Float Switch	Pass

9.2.1 – Flowrate from Shower to Tank

The flowrate from the shower to the tank was tested by timing how long the tank takes to fill up when the pump is drawing water from a source. Our source used was a bin full of water which has the same effect as the shower floor would. Filling the tank to 20 gallons was timed to be 7 minutes and 25 seconds, giving a flow rate of 2.7 gpm, which is slightly higher than the average shower head flow rate of 2.1 gpm. The 2.7 gpm is accepted by our criteria of having a system flow rate that is higher than the shower flow rate and will be convenient to the user because they will not have to leave the pump running for much longer after the shower is turned off.

9.2.2 – Installation Time

Although the system was not fully installed into a bathroom, we still have a good idea of how long the installation process will take. The table below shows the amount of time that each part of the installation process took. The last six rows of the table were only estimated which is denoted by the asterisk.

Table 12: Times to Install Parts

Task	Time [min]
Assemble Stand	5
Bolt Tank	10
Bolt Switch	5
Cut Tubes	5
Connect Tubes	5
Plug in Pump	1
Attach Suction Cup	2
Attach Zip ties	2*
Attach Filter	5*
Install T-Flange	5*
Connect toilet pipes	5*
Connect Backflow Preventer	2*
Total	**52**

9.2.3 – Maintenance Frequency

The maintenance frequency of our system is compared to other systems with similar aspects. Cleaning the tank for should occur once a month by using bleach to clear out residue bacteria. The filter should be switched out every three months for optimal use. The suction cup should be able to be used for multiple months without having to replace it.

9.2.4 – Leakage

The leakage test consisted of filling the tank up with water, in order to ensure the hydrostatic pressure seen by the outlet barbed fitting and sealed bolts will be equal to what it would be during operation; and inspecting the system for any leaks. No leaks were observed, resulting in a pass.

9.2.5 – Manual Labor

After the system is installed there will be no manual labor left. The only actions that will need to be taken are turning on and off switches and moving the pipes for convenience. The rest of the system will not be tampered with.

9.2.6 – Tank Tipping

The tank tipping test was intended to simply be a look at how stable the system was when the tank was full of water. Team members applied lateral forces on the system and observed system behavior. The system remained stable during all applied forces and therefor passed the test.

9.2.7 – Minimum Water Height

The minimum water height for the system to run properly was found to be 3/8". In a 4'x5' shower running at 2 gpm this will take between two and three minutes to get to this height.

9.2.8 – Float Switch

The float switch test was conducted in order to ensure it would interrupt power to the pump when the volume of water in the tank reaches approximately 25 gallons. To conduct this test, the pump was switched on and water was pumped into the tank. The water level rose and activated the float switch which then interrupted power to the pump. This resulted in a passing grade for this test.

10 – Conclusions

In the beginning of our design process we had a certain visualization of what our end product would look like. Initially, we were set to design and build a transportable system that would lie underneath the sink. This particular system might have been very simple and would have satisfied our sponsor's requirements; but after undergoing a rigorous idea generation process, we realized that we can maximize our water savings if we used our system with the shower water as the source and our toilet as the destination. As time passed, we realized just how much thought would be needed to go into the design process. Sometimes, we felt that we were doing a bunch of unnecessary tasks and that some of the senior project tasks were a bit overkill. We soon found out that all of the tasks we performed were necessary, otherwise we might not have come up with an alternate solution to the initial idea that was proposed by our sponsor. Through this whole process, much was learned in terms of working on a team and undergoing a "real life" engineering process that would be similar to industry.

The engineering process of design, build and report writing that our group has gone through over the past school year has been both exciting and challenging. There were at time a lot of pressure between meeting deadlines and juggling our other classes. However, in the end we realized that despite all of the tough times we had, this experience has ultimately been a benefit for each of us. This experience has taught us to be even more considerate of other people's time and further understand the meaning of team work. Each person in our group has different strengths and weaknesses but together we have learned to understand and work with each other to produce positive results. It's hard to believe that we have been working on this project for 9 months and now it's coming to an end.

11 – Resources

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23

QFD: House of Quality
Projec Greywater Capture
Revis 1
Date: 18-Nov-16

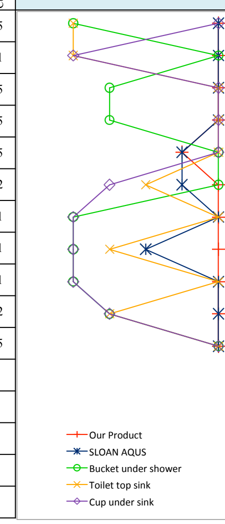
Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

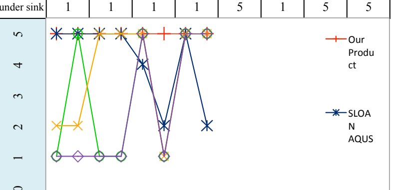
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Row #	WHO: Customers – Weight Chart	Relative Weight	Sponsor	Avg. Homeowner			Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	1 Capacity ◇	2 Size ◇	3 Watertight ◇	4 Chemically Treated ◇	5 Threaded and QD Fittings ◇	6 Must offset at least $5 per month ◇	7 Chlorine tablets and filter life ◇	8 Low capital cost ◇	NOW: Our Current Product	SLOAN AQUS	Bucket under shower	Toilet top sink	Cup under sink	Row #
1		11%	10	10			9	Non-intrusive in daily life	○	●	▽	●	▽	●	●	▽	5	5	1	1	5	1
2		6%	5	5			9	Economically positive	●	●	▽	▽	▽	●	○	●	5	5	5	1	1	2
3		11%	10	10			9	Chemically safe to use	▽	▽	●	●	▽	▽	●	▽	5	5	2	5	5	3
4		9%	8	8			9	No smell	▽	▽	▽	●	▽	▽	●	▽	5	5	2	5	5	4
5		9%	8	8			9	Easy to install	▽	●	▽	▽	●	▽	○	○	4	4	5	5	5	5
6		11%	10	10			9	Pipes hidden, if pipe system	●	●	●	●	●	○	▽	▽	5	4	5	3	2	6
7		6%	5	5			9	Minimal maintainence	▽	▽	●	●	○	▽	●	▽	5	5	1	5	1	7
8		8%	7	7			9	Aesthetically pleasing	●	●	●	▽	▽	▽	▽	○	5	3	1	2	1	8
9		11%	10	10			9	Does not leak	▽	▽	●	▽	●	○	▽	○	5	5	1	5	1	9
10		9%	8	8			9	Portable by average person, if necessary	●	●	●	●	●	○	▽	○	5	5	2	2	2	10
11		9%	8	8			9	Low capital cost	○	○	○	○	○	●	▽	○	5	5	5	5	5	11
12		0%																				12
13		0%																				13
14		0%																				14
15		0%																				15
16		0%																				16



	1	2	3	4	5	6	7	8
HOW MUCH: Target	5.5 Gallons	Dimensions = x * 2x * 3x	No water drips	Water stable for 24 hours	Can be installed by homeowner in 1 hr	$5 savings per month	3 monthes	$100 Maximum
Max Relationship	9	9	9	9	9	9	9	9
Technical Importance Rating	410.112	549.438	567.416	576.404	452.809	369.663	425.843	237.079
Relative Weight	11%	15%	16%	16%	13%	10%	12%	7%
Weight Chart								
Current Product Assesment - Engineering Specifications: Our Product	5	5	5	5	5	5	5	5
SLOAN AQUS	5	5	5	5	4	2	5	2
Bucket under shower	1	5	1	1	5	1	5	5
Toilet top sink	2	2	5	5	5	1	5	5
Cup under sink	1	1	1	1	5	1	5	5



Column # 1 2 3 4 5 6 7 8

Appendix B: Idea Sketches

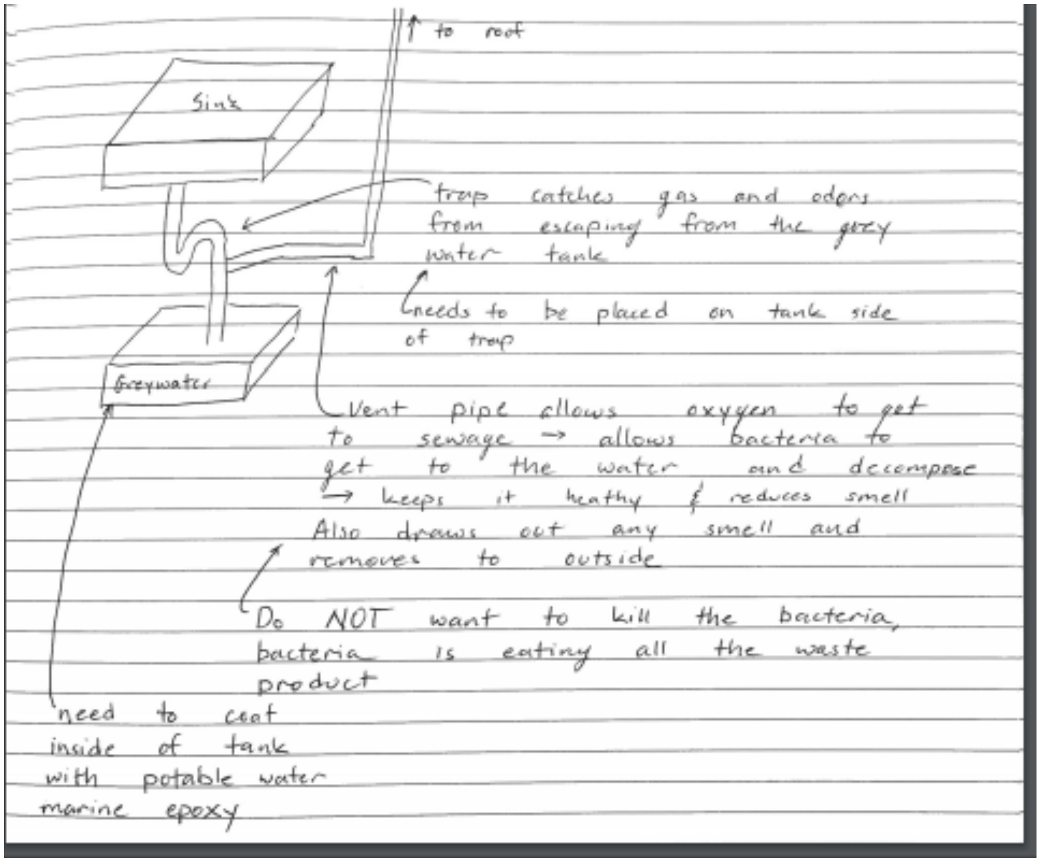


Figure B-1: Modifying Sink Piping to Extract Grey Water

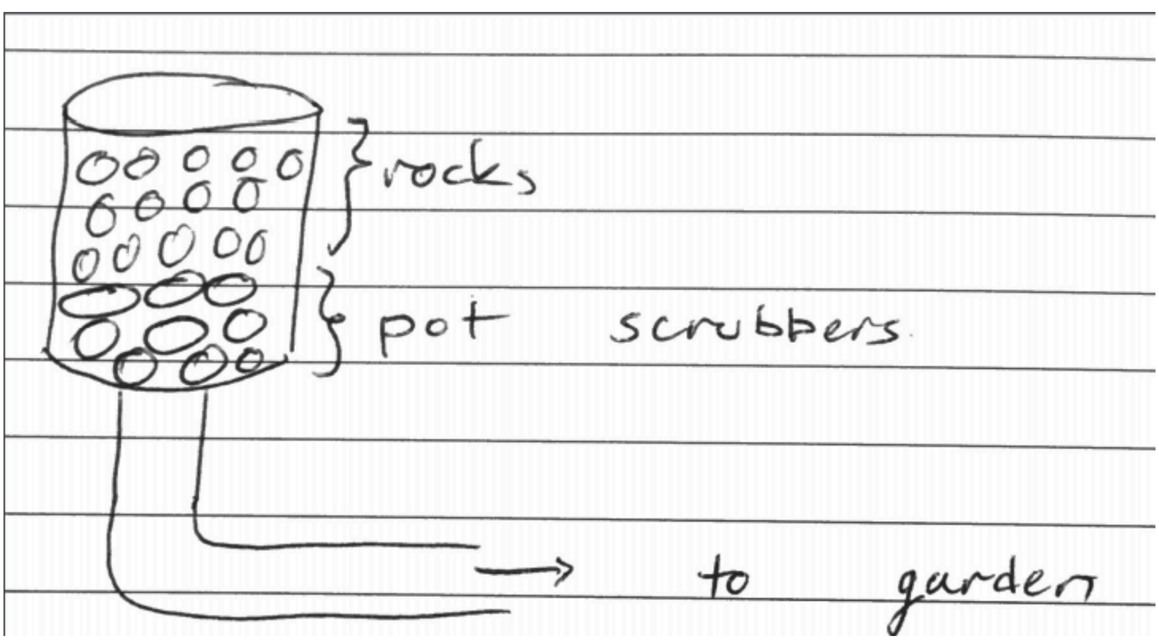


Figure B-2: Using Rocks and Pot Scrubbers to Filter Grey Water for Irrigation

Appendix B: Idea Sketches (Continued)

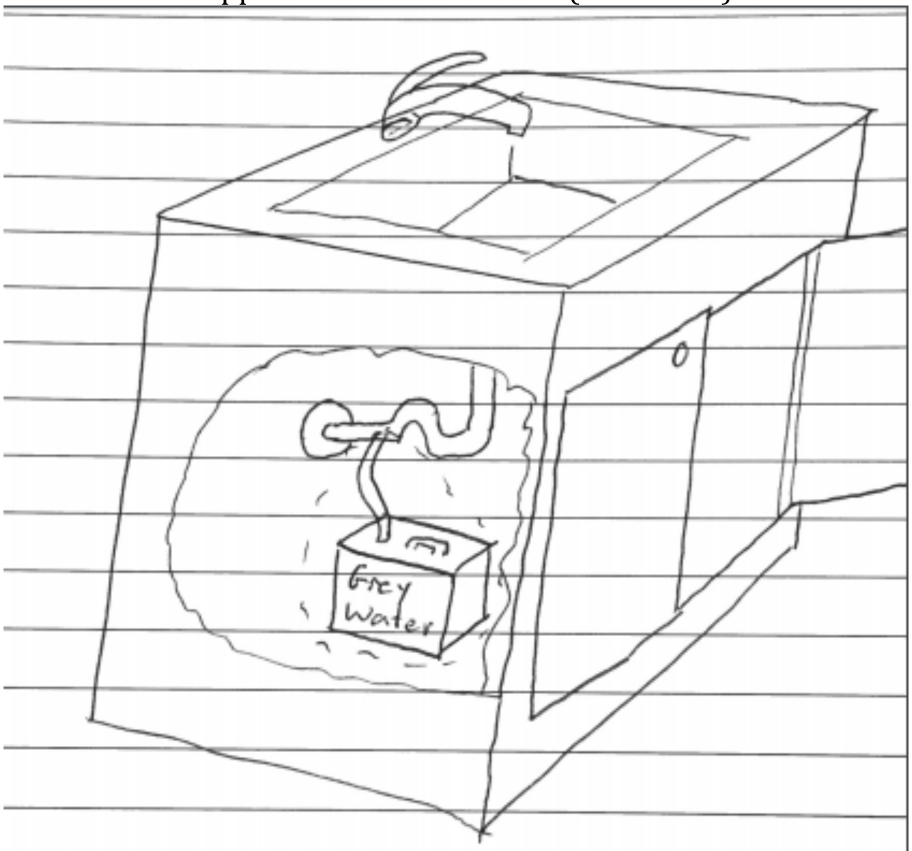


Figure B-3: Capturing Grey Water from Sink using Tank

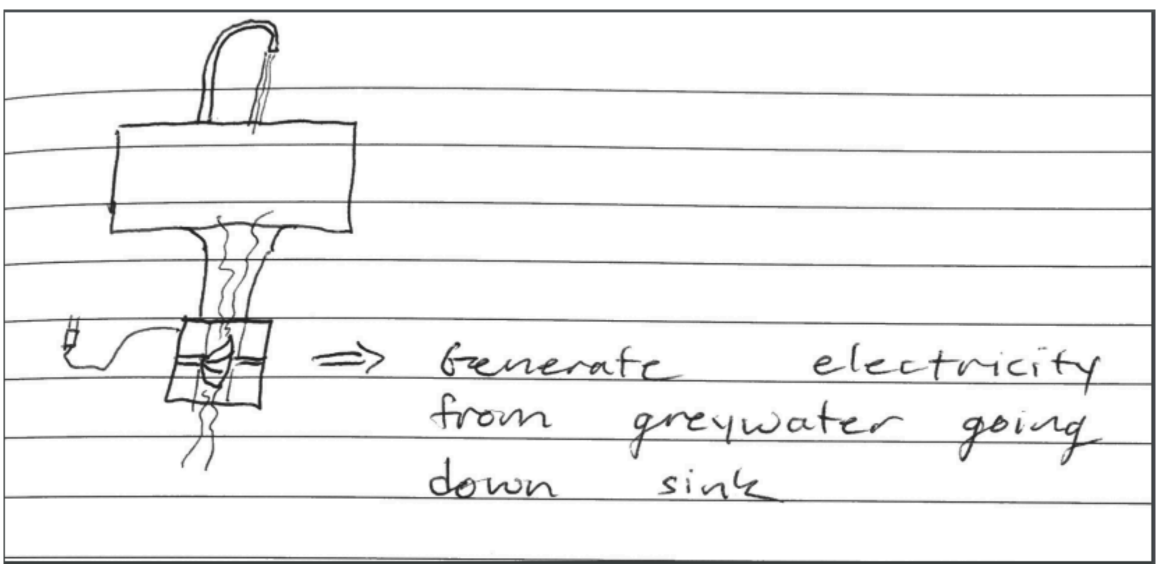


Figure B-4: Using Grey Water Flow to Generate Electricity

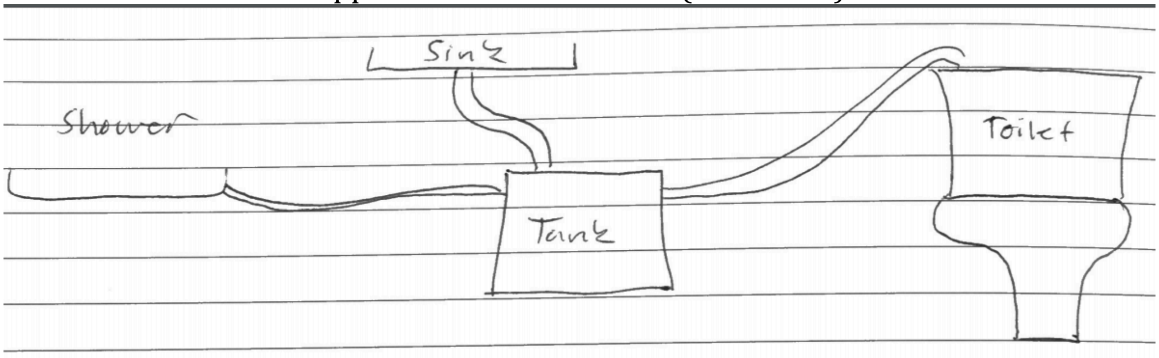


Figure B-5: Multiple Ways to get Grey Water for Toilet Flushing

Appendix C: Pugh Matrices

11/7

PUGH MATRIX

Functions \ Ideas	Sink to toilet	Bucket in shower	Rainwater to toilet	Sink to plants	Sink positive	Washer machine to outside
Amount of water saved	+1	+1	Depends +1	+1	+1	+2
Inconvinience + ugliness	0	-2	-1	0	+1	0
Install-ation	+1	+2	-2	0	+1	-1
Works in most homes	0	+1	-1	+1	+1	0
$ Cost	0	+1	-1	0	0	-1
Chance of leakage	-1	+1	-1	-1	0	-1
Σ	1	4	-5	1	4	-1

PUGH MATRIX TANK

11/10

IDEAS / Functions				
TIME IT TAKES WATER TO GET FROM TANK TO TOILET	+2	-1	+1	Ø
VISIBILITY	-1	+1	-1	0
EFFICIENCY ~~H~~ FOR PUMP	1	-1	0	+1
~~AFFORDAB~~ ~~OF~~ MAXIMUM VOLUME	0	0	+1	-1
WORKS FOR MOST BATHROOMS	+1	-1	0	+1
Σ	3	-2	+1	+1

WATER FROM SHOWER BEATS WATER FROM WATER LINE

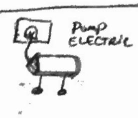
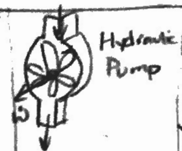
FUNCTIONS

1. CAPTURE WATER
2. deliver WATER
3. STORE WATER

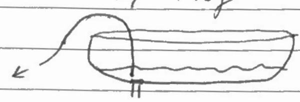
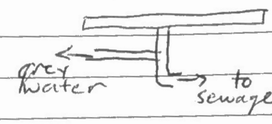
SHOWER TO TOILET

FUNCTION: Deliver WATER

PUGH MATRIX -2 + 2

CONCEPT / CRITERIA				
SAFETY	+1	+1	1	0
INSTALLATION	-1	-2	-1	2
Feasability	+1	-1	-1	1
COMFORT	+1	1	-1	-2
SUM (+)	3	2	1	2
SUM (-)	1	3	3	2

Pugh - Matrix : Capture Grey Water

Concept / Criteria	Inlet tube w/ Plug	Tap into Drain Pipe	Bucket	Weight
				
Safety	2	2	-2	2
Installation	1	-2	2	2
Aesthetics	-1	2	-2	1
Captures enough water	2	2	-1	2
Non-intrusive	-1	2	-2	1
Unweighted Totals	+5/-2	+8/-2	+2/-7	
Weighted Totals	+10/-2	+12/-4	+4/-10	

∴ Inlet tube is best

Idea: suction foot on inlet

Appendix D: Decision Matrix

		Criteria									
Concepts		Installation	Works in most homes	Amount of water saved	Cost (Up-front + ongoing)	Chance of leakage	Safety	Cleanliness/ odor of water	Aesthetics	Ease of use	Total
Weights	Rating	3	3	4	1	2	3	2	1	2	21
	Percentage	14%	14%	19%	5%	10%	14%	10%	5%	10%	100%
Baseline	Rating	0	0	0	0	0	0	0	0	0	0
	Weighted Rating	0	0	0	0	0	0	0	0	0	0
Shower to Toilet (Stacked Tank, Electric Pump)	Rating	6	6	8	5	10	9	8	8	10	70
	Weighted Rating	0.86	0.86	1.52	0.24	0.95	1.29	0.76	0.38	0.95	7.81
Shower to Toilet (Stacked Tank, Hydraulic Pump)	Rating	4	6	8	5	10	9	8	8	10	68
	Weighted Rating	0.57	0.86	1.52	0.24	0.95	1.29	0.76	0.38	0.95	7.52
Shower to Toilet (Floor Tank, Electric Pump)	Rating	5	5	8	3	10	9	8	5	10	63
	Weighted Rating	0.71	0.71	1.52	0.14	0.95	1.29	0.76	0.24	0.95	7.29
Shower to Toilet (Floor Tank, Hydraulic Pump)	Rating	4	5	8	3	10	9	8	5	10	62
	Weighted Rating	0.57	0.71	1.52	0.14	0.95	1.29	0.76	0.24	0.95	7.14
Sink to Toilet (Vanity Tank, Electric Pump)	Rating	4	4	6	4	10	10	8	10	10	66
	Weighted Rating	0.57	0.57	1.14	0.19	0.95	1.43	0.76	0.48	0.95	7.05
Container, from shower to landscape	Rating	7	8	4	9	3	2	8	2	3	46
	Weighted Rating	1.00	1.14	0.76	0.43	0.29	0.29	0.76	0.10	0.29	5.05
Multiple carried tanks, from sink to landscape	Rating	4	7	4	4	6	5	4	10	6	50
	Weighted Rating	0.57	1.00	0.76	0.19	0.57	0.71	0.38	0.48	0.57	5.24
Adjustable faucet for toothbrush	Rating	10	8	3	5	10	7	8	6	6	63
	Weighted Rating	1.43	1.14	0.57	0.24	0.95	1.00	0.76	0.29	0.57	6.95
Sink or shower to landscape via wheeled tank	Rating	7	6	6	4	8	6	3	2	8	50
	Weighted Rating	1.00	0.86	1.14	0.19	0.76	0.86	0.29	0.10	0.76	5.95
Bucket, from shower to toilet	Rating	10	#REF!	2	10	3	1	10	1	4	#REF!
	Weighted Rating	1.43	#REF!	0.38	0.48	0.29	0.14	0.95	0.05	0.38	#REF!
Sink to plants in bathroom	Rating	4	3	1	4	5	8	8	#REF!	#REF!	#REF!
	Weighted Rating	0.57	0.43	0.19	0.19	0.48	1.14	0.76	#REF!	#REF!	#REF!
Toilet top sink	Rating	8	#REF!	1	8	8	6	4	1	#REF!	#REF!
	Weighted Rating	1.14	#REF!	0.19	0.38	0.76	0.86	0.38	0.05	#REF!	#REF!
Washing machine to landscape	Rating	3	3	6	4	5	10	4	8	10	53
	Weighted Rating	0.43	0.43	1.14	0.19	0.48	1.43	0.38	0.38	0.95	5.81

ME 428/429/430 Senior Design Project 2016-2017

DESIGN HAZARD CHECKLIST

Team: Grey Water Capture Advisor: Rossman

Y	N	
☑	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☑	2. Can any part of the design undergo high accelerations/decelerations?
☐	☑	3. Will the system have any large moving masses or large forces?
☐	☑	4. Will the system produce a projectile?
☑	☐	5. Would it be possible for the system to fall under gravity creating injury?
☐	☑	6. Will a user be exposed to overhanging weights as part of the design?
☑	☐	7. Will the system have any sharp edges?
☐	☑	8. Will any part of the electrical systems not be grounded?
☐	☑	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☑	☐	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☑	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☑	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	☑	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☑	14. Can the system generate high levels of noise?
☑	☐	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☑	☐	16. Is it possible for the system to be used in an unsafe manner?
☐	☑	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

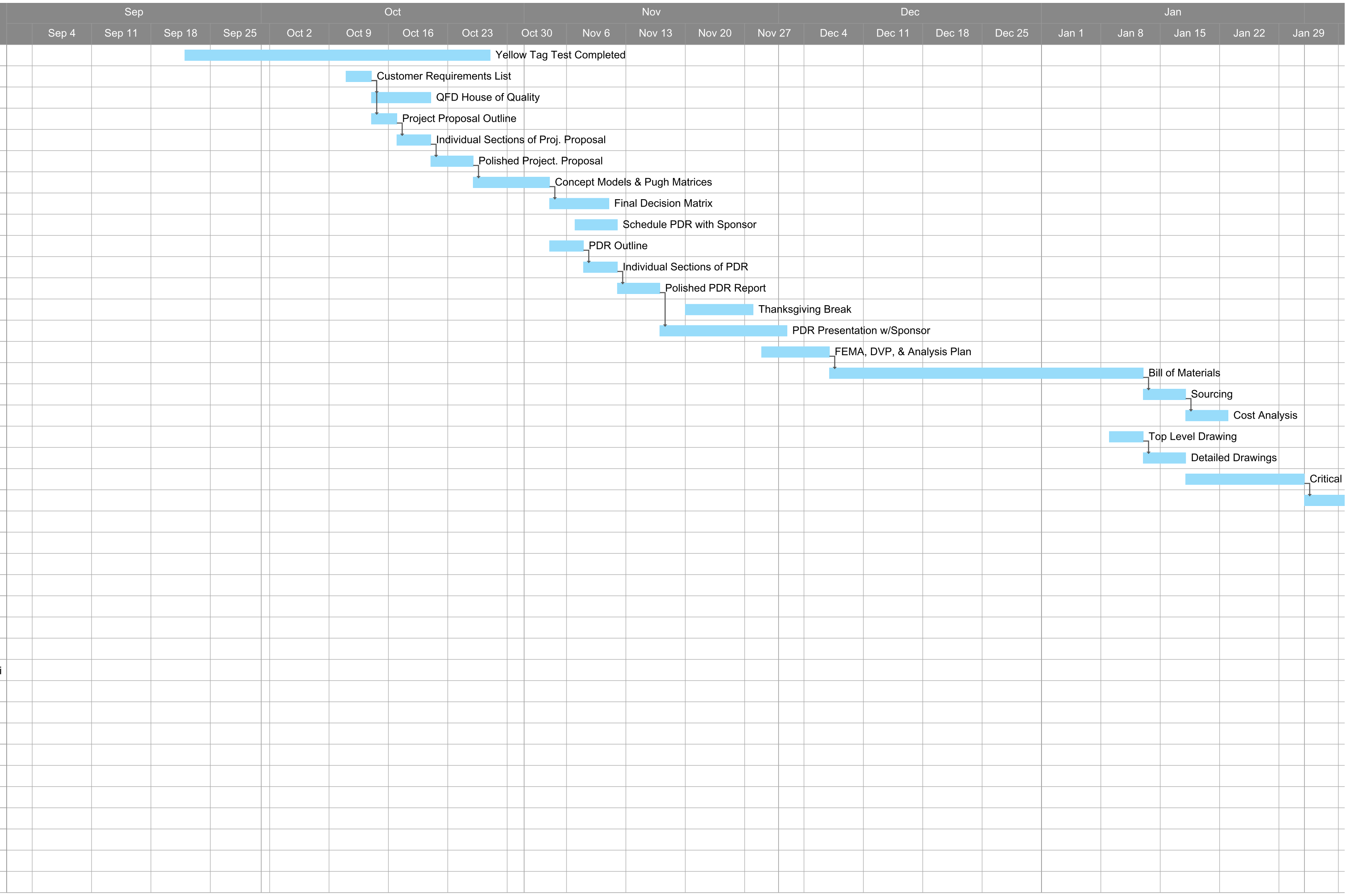
Figure 4: Design Hazard Checklist, Page 1

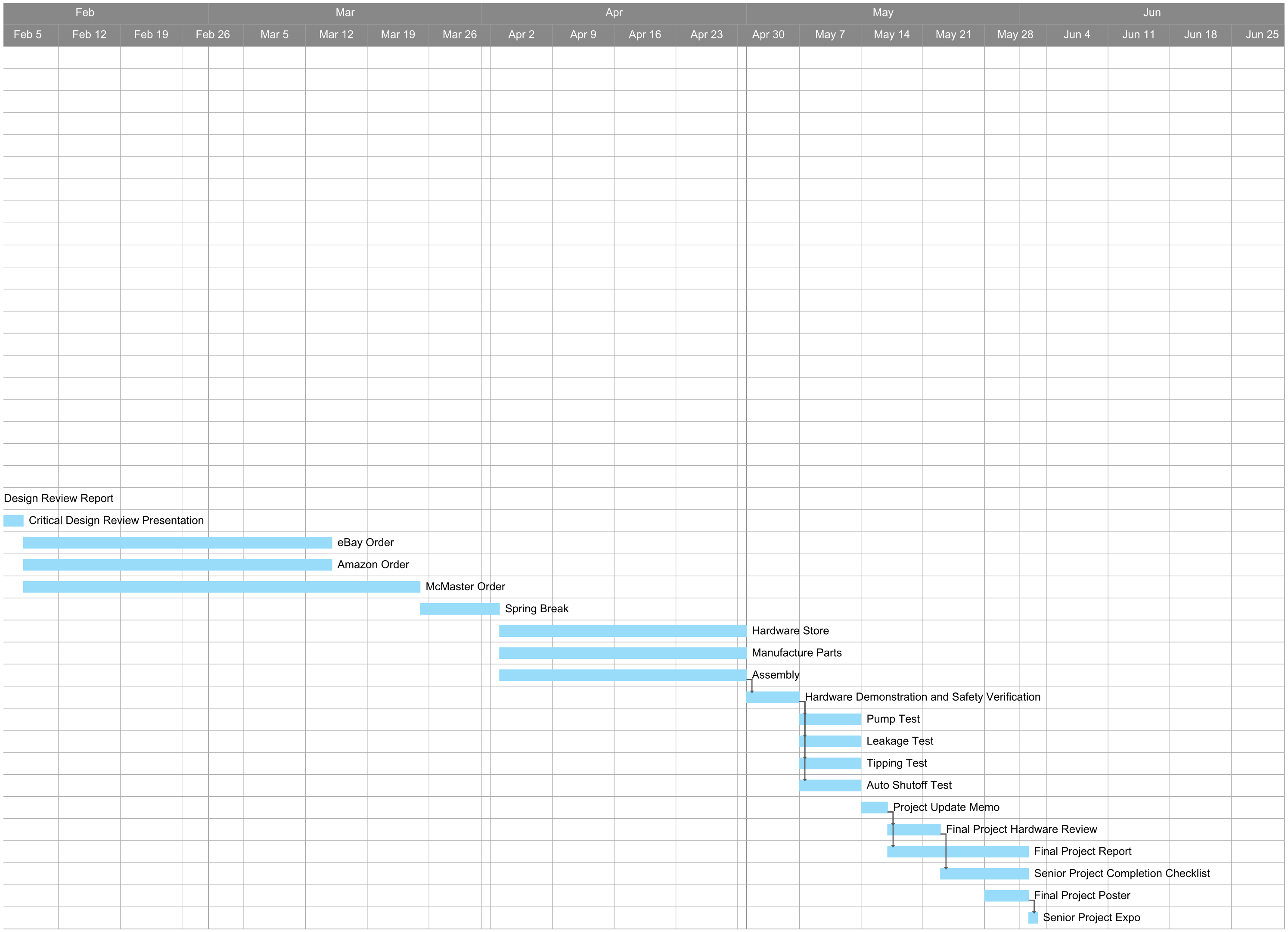
Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Spinning pump, could pinch fingers	Warning label and clear instructions in instruction manual.		
Heavy water tank placed on top of toilet resevoir	Ensure the tank will be firmly mounted to shelves. Warning in instruction manual.		
Potential for sharp edges on tank, pump, and inlet	Warn the user in the instruction manual, round edges when possible.		
System will have tank up high, stored potential energy	Bolt the tank to shelves		
System will be operating in hot/ humid bathroom	Use a waterproof pump, test to ensure safe operation. Instruct user to run ventilation fan.		
Potential for unsafe use	There is always the possibility for things to be used unsafely, need good disclaimers in instruction manual.		

Figure 5: Design Hazard Checklist, Page 2

Grey Matter Industries - Project Calendar

	Task Name
1	Yellow Tag Test Completed
2	Customer Requirements List
3	QFD House of Quality
4	Project Proposal Outline
5	Individual Sections of Proj. Proposal
6	Polished Project. Proposal
7	Concept Models & Pugh Matrices
8	Final Decision Matrix
9	Schedule PDR with Sponsor
10	PDR Outline
11	Individual Sections of PDR
12	Polished PDR Report
13	Thanksgiving Break
14	PDR Presentation w/Sponsor
15	FEMA, DVP, & Analysis Plan
16	Bill of Materials
17	Sourcing
18	Cost Analysis
19	Top Level Drawing
20	Detailed Drawings
21	Critical Design Review Report
22	Critical Design Review Presentation
23	eBay Order
24	Amazon Order
25	McMaster Order
26	Spring Break
27	Hardware Store
28	Manufacture Parts
29	Assembly
30	Hardware Demonstration and Safety Veri
31	Pump Test
32	Leakage Test
33	Tipping Test
34	Auto Shutoff Test
35	Project Update Memo
36	Final Project Hardware Review
37	Final Project Report
38	Senior Project Completion Checklist
39	Final Project Poster
40	Senior Project Expo

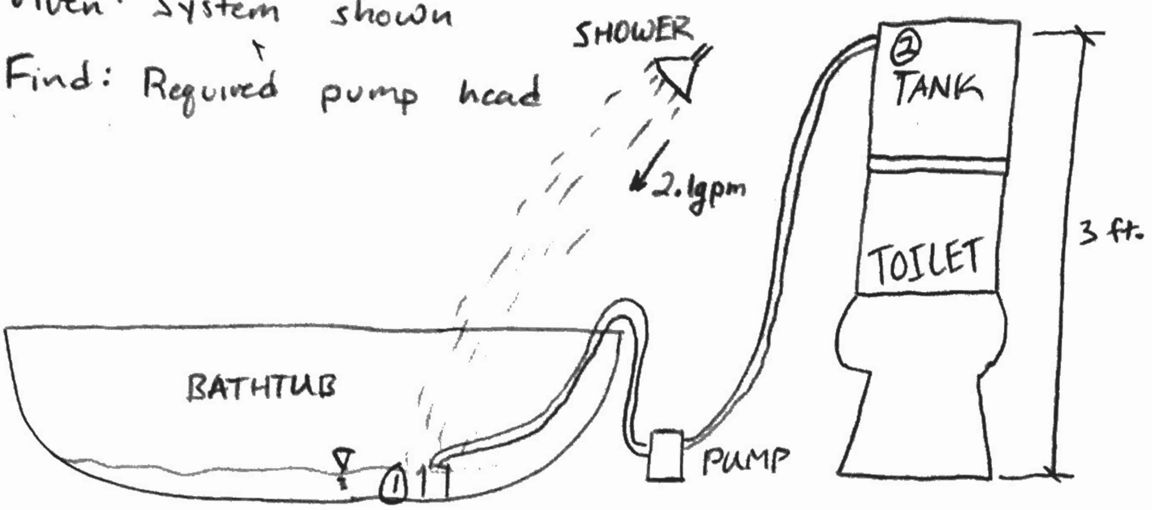



Feb
Mar
Apr
May
Jun
Feb 5
Feb 12
Feb 19
Feb 26
Mar 5
Mar 12
Mar 19
Mar 26
Apr 2
Apr 9
Apr 16
Apr 23
Apr 30
May 7
May 14
May 21
May 28
Jun 4
Jun 11
Jun 18
Jun 25
Design Review Report
Critical Design Review Presentation
eBay Order
Amazon Order
McMaster Order
Spring Break
Hardware Store
Manufacture Parts
Assembly
Hardware Demonstration and Safety Verification
Pump Test
Leakage Test
Tipping Test
Auto Shutoff Test
Project Update Memo
Final Project Hardware Review
Final Project Report
Senior Project Completion Checklist
Final Project Poster
Senior Project Expo

Modified Bernoulli's Analysis

Given: System shown

Find: Required pump head



$$\frac{P_1}{\rho} + \frac{V_1^2}{2g} + h_1 + h_p = \frac{P_2}{\rho} + \frac{V_2^2}{2g} + h_2 + h_L$$

Assume $V_1 = V_2 = 0$, $h_1 = 0$, $P_1 = P_2 = 14.7\,psia$

$$h_p = h_2 + h_L$$

$$h_L = h_{L,minor} + h_{L,major}$$

Assume $h_{L,minor} \ll h_{L,major}$

$$h_L = h_{L,major}$$

$$h_L = f \frac{L}{D} \frac{V^2}{2g}$$

Assume fully developed laminar flow

$$f = \frac{64}{Re}$$

$$Re = \frac{VD}{\nu}$$

Lookup: $\nu_{H_2O,\,80°F} = 0.926\ ft^2/s \times 10^{-5}$

$$V = \frac{Q}{A}$$

Use 0.5 in diameter tube

$$A = \pi \left(\frac{d}{2}\right)^2 = \pi \left(\frac{0.5}{2}\right)^2 = 0.19635\ in^2$$

$$V = \frac{2.1\ gal/min}{0.19635\ in^2} \left(\frac{231\ in^3}{1\ gal}\right)\left(\frac{1\ min}{60\ sec}\right)$$

$$V = 41.18\ in/s$$

$$Re = \frac{VD}{\nu} = \frac{(41.18\ in/s)(0.5in)}{\left(0.926\ \frac{ft^2}{s}\ \frac{144in^2}{1ft^2}\right) \times 10^{-5}} = 15,441.3$$

Transition from laminar to turbulant for pipe flow is 2300 - 4000, flow is turbulant

Cannot use friction factor equation

Lookup: equivalent roughness for drawn tubing

$$\varepsilon = 0.000005$$

$$\frac{\varepsilon}{D} = \frac{0.000005}{0.5} = 0.00001$$

From Moody Chart for round pipes

$$f = 0.04$$

$$h_L = f\frac{L}{D}\frac{V^2}{2g} = (0.04)\frac{L}{0.5in\left(\frac{1ft}{12in}\right)}\frac{\left(41.18\ in/s\ \frac{1ft}{12in}\right)^2}{2\,(32.174\ ft/s^2)}$$

$$h_L = 0.17535L$$

Pump head required

$$h_p = h_z + 0.17535L$$

Use $h_z = 3$ ft and $L = 10$ ft to get ballpark estimate

$$h_p = 3ft + 0.17535\,(10\,ft)$$

$$\boxed{h_p = 4.75\ ft}$$

Convert to psi Lookup: $SG_{H_2O,80°F} = 0.955$

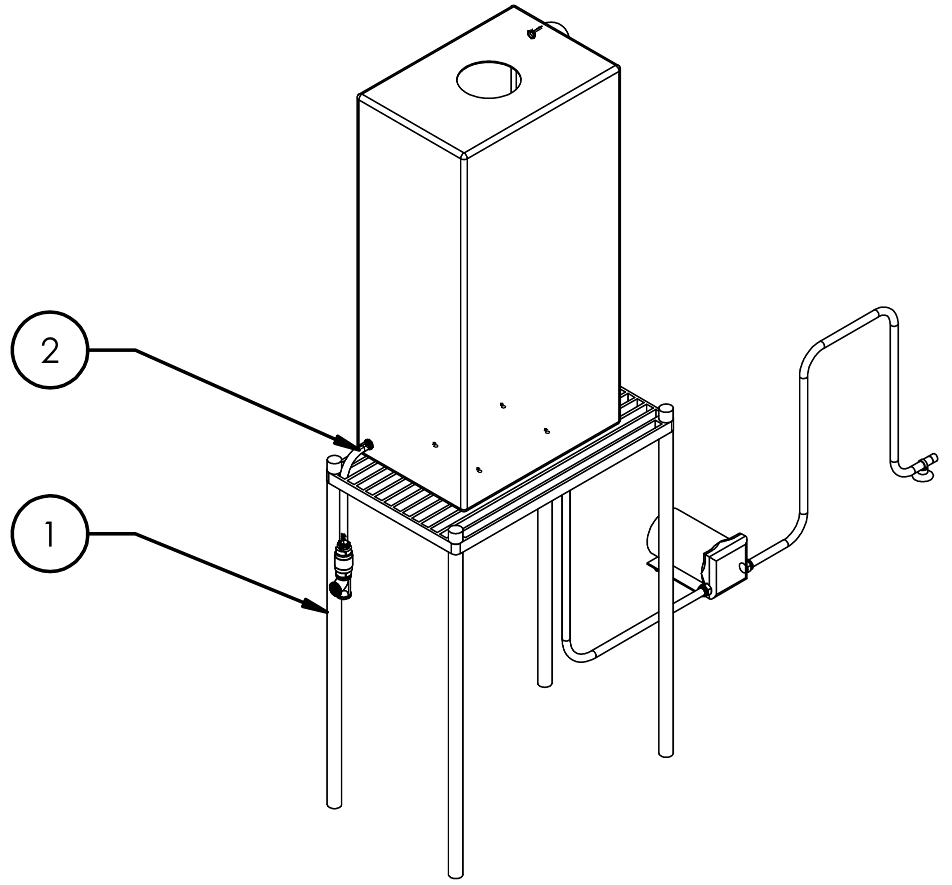
$$p = 0.433\,h\,(SG)$$

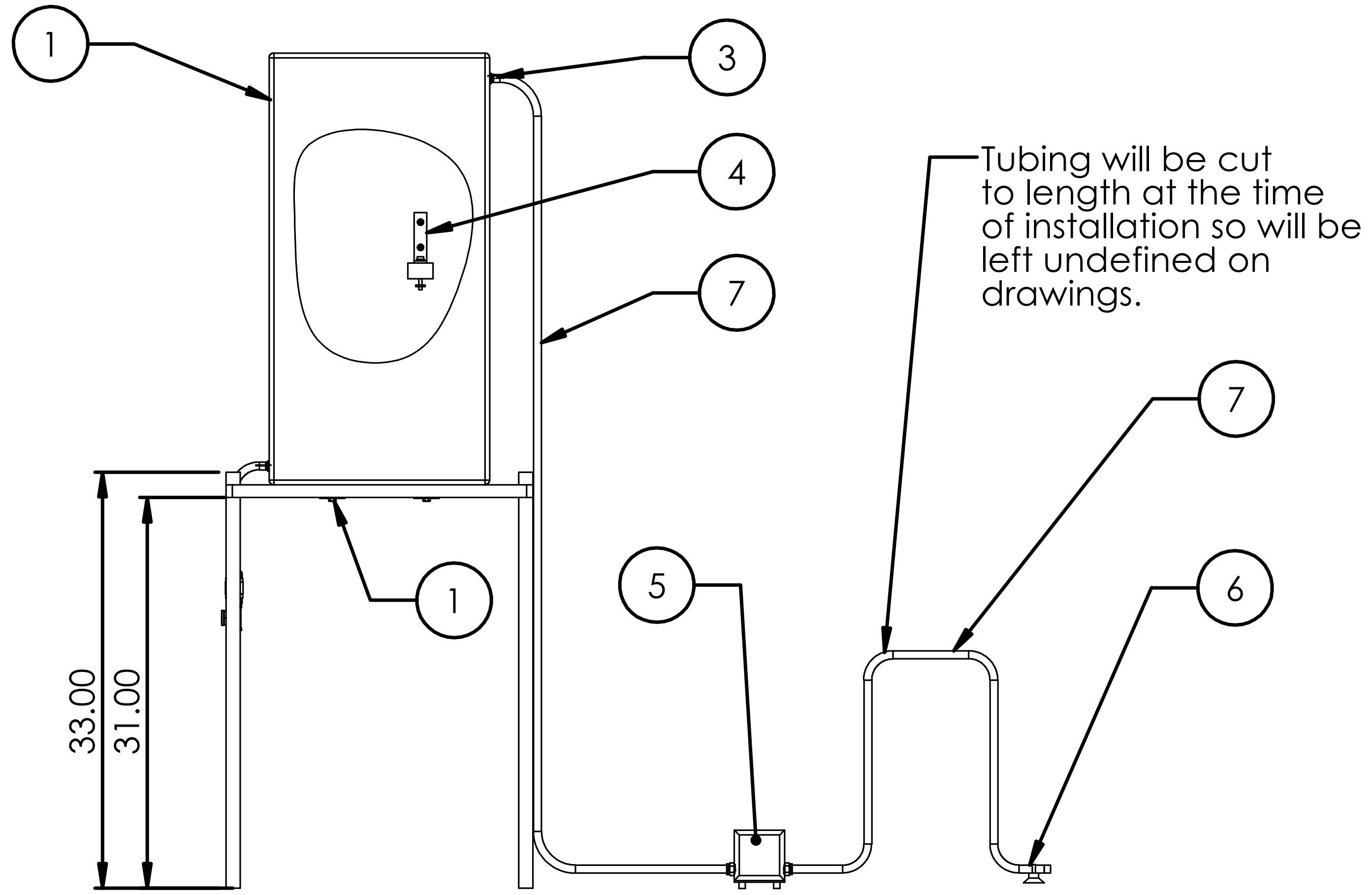
$$p = (0.433)(4.75\,ft)(0.955)$$

$$\boxed{p = 1.96\ psi}$$

4.75 ft of pump head or 1.96 psi required. Very do-able with small fish-tank pump.

APPENDIX H: CAD DRAWINGS





ITEM NO.	PART NO.	DRAWING NO.	DESCRIPTION	MATERIAL	VENDOR	QTY.
7	5233K66	-	1/2 in. Tubing	PVC	McMaster Carr	
6	-	0007	Inlet Sub Assembly	-		1
5	-	0009	Pump Sub Assembly	-		1
4	-	0005	Float Switch Sub Assembly	-		1
3	-	0004	Tubing-Tank Interface Sub Assembly	-		1
2	-	0003	Tank to Toilet Line Sub Assembly	-		1
1	-	0002	Tank to Shelf Attachment Sub Assembly	-		1

TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.

ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: -

DO NOT SCALE DRAWING

REVISION 1

Grey Water Capture

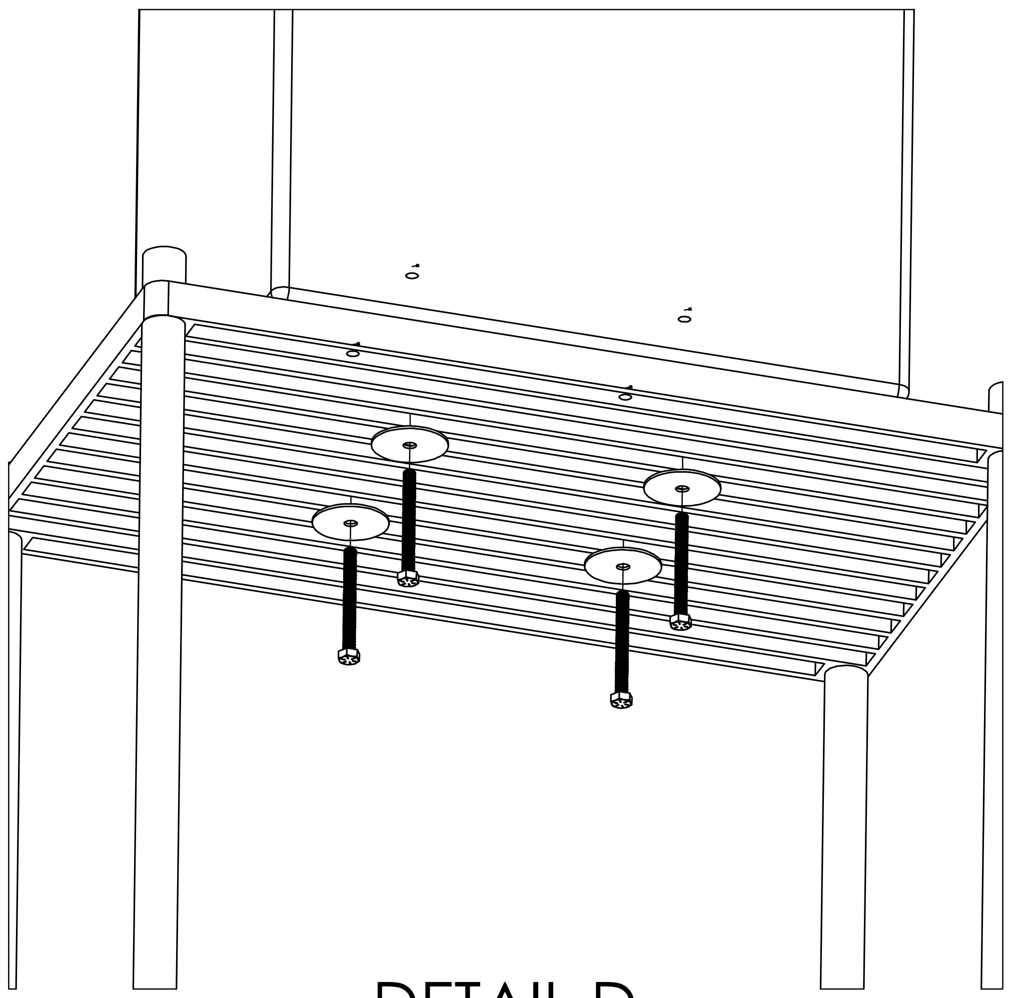
TITLE: Main Assembly

DWG NO. 0001

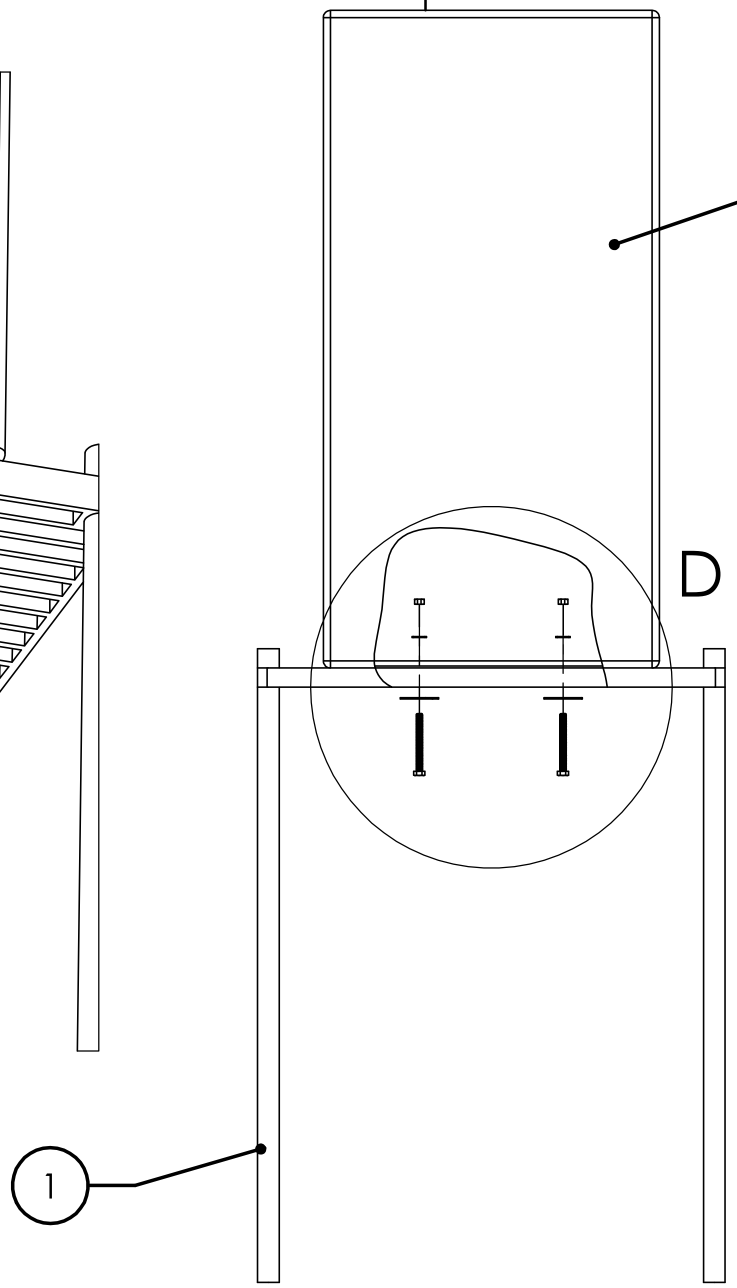
A3

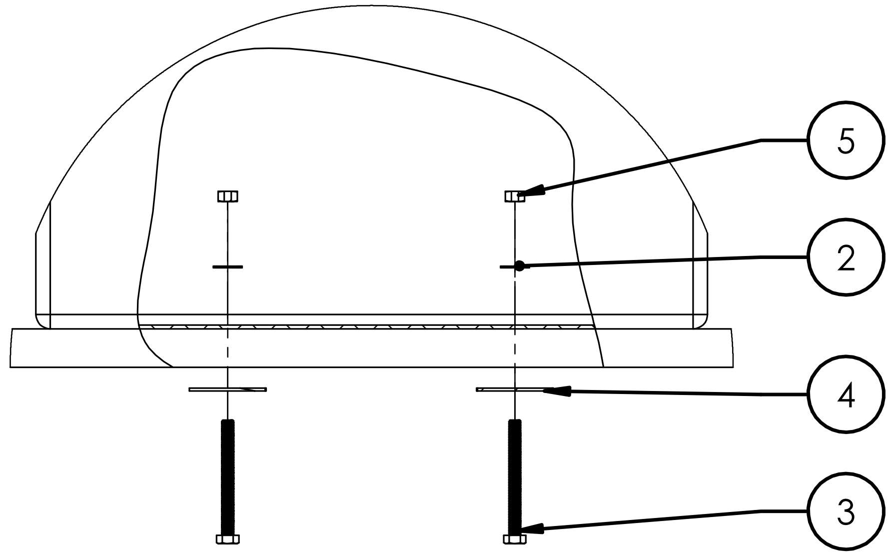
SCALE:1:15

SHEET 1 OF 1



DETAIL D
SCALE 1 : 5





DETAIL D
SCALE 1 : 5

ITEM NO.	PART NUMBER	DRAWING NO.	DESCRIPTION	MATERIAL	VENDOR	QTY.
5	94895A810	-	5/16 in. - 24 Nut	Steel	McMaster Carr	4
4	91525A133	-	5/16 in ID, 2 in. OD Washer	Steel	McMaster Carr	4
3	92620A614	-	5/16 in. - 24 x 3 in. Bolt	Steel	McMaster Carr	4
2	W0064	0008	30 Gal. Tank	Plastic	AdventureRV.net	1
1	1001844191	-	Wire Shelving	Steel	Home Depot	1

TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.
ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

MATERIAL: -

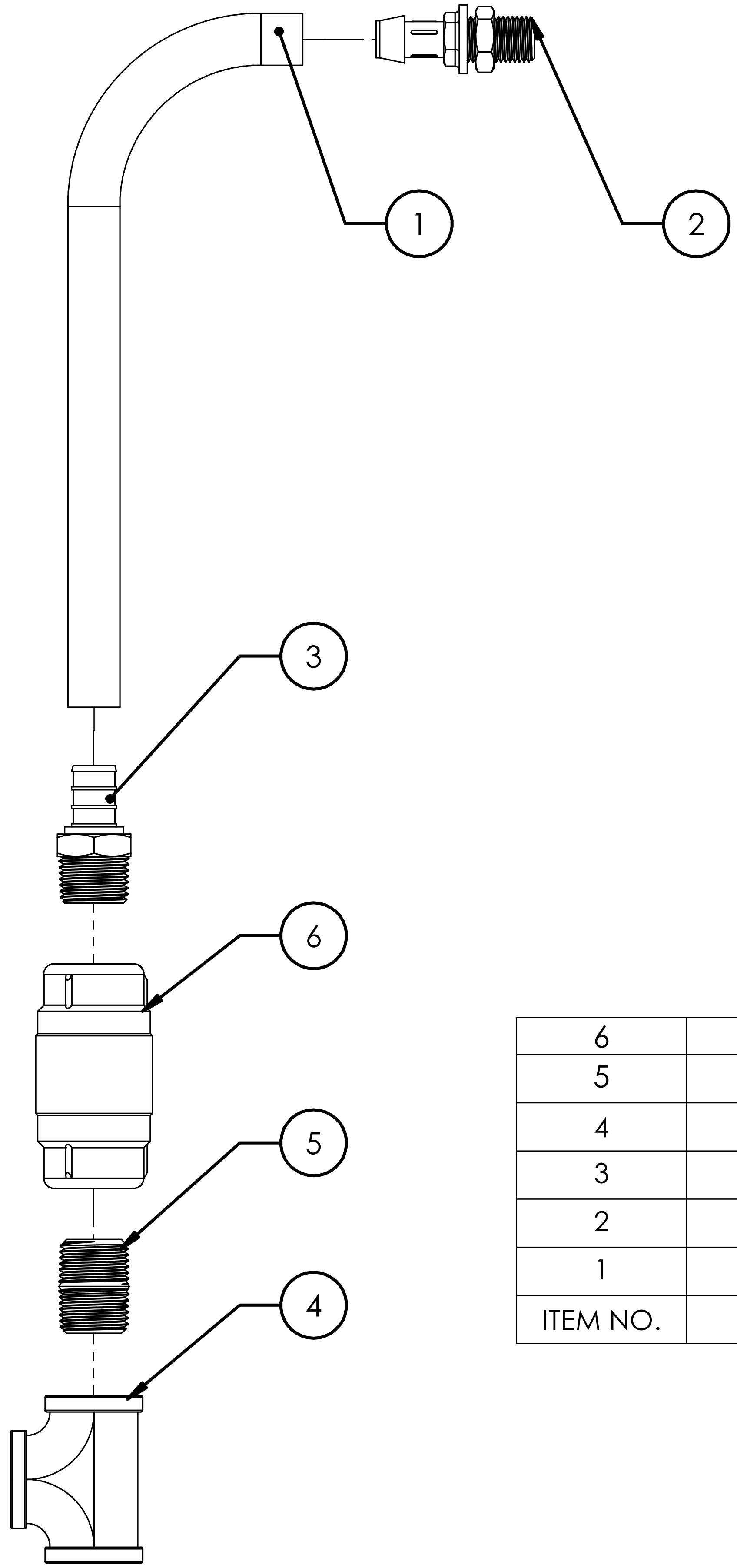
DO NOT SCALE DRAWING — REVISION 1

Grey Water Capture

TITLE: Tank to Shelf Attachment Sub Assembly

DWG NO. 0002 — A3

SCALE:1:10 — SHEET 1 OF 1



TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.
ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.
6	7746K390	Backflow Prevention Valve	Brass	McMaster Carr	1
5	4568K171	Pipe Nipple	Brass	McMaster Carr	1
4	4429K253	Tee Junction	Brass	McMaster Carr	1
3	3528T23	Barbed Fitting	Brass	McMaster Carr	1
2	5463K861	Barbed Through Wall Fitting	Nylon	McMaster Carr	1
1	5233K66	1/2 in. Tubing	PVC	McMaster Carr	1

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: -

DO NOT SCALE DRAWING

REVISION 1

Grey Water Capture

TITLE: Tank to Toilet Line Sub Assembly

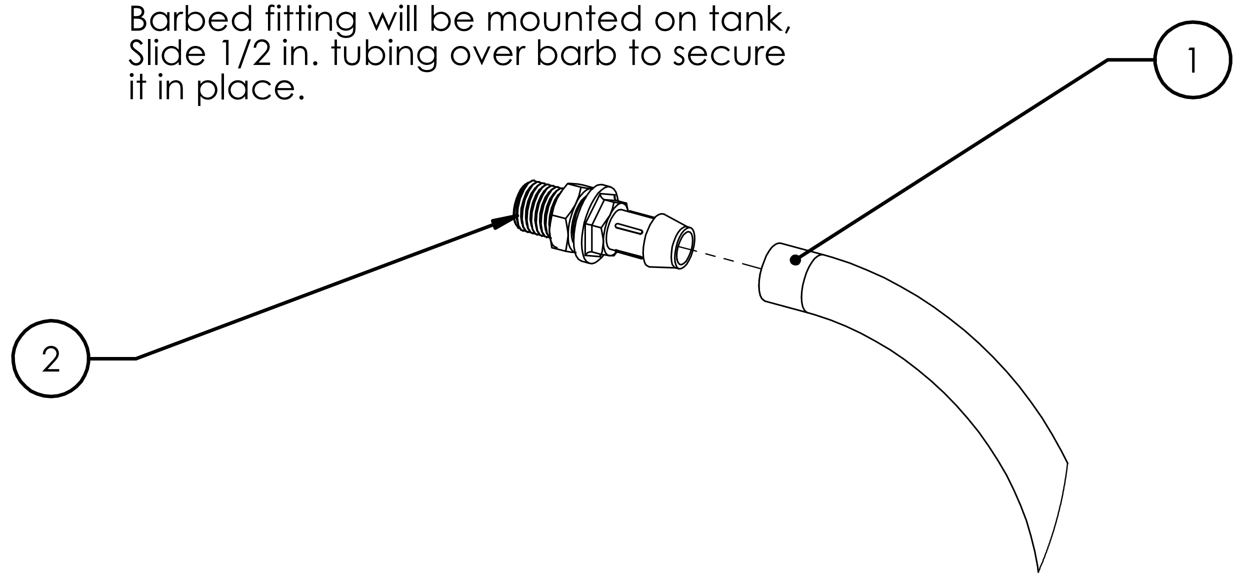
DWG NO. 0003

A3

SCALE:1:2

SHEET 1 OF 1

Barbed fitting will be mounted on tank,
Slide 1/2 in. tubing over barb to secure
it in place.



TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.
ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.
2	5463K861	Barbed Through Wall Fitting	Nylon	McMaster Carr	1
1	5233K66	1/2 in. Tubing	PVC	McMaster Carr	1

DO NOT SCALE DRAWING | REVISION 1

Grey Water Capture

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

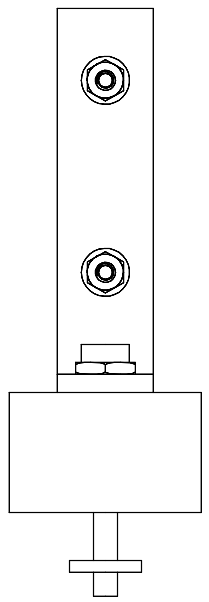
UNIT: INCH

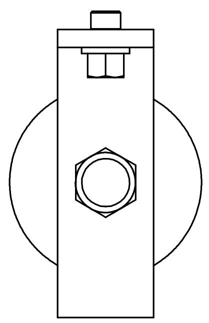
MATERIAL: -

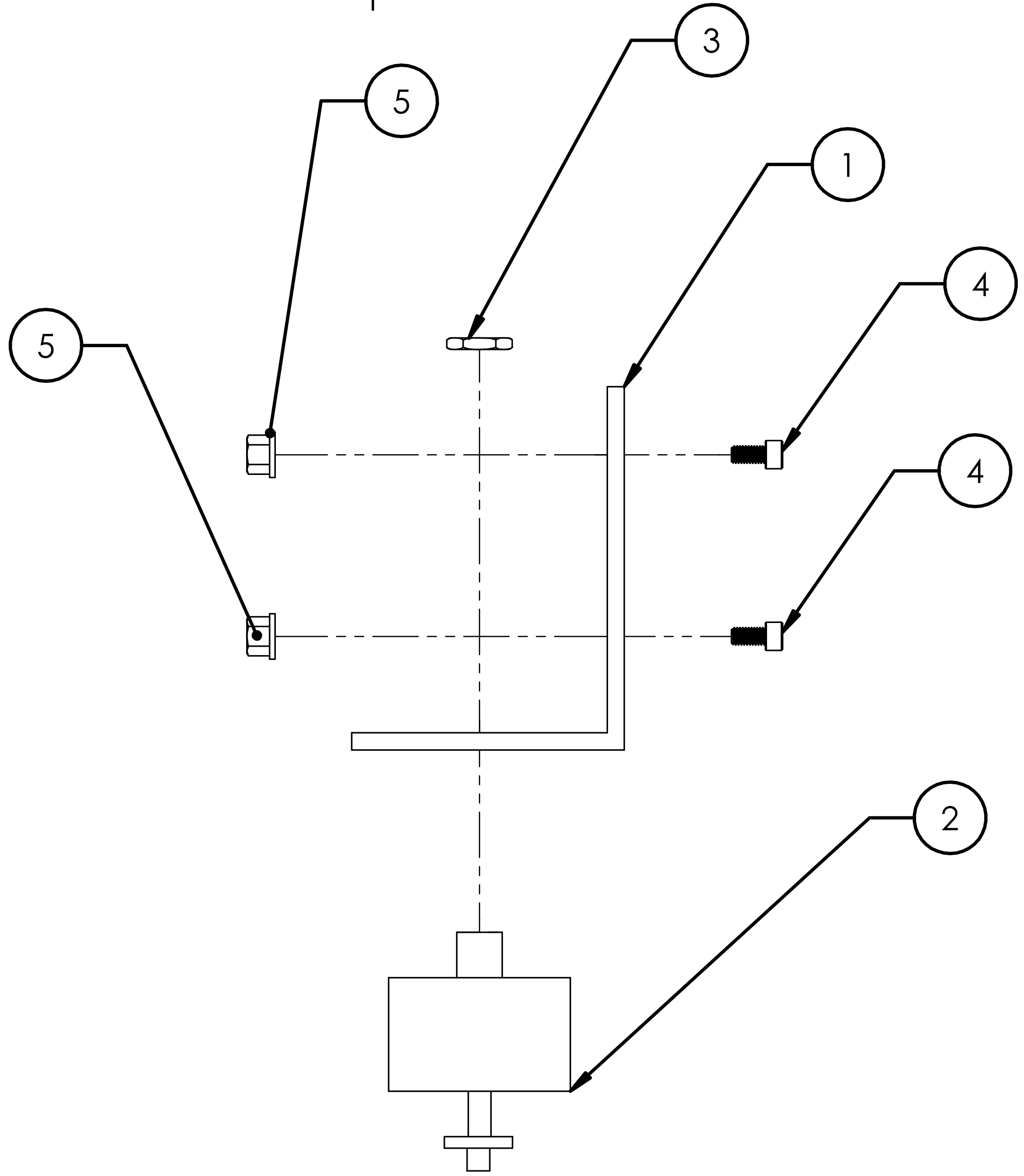
TITLE: Tubing-Tank Interface Sub Assembly

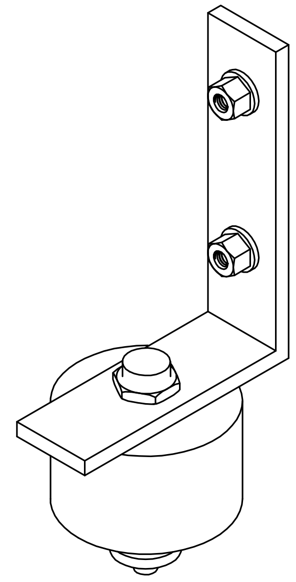
DWG NO. 0004 | A3

SCALE:1:2 | SHEET 1 OF 1









TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.
ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

5	94758A105	10-32 Flanged Nut	Stainless Steel	McMaster Carr	2
4	92196A267	10-32 Socket Head Cap Screw	Stainless Steel	McMaster Carr	2
3	91862A306	1/8 NPT Panel Nut	Stainless Steel	McMaster Carr	1
2	10010988868	Float Switch	-	Home Depot	1
1	0006	Float Switch Bracket	Low Carbon Steel	Team Manufactured	1
ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QUANTITY

DO NOT SCALE DRAWING | REVISION 1

Grey Water Capture

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

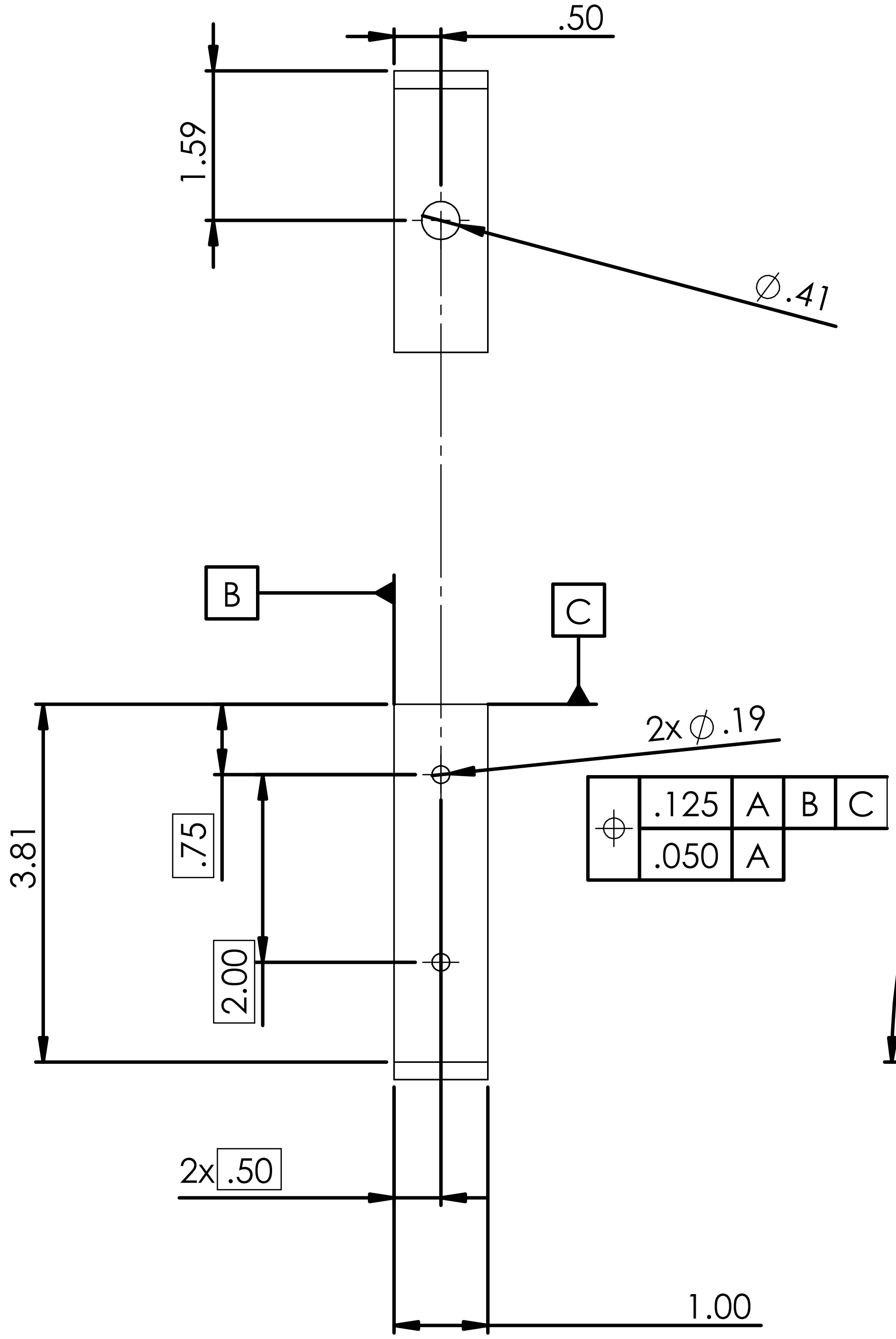
TITLE:

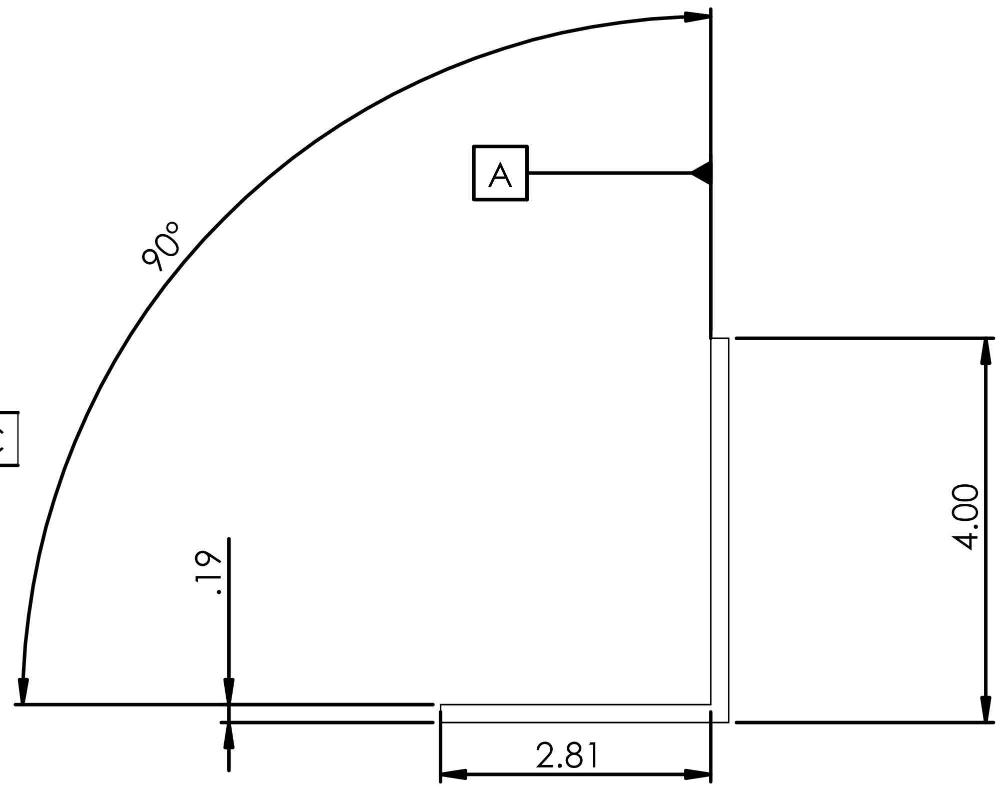
Float Switch Sub Assembly

MATERIAL: -

DWG NO. 0005 | A3

SCALE:1:2 | SHEET 1 OF 1





TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.

ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

1	8910K395	1/8" X 1" X 6" BAR	Low Carbon Steel	McMaster Carr	1
ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.

NOTE:

TANK WILL BE PURCHASED AND HOLES WILL BE DRILLED BY TEAM.

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: Low Carbon Steel

DO NOT SCALE DRAWING

REVISION 1

Grey Water Capture

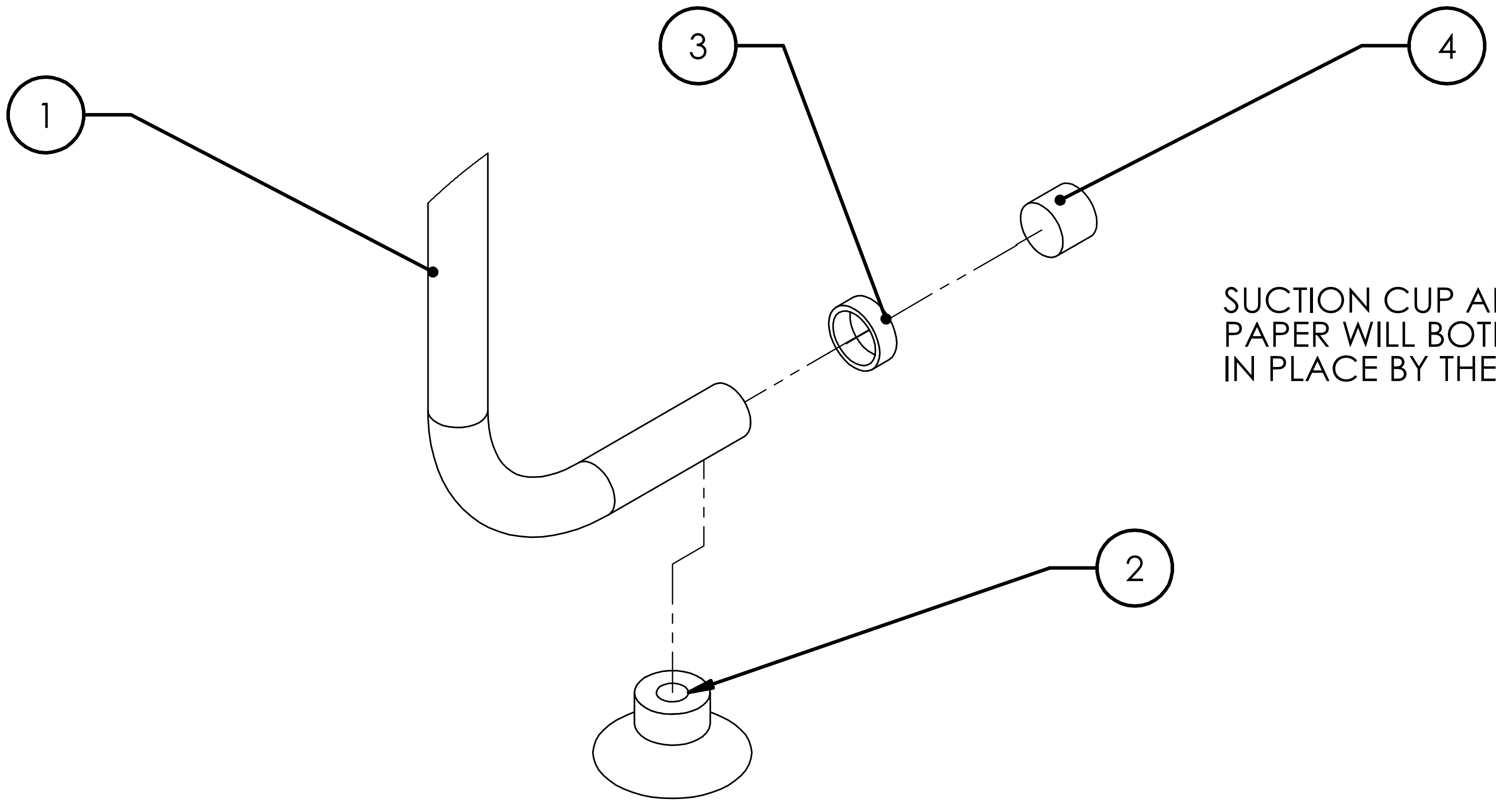
TITLE: Switch Bracket

DWG NO. 0006

A3

SCALE:1:3

SHEET 1 OF 1



SUCTION CUP AND FILTER PAPER WILL BOTH BE HELD IN PLACE BY THE CABLE TIE.

TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.
ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.
4	8997T61	Filter Felt Sheet	Carbon	McMaster Carr	1
3	5463K86	Cable Tie	Nylon	McMaster Carr	1
2	78410	Suction Cup	-	Amazon	1
1	5233K66	1/2 in. Tubing	PVC	McMaster Carr	1

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: -

DO NOT SCALE DRAWING

REVISION 1

Grey Water Capture

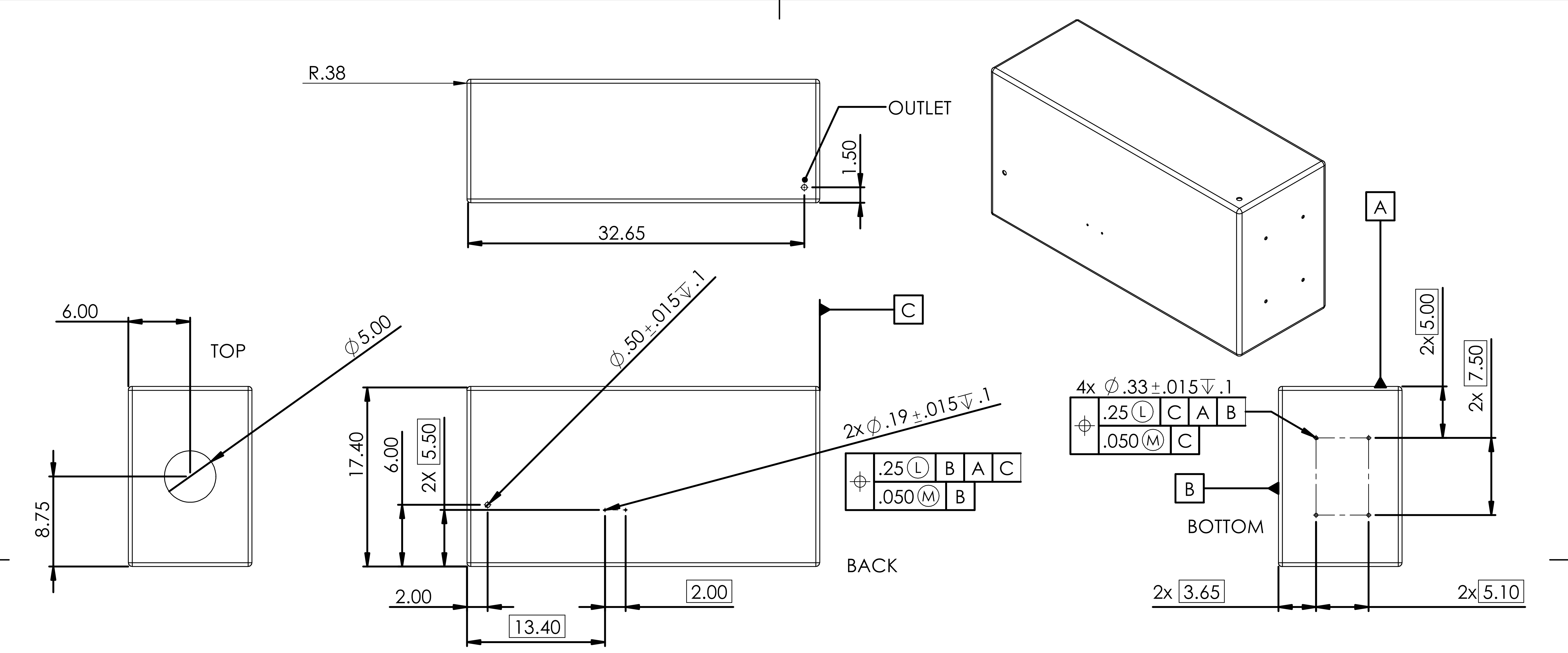
TITLE: Inlet Sub Assembly

DWG NO. 0007

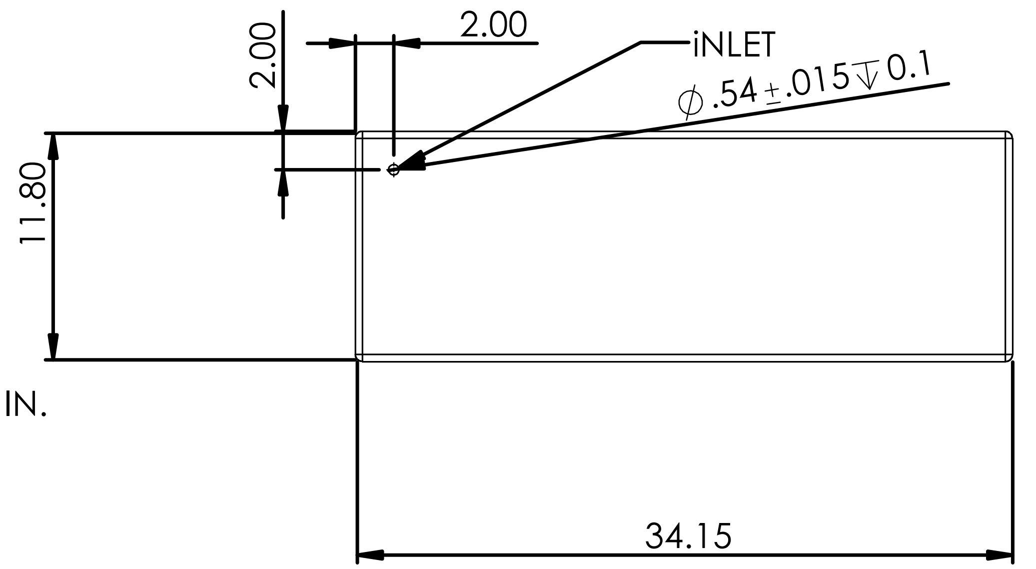
A3

SCALE:1:2

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.
1	W0064	30 Gal. Tank	POLYETHELYNE	AdventureRV.net	1



NOTE:

TANK WILL BE PURCHASED AND HOLES WILL BE DRILLED BY TEAM.

TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.

ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: -

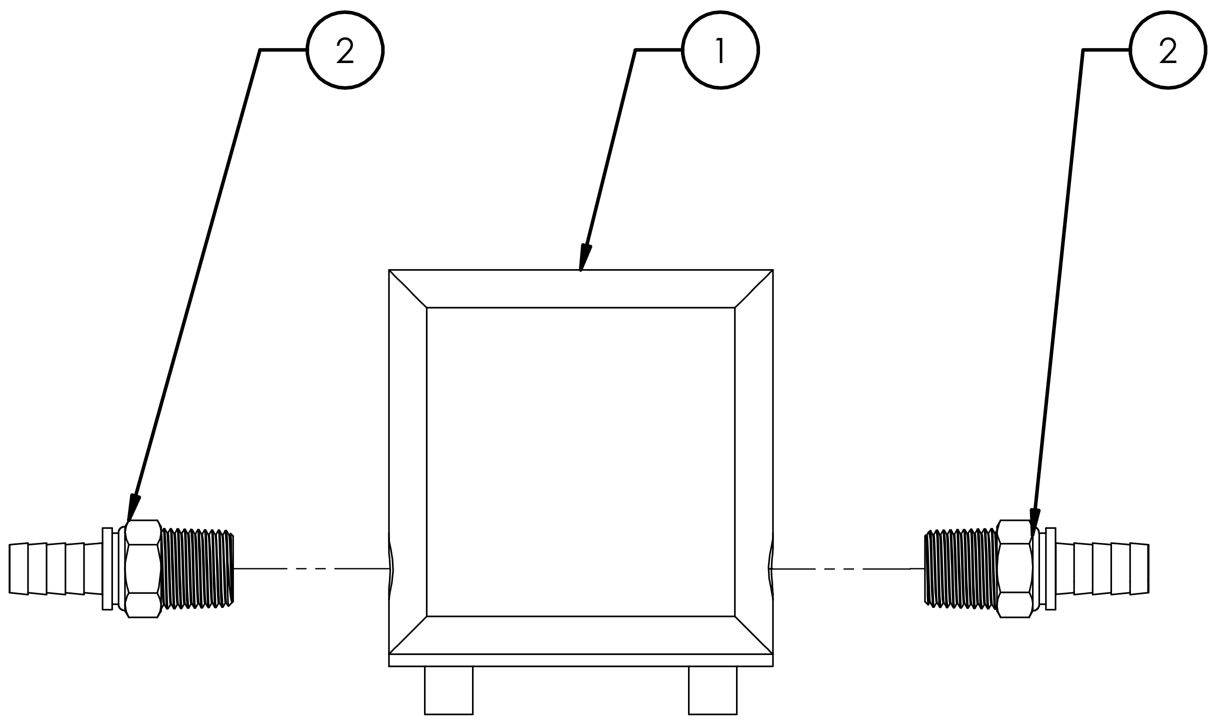
DO NOT SCALE DRAWING | REVISION 1

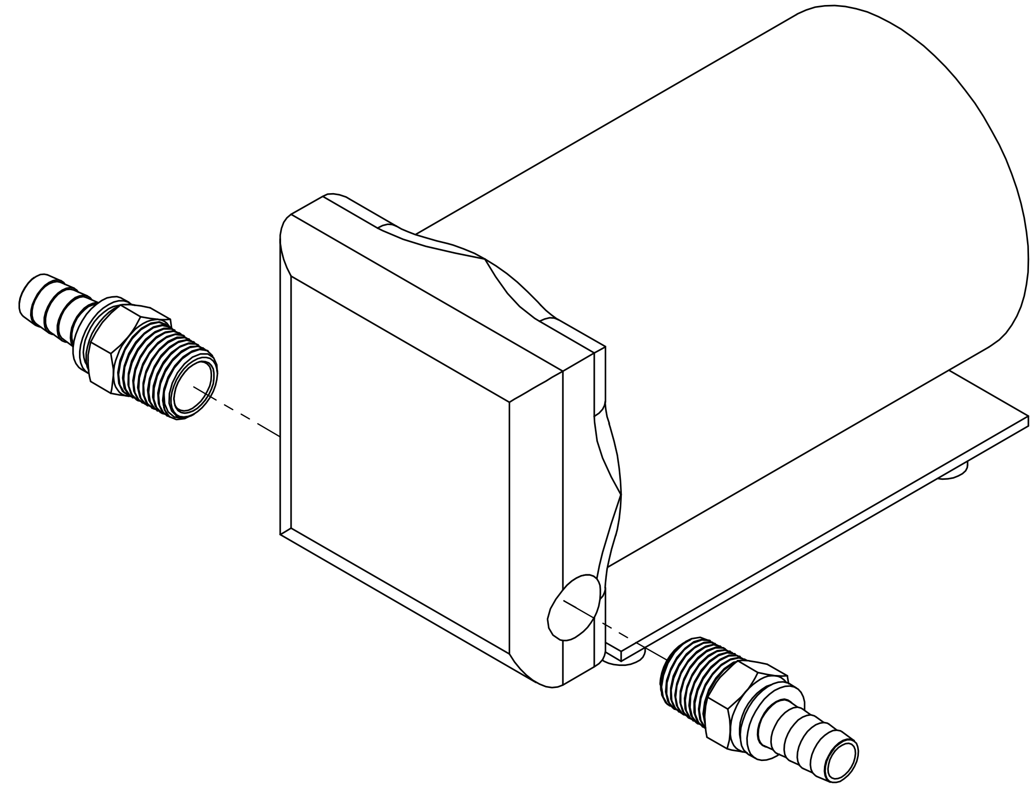
Grey Water Capture

TITLE: Tank

DWG NO. 0008 | A3

SCALE:1:3 | SHEET 1 OF 1





TOLERANCES: X.XX = ± .25 IN.

X.XXX = ± .050 IN.

ANGLES = ± 5°

UNLESS OTHERWISE SPECIFIED

2	5346K36	Barbed Hose Fitting	Brass	McMaster Carr	2
1	2088-594-154	SHURflo Pump	-	Amazon	1
ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	VENDOR	QTY.

DO NOT SCALE DRAWING | REVISION 1

Grey Water Capture

	NAME	SIGNATURE	DATE
DRAWN	Paul Brenneman		2/1/17
CHK'D	Vicente Ramirez		2/1/17
APPV'D	Kevin Alexander		2/1/17

UNIT: INCH

MATERIAL: -

TITLE: Tubing-Tank Interface Sub Assembly

DWG NO. 0009

A3

SCALE:1:2

SHEET 1 OF 1

Appendix I: Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results			
									Actions Taken	Severity	Occurence	Criticality
Capture	Does not aquire water	Tube not submerged	8	Water level low	7	56	Suction cup inlet mount	Team, Jan 25th				
			9	Tripping and slipping	3	27	Streamlined tube position	Team, Jan 25th				
			8	Tube floats	1	8	Suction cup inlet mount	Team, Jan 25th				
		Not enough suction	8	Not enough pump power	1	8 0 0 0	Thorough design and analysis	Completed				
Transport	Does not transport water	Not enough power	8	Not enough pump power	1	8	Thorough design and analysis	Completed				
		Leakage	5	Manufacture defect	2	10	Quality control	Team, Jan 25th				
			5	Bad installation	3	15	Clear instructions, simple design	Team, Jan 25th				
Store	Odors/cleanliness	Smells/ bacterial growth/ discolored water	5	Store water too long	4	20	Not oversizing tank	Team, Jan 25th				
			5	Dirty water	4	20	Filter	Team, Jan 25th				
	Tank Cracks/ Leaks	Water on floor	9	High pressure	1	9	Thorough design and analysis	Team, Jan 25th				
			8	Manufacture (stress conc.)	1	8	Thorough design and analysis	Team, Jan 25th				
			8	Overflow	1	8	Overflow return line	Team, Jan 25th				
			8	Bad installation	3	24	Clear instructions, simple design	Team, Jan 25th				
			8	Manufacture defect	2	16	Quality control	Team, Jan 25th				
		Ceramic pieces on floor	8	Tank rupture	1	8	Overflow return line	Team, Jan 25th				
Deliver	Does not deliver water	Valve gets stuck	5	Dirty water	4	20	Filter	Team, Jan 25th				
		Tube disconnects	8	Fatigue	3	24	Thorough design and analysis, material choice	Team, Jan 25th				
			8	Poor installation	4	32	Clear instructions, simple design	Team, Jan 25th				
			8	Manufacture defect	2	16	Quality control	Team, Jan 25th				
			8	Dirty water	4	32	Filter	Team, Jan 25th				
Safety	Hazard	Tripping	9	Pipes on the floor	3	27	Streamlined tube position	Team, Jan 25th				
		Electrocution	10	Valve stuck open, overflow	1	10	Filter, overflow return line	Team, Jan 25th				
			10	Leakage	1	10	Thorough design and analysis	Team, Jan 25th				
		Slipping	9	Valve stuck open, overflow	1	9	Filter, overflow return line	Team, Jan 25th				
			9	Water in shower	2	18	Recommend use of bath mat in owners manual	Team, Jan 25th				

Appendix J: Bill Of Materials

Part	Distributer	Part Number	Cost (each)	Quantity	Cost (quantity)	Shipping	Part Cost	Tax	Total Cost	Weight (lbs)
SHURflow Pump	Amazon	2088-594-154	$78.99	1	$78.99	FREE	$78.99	$6.32	$85.31	5
30 Gallon Tank	Ameri-Kart	W0064	$69.10	1	$69.10	$18.35	$87.45	$7.00	$94.45	15
Float Switch	Home Depot	1001098868	$36.98	1	$36.98	FREE	$36.98	$2.96	$39.94	1.25
Shelf	Home Depot	1001844191	$39.97	1	$39.97	FREE	$39.97	$3.20	$43.17	25
Backflow Prevention Valve	McMaster-Carr	7746K39	$29.83	1	$29.83	$4	$33.83	$2.71	$36.54	1
Brass Barbed Fitting (Female)	McMaster-Carr	3528T23	$3.96	1	$3.96	$2	$5.96	$0.48	$6.44	1
Brass Barbed Fitting (Male)	McMaster-Carr	5346K36	$5.90	2	$11.80	$2	$13.80	$1.10	$14.90	1
Brass Pipe Nipples	McMaster-Carr	4568K171	$2.29	1	$2.29	$1	$3.29	$0.26	$3.55	1
Filter Sheet	McMaster-Carr	8997T61	$7.35	1	$7.35	$2	$9.35	$0.75	$10.10	0.1
Hex Panel Nut	McMaster-Carr	91862A306	$3.80	1	$3.80	$1	$4.80	$0.38	$5.18	1
Nylon Barbed Fitting	McMaster-Carr	5463K86	$1.29	10	$12.86	$2	$14.86	$1.19	$16.05	1
PVC Tubing	McMaster-Carr	5233K66	$.42/ft	25 ft	$10.50	$5	$13.50	$1.08	$14.58	1
Socket Head Screw	McMaster-Carr	92196A267	$0.08	100	$7.57	$3	$10.57	$0.85	$11.42	1
Steel Flange Nut	McMaster-Carr	94758A105	$3.80	2	$7.60	$2	$9.60	$0.77	$10.37	1
Steel Hex Nut	McMaster-Carr	94895A810	$0.05	100	$5.29	$2	$7.29	$0.58	$7.87	1
Steel Rectangular Bar	McMaster-Carr	8910K395	$1.44	1	$1.44	$2	$3.44	$0.28	$3.72	8
Steel Washer	McMaster-Carr	91525A133	$1.42	5	$7.12	$2	$9.12	$0.73	$9.85	0.5
Suction Cup	McMaster-Carr	65825A3	$0.39	25	$9.68	$3	$12.68	$1.01	$13.69	0.3
Tee Joint (Pipe Fitting)	McMaster-Carr	4429K253	$7.97	1	$7.97	$2	$9.97	$0.80	$10.77	3
Zip Tie	McMaster-Carr	7130K53	$4.80	1	$4.80	$1	$5.80	$0.46	$6.26	0.1
Switch Tap	Walmart	C22-011470-00W	$7.50	1	$7.50	FREE	$7.50	$0.60	$8.10	1
						Total Cost:	**$418.75**	**$33.50**	**$452.25**	

					Sponsor	Michael Allwein						
TEST PLAN												
Item No	**Specification or Clause Reference**	**Test Type**	**Test Description**	**Equipment Required**	**Acceptance Criteria**	**Test Responsibility**	**Test Stage**	SAMPLES TESTED	TIMING			
Quantity	Type	Start date	Finish date	Status								
1	Pump flowrate > shower flowrate	Testing	Measure pump flowrate and compare to average shower flowrate	Stop watch, water	> 2.1 gpm	ALL	DV	1	B	5/11/17	5/11/17	Complete
2	Installation Time	Similitude	Estimate complete installation time for system based on individual installation steps	Necessary installation tools	Less than 1 hour	ALL	DV	1	B	5/11/17	5/11/17	Complete
3	Maintenance Frequency	Similitude	Look at similar systems to estimate maintenance frequency	No additional equipment.	Every 3 monthes or less frequently	ALL	DV	1	B	5/11/17	5/11/17	Complete
4	Leakage Test	Inspection	Inspect the system for leaks	No additional equipment.	No leaks	ALL	DV	1	B	5/11/17	5/11/17	Complete
5	Manual Labor	Inspection	Inspect system to ensure no maual labor is required	No additional equipment.	No manual labor	ALL	DV	1	B	5/11/17	5/11/17	Complete
6	Tank Tipping	Testing	Apply lateral forces and observe system behavior	No additional equipment.	Tank does not tip	ALL	DV	1	B	5/11/17	5/11/17	Complete
7	Minimum Water Height	Testing	Measure the minimum water level height which the system is able to pump water to the storage tank	Water	> 1/2 in. of water	ALL	DV	1	B	5/11/17	5/11/17	Complete
8	Float Switch	Testing	Check that the float switch properly switches off pump	Water	Switches off	ALL	DV	!	B	5/11/17	5/11/17	Complete

Appendix L: Spec Sheets

Model # SL-THDUS-006C Internet #207132406 Store SKU #1001844191

Save to List

HDX

60 in. H x 23.23 in. W x 13.39 in. D 6-Shelf Storage Unit

★★★★★ (1) Write a Review Questions & Answers (6)

$39.97 /each

Quantity - 1 +

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Product Overview

Get your rooms organized by adding extra storage space with this shelving unit. It is versatile enough to be positioned anywhere in the home, such as in your laundry room, kitchen, garage and many other rooms. The shelves can hold a great deal of stuff - each one can accommodate up to 250 lbs. when the weight is evenly distributed. This unit lets you neatly store all your belongings in your house.

- Weight capacity of 1500 lbs. total (when evenly distributed)
- Steel construction for strength and durability

- 6-adjustable shelves to house a variety of food, laundry supplies, tools and more
- Easy, no-tool assembly
- Adjustable legs for leveling on uneven floors

Specifications

Dimensions

Assembled Depth (in.)	13.39 in	Assembled Width (in.)	23.23 in
Assembled Height (in.)	60.00 in	Shelf Weight Capacity (lb)	250

Details

Color Family	Chrome	Number of Shelves	6
Color/Finish	chrome	Shelf Material	Wire
Durability	General purpose	Storage Product Type	Shelving Units
Features	No Additional Features	Total Weight Capacity (lb.)	1500
Material	Steel		

Warranty / Certifications

Manufacturer Warranty	N/A

All suction cup

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Cruiser Accessories

Cruiser Accessories 78410 Suction Cups, Clear, 4 pack

85 customer reviews | 6 answered questions

Price: $2.00 **Free shipping** for Prime members when buying this Add-on Item. Details

Your cost could be **$0.00**: Qualified customers get $5 in Gift Card funds on first $100 reload of their Amazon Gift Card Balance. Learn more

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Want it Friday, Feb. 10? Add it to a qualifying order within **23 hrs 48 mins** and choose **One-Day Shipping** at checkout. Details

Ships from and sold by Amazon.com.

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- These multi-purpose suction cups are designed for use with novelty plates to help keep the novelty/license plate secure
- Made of durable, clear plastic
- Versatile uses
- Includes four (4) clear suction cups
- User friendly and easy to install, see back of package for installation instructions
- Multi-purpose accessory-ideal for use with novelty plates
- Packaging Dimensions: 4.5 x 1.8 x 0.8 inches
- Individual product diameter is approximately 1 inch

› See more product details

Add-on Item

This item is available because of the Add-on program
The Add-on program allows Amazon to offer thousands of low-priced items that would be cost-prohibitive to ship on their own. These items ship with qualifying orders over $25. Details

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- [x] **This item:** Cruiser Accessories 78410 Suction Cups, Clear, 4 pack $2.00 Add-on Item
- [x] mDesign Wide Shower Caddy, Storage for Shampoo, Conditioner, Soap - Satin/White $18.99

Sponsored Products Related To This Item (What's this?)

Leadrise® 5 inch Aluminum Suction Cup Puller Lifter 110 Lbs. Dent Remover,glass,…
45
$15.99

Car Sun Shade by NimNik Baby, 2-Pack, Black
22
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Car Phone Mount Holder, LESHP Universal Car Air Vent Phone Holder Car Bracket with Multi…
6
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19
$9.90

Clear Plastic Suction Cups with Loops, 4.5 cm (1.75 in) Wide, Set of 10
6
$8.95

Double Sided Suction Cups, 20 mm, Set of 10, Clear
29
$7.95

Cruiser Accessories 76200 Tuf Flat Shield Novelty / License Plate Shield, Smoke
270
$7.28

Adams Manufacturing 6000-74-3040 2-1/2-Inch Suction Cup Hook, Large, 2-Pack
479
$5.23

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Product Information

Technical Details

Brand	Cruiser Accessories
Item Weight	0.3 ounces

Additional Information

ASIN	B00032KBEA
Customer Reviews	

Product Dimensions	4.5 x 1.8 x 0.8 inches
Item model number	78410
Manufacturer Part Number	78410

	85 customer reviews 4.1 out of 5 stars
Best Sellers Rank	#8,461 in Automotive (See top 100) #15 in Automotive > Exterior Accessories > License Plate Covers & Frames > Fasteners
Shipping Weight	0.3 ounces (View shipping rates and policies)
Domestic Shipping	Item can be shipped within U.S.
International Shipping	This item can be shipped to select countries outside of the U.S. Learn More
Date First Available	September 14, 2005

Warranty & Support

Warranty, Parts: Parts

Feedback

If you are a seller for this product, would you like to **suggest updates through seller support**?
Would you like to **tell us about a lower price**?

Important Information

Safety Warning
None

Product Description

These multi-purpose suction cups are designed for use with novelty plates. Cruiser Accessories is a family owned business that has been manufacturing and selling license plate frames for over 30 years. Through innovation, attention to detail and many patented designs, Cruiser has evolved into the largest supplier of license plate frames, novelty plate shields and mounting hardware in the automotive aftermarket. Cruiser's product line also includes both standard and exclusive Star Pin locking hardware, designer fastener caps, mounting accessories, motorcycle frames and 3d-Cals decals. Let Cruiser Accessories complete your ride's look today!

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Ameri-Kart Fresh Water Holding RV Tank 30 Gallon W0064

[A411-681460]

~~$87.50~~ **$69.10**

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Manufacturer's Number: W0064

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Water Tank 17 1/2" W X 34 1/4" L X 12" D Picture is Generic.

Also purchased with this product:


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12 Volt 2-Speed Heavy Duty Chrome Fan


12V Mini Plate Receptacle


FloJet Triplex Water Pump


Double Bottle Rack, 30 lb. Cylinder Kit


LP Cylinder, 30 lbs.

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RV Parts Special


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Everbilt

Vertical Float Switch for Sump Pumps

★★★★☆ (14) Write a Review Questions & Answers (7)

$36.98 /each

Quantity - 1 +

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Product Overview

This vertical float switch is a replacement switch for sump and sewage pumps. This float switch is compatible with various sump pumps and includes brackets and clamps for installation to the discharge pipe. Use of this vertical float switch is ideal for use in small diameter pits or basins. California residents: see Proposition 65 information ↗

- Approximately a 4 in. on/off span
- On/off height can be adjusted by moving rubber grommet

- 8 ft. cord
- Works with pumps up to 1/2 HP at 120 VAC and 1 HP at 230 VAC
- 115-Volt plug attached can be removed for direct wiring

Specifications

Dimensions

Product Depth (in.)	3.75	Product Width (in.)	2.6
Product Height (in.)	4.53		

Details

Brand compatibility	Compatible with all models	Returnable	90-Day
Product Weight (lb.)	1.25lb		

Warranty / Certifications

Manufacturer Warranty	1 year

McMASTER-CARR®

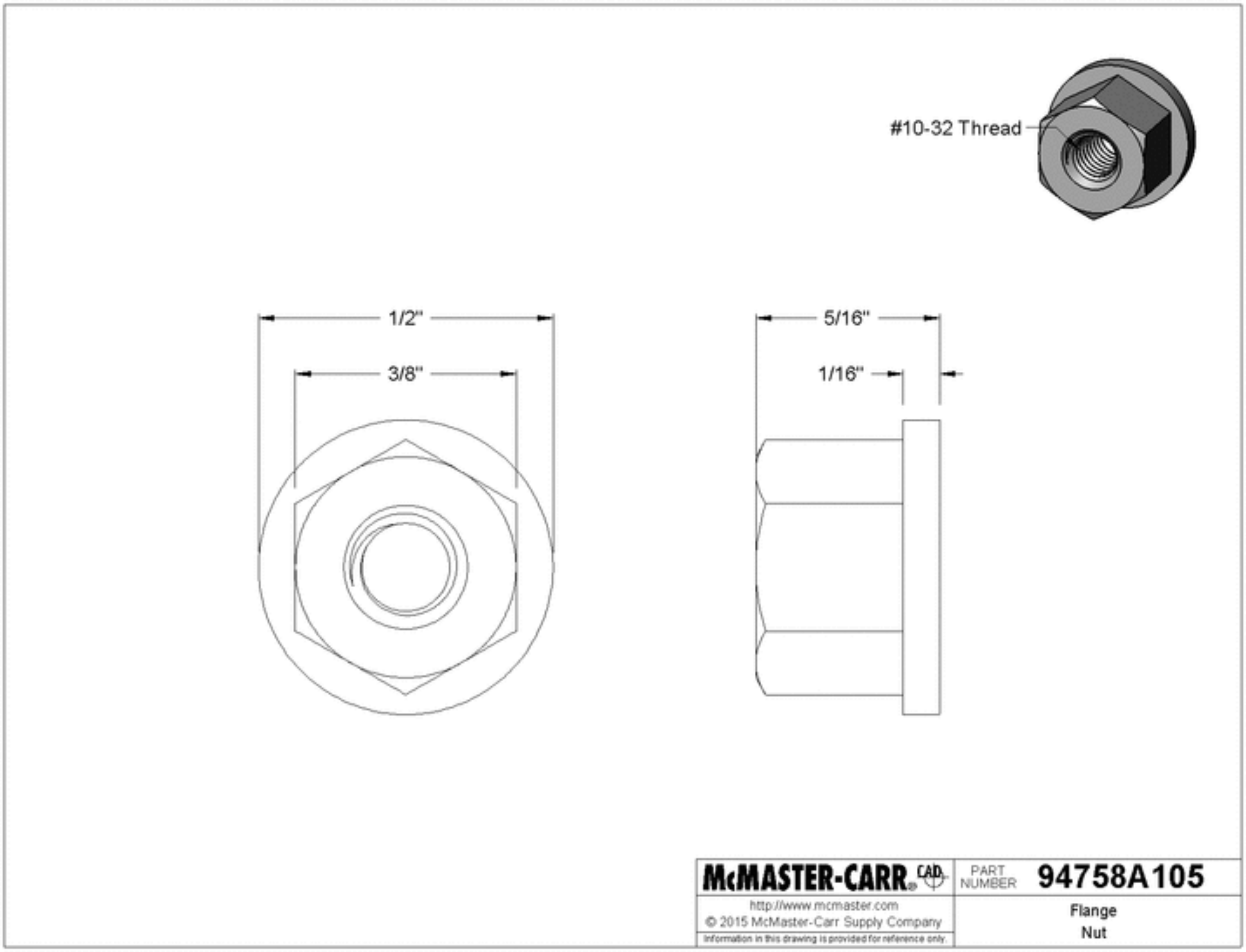
18-8 Stainless Steel Flange Nut

10-32 Thread Size

In stock
$3.80 Each
94758A105

Material	18-8 Stainless Steel
Thread Size	10-32
Thread Type	UNF
Thread Spacing	Fine
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	3/8"
Height	5/16"
Flange	
Diameter	1/2"
Thickness	0.06"
Drive Style	External Hex
Nut Type	Flange
Hex Nut Profile	Standard
System of Measurement	Inch
RoHS	Compliant

Made from 18-8 stainless steel, these flange nuts have good chemical resistance. The flange distributes pressure where the nut meets the material surface, eliminating the need for a separate washer. Height includes the flange.



The information in this 3-D model is provided for reference only.

McMASTER-CARR®

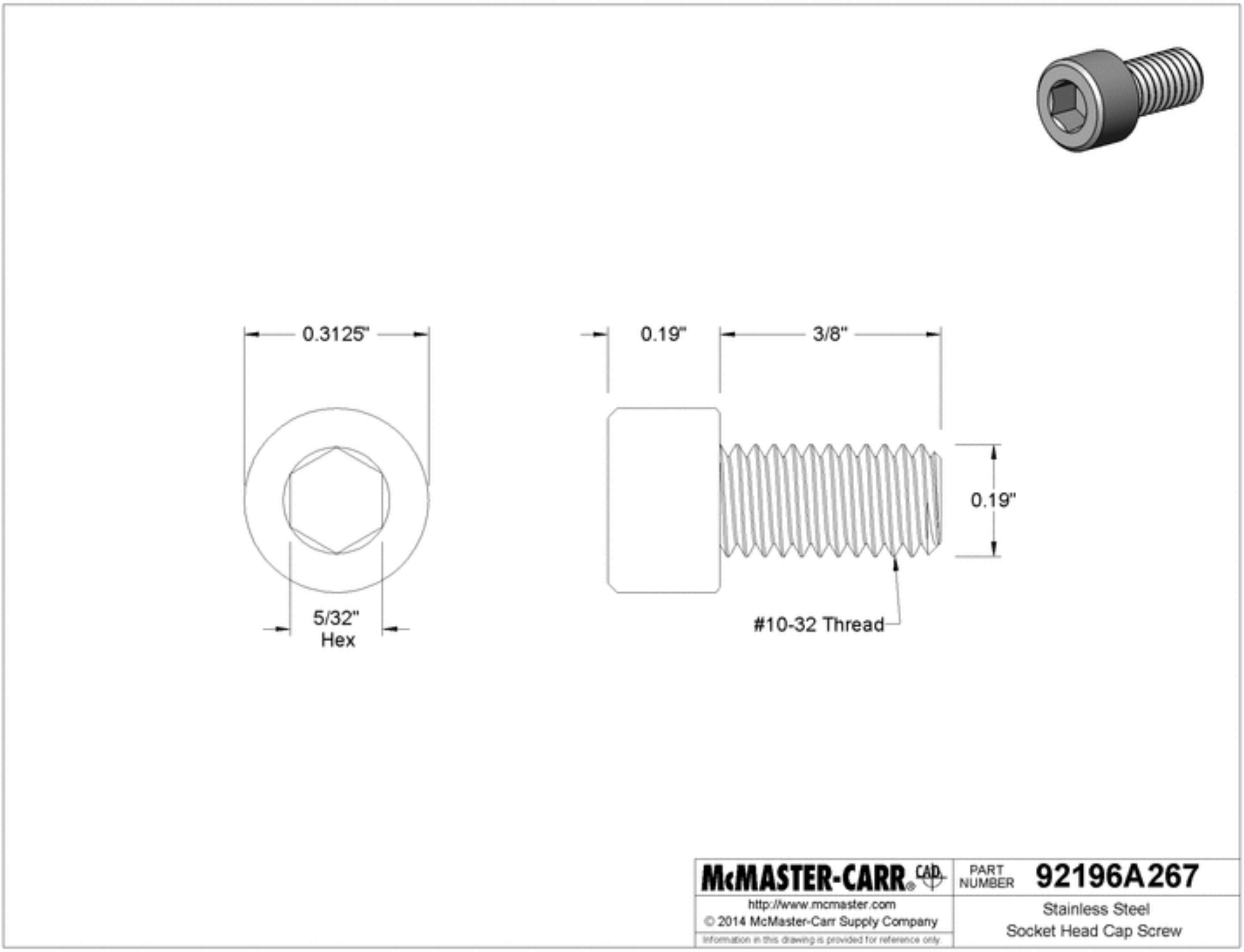
18-8 Stainless Steel Socket Head Screw

10-32 Thread Size, 3/8" Long

In stock
$7.57 per pack of 100
92196A267

Thread Size	10-32
Length	3/8"
Threading	Fully Threaded
Head Diameter	0.312"
Head Height	0.19"
Drive Size	5/32"
Material	18-8 Stainless Steel
Hardness	Rockwell B70
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.190"
Thread Type	UNF
Thread Spacing	Fine
Thread Fit	Class 3A
Thread Direction	Right Hand
Head Type	Socket
Socket Head Profile	Standard
Drive Style	Hex
System of Measurement	Inch
RoHS	Compliant

Made from 18-8 stainless steel, these screws have good chemical resistance and may be mildly magnetic. Length is measured from under the head.



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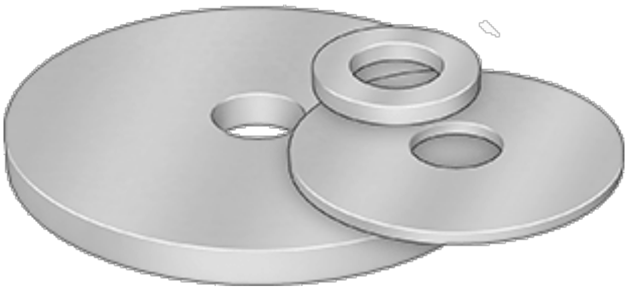
316 Stainless Steel Washer

Oversized, 5/16" Screw Size, 0.344" ID, 2" OD

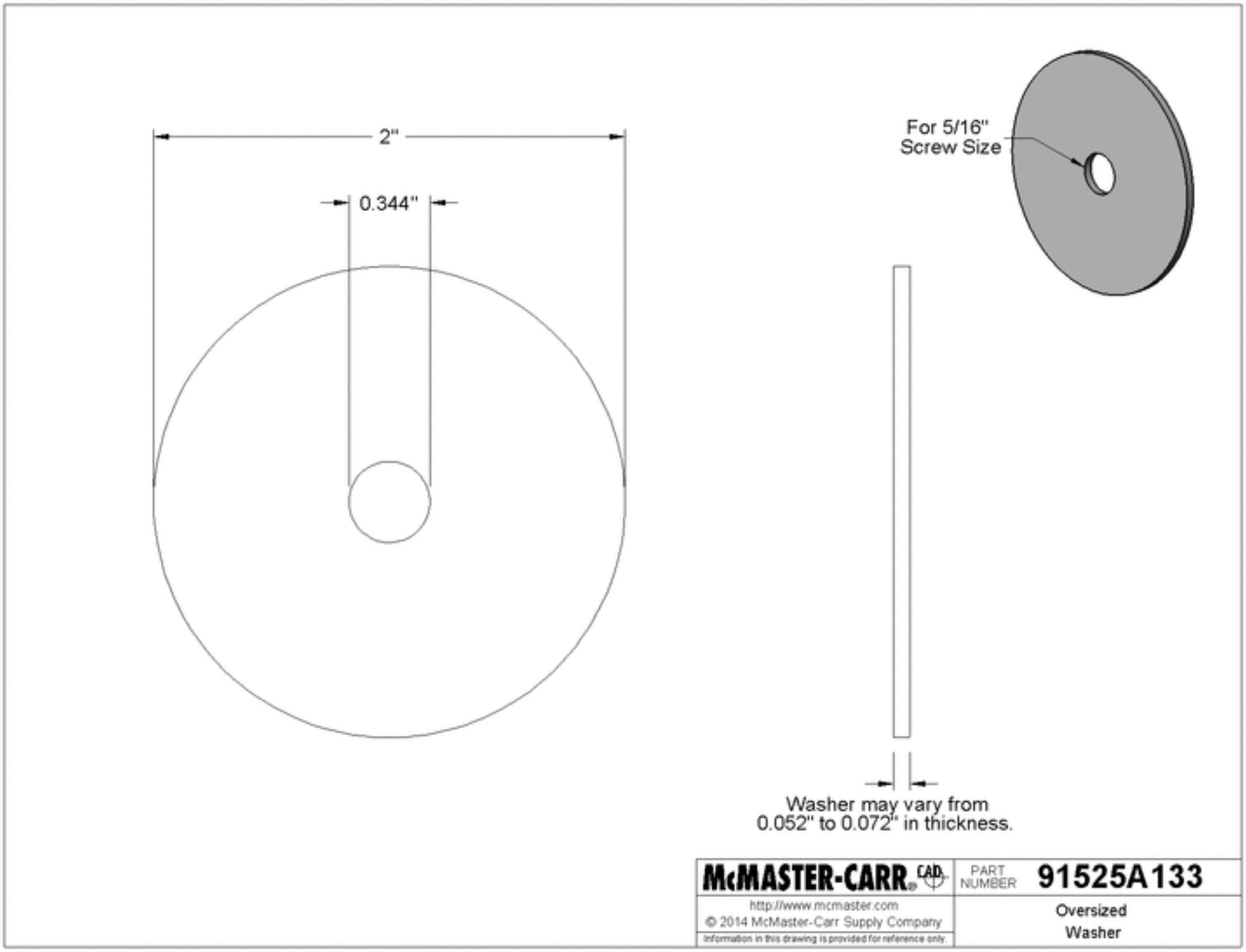
In stock
$7.12 per pack of 5
91525A133



Material	316 Stainless Steel
For Screw Size	5/16"
ID	0.344"
OD	2.000"
Thickness	0.052"-0.072"
Washer Type	Flat
System of Measurement	Inch
Hardness	Not Rated
RoHS	Compliant

Compared to our general purpose washers, these have exaggerated diameters and/or thicknesses for covering oversized holes or for use as spacers and levelers.

316 stainless steel washers have excellent resistance to chemicals and salt water. They may be mildly magnetic.



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McMASTER-CARR®

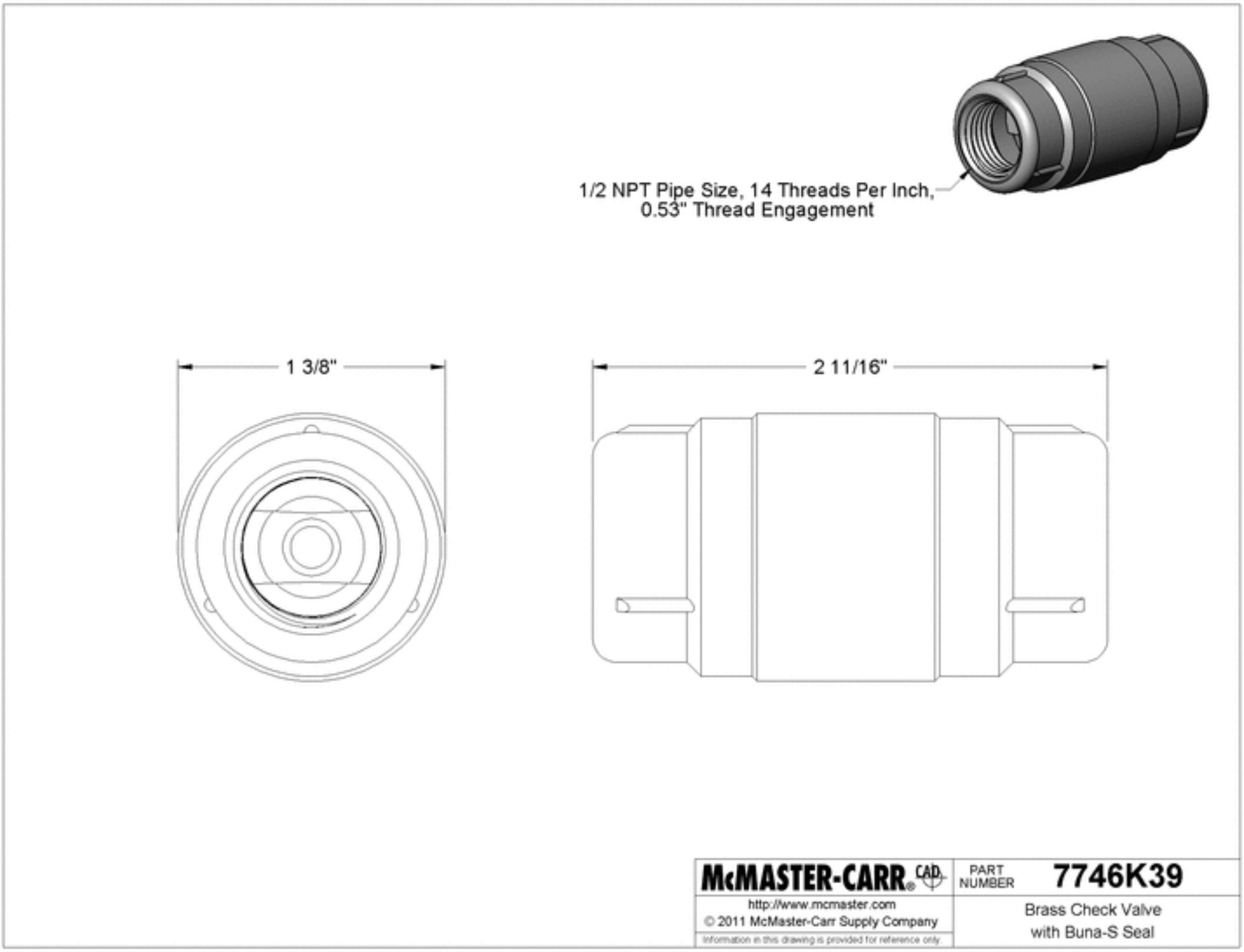
Backflow-Prevention Valve

for Water and Inert Gas, Brass Body, 1/2 NPT Female

In stock
$29.83 Each
7746K39

Valve Function	Backflow Prevention
For Use With	Air, Inert Gas, Water
Activation	Pressure Driven
Connection Type	Pipe
Connection	Threaded NPT Female
Pipe Size	1/2
Maximum Pressure	400 psi @ 70° F
Minimum Opening Pressure	2 psi
Temperature Range	33° to 225° F
Material	
Body	Brass
Seal	SBR
Shape	Straight
End-to-End Length	2 11/16"
Mounting Orientation	Any Position
Valve Type	Check
Check Valve Type	Spring Loaded
Flow Coefficient (Cv)	3

These valves open to allow flow in one direction and close when flow stops or reverses.



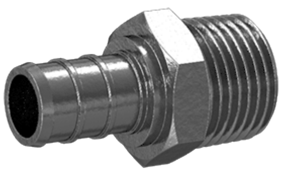
The information in this 3-D model is provided for reference only.

McMASTER-CARR®

Brass Barbed Fitting for Drinking Water

Straight for 1/2" Tube ID x 1/2 Male Pipe Size

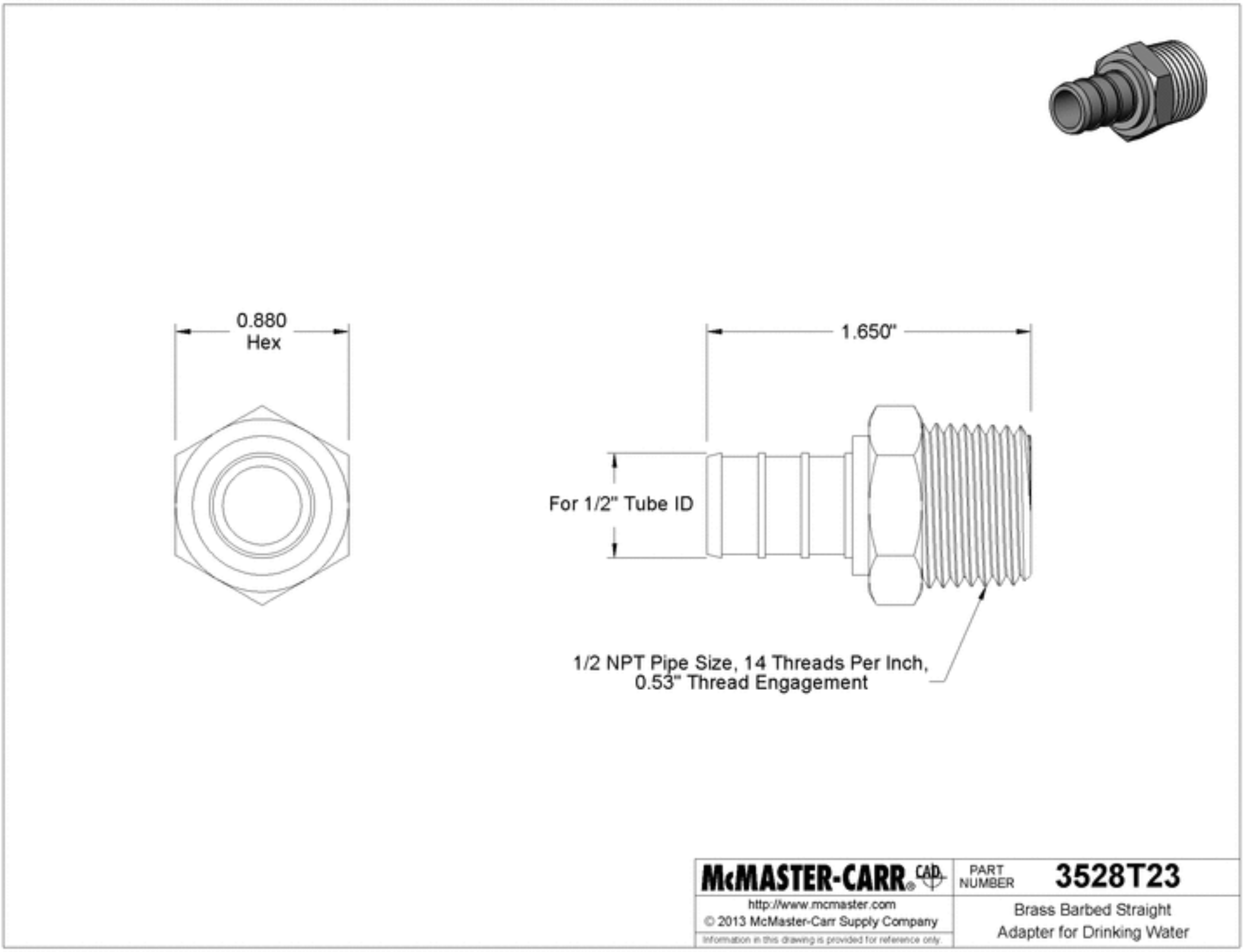
In stock
$3.96 Each
3528T23



For Tube ID	1/2"
Pipe Size	1/2
Maximum Pressure	160 psi @ 73° F
Temperature Range	–30° to 180° F
Tubing	Use with 51275K (PEX) polyethylene for drinking water
Additional Specifications	Straight Adapters, Tube-to-Male Threaded Pipe
RoHS	Compliant

When it comes to drinking water applications, these multi-barbed fittings are a handy alternative to solder-joint copper tube fittings. They connect to tubing with a ring and a crimping tool for a quick installation, with no heat or solvents required. Compatible with Viega PEX fittings, they meet NSF/ANSI Standard 61 for use with hot and cold drinking (potable) water. Material meets ASTM F1807.

Connections: Barbed or NPT threads.



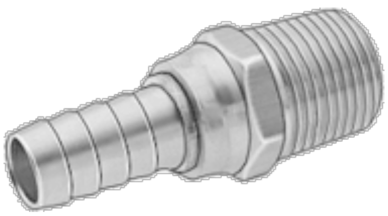
The information in this 3-D model is provided for reference only.

McMASTER-CARR®

Brass Barbed Hose Fitting

1/2" ID, Swvls Until Tightened, 1/2 NPTF Male End

In stock
$11.79 per pack of 2
5346K36

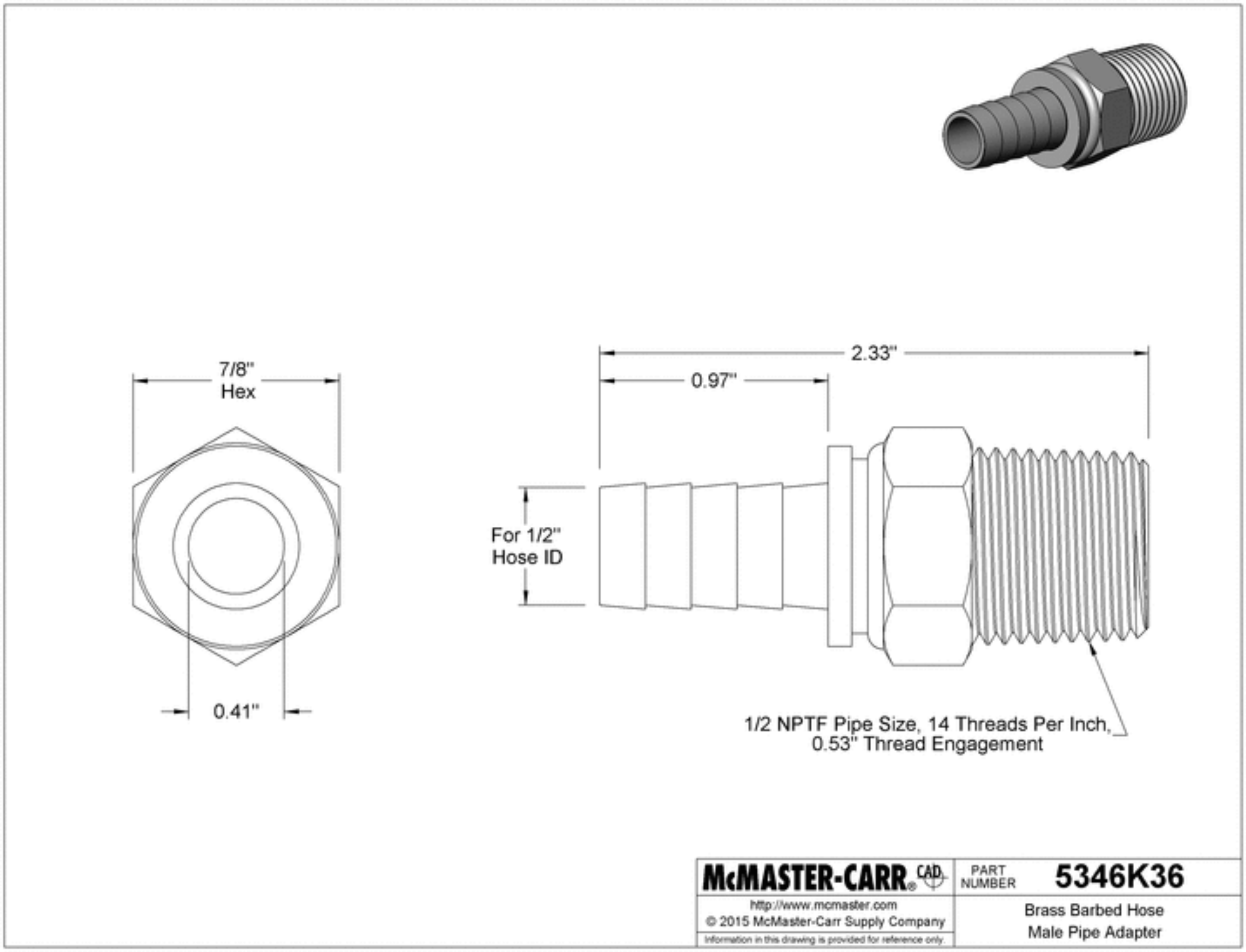


For Hose ID	1/2"
Pipe Size	1/2
Thread Type	NPTF
Swivel Type	Swivels Until Tightened
Connections	Barbed Male Hose Connection with Threaded Male Pipe Connection
Maximum Pressure	120 psi @ 72° F
Temperature Range	-40° to 160° F
Maximum Vacuum	Not Rated
For Hose Type	Reinforced Rubber
Material	Brass
For Clamp Type	Low-Profile Band Clamps
Seal Material	Buna-N Rubber
Specifications Met	SAE J476
For Use With	Air, Water
Shape	Straight
Type	Adapter
RoHS	Not Compliant

Also known as hose nipples, these fittings connect hose to threaded pipe. Fittings that swivel until tightened are easy to install.

Brass fittings have good corrosion resistance and are softer and easier to thread than steel fittings.

NPTF (Dryseal) threads are compatible with NPT Threads. Female NPSM (National Pipe Straight Mechanical) threads are compatible with male NPT threads.



The information in this 3-D model is provided for reference only.

McMASTER-CARR®

Durable Nylon Tight-Seal Barbed Tube Fitting

Through-Wall Straight for 1/2" Tube ID

In stock
$12.86 per pack of 10
5463K86

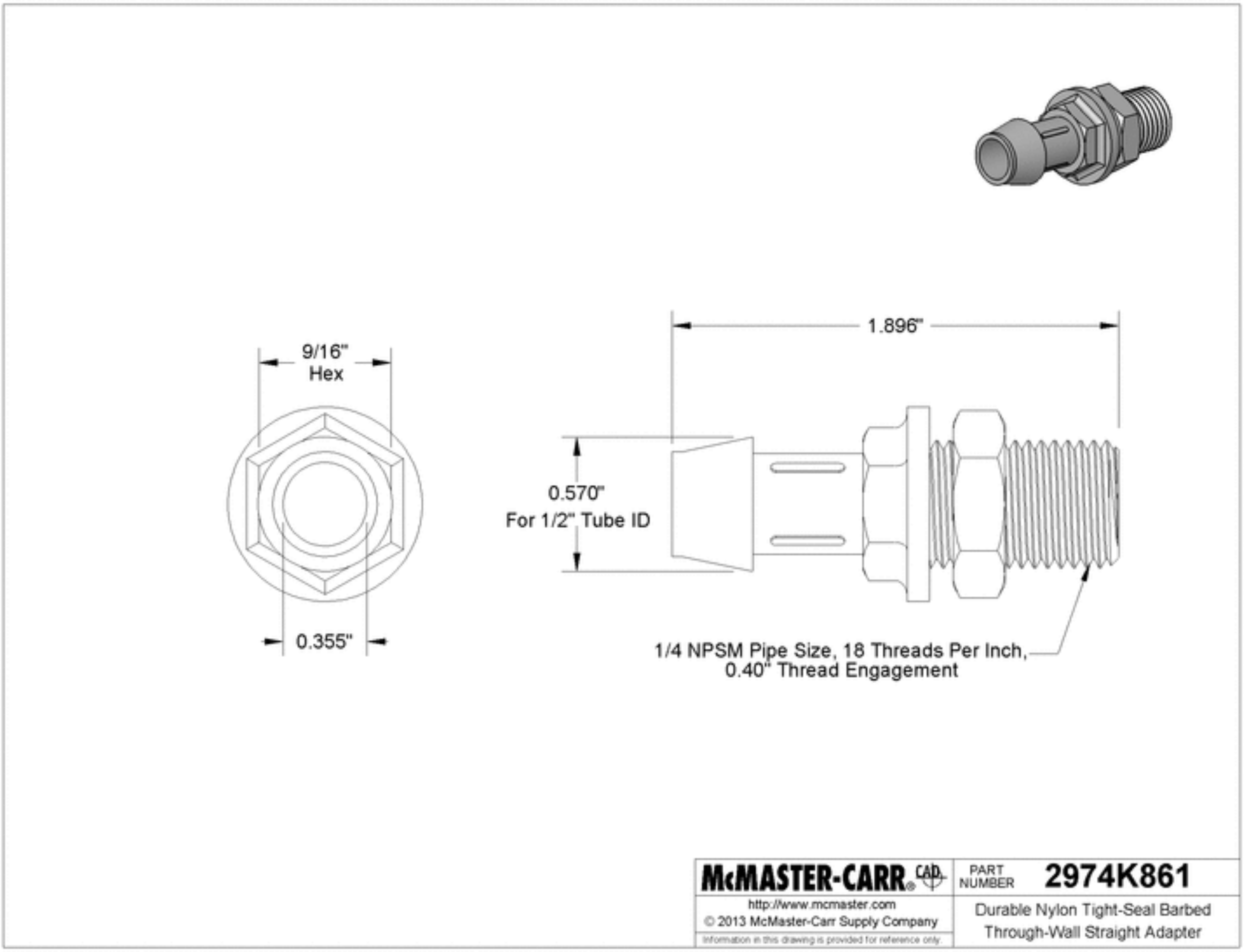
For Tube ID	1/2"
Pipe Size	1/4
Color	Semi-Clear White
RoHS	Compliant

Minimize leaks in your lines—these single-barbed fittings have a smooth surface that creates snug tubing connections. Use with water, air, and hydraulic fluid, unless noted. These durable nylon fittings are also very impact and abrasion resistant. Fittings can be sterilized with steam (autoclaving), unless noted.

Connections: Barbed or NPT threads, except 10-32 are UNF straight threads, and through-wall straights have an NPSM (National Pipe Straight Mechanical) connection.

Also known as bulkhead couplings, these adapters require a 1/2" hole size.

Color: Semi-Clear White



The information in this 3-D model is provided for reference only.

McMASTER-CARR®

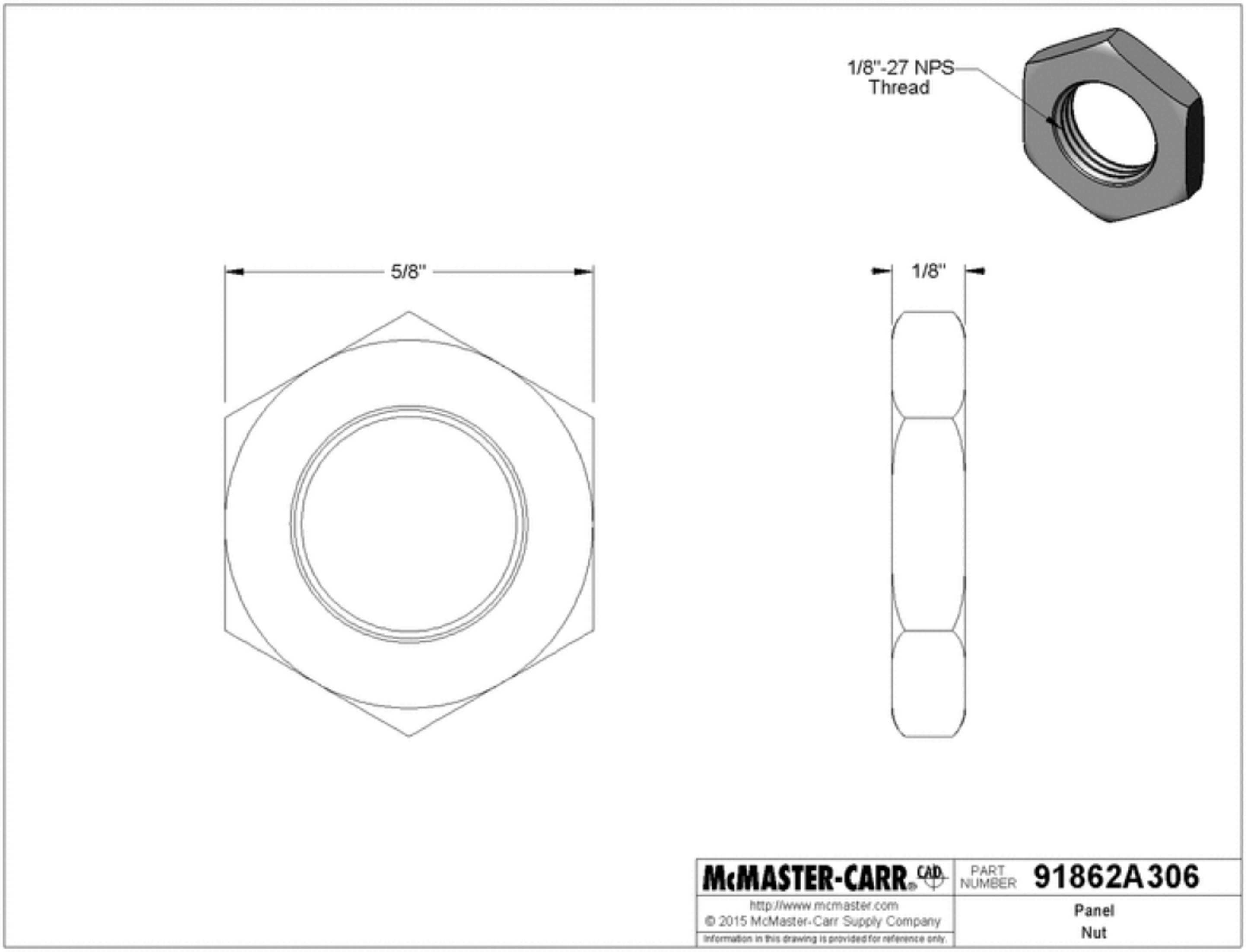
Hex Panel Nut

18-8 Stainless Steel, 1/8 NPT, 1/8" High

In stock
$3.80 per pack of 1
91862A306

Material	18-8 Stainless Steel
Pipe Size	1/8
Thread Type	NPT
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	5/8"
Height	1/8"
Drive Style	External Hex
Nut Type	Panel
Panel Nut Shape	Hex
Hex Nut Profile	Thin
System of Measurement	Pipe
RoHS	Compliant

These panel nuts have good chemical resistance and may be mildly magnetic. They can be fastened with a wrench for more torque while tightening than knurled panel nuts. Also known as dress nuts, they are extremely thin for use in tight spaces such as electrical panels.



The information in this 3-D model is provided for reference only.

High-Strength Steel Hex Nut

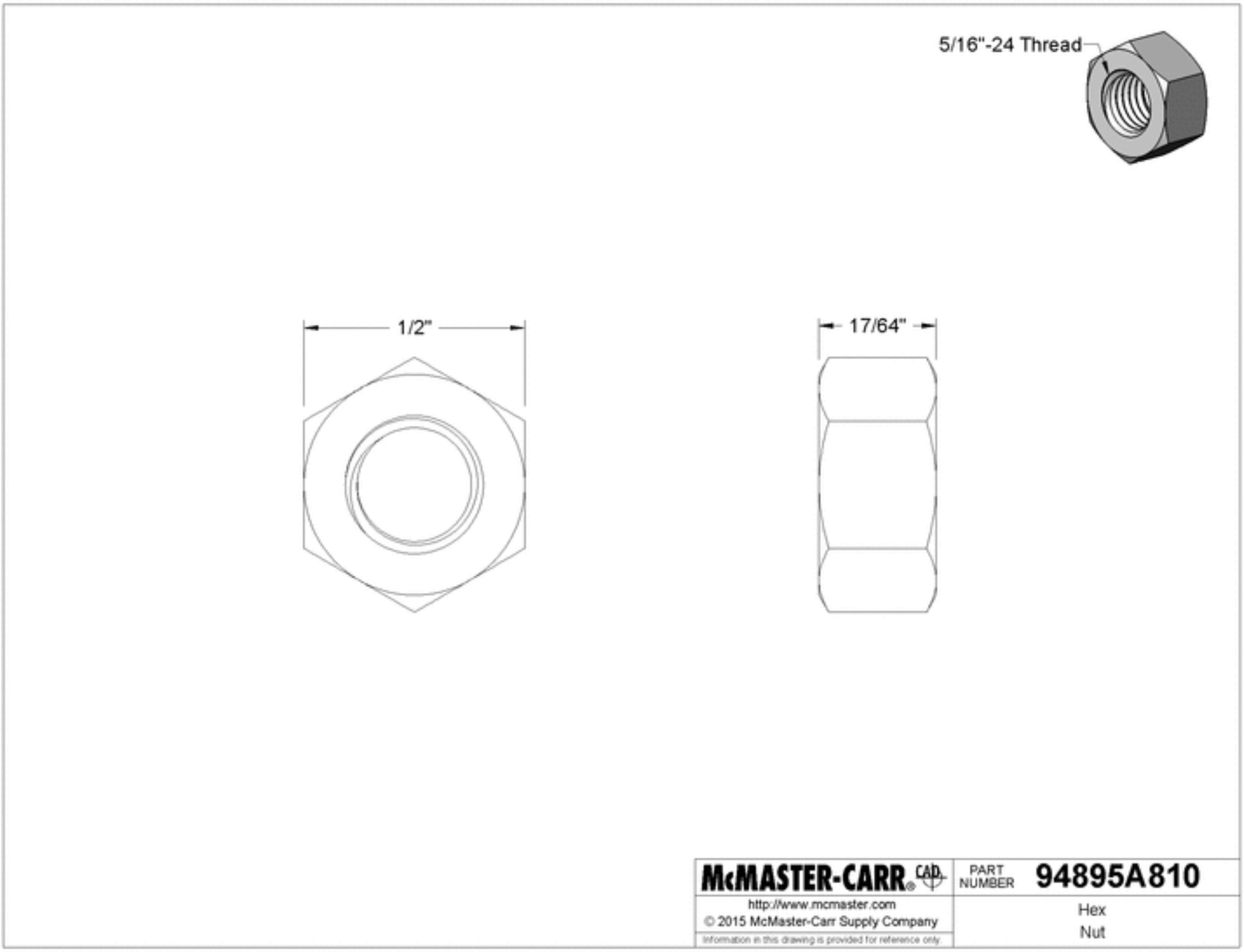
Grade 8, Zinc Yellow-Chromate Plated, 5/16"-24 Thread Size

In stock
$5.29 per pack of 100
94895A810

Material	Zinc Yellow-Chromate Plated Steel
Fastener Strength Grade/Class	Grade 8
Thread Size	5/16"-24
Thread Type	UNF
Thread Spacing	Fine
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	1/2"
Height	17/64"
Drive Style	External Hex
Nut Type	Hex
Hex Nut Profile	Standard
System of Measurement	Inch
RoHS	Not Compliant

These nuts are about 25% stronger than medium-strength steel nuts.

Zinc yellow-chromate plated steel nuts resist corrosion in wet environments.

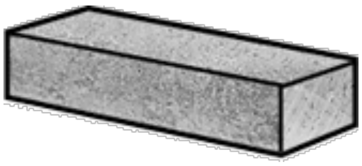


The information in this 3-D model is provided for reference only.

Low-Carbon Steel Rectangular Bar

1/8" Thick, 1" Width

8910K395



Grade	1018
Shape	Rectangular Bar
Finish	Unpolished
Thickness	1/8"
Thickness Tolerance	-0.006"
Width	1"
Width Tolerance	-0.006"
Yield Strength	54,000 psi
Hardness	Medium (Rockwell B70)
Specification Met	ASTM A108
Construction	Cold Drawn
Material Composition	
Carbon	0.13-0.20%
Manganese	0.30-0.90%
Silicon	0.15-0.30%
Phosphorus	0.04% Max.
Sulfur	0.50% Max.
Iron	98.06-99.42%
Nominal Density	0.283 lbs./cu. in.
Electrical Resistivity	15.9 microhm-cm @ 32° F
Thermal Conductivity	29.4 Btu/sq. ft./ft./hr./°F @ 212° F
Coefficient of Thermal Expansion (Text)	6.7-7.5 × 10^{-6}
Elongation Range	10-36%
Length	1/2 ft., 1 ft., 2 ft., 3 ft., 6 ft.
RoHS	Compliant

One of the most widely used types of steel, low-carbon steel is weldable, machinable, and can be surface hardened by heat treating. It is suitable for a variety of applications, such as structural and power transmission components.

Warning: Physical, mechanical, and chemical properties are not guaranteed and are intended only as a basis for comparison.

Material is 1018 carbon steel. Thickness and width tolerances are -0.006" for 1/8" to 4" wide bars; they are -0.010" for 4 1/2" to 6" wide bars; and they are -0.013" for bars 7" and wider. Length tolerance is ±1/8" for 1/2-ft. lengths, ±1" for 1-ft. lengths, ±2" for 2-ft. lengths, ±3" for 3-ft. lengths, and ±6" for 6-ft. lengths.

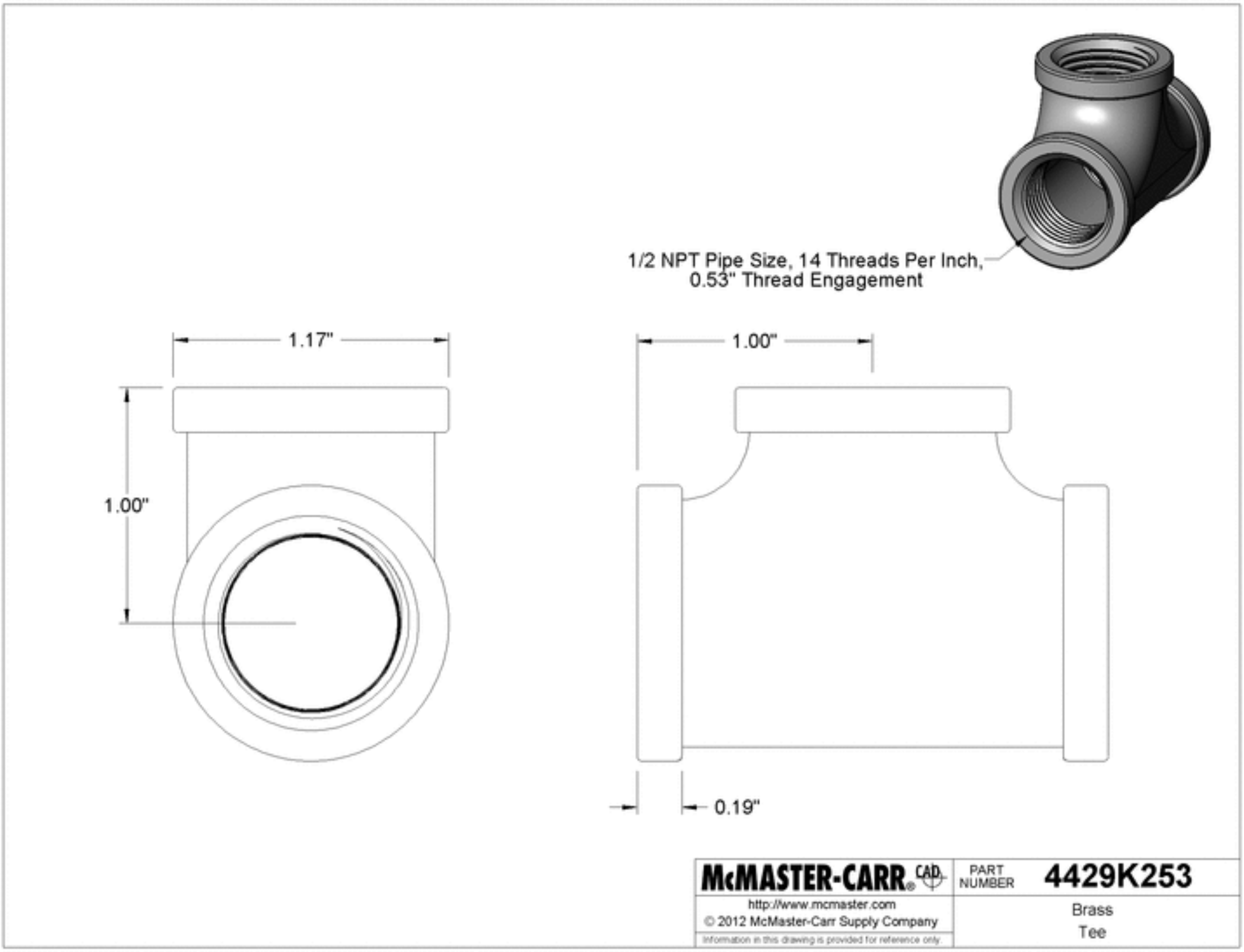
Low-Pressure Brass Threaded Pipe Fitting

Tee Connector, 1/2 NPT Female

In stock
$7.97 Each
4429K253

For Use With	Air, Drinking Water, Natural Gas, Oil, Steam
Shape	Tee
Type	Connector
Connection Type	Pipe
Pipe Connection Type	Threaded
Connection	NPT Female
Pipe Size	1/2
Material	Brass
Maximum Pressure	200 psi @ 72° F
Maximum Steam Pressure	125 psi @ 400° F
For Flange	
Material	Brass
Class	150
For Pipe	
Material	Brass
Schedule	40
Class	125
Specifications Met	ANSI/ASME B1.20.1, ANSI/ASME B16.15, NSF/ANSI Standard 61 for Drinking Water
RoHS	Compliant

Designed for use in low-pressure applications, these fittings are also known as Class 125 fittings. They are brass for good corrosion resistance.



The information in this 3-D model is provided for reference only.

McMASTER-CARR®

Masterkleer PVC Clear Tubing

1/2" ID, 5/8" OD

In stock
$10.50 Each
5233K66

For Use With	Air, Water
Hardness Rating	Soft
Hardness	Durometer 65A
Clarity	Clear
Material	PVC Plastic
ID	1/2"
OD	5/8"
Wall Thickness	1/16"
Flexibility	Very Flexible
Bend Radius	2 3/4"
Temperature Range	-40° to 160° F
Maximum Pressure	20 psi @ 72° F
Maximum Vacuum	Not Rated
Compatible Tube Fittings	Barbed
For Use With Metering Pumps	No
Sterilize With	Gas, Steam (Autoclaving)
Color	Clear
Length	25 ft.
RoHS	Compliant

This general purpose PVC tubing is an economical choice for air and water applications. Tubing is clear, so you can easily monitor flow.

McMASTER-CARR®

Nylon Cable Tie

5-1/2" Long, 1" Bundle Diameter, 40 lb. Break Strength, Black

In stock
1-9 Packs $4.80
10 or more $3.93
7130K53

Cable Tie Style	Standard
Overall Length	5 1/2"
For Maximum Bundle Diameter	1"
Breaking Strength	40 lbs.
Reusable	No
Width	0.14"
Thickness	0.05"
Material	Nylon
Closure Type	Lock
Body Style	Solid
For Use Outdoors	No
Specifications Met	MS 3367-5, UL 62275, UL 94V2
Temperature Range	32° to 180° F
Color	Black
RoHS	Compliant

Bundle and secure your cable, wire, and hose. Also known as zip ties.

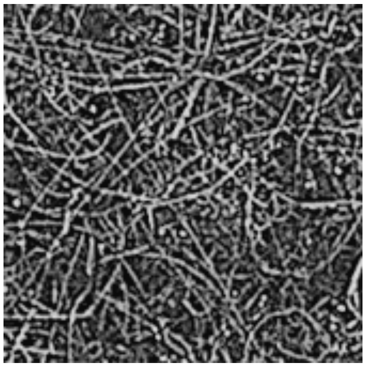
Standard ties balance flexibility and strength, making them good for most bundling applications.

McMASTER-CARR®

Odor-Removing Filter Felt Sheet

10" x 10", 265 Grams/Square Meter Density

In stock
$7.35 Each
8997T61



Thickness	0.1875"
Additional Specifications	10" × 10"

Less messy than carbon granules, this carbon-impregnated felt removes odor from liquids and air. It’s good for use with Fill-Your-Own Filter Cartridges. Maximum temperature is 150° F.

McMASTER-CARR®

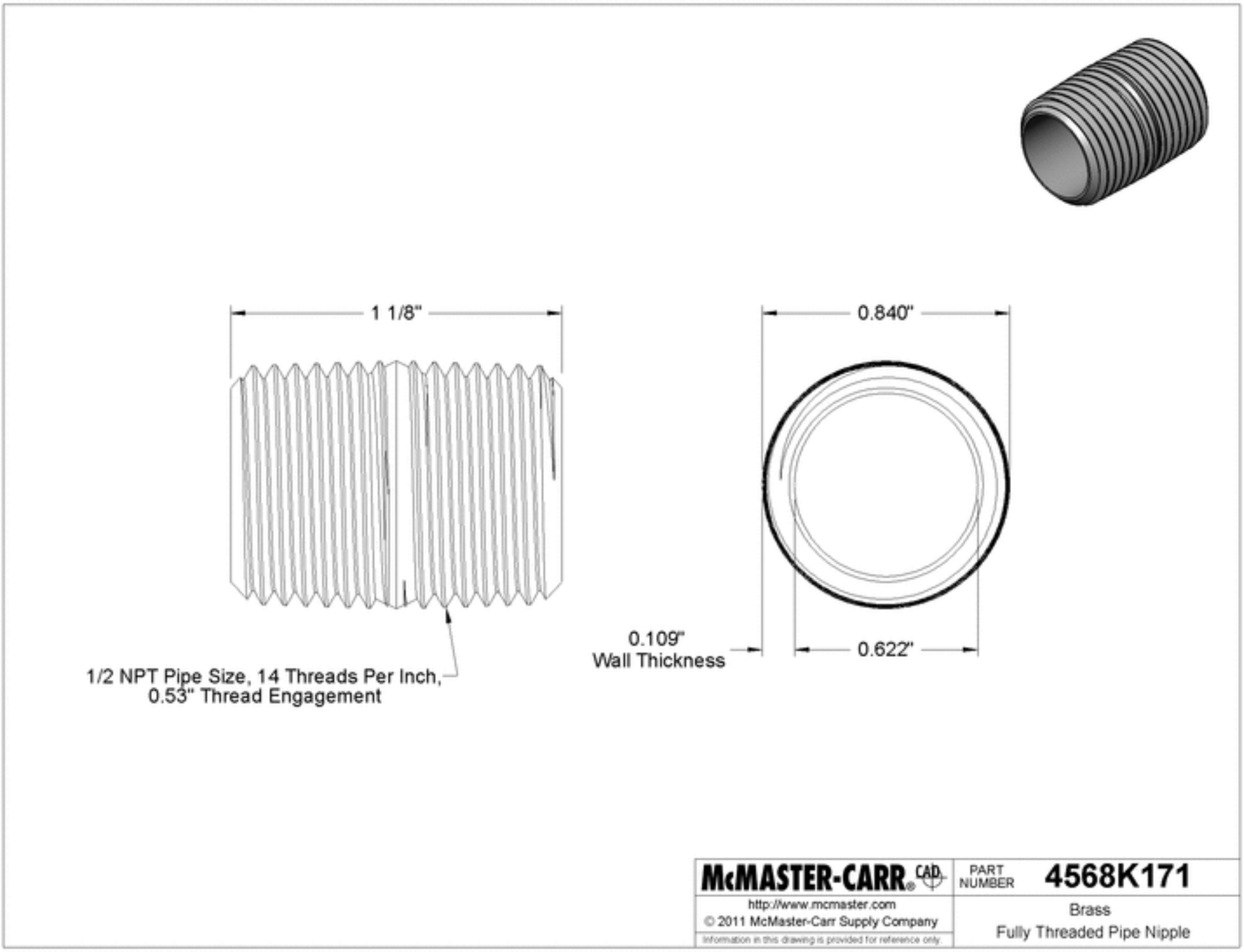
Standard-Wall Brass Pipe Nipple
Fully Threaded, 1/2 Pipe Size

In stock
$2.29 Each
4568K171

For Use With	Air, Drinking Water, Natural Gas, Oil, Steam
Shape	Straight
Type	Pipe
Schedule	40
Threading	Fully Threaded
Connection Type	Pipe
Pipe Connection Type	Threaded
Gender	Male
Pipe Size	1/2
Length	1 1/8"
Thread Type	NPT
Material	Brass
Construction	Seamless
For Fitting	
Material	Brass
Class	125
For Flange	
Material	Brass
Class	150
Specifications Met	ASTM B687, NSF/ANSI Standard 61 for Drinking Water
RoHS	Compliant

Also known as Schedule 40 pipe, this is a common choice for low-pressure applications. It is seamless, which provides a smooth interior for unrestricted flow. Pipe is brass for good corrosion resistance.

Fully threaded pipe is also known as a close nipple; it is threaded on each end to the center.



The information in this 3-D model is provided for reference only.

Click to open expanded view

SHURFLO

Shurflo 2088-594-154, 2088 Series, 198 GPH, 115 VAC Diaphragm Industrial Pump

357 customer reviews
| 189 answered questions

Price: $78.99

Get $50.00 off instantly: Pay $28.99 upon approval for the Amazon.com Rewards Visa Card. Learn more

In Stock.
Want it Wednesday, Feb. 8? Order within **19 hrs 48 mins** and choose **One-Day Shipping** at checkout. Details
Sold by The Pump Force and Fulfilled by Amazon. Gift-wrap available.

Eligible for amazonsmile donation.

- N/A
- Imported
- self-priming up to 9 vertical lift feet
- used in delivery and transfer of liquid applications up to 3 GPM (11.4LPM)
- 1/2" MPT, 115VAC 60Hz, non-corded 3 wires, built-in check valve prevents back flow of fluid
- built-in pressure switch, turn on/off at 45psi, adjustable pressure setting
- Santoprene valves and diaphragm

› See more product details

New (20) from $78.99

Report incorrect product information.

Share 50+ Shares

Qty: 1

Include 4-Year Protection for $12.46
Include 3-Year Protection for $7.83

Add to Cart

Turn on 1-Click ordering for this browser

Ship to:
Paul Brenneman- San Luis Obisp - 93401

Add to List

Add to your Dash Buttons

Other Sellers on Amazon

$78.99 Add to Cart
Sold by: Ernest F Mariani Company

$82.90 Add to Cart
Sold by: Amazon.com

New (20) from $78.99

Have one to sell? Sell on Amazon

Frequently Bought Together

 +  + 

Total price: $125.03
Add all three to Cart
Add all three to List

These items are shipped from and sold by different sellers. Show details

- ☑ **This item:** Shurflo 2088-594-154, 2088 Series, 198 GPH, 115 VAC Diaphragm Industrial Pump $78.99
- ☑ SHURFLO (255-213) 1/2" Twist-On Pipe Strainer $5.00
- ☑ SHURflo 182-200 Pre-Pressurized Accumulator Tank $41.04

Customers Who Bought This Item Also Bought

Page 1 of 28

SHURFLO (255-213) 1/2" Twist-On Pipe Strainer
435
$5.00

SHURflo 182-200 Pre-Pressurized Accumulator Tank
239
$41.04

SHURflo 234-2926 1/2" FPT X 1/2" Barb Straight Swivel
28
$5.83

Sponsored Products Related To This Item (What's this?)

Page 1 of 10

Homdox 1.6HP Booster Pump Stainless Shallow Well Pump Lawn Sprinkling Pump for…
9
$88.99

Aquatec (5853-1E12-J574) Delivery Pump; 0.9 GPM; 130/60 PSI; 3/8" JG; 120V With Cord
$116.98

Aquatec 5513-1E12-J526 Pump 4.9 gpm 1/2 FPT 115VAC
2
$170.82

[Update]Favson Diaphragm Pump DC 12V Fresh Water Pump 4.0 L/min 100 PSI Self…
27
$25.12

Seaflo 12V 100PSI Self-priming Diaphragm Pump
5
$39.99

Ad feedback

Special Offers and Product Promotions

- **Your cost could be $8.99 instead of $78.99**! Get a **$70 Amazon.com Gift Card** instantly upon approval for the **Amazon Prime Rewards Visa Card** Apply now

Product Description

This SHURflo Industrial on-demand positive displacement, 3 chamber diaphragm pump has a permanent magnet, thermally protected 115V AC motor that delivers reliable performance in high-flow, moderate pressure applications. Self-priming up to 9 ft. vertical. Max. 50 PSI; max. 30 PSI inlet pressure. Discharge Port (in.): 1/2, Self-Priming: Yes, Thermal Overload Protection: Yes, Suction Port (in.): 1/2, Max. Total Head (ft.): 100, Flow (GPH): 198, Max. PSI: 50, Volts: 115

Product Information

Technical Details

Part Number	52067
Item Weight	5 pounds
Product Dimensions	8 x 4 x 4 inches
Item model number	2088-594-154
Size	1

Additional Information

ASIN	B0001FAA5Y
Customer Reviews	357 customer reviews 4.4 out of 5 stars
Best Sellers Rank	#2,584 in Home Improvements (See top 100)

Color	Silver
Material	metal, aluminum
Power Source	ac
Voltage	115 volts
Wattage	104 watts
Amperage Capacity	0.9 A
Item Package Quantity	1
Flow Rate	3.3 GPM
Batteries Included?	No
Batteries Required?	No

	#4 in Home Improvement > Rough Plumbing > Water Pumps, Parts & Accessories > Power Water Pumps
Shipping Weight	5.2 pounds (View shipping rates and policies)
Domestic Shipping	Currently, item can be shipped only within the U.S. and to APO/FPO addresses. For APO/FPO shipments, please check with the manufacturer regarding warranty and support issues.
International Shipping	This item can be shipped to select countries outside of the U.S. Learn More
Date First Available	July 8, 2007

Warranty & Support

Product Warranty: For warranty information about this product, please click here. [PDF]

Feedback

If you are a seller for this product, would you like to **suggest updates through seller support**?
Would you like to **tell us about a lower price**?

Appendix M: User’s Manual

Grey Water Capture

Operation Manual

Warnings

1. Sitting under the tank can lead to serious injury or death
2. Do not push or tip over the tank
3. Avoid getting water on the pump
4. Do not drink grey water
5. Avoid tripping over the tubes

Device Installation

1. Connect the pump power cable to the float valve power plug
2. Construct stand by using the provided screws to affix the four legs to the rectangular base
3. Position the stand so it is over the toilet and as close to the wall as possible
4. Place tank on top of stand
5. Bolt the tank to the stand to ensure rigidity
6. Turn off the valve on the fresh water line and disconnect the main water line from the toilet
7. Connect the outlet of the T-Flange to the toilet water inlet
8. Connect the main water line to one end of the T-Flange
9. Connect the barbed fitting assembly to the other end of the T-Flange
10. Measure the length of PVC tube needed to go from the T-Flange to the tank outlet
11. Cut the PVC tube to length based on the users bathroom layout
12. Connect the tank to the toilet with the tube
13. Install a barbed fitting into the toilet's inlet hole
14. Measure/Cut length needed for PVC tube to go from tank to pump
15. Install a barbed hose fitting on both sides of the pump
16. Connect the tank to the pump with PVC tube
17. Measure/Cut length needed for PVC tube to go from pump to shower
18. Connect suction cup to end of PVC tube using zip ties
19. Connect filter to end of PVC tube (before suction cup)
20. Using the suction cup, attach the end of the tube to the shower floor
21. Connect pump power cable to float switch piggy back plug
22. Connect float switch piggy back plug to wall to turn the pump on before each shower
23. Unplug the pump from the wall after each shower

Pre-Operation Inspection

1. Check system for leaks
2. Check tank for cracks, dents or other damage.
3. Check all electrical components and ensure that wiring is correct.
4. Check if there is any damage to insulation
5. Be sure that all structural and critical components are present and associated fasteners are in place and correctly tightened

Operations

1. Plug pump into wall outlet, pump will turn on
2. Turn on shower, take shower
3. Pump will deliver water to tank until tank is full, than automatically shut off
4. Unplug pump after getting out of the shower
5. Use toilet as normal throughout the day and the system will supply water until tank is empty

Troubleshooting

- Why isn't the tank filling with water?
    a. Check tank to see if it already has water in it. If tank is full, the float valve will prevent the pump from turning on.
    b. Ensure pump is on while taking a shower
    c. Ensure suction cup is stuck to the floor of the shower, and the inlet tube is attached to suction cup
    d. Ensure inlet tube is not obstructed, check the filter for excessive debris
    e. Check tubes for kinks or blockages
    f. Check tube connections to ensure nothing has been disconnected
- Why does the toilet not flush?
    a. Check the tank to see if there is water in it. If there is no water in the tank but there should be, see the "why isn't the tank filling with water?" section
    b. Check the toilet valve by opening the fresh water valve and supplying fresh water to the toilet. If the toilet still does not flush than the problem is with your toilet – most likely the valve system.

Maintenance

1. Clean the tank at suggested frequency (every 3 months)
2. Replace the filter at suggested frequency (every 3 months)
3. Replace any damaged component (dependent on system wear)