# The Maqueduct Guide


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## Contents

# Materials

The maqueduct has many different parts and most are inexpensive. It can be built for about $35 depending on how many tools you need to buy.

## Tubing

The clear vinyl tubing you will need to build the maqueduct is often called “mangera de nivel” in Panama. You will need 1/4 in, 3/8 in. and 1/2 in. diameters. It is sold with different wall thicknesses. Buy the thick stuff but don’t buy the tubing that has reinforcement strings inside. You will know you have the right tubing if the 1/4 in. tubing fits snugly inside of the 3/8 in. tubing and the 3/8 in. tubing fits snugly inside the 1/2 in. tubing. Buy the following amounts:

| Tubing Inside Diameter | Feet Needed | Cost per Foot | Total Cost |
|---|---|---|---|
| 1/4 | 34 | $0.15 | $5.10 |
| 3/8 | 23 | $0.20 | $4.60 |
| 1/2 | 5 | $0.30 | $1.50 |
| 5/8 | 1 | $0.40 | $0.40 |
| | | Total | $11.60 |

## Other Stuff from the Hardware Store

| Item | See Note # | Quantity | Unit Cost | Total Cost |
|---|---|---|---|---|
| 1/2 in. male threaded coupling, PVC | 2 | 4 | $0.80 | $3.20 |
| Plastic nut with gasket | 3 | 4 | $0.75 | $3.00 |
| 1/2 in. tube, PVC (ft.) | 1 | 1 | $0.30 | $0.30 |
| 1/2 in. elbow, PVC | | 2 | $0.20 | $0.40 |
| 1/2 in. end cap, PVC | 4 | 4 | $0.15 | $0.60 |
| 1/2 in. **CPVC** Tee | 5 | 4 | $0.20 | $0.80 |
| 1/2 in. ball valve, PVC | | 1 | $1.90 | $1.90 |
| Galvanized wire or coat hangers (ft.) | 1 | 3 | $0.05 | $0.15 |
| Strong String (ft.) | 1, 6 | 18 | $0.01 | $0.18 |
| | | | Total | $10.53 |

**Notes**

1) This is an item that you can probably find lying around and isn’t always necessary to buy

2)

The threaded couplings should not have a tapered transition between the threads and the base like the coupling on the right. The tapered transitions tend to wedge open the holes in the bucket and can make the bucket begin to crack.

3)

I don't know what these things are called. I think that they are used in toilets or some other pluming fixture. You could also use a 1/2 in. female threaded coupling but I think these things work better and they come with a gasket.

4) You may want more if you want to make the source able to flow at other rates.
5) You will know you have the right one if 1/2 in. vinyl tube fits in really tight. They are creamier colored and smaller in size than the normal tees.
6) Use the kind of string that people use to tie penca onto the roof. It is strong and doesn't stretch much.

## Items from Other Stores

| Item | See Note # | Quantity | Unit Cost | Total Cost |
|---|---|---|---|---|
| Big Round Fake Pearl Earrings (pair) | | 1 | $0.25 | $0.25 |
| Used Buckets | 1 | 2 | $2.50 | $5.00 |
| Syringes, 3 cc | 2 | 4 | $0.15 | $0.60 |
| | | | Total | $5.85 |

## Notes

1) I have found them as low as $1.00 at supermarkets. They must stack and you should have one lid. If you buy 4, you won't need to borrow two for your demonstrations.
2) You will know you have the correct size if they fit tightly inside of your 3/8 in. vinyl tubing.

## Materials You Can Find for Free

| Item | Where to Look/Description | Quantity |
|---|---|---|
| 1 L pop bottle | Garbage. No lid needed. These are for measuring the flow. Use colorless plastic. All the same. | 3 |

| | | |
|---|---|---|
| Pop bottle with lid | Garbage. These are for the tank fittings. Colorless plastic. Lids all the same color. Any size works. | 3 |
| Pop bottle with lid | Garbage. This is for the hole in the tube demo. Colorless plastic. Lids the same color as the others. Not too curvy. Around 500 mL. | 1 |
| Pop bottle caps | Garbage. For flow restrictors. | 2 |
| 1 gal. water jug | Your house, friend's house, garbage. Colorless plastic with flat spots for making the holes. See the picture in the section on making the tank. | 1 |
| Car tire inner tube | Car tire repair shop | 1 |
| Styrofoam or flip-flop foam | Garbage. For the air release valves. Look for buoyant stuff. | 1 |
| Plastic bag | Garbage. Clear and somewhat stretchy. For various things. | 1 |
| Bamboo poles | Around town, in the bush. For supporting the tubes. | 4 |
| Borrowed buckets | Ask a friend. For catching the spill and storing excess water. They won't be damaged and you can return them after the demonstration. | 2 |
| Plastic pitcher | For adding water to the source bucket. You can return it when you are done. | 1 |
| Used coffee grounds | Bottom of the pot. For hole in tube demo. | 2 scoops |
| Washed Sand | Riverbed. For Sediment block demo. Remove the silt so it doesn't make the water dirty. | 1 cup |

## Tools

The cost of the tools has not been figured into the overall cost of the maqueduct. If you don't have them, borrow them from a friend. I included **approximate** prices here so you have an idea of what you are getting into if you decide to buy them.

| Item | See Note # | Cost |
|---|---|---|
| Drill bit, 1/4 | 1 | $1.50 |
| Drill bit, 7/32 | 1 | $1.35 |
| Drill bit, 5/32 | 1 | $0.85 |
| Drill bit, 1/8 | 1 | $0.80 |
| Drill bit, 3/32 | 1 | $0.75 |
| Sharp, pointy knife | | $3.00 |
| Hammer or rock | | $5.00 |
| Scissors | | $2.00 |
| Pointy permanent marker | | $0.75 |
| 10 ft. Measuring Tape | 2 | $1.50 |
| 1/2 in. hole punch | 3 | $3.50 |
| 3/8 in. hole punch | 3 | $3.50 |

| | | |
|---|---|---|
| Triangular file | 4 | $3.00 |
| Brace or hand drill | 5, 9 | $20.00 |
| Hacksaw | 6, 9 | $8.00 |
| 1/4 in chisel | 9 | $2.00 |
| Pliers | 9 | $3.00 |
| 6 in. Half round file | 7, 9 | $5.00 |
| Small Round File | 8, 9 | $2.00 |
| | Total | $67.50 |

**Notes**

1) It might be cheaper to buy a small set. Mine cost $3.00.
2) You will also use this every time you setup the maqueduct.
3) Like what you would use for punching holes in leather. Buying a set might be cheaper than buying these individually.
4) What is commonly called a "lima" and is used to sharpen a machete. Borrow an old one instead of buying a new one. It will be used to ream out holes not to file.
5) If you decide to buy a brace, make sure it will hold the small drill bits. Truper makes one with a universal chuck but it is expensive $36.00. Even with this I still have to wrap tape around the small bits to bulk them up so that the chuck can grip them. If you don't have a brace or a drill, you can just start the hole with a knife (just a little bit). Then hold the drill bit with some pliers and twist it into the plastic. It is a bit slower but it works.
6) You can get away with using a hacksaw blade without the handle. There isn't much cutting to do and plastic is soft.
7) This file is normally used for mild steel. The teeth are bigger than a file used for sharpening a machete but not so big as the teeth on a wood file. It has a flat side and a curved side.
8) Same size teeth as the half round file. This is NOT a chain saw sharpening file, which has small teeth.
9) This tool is not absolutely necessary but helps out. It probably is not worth buying just for this project. Try to borrow it.

## Building the Maqueduct

Building the maqueduct takes some time. It is important to pay attention to the details and there are lots of them. If you make a part and it doesn't work, remake it rather than trying to stop the leaks with glue, etc. A properly made part will work better and last longer. Using a maqueduct that was never completely finished or has parts that aren't built properly is frustrating to say the least. It does no good (and often has negative results) to do a demonstration that doesn't work. It is hard to get the audience to focus on the lesson while water is leaking all over the place. Minds drift while on the fly repairs are made. So, begin by following the guide and testing all of the parts before they are used during a lesson. After you have your basic maqueduct, feel free to experiment and modify the parts. When you make something that works better or allows a new demonstration add it to the guide so that others can benefit from your work. Have fun and remember safety first.

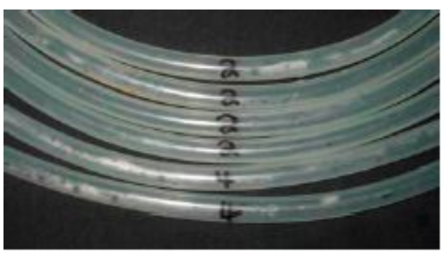
## The Main Lines

### Description

The maqueduct uses two different sizes of tubing, 1/4 inch and 3/8 inch for the main lines. The main lines are both 16 ft. long but are cut into smaller lengths so that they can be rearranged for the various demonstrations (A few extra pieces are used for other jobs as well). **Note:** In this document, all vinyl tubing sizes are named by their inside diameter.

Cut the tubing according to the table below:

| | Number of Pieces | Length (ft.) |
|---|---|---|
| **1/4 inch tubing** | 2 | 4 |
| | 4 | 2 |
| | 3 | 6 |
| **3/8 inch tubing** | 3 | 4 |
| | 2 | 2 |
| | 2 | 1 |
| | 1 | .5 |

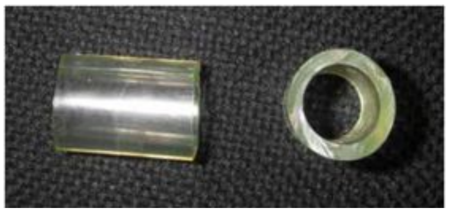


After cutting the tubing to the required lengths, use a permanent marker to write the length of the section in the middle of each section. This will help you to be fast when switching between demonstrations.

## The Couplings

### Description

There are three different couplings used with the maqueduct; 3/8 in. couplings, 1/2 in. to 1/4 in. couplings and 1/4 in. couplings. All of them are made from sections of tubing 1 1/4 in. long. Make sure you have bought the correct tubing or none of this will work. These couplings get misplaced easily. It may be better to make even more than recommended. Find some small containers (e.g. yogurt) to keep them in.



**3/8 couplings:** Cut a piece of 1/2 in. tubing 1 1/4 in long. Make at least 6.

**1/2 to 1/4 couplings:** cut a piece of 3/8 in. tubing 1 1/4 in. long. Make at least 6.

**1/4 couplings:** 1/4 in. tubing fits a bit too loosely into to 3/8 in. tubing to just use 3/8 in tubing as the coupling. If you pound a piece of 3/8 in. tubing into a piece of 1/2 in. tubing the resulting inner diameter is just right. Get the tubing wet and use a little soap to help get the 3/8 in. into the 1/2 in. Trim the edges when you are done to make them look nice and pretty. Make at least 6. **Note:** These are not necessary if the 1/4 in. tubing you have is thick walled. Try using a plain 1/2 to 1/4 in coupling first.

## The Tees

### Description

The tees are made from 1/2 in. high temperature PVC tees and 1/2 in. vinyl tubing. Making them may seem like extra work, but normal tees designed for vinyl tubing are significantly smaller in diameter than the tubing itself. The head loss through these is probably large enough to mess with the some of the demonstrations. Make five tees. **Note**: One of the tees for the maqueduct has an end cap in one side (See right photo below). This one will serve as the end of the line in the distribution system.

**Step 1:** Cut three pieces of 1/2 in. tubing 1.25 in. long. Insert them into the openings of a 1/2 in. CPVC tee. You will probably have to pound them in with a hammer or rock.

**Step 2:** For the tee that will serve as the end of the line, cap one side by putting a piece of plastic bag and a short piece of 3/8 in. tubing into the opening.

## Making Holes in Buckets

### Description

This section is included to offer some help for cutting the holes in the buckets. If it is useful great, if not, use whatever method works for you. I didn’t have a bucket available when I took these photos so I used a coffee cup.

**Step 1:** Lay out the hole using the threaded coupling. The hole should end up just big enough that the coupling fits in snugly.

**Step 2:** Cut the plastic from the hole with a sharp pointy knife. This is a rough cut, give your self some space and you will clean it up later with a file.

**Step 3:** Use a half-round file to clean up the hole. Check every so often to make sure you don’t oversize the hole. Make sure the fit is snug, but not too tight. If the fitting warps the bucket when it is screwed in, it may eventually crack the bucket.

Assembling the through bucket fitting is a little different than one might think.

**Step 4:** Place the gasket around the threaded coupling and then screw it into the hole in bucket.

**Step 5:** Thread the plastic nut onto the coupling inside the bucket with the small side of the nut towards the bucket wall. This is backwards, but it keeps the pressure from warping the wall of the bucket and cracking it.

## The Source

**Description**
The source is made from a bucket. When complete it will hang from a beam or a bamboo pole and is made so that the intake can be attached to it. Water flows from the source through a small hole in the bottom of the bucket. In order make the demonstrations easily repeatable, the flow of water from the source must remain constant. To achieve this, the depth of water in the bucket must be maintained at a relatively constant level. A hole in the side of the bucket allows excess water to escape via alternate route. This overflow also provides a visual cue as to when the source has the correct amount of water. To obtain a different flow, the PVC end cap on the bottom of the bucket is changed for another end cap with a different sized hole.


**Step 1:** Make a hole in the center of the bottom of the bucket for a 1/2 in. male threaded coupling.

**Step 2:** Make a hole in the side of the bucket 4 1/8 in. up from the bottom of the <u>inside</u> of the bucket and a few inches over from where the handle attaches.

**Step 3:** Make a notch in the top edge of the bucket on both sides just behind to one side of where the handle would be if it were vertical. The handle (or modified handle) of the intake bucket will sit in this notch when the maqueduct is in use.

Don’t make the notch too big. It should be easy to remove the intake bucket and we don’t want to weaken the lip of the source bucket too much.

**Step 4:** Install the 1/2 in. male threaded couplings with the plastic nuts and gaskets into each hole as shown in the “Making Holes in Buckets” section.

**Step 5:** Cut 2 pieces of 1/2 in. PVC just long enough that they can be fully inserted into the fittings (The one in the photo is too long). Glue them into the threaded couplings sticking out of each hole. Add a 1/2 elbow to the fitting on the side of the bucket (no glue).

**Step 6:** Insert a 1.75 in. long piece of 5/8 in. tubing into the elbow. Insert a 1/4 in. coupling into this to allow tubes to be attached to the overflow.


**Step 7:** In the center of each of the 1/2 in. end caps, drill the following holes: 1/4, 7/32, 5/32 and 1/8 in. These are put on the PVC sticking out of the bottom of the bucket to regulate flow.

**Step 8:** Hang the source bucket from something and fill it with water to verify the following flows:

| Hole Size | Flow (L/min) |
|---|---|
| 1/4 | 3 |
| 7/32 | 2 |
| 5/32 | 1 |
| 1/8 | .62 |

**Step 9:** Some of the holes will have to be adjusted a bit in order to get the correct flow. The stem of a file works well for reaming the holes out. Do this a little at a time and test frequently so you don't over shoot the mark. If you do overshoot, put a bit of PVC glue on the hole; let it dry thoroughly and then try again.

## The Intake Works

**Description**

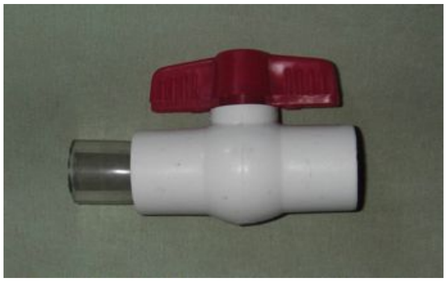
The intake is also made from a bucket. When complete it will hang the source bucket. It will capture the water from the source and direct it into the outlet. When water is entering the intake faster that it can leave through the outlet, the water begins to exit through the overflow. Keep in mind that the intake will have a small storage capacity and may at times deliver more flow than the source. There is no cleanout in the maqueduct but one could easily be added, if desired, with a little modification to the locations of the holes.



**Step 1:** Make a hole in the side of the bucket 5/8 in. up from the bottom of the inside of the bucket and in the middlebetween where the handles attach (see photo above). The fit should be snug for a 1/2 in. male threaded coupling.

**Step 2:** Make an identical hole 1 7/8 in. up from the bottom of the inside of the bucket and a little to the side of the other. Make sure there is sufficient space between the two holes for the nut that will be used to attach the threaded couplings.

**Step 3:** Attach the 1/2 in. threaded couplings to the bucket and cut two more sections of 1/2 in. PVC (the same size as with the source bucket) to glue into the couplings. Attach (but don't glue) a 1/2 in. ball valve to the outlet and an elbow to the overflow.



**Step 4:** Insert a 1.75 in. long piece of 5/8 in. vinyl tubing into both the outlet valve and the elbow. During demonstrations 1/2 in. and then 3/8 in. tubing can be inserted into the 5/8 in. tubing.


**Step 5:** A slot must be cut into the intake bucket so that there is a space for the over flow tube of the source bucket when the two buckets are coupled. When the two buckets are coupled, the end cap on the bottom of the source bucket should be about 3 in. above the bottom of the intake bucket. This keeps the end cap on the source bucket from entering the water in the intake bucket. Also the slot should be cut such that the handle of the intake bucket is lined up vertically with the handle of the source bucket.

To get all of this lined up properly, you could be clever and make some measurements and do a little math. Alternatively, remove the overflow fittings from the source bucket but leave the end cap in place. Place a 3 in. thick object (block of wood, stack of paper etc.) in the bottom of the intake bucket. Put the source bucket into the intake bucket and line the handles up. With a flashlight you should be able to see where the overflow hole is in the source bucket. Mark its location and lay out the lines needed to cut the slot. Make sure to leave a rounded bottom on the slot so that it doesn't tend to crack. Cut it out with a hacksaw and smooth out the curve with a half round file.

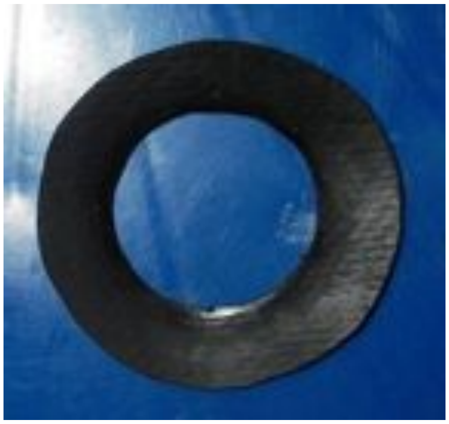
**Step 6:** Check to see that everything fits together. If the handle of the intake bucket does not fit into the notch that was cut in the source bucket, you will have to modify the handle so that it does. Possibly replace the handle of the bucket with 12 or 14 gauge galvanized wire. (Ignore the brass barbs in the photo. These were from an earlier design.)

## The Tank

### Description

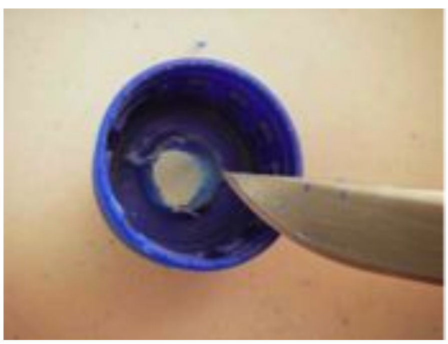
The tank has a capacity of 3 L and can be very useful for educating about tank sizes and what happens when people leave their faucets running. It is made from a 1 gal. clear plastic jug. It too does not have a cleanout, but one could be easily added.

**Step 1:** Cut the openings off of three pop bottles with a hacksaw and clean them up with a file so that they look nice. Remove the little ring of colored plastic that is located below the cap (It is the same color as the cap and is separates from the cap when the bottle is first opened). Try not to damage it because it will be used later. Remove the bump of plastic located just past the threads (See arrow in photo). I used a 1/4 in. chisel for this but you could probably do it with a file or a knife. Take your time and don't cut your fingers.



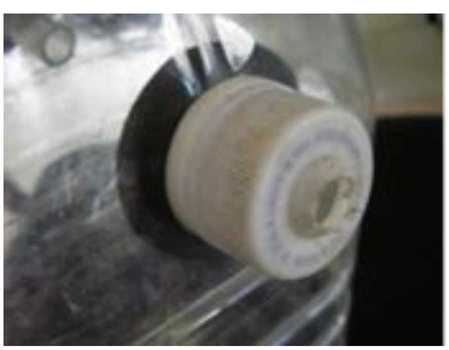
**Step 2:** Make 3 rubber gaskets for the bottlenecks out of car tire inner tube.  Use a compass or round objects to layout your cuts. Cut them with scissors. Make them look nice and make sure the inner hole fits snuggly around the bottlenecks.

**Step 3:** Make holes in the center of the bottle caps. Begin by rotating a sharp pointy knife back and forth, working from the inside of the cap. When the hole is opened a bit, use a triangular file to open up the hole in the same way. Start with the stem of the file and when the hole is big enough use the triangular side to open it further. Don't force the file into the hole you are making as this will tear the burr. Periodically check with a piece of 3/8 in. tubing to make sure the hole isn't oversized. The fit should be nice and snug.



**Step 4:** Trim off the burr on the inside of the bottle but not on the outside. I used a 1/4 in. chisel to do this but a sharp knife works ok (a bit awkward).

**Step 5:** Clean up but don't cut off the burr on the outside of the cap with scissors and test that a 3/8 in. vinyl tube will fit into it. Look close and you will see that the cap on the right looks nicer. Make it look professional and people will treat you like a professional.



**Step 7:** Place the jug on a level surface and fill it with 3 L of water. Mark the locations for the inlet and over flow holes so that they are just above the surface of the water. Then fill the jug up to a location above the inlet and outlet holes and draw a line around the jug. Cut the top off with scissors. You can also use the same method to locate volume markings on the tank 1, 2 and 3 L.

**Step 8:** Mark and cut 3 holes in the jug the same size as the core diameter of the bottle threads. Be careful cutting because this type of plastic tears easily. Use a sharp knife or scissors. When you are done the bottle parts should be able to screw into the holes without stressing the plastic on the jug.

**Step 9:** Now install the fittings into the holes. Note that the gasket is inside the jug. Make sure to replace the little ring of plastic below the cap. As you are tightening down the cap make sure that it is centered on the ring.

**Step 10:** Bend up some galvanized wire to make the hanger for the tank. The loops should grip the fittings on the tank snuggly so that they don't fall off. I'd recommend a double loop.

**Step 11:** Make a hook for attaching the tank to the bamboo poles. Double up your wire or use a piece of 12 gauge wire because the tank gets heavy when it is full.

**Step 12:** Cut a two pieces of 3/8 in. tube 3 in. long to install in the inlet and the outlet holes and a few pieces of 1/2 in. tube to serve as couplers (1.25 in. long). See photo at beginning of section.

**Step 12:** Put the tank together and check for leaks. If it leaks, identify the problem and redo it. Don't load it up with glue. It doesn't look nice and will likely start leaking later on.

## The Hole in the Line

### Description

The hole in the line is used for demonstrations that highlight some of the dangers of having tubes under negative pressure. These demonstrations have always been surprising, convincing and of much interest during seminars. It is definitely worth including in your maqueduct. Make sure that the plastic bottle is not colored as it makes it much harder to see through the plastic.

**Step 1:** Make a hole in a pop bottle cap the same as was done for the tank. There is no need to do any modifications to the neck of the bottle.

**Step 2:** In the bottom of the bottle, make a hole in the same manner as is done with the bottle caps; the only difference is that the burr will be on the inside.

**Step 3:** Cut an opening into the side of the bottle. This will give you access for threading the tube through the holes and will be where you put the coffee grounds in. Try not to make the hole too large. If the hole is too large, it is hard to keep water from spilling out and the bottle loses too much of its strength.

**Step 4:** Cut a section of 3/8 in. tube to the appropriate length (not too long) and use a sharp knife to make a **small** hole in the tube. If the hole is too big, it will leak very quickly and will make it necessary to rush the demonstration or deal with water spillage.

**Step 5:** Feed the section of tubing through the bottle starting at the bottom and out the open top.

Push the tubing through the cap and then screw the cap onto the bottle. Arrange the tube so that it lies along the bottom of the bottle with the hole on top.

**Step 6:** Add a few 1/2 in. pieces to serve as couplings for the hole in the line. Tie a string onto the 3/8 in. tube and make a loop in the middle. Use a paperclip as a hanger for the hole in the line.

## The Automatic Air Release Valves

### Description

The automatic air release valves are included for demonstrations involving air-blocks. They can be a bit temperamental and you may have to play with them a bit to get them working right. The main difficulties are that they are very small so the floating ball just isn't buoyant enough to make a tight seal every time and the pressures are low enough that the ball isn't forced upwards very hard. Make 2 of them.

**Step 1:** Cut the following pieces of tubing:

| Tubing Diameter (in.) | Length (in.) |
|---|---|
| 3/8 | 1 |
| 1/2 | 2 1/4 |
| 5/8 | 3/8 |

**Step 2:** With a razor blade cut down a piece of Styrofoam or flip-flop foam so that it fits smoothly inside of the 1/2 in. tubing. Then stick a ball earring into the top of the foam. Styrofoam is hard to cut cleanly but is more buoyant.

**Step 3:** Place a piece of plastic bag over the 1/2 in. tubing and secure it into place with the ring. Heat up the stem of the earring or a paper clip over a flame and use it to melt a small hole in the middle bag. Then push the Styrofoam-earring assembly up into the plastic bag so that the bag molds to the earring. Don't push too hard or the hole will tear. Put the 3/8 in. piece of tubing on and check for air tightness by blowing through the valve. When the earring covers the hole, no air should get through. If there is a leak repeat the process with a new piece of bag until it is airtight. This might take several tries. The hole must be clean and the earring must seat well for it to work.

## The Faucets

### Description

The faucets are made from syringes and work fairly well. I have looked for a cheap, small, off the shelf valve that has low head loss but have not found one. If you find one, add info on how to get them to the manual. The valves are definitely recommended over a simple plug, because the plugs get lost and water gets spilled all over the place (that's how I started). The valves are used for demonstrations involving the distribution system as well as in demonstrations of manual air release valves. Make three of them.

**Step 1:** Remove the stem inside of the tip of the syringe that the needle attaches to. And ream it out so that the hole is the same diameter as the syringe body. A small drill bit and a round file work well for this.

**Step 2:** Cut a hole in the syringe where the water will exit. This hole will be on the bottom side of the syringe and should not be longer than 1/2 in. The hole should also be oblong, lined up with the syringe, so that there is still enough of the syringe body to guide the plunger. A sharp knife or a round file work well for this.

**Step 3:** Cut a piece of 1/2 in tubing 1 1/4 in. long and use a 3/8 in hole punch to make a hole through the tube perpendicular to the tube. Slide the syringe through this hole so that the hole in the syringe is completely inside the 1/2 in. tubing pointed down.

**Step 4:** Cut two pieces of 3/8 in. tubing 1 1/4 in. long and attach them to the syringe as shown.

**Step 5:** Cut a third piece of 3/8 tubing 3/8 in. long and push it into the top of the 1/2 in. tubing with a piece of plastic bag. This will keep water from shooting out of the top of the valve.

## The Flow Reducers

### Description

The flow reducers are small disks of plastic with a small hole in the middle that can be installed in the service lines (lines that go to the faucets) or in the main line. They are used to show how a distribution system can be balanced so that users don't lose pressure when other users open their taps. They can also be used to demonstrate a method for keeping the HGL of the main line positive by restricting flow at the outlet into the tank. Make two.

**Step 1:** Drill a 3/32 in. hole through the center.

**Step 2:** Use a 1/2 in. hole punch to punch out a disk with the hole in the center. Then remove the rubbery coating what was the inside.

**Note:** These disks can also be made out of flattened PVC. No hole punch? Try a saw and file.

**Step 3:** Cut 2 pieces of 3/8 in. tubing and 1 piece of 1/2 in. tubing 1 1/4 in. long. Set up the flow reducer as shown in the photo.

## The Air Vent

### Description

The air vent is used to prevent air-blocks at the outlet of the intake works. It is also used for adding sand during the sediment block demonstration. It is made from a small bottle with the bottom cut off so that the opening is big enough to get sand into it. To make the air vent, simply but the bottom off of the bottle and then make a hole in the cap as described in the section for making the tank. Put a short section of 3/8 in. tubing into the hole so that it can be connected to a tee.

## The Rubber Straps

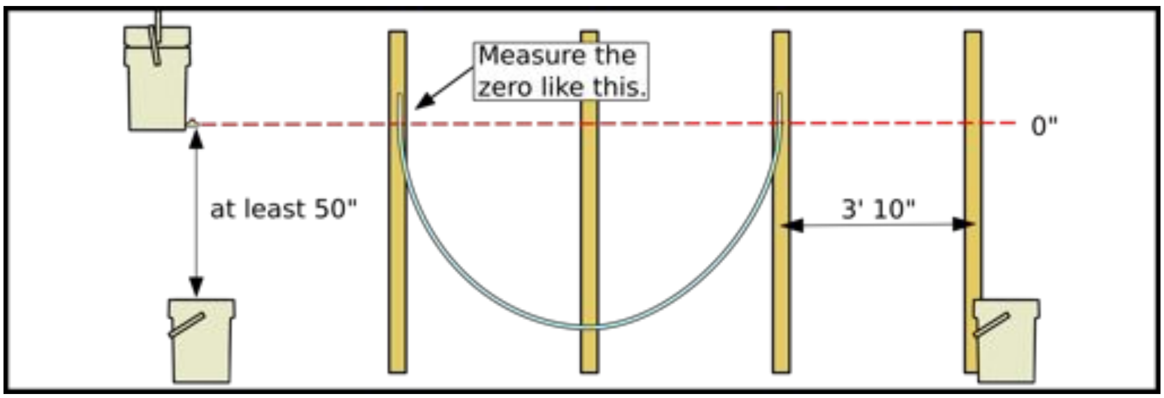
### Description

Straps cut from car tire inner tube work well for tying the tubing to the bamboo poles at the proper heights. Cut the straps about 3/8 in. wide and 1 1/2 ft long. Lay them out with a ruler and cut them evenly. If there are notches or skinny spots they will tend to break. Make 8 of them, which will be more than enough.

# Setup

## Location

The location is important when setting up the maqueduct, and the setup often changes a bit due to the circumstances. Pick a place that can get wet. Some water always gets spilled. Bare dirt can get kind of messy if lots of water gets spilled. Grass or concrete are better. You will need a level space that at a minimum is 18 feet wide and 8 feet high to set up the maqueduct. You will also need a means for hanging the source bucket and setting up the posts. The posts can often be tied to a beam under the eaves of a building or set in holes in the ground. The source can be tied to a similar beam, or hung from ladder or post. Make sure that it is strong enough to hold up the buckets when they are filled to their working levels.




## Hanging the Source

Hang the source bucket so that, when the intake works bucket is connected, the outlet is at least 50 inches above the rim of any bucket you will use for collecting water as it comes out the end of the line or overflow.

## Setting up the Posts

You will need 4 straight posts. Bamboo works very well for this. Cut them to the appropriate length, which depends on how you will set them up. Measure 3’ 10” over from the outlet and tie or set a post in place. Do the same with 3 more posts so that they are all 3’ 10” apart. (Yes, not 4 ft. because the tubes always go down at an angle). Another way to set this up is to join the 3/8 in. tubing into a 16 ft. tube with couplings located every 4 feet. Stretch it out diagonally from the outlet of the intake works to the far end where the last pole will be. The other poles should be placed where the couplings in the 3/8 in. tube end up.

## Marking the Posts

Join a bunch of 3/8 in. tubes together to make a 16-foot long tube. Connect it to the outlet and, while holding the lose end of the tube higher than the outlet, fill the source with water until water overflows from the intake works.  Move the tube to each post and mark the height to which the water rises. Use a permanent marker so that the ink doesn't run when it gets wet and so the measurements are easy for the audience to see. This is the static water level. For the posts that are farther away from the source, it can be easier to disconnect the tube and use it to transfer the static level from the posts that have already been marked (see picture above).

Go through the setups for all of the demonstrations you plan to do and mark the posts with the measurements you will need. This way you can more quickly change from one setup to the next. All the measurements are measured down from the zero.

## Getting Ready to Teach

Fill your buckets and setup a table with all the parts you will need. Keep all of the little parts as organized as well you can. Use yogurt cups or something similar to contain and separate the various types of couplings. The attention of the audience drifts quickly in the spare time while switching between demonstrations. If you work with a partner, one person can continue teaching while the other is changing between setups. The person who is not teaching should try keep the maqueduct organized and ready. Good planning and communication helps a bunch.

# Demonstrations and Lesson Ideas

The following demonstrations are here to help you get started teaching with the maqueduct. Don't let the suggestions cramp your style. There are millions of different ways to set it up. Often a question from a member of the audience prompts a new setup on the fly. Take what is here and modify it to suit your purposes. If you come up with new demonstrations or improvements of those included here, please send me what you have come up with so that the guide can be improved. If you make new parts for your demonstrations, send them as well. Finally, it is strongly recommended that you practice your demonstrations numerous times before attempting to use the maqueduct in front of an audience.

The demonstration section does not contain much in the way of explanation. If you are not comfortable with the topics, look elsewhere for understanding. I would recommend *Gravity Flow Water Systems* by Thomas Jordan and *Air in Water Pipes* by Gilles Corcos as starting places. The board work and talking points sections are included as suggestions not requirements. The maqueduct can be used to teach a wide range of audiences. Some of the talking points may be too advanced or basic for the purposes of the lesson. Pick and choose.

# The Source

**Objectives**

- Practice measuring flow and understand its meaning.
- Convey the idea that the flow at the source sets the limit on the amount of water moving through the aqueduct.

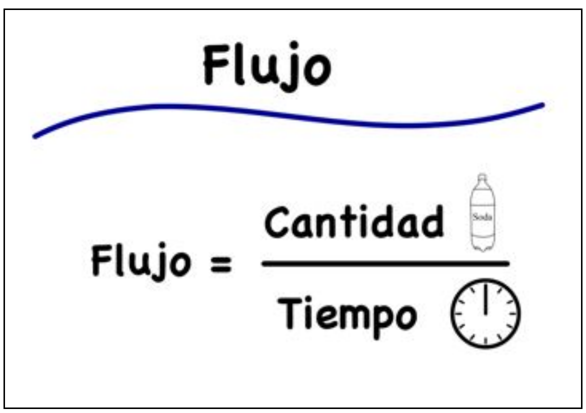
**Setup**

Simply have the source hanging in its place.

**Doing the Demonstration**

1) With the group, discuss the importance of the source, the meaning of flow and how to measure it.
2) Introduce the group to the maqueduct source and explain what it represents. Possibly point out that the overflow is there just to make it work right.
3) Determine how many liters come out of the source in one minute. Have one participant fill liter bottles, while another participant times one minute with a watch or cell phone that can time to the second. Do this for both the 1 L/min and 2 L/min end caps.
4) Discuss the results.

**Board Work**




**Talking Points**

- What type of source do they have?
- What is the water like (cloudy, clear, flavor)?
- Is it always the same or does it change?
- Has it been tested? For what?
- Do they know the flow of their sources? Max? Min?
- How could one measure the flow with a bucket?
- Do bigger tubes and tanks always mean more water? (You can't get more water out than the source produces.)

**Tips**

- Always measure the flow for a set time of 1 minute. Even if some of the group can tell that filling a 1 L bottle in 30 seconds means the flow is 2 L/min, those in the group that struggle with math will be left behind.
- Draw attention to the difference between flow and pressure. Many people use them interchangeably.

# The Intake Works

**Objectives**

- To understand the various parts and functions of the intake works.
- To understand what it means when the intake works is overflowing.

**Setup**

Put the intake works in place with the source set to flow at 2 L/min.

**Doing the Demonstration**

1) Discuss the importance of the intake works. (See the talking points.)
2) Ask what it means when the intake works is overflowing. Why is it good to have an overflow? You could show the overflow in action by barely opening the outlet and filling the source until the intake works overflows while it is also losing water from the outlet.

**Talking Points**

- Go over the parts of the intake works. Point out that there should also be a cleanout.
- Why is the overflow important? Back pressure on springs, erosion control for surface water intakes.
- What is the maximum flow that can be expected out of the intake works (assuming that the intake is not also used for storage)? Could using bigger tubes get more water out of it?

**Tips**

- Be sure to point out when the intake overflows during the following demonstrations. When it isn't over flowing note if the tubes are partially filled with air.

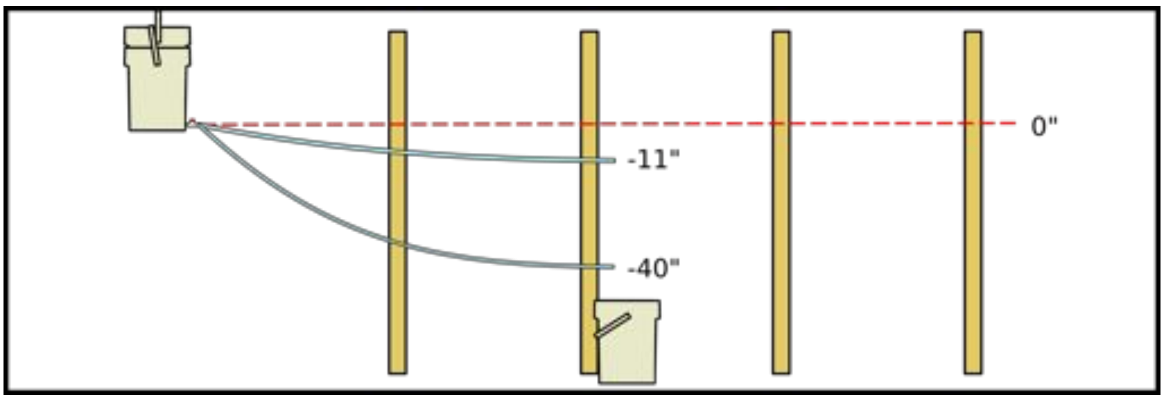
# Pipe Basics: Difference in Height

**Objectives**

- Show how the change in height affects the flow.

**Setup**

| | |
|---|---|
| **Flow at Source:** | 2 L/min. |
| **Tubing Size** | 1/4 in. |
| **Tubing Length** | 8 ft. |




**Doing the Demonstration**

1) Begin with the following demonstration: Have a participant place their hand on a table. Ask permission to drop a rock (appropriately sized) onto their hand from 2 in. above. No problem. Now raise the rock up 4 feet and ask permission (don't drop it). Now place the rock 2 in above the table, but have the person place their hand on the ground and ask permission to drop the rock (don't do it). Discuss the results and the importance of change in elevation.
2) Draw a picture of the situation with a source and two houses at different elevations. Have the audience predict who will have a higher flow at their tap.
3) Once the audience has made their predictions, measure the flow at both -10 in. and -48 in. using participants to do the measurements.
4) Write up the rule. More height = Higher flow.

**Board Work**


**Talking Points**

- Did the intake works overflow? Why?
- Are the height differences between the source, tank and houses easy or hard/impossible to change?
- Where does the energy required to move the water come from?

**Tips**

- This is generally the easiest of the three for the audience to understand.

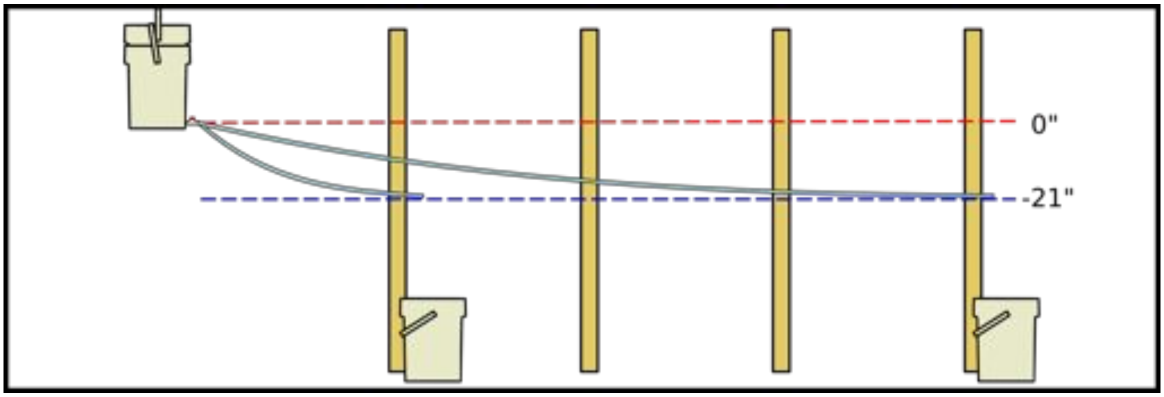
# Pipe Basics: Difference in Length

**Objectives**

- Show how change in tube length affects the flow.

**Setup**

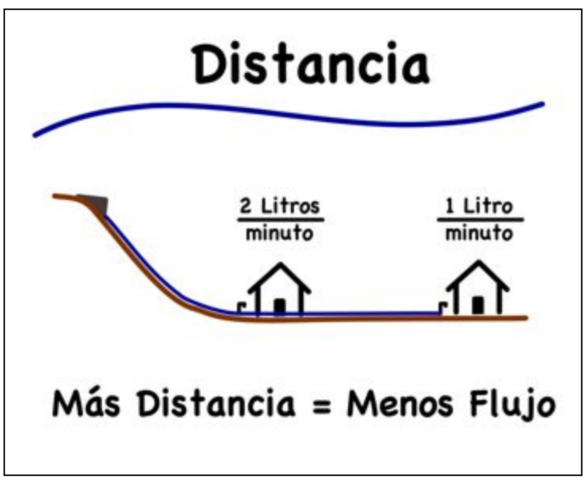
| | |
|---|---|
| **Flow at Source:** | 2 L/min. |
| **Tubing Size** | 1/4 in. |
| **Tubing Length** | 4 ft. and 8 ft. |




**Doing the Demonstration**

1) Draw a picture of the situation with a source and two houses at different distances. Have the audience predict who will have a higher flow at their tap.
2) Once the audience has made their predictions, measure the flow at both 4 ft. and 16 ft. using participants to do the measurements.
3) Write up the rule: Greater Distance = Lower Flow.

**Board Work**



**Talking Points**

- Discuss how the water touches all the sides of the tube. Imagine trying to run through a tunnel while scraping up against the walls. Which would require more energy: a short tunnel or a long tunnel? How much energy did each of the situations have available?

**Tips**

- Members of the audience can try blowing through short and long sections of 1/4 in. tubing to actually feel the difference in the resistance to flow.
- This is the most difficult of the three for the audience to understand. Often the audience will think that the longer tube will have the higher flow because it is at the end of the line. For real aqueducts the end of the line is often lower then the others. Point this out.

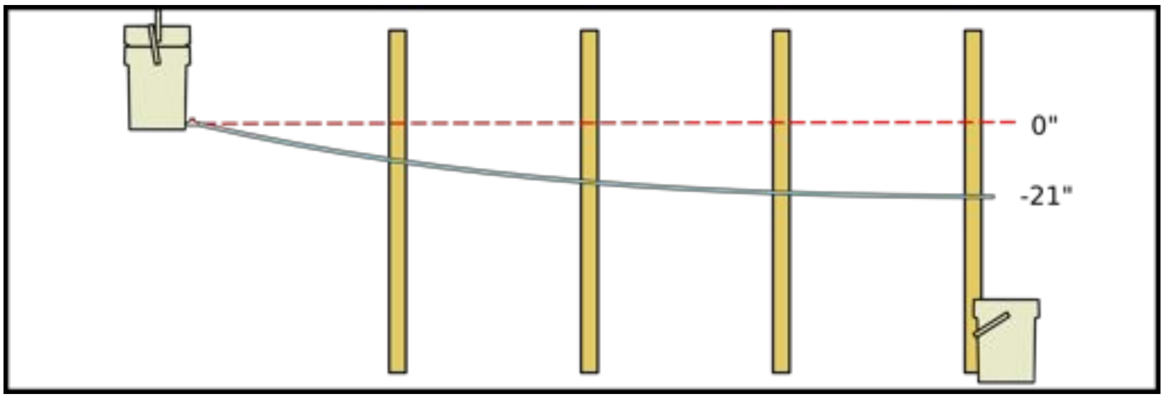
# Pipe Basics: Difference in Diameter

**Objectives**

- Show how pipe diameter affects flow.

**Setup**

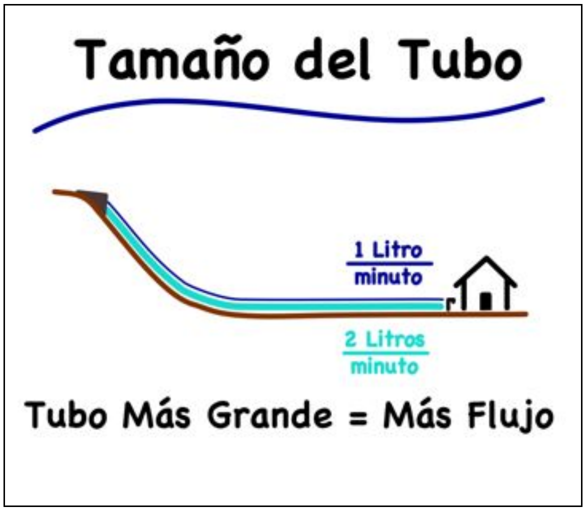
| | |
|---|---|
| **Flow at Source:** | 2 L/min. |
| **Tubing Size** | 1/4 in. and 3/8 in. |
| **Tubing Length** | 16 ft. |




**Doing the Demonstration**

1) Draw a picture of the situation with a source and two differently sized pipelines going to the same house. Have the audience predict which one will have a higher flow at the tap.
2) Once the audience has made their predictions, measure the flow for both of the tube sizes using participants to do the measurements. **Note:** Do not begin measuring the flow with the 3/8 in tube until there is air in the tube. The natural flow for the 3/8 in. tube with this setup is higher than 2 L/min. Starting early will result in a higher flow as the intake works may act like a tank. This may confuse the audience.
3) Point out the air in the tubes. Hmmm, what does this mean???
4) Write up the rule: Bigger Tube Diameter = Higher Flow.

**Board Work**




**Talking Points**

- Extend the analogy of running through a tunnel. Which tunnel would be easier a small one or a big one?
- Why was there air in the 3/8 in. tube? Could a bigger tube have carried more water in this situation? Are bigger tubes always better? Discuss cost, HGL during open channel flow, etc.

**Tips**

- You just measured the flow for the 1/4 in. tube in the previous demonstration. You may be able to save some time by reminding your audience of this and skipping the first measurement.

# Visualizing Static Pressure

# and

# The Hydraulic Grade Line

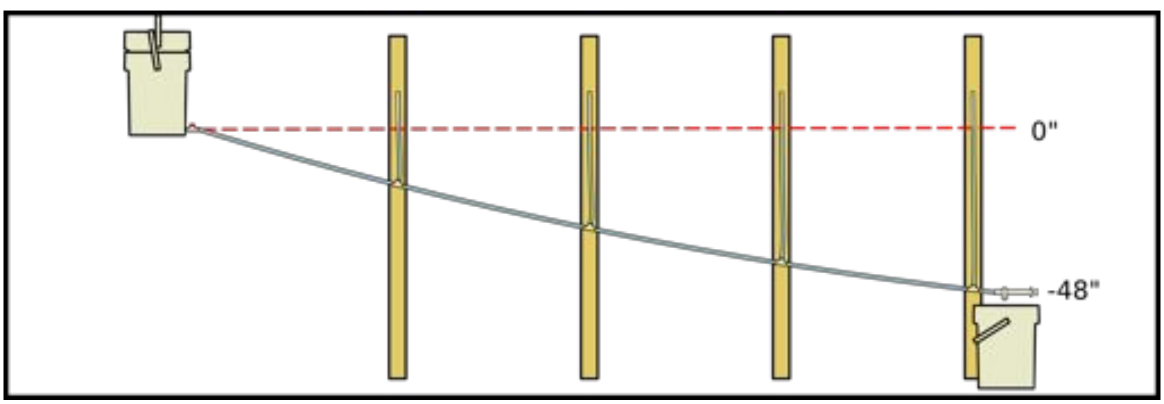
**Objectives**

- Show what is meant by static pressure
- Show how HGL changes with increasing flow.
- Show how HGL is related to tube length.
- Show how HGL changes with tube size.

**Setup**

| | |
|---|---|
| **Flow at Source:** | 3 L/min. |
| **Tubing Size** | 1/4 in. and 3/8 in. |

Use 1/4 in tubing for the vertical parts and 3/8 in for the main line. It is necessary to bleed the air out of the system before beginning the demo. Do this by beginning at the lower end and lowering the vertical tube and draining water out of it until there is no air. Then tie it back into position. Place a valve at the end of the line so that you can control the flow.




**Other Materials**

- Brightly colored string

**Doing the Demonstration**

1) Begin by discussing pressure, and how pressure can be measured with a column of water. Depending on your audience, there may be no need to get too technical here with definitions and all that. Just develop a feeling for what pressure is. Maybe rig something up to see how tall of a column a person can support with their breath. Draw a picture of a U-tube and relate it to the setup of the

maqueduct for this demonstration under static conditions. It is like there is a bunch of U-tubes linked together.

2) Have three participants hold an easy-to-see string from the source to the final vertical tube. Their job is to keep the string even with the water in the top of the tubes. Make sure everyone sees the static pressure line.
3) Crack the valve open and have the participants move their string to keep it lined up with the top of the water in the columns. Everyone should see the line now slant down but remain straight. Open the water further and see what happens.
4) Discuss these results. Why does the water level change? What does it mean that that HGL was a straight line in this situation? Talk about head loss per foot of tube. For advanced audiences, introduce head loss tables at this point.
5) In order to introduce combinations of tube sizes and fitting the HGL to the terrain, do a demonstration using different tube sizes. Change out the last 8 feet of 3/8 in. tubing for 1/4 in. tubing. Run the demo again with the string and discuss the new results. What was the difference in the HGL over the two different sections?

**Talking Points**

- What is HGL?
- How can it be calculated?
- What is natural flow?
- What is residual head?
- How does one decide on what tube size to use?

**Tips**

- Be careful not to confuse your audience with this demo. Know your audience's abilities and teach accordingly.
- This demo can be used to show the concept of head loss and HGL but it could also be used to practice calculations if the audience had access to the correct head loss charts.

# Hole in the Main Line

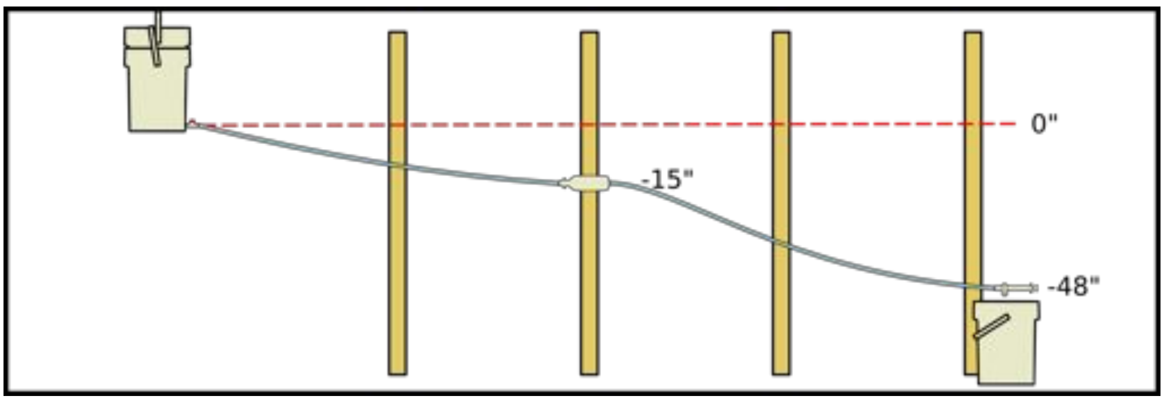
**Objectives**

- Demonstrate the potentially dangerous consequences of negative HGL.

**Setup**

| | |
|---|---|
| **Flow at Source:** | 2 L/min. |
| **Tubing Size** | 3/8 in. |

Place the hole in the line bottle 15 in. down on the second post. Include a valve at the end of the line.




**Other Materials**

- Used coffee grounds

**Doing the Demonstration**

1) Once the demo is ready, discuss the topography of the example. Also, talk with the audience about holes in the main line. Do they happen? Where? What kinds of contaminants are encountered in the land surrounding the main line?
2) Add the coffee grounds to the bottle explaining that they could represent a variety of things we don't want in our water (like cow poop).
3) Have the audience gather around the bottle and start up the system with the main line closed so that a puddle forms in the bottle.
4) Open the valve at the end of the line and have the audience observe what is happening to the puddle. Collect a sample of the water coming out the main line so that the audience can observe it. Point out that when the puddle dries up air is drawn into the tube. Listen to the sucking sound. Has anyone ever heard that in their system before?
5) Discuss what could be done to fix the system so that it never has negative HGL. Then do it. Limit the flow with the valve, or replace the second half of the line with a 1/4 in. tube. You could also make a flow reducer disk and install it in the end of the line. You will have to experiment to find a good size.

**Talking Points**

- Why is it important to keep the tubes in good repair?
- What are the causes of holes?
- Do we always know when there is a hole in the line?
- Why did the puddle get sucked into the tube? What is negative HGL?
- The importance of a good survey and proper design.
- Why is it not always good to have bigger tubes?

**Tips**

- This is usually a pretty powerful and surprising demo. Great for convincing community members why they may not need big tubes all the way to the tank.
- This could be easily combined with the HGL demo to show what happens with the hole when it is above and below the HGL. Just remove one of the vertical tubes and add the hole in the line is its place.

# Distribution System Basics

The distribution system setup can be used to demonstrate many different issues. Not all are mentioned here. Tailor this demo to the audience. You can keep it simple or, you can get a bit more complicated and calculate the HGL with and without the flow reducers.

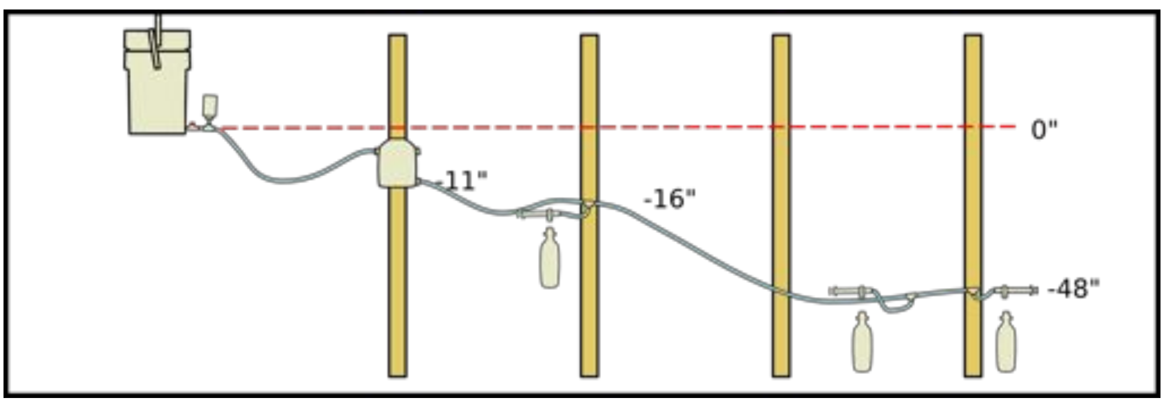
**Objectives**

- Show a basic distribution system.
- Show potential problems of an “unbalanced” distribution system.
- Show the use of flow reducers to “balance” a distribution system.

**Setup**

| | |
|---|---|
| **Flow at Source:** | 1 L/min. |
| **Tubing Size** | 3/8 in. |

Hang the tank so that its outlet is at -11 in. The service lines are made with a tee, a small piece of 3/8 in. tubing, a 2 foot piece of 1/4 in. tubing, and a valve. Make sure that the tee at the end of the line has a cap in the unused hole so that the water doesn’t just leak out. Installing the vent just after the outlet of the intake works will prevent a potential air-block from forming (or you can just lift the tube up to get it going). The lengths of 3/8 in tubing that are needed are, beginning from the source: 4, 4, 7 and 1 feet.




**Other Materials**

- 3 identical 1 liter pop bottles.
- Used coffee grounds
- Hole in the line setup.

**Doing the Demonstration**

1) Discuss the setup with the audience. Point out the parts of the tank and that the houses are located at different levels. Have three participants come up to play the role of users. Explain that the users must keep their faucets at the same level as

their junction. (This is how it is in real life. You can't just put your house into a 20-foot deep hole to get more flow.)

2) Start the maqueduct and fill the tank. One at a time, beginning at the top of the line, have the participants open their faucets so that everyone can see that the faucets are working. It is common for more than one faucet at a time to be open, so have the upper user open their faucet followed by the other users. Note what happens to the upper user when the lower users have their faucets on.
3) Discuss what is happening. Have any of the participants observed this in their communities? **Note:** Losing water when the tank is full is very different from losing water when the tank is empty (see demonstration: Tank Basics).
4) Show what happens when there is a hole in the line near the house of the upper user by replacing their service line with the hole in the tube. Start up the maqueduct and add some coffee grounds to the hole in the line. After the bottle has filled up a bit with water have the lower users open their faucets. Note the quality of the water they are now receiving. Point out that a poorly designed distribution system is bad for everyone not just the users that lose water.
5) Discuss possible solutions for this situation (tube sizing or flow reducers). Then fix the system by installing flow reducers into the lower users lines and retest the system. You could also try installing a 1/4 in. main line after the upper user to fix the problem.

**Talking Points**

- Importance of proper survey and design.
- How could flow reducers be made/installed in a real system?
- How many users have their faucets open at any one time?
- Is the HGL always the same?
- Importance of having water in the tank.
- What are the flows in the different runs of tubing?

**Tips**

- This could be used for both beginning and advanced groups. Choose your talking points appropriately.
- Advanced groups could use this setup to help understand or even practice calculations using tabulated design as described in *Gravity Flow Water Systems* by Thomas Jordan.

# Tank Basics

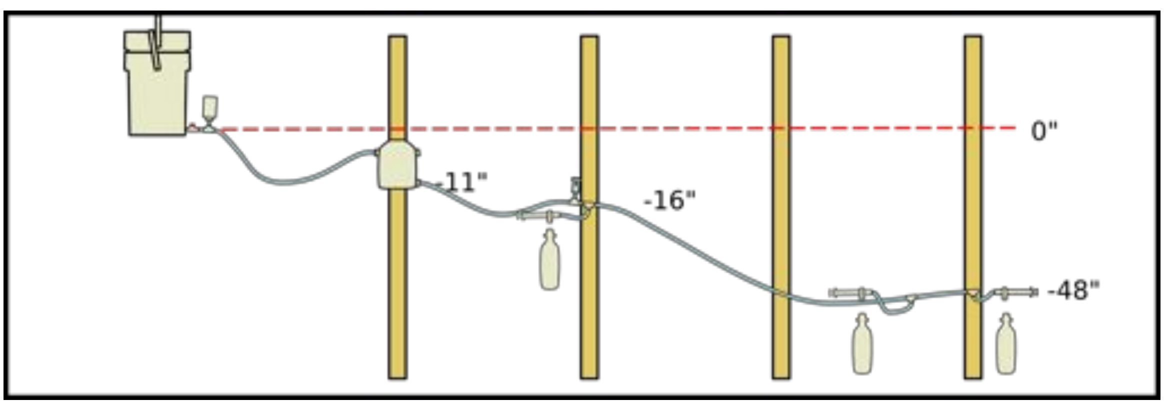
**Objectives**
- Demonstrate how a tank functions.
- Demonstrate the importance of keeping faucets turned off when not in use.

**Setup**

**Note:** The setup is the same as for Distribution System Basics but with the flow reducers in place.

| | |
|---|---|
| **Flow at Source:** | 1 L/min. |
| **Tubing Size** | 3/8 in. |

Hang the tank so that its outlet is at -11 in. The service lines are made with a tee, a small piece of 3/8 in. tubing, a 2 foot piece of 1/4 in. tubing, and a valve. The two lower service lines should have flow reducers installed as well. Make sure that the tee at the end of the line has a cap in the unused hole so that the water doesn't just leak out. Installing the vent just after the outlet of the intake works will prevent a potential air-block from forming (or you can just lift the tube up to get it going). Install and automatic air release valve just above the first user to keep air-blocks from forming in the distribution system. The lengths of 3/8 in tubing that are needed are, beginning from the source: 4, 4, 7 and 1 feet.




**Other Materials**
- 3 identical 1 liter pop bottles.

**Doing the Demonstration**
1) Discuss when people use water and when they don't. When would one expect the tank to be full or nearly empty? In this demonstration three participants will be a "community" and will go through 2 day and night cycles (24 hours will be equivalent to 6 minutes). During this time all can observe how the level in the tank changes and what happens when someone leaves their faucet on.

2) Begin at the beginning of night with the tank empty. Let the tank fill for 3 minutes at which time it should be full.
3) Good morning…(at three minutes) Each participant needs 1 L of water for breakfast and bathing. Note the water levels. Close taps and go to the farm.
4) At five minutes, the participants return from farm and fetch 1 L of water for their dinner and cloths washing needs. Note at this point the tank should be basically empty.
5) All close their taps except for the participant at the end of the line. Good night…
6) For three minutes the tank doesn't fill.
7) Good morning… Participants try to get their needed 1 L of water. Note who gets it in their first minute.
8) Discuss the results

**Talking Points**

- Importance of community cooperation, education and regulations regarding water use and misuse.
- Would a bigger tank have made a difference?
- How is tank size determined?
- With more advanced groups, relate the demonstration to the math used to determine tank size.
- Under what conditions is a tank unnecessary?

**Tips**

- Air-blocks can wreck this demonstration. Practice it first and make sure it works.
- When starting up the maqueduct, have the main line before the tank disconnected from the tank. Let it flow until the output stabilizes (1 L/min). Other wise the first night the tank might fill unexpectedly fast or slow.

# Air-Bocks

**Objectives**

- Show how air-blocks form and how to resolve them.

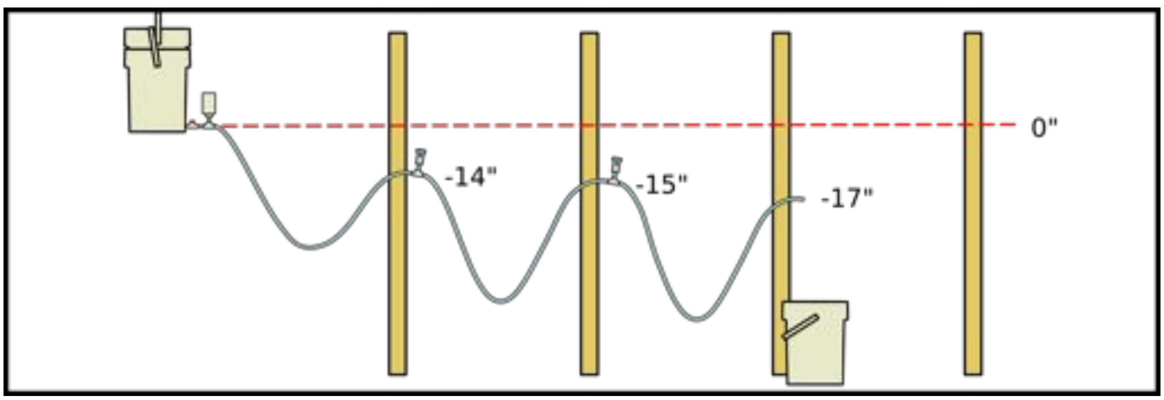
**Setup**

| | |
|---|---|
| **Flow at Source:** | 1 L/min. |
| **Tubing Size** | 3/8 in. and 1/4 in. |

The tubing lengths are as follows:

| | |
|---|---|
| Between the tank and the first post | 5 ft. |
| Between the first post and the second post | 6 ft. |
| Between the second post and the third post | 4 ft. of 3/8 in and 4 ft. of 1/4 in. |

Begin the demonstration without the vent, or the air release valves. **Note:** The intake works must not be full of water before starting this up. Before starting, pull out the outlet valve and let the water drain out. In place of air release valves, a normal valve can be attached to the tee in order to show a manual air release valve.




**Doing the Demonstration**

1) Set the main line up without the vent, air release valves or tees. Discuss with the audience whether or not they think the water will make it out of the end of the main line.
2) Drain the intake works and then start up the system. Have the audience watch closely how the tubes fill.
3) Discuss the problems and then fix the system in stages (one air release valve at a time) or all at once.

**Talking Points**

- Under what types of conditions do air-blocks form?
- How do automatic air release valves work?

- Different methods for releasing the air. Pros and cons. (Using sharpened sticks to plug air release holes is bad. Screws are better.)

**Tips**

- Be careful on the startup. Make sure that the intake works is relatively empty.
- Check the air release valves before trying this demo. They are a bit touchy. If they drip during the demo, just tap the ball a bit and they usually stop leaking.

# Sediment and Cleanouts

**Objectives**

- Show how sediment collects and restricts flow.
- How to clean out the tubes

**Setup**

Use the same setup as for the air-block demo with the air release valves in place. You will also need cup of washed sand. Wash it by putting it in a bucket and repeatedly filling the bucket and pouring off the silty water. Add a valve to the end of the line so that you can control the flow of the water.

**Doing the Demonstration**

1) Begin by with a low flow and add a scoop of sand to the vent just after the outlet of the intake works. Have the audience gather around to see where it gathers.
2) Continue adding sand and watch what happens. Notice changes in the flow at the outlet.
3) Now increase the flow and see what happens to the sediment blocks. Continue increasing the flow until the sediment is flushed from the system.
4) Discuss the differences seen in high and low flow systems.
5) Add tees with valves attached at the low spots. These will be your cleanouts. Re-form the sediment blocks under low flow and then clean them out by opening up the cleanouts.
6) Discuss the importance of regular maintenance. If sediment is left in the tubes for a long time and it compacts into a thick lump will the cleanouts work? How could you clean this out?

**Talking Points**

- How does the velocity of the water effect the formation/location of sediment blocks?
- Why is too high of a velocity also bad for the aqueduct?
- Potential for using a settling tank just after the intake works to reduce the amount of sediment that enters the system.
- Importance of having a pre-filter in the intake works.

**Tips**

- Use washed sand to make it easy to see.

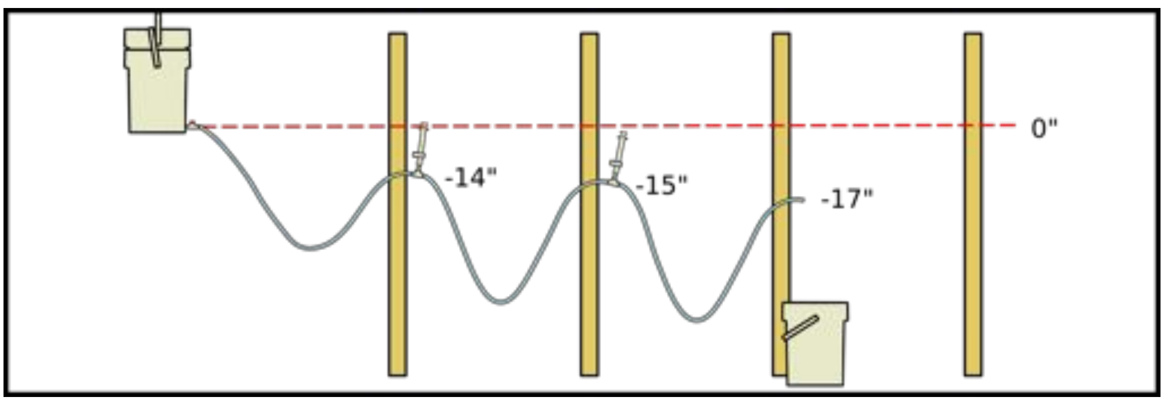
# Advanced Air-Blocks

**Objectives**

- Introduce the concepts of critical, subcritical and supercritical flow.
- Show how a system that remains at supercritical flow responds to changes in flow.
- Show how in air-blocks can reform as the flow at the source changes from supercritical to subcritical.

**Setup**

The setup is the same as it is for the normal air-blocks demonstration with a few small changes. To help get more air into the pipes attach a coupling onto a .5 ft. length of 3/8 in. tubing. Remove the valve from the outlet of the intake works and insert this section of tubing so that the coupling plugs into the fitting on the bucket. Make sure the section of 3/8 in tubing is relatively horizontal to keep an air-block from forming in the outlet. You wouldn't normally make an aqueduct like this, but remember this one is made so that it won't work. Install manual air release valves on the mainline and no vent. The flow at the source will be both 1 L/min and 0.6 L/min.




**Doing the Demonstration**

1) Define terms critical, subcritical, supercritical and transitional flow.
2) Install the 1 L/min nozzle and let the intake works fill until it is overflowing with the outlet valve closed.
3) Make sure that the tubes are empty (no air-blocks) and then open the outlet. Water should rush through the tubes without forming air-blocks.
4) Measure the flow at the outlet. This is the natural flow.
5) Air will begin to enter the tubes as the intake works empties. Notice how the bubbles move and where they collect. Watch as they change velocity when moving from the 3/8 in. tube to the 1/4 in. tube. Notice how the air pockets form. Discuss supercritical flow.
6) When the system has stabilized, remeasure the flow. Hopefully 1 L/min.
7) Now repeat the demonstration with the 0.6 L/min nozzle. Again note what happens as the air enters the tubes. After measuring the final flow, discuss subcritical flow.

**Talking Points**

- Difficulties in designing an aqueduct that does not always flow with full pipes.
- The dependence of the design on both maximum and minimum flows expected.
- The potential to quickly destroy automatic air release valves as bubbles move down the pipes.
- Critical flow only depends on tube diameter. How can tube sizes be arranged to avoid problems?

**Tips**

- This demonstration may not work correctly. It will take practice and possibly some modification (possibly a slightly lower flow nozzle?). Play around with the .5 ft. 3/8 in. tube to learn how to get it adjusted correctly.
- When the system goes from super critical to subcritical flow the air-blocks that form don't always shut down the system. It depends on where the air bubbles are and how many of them are there when the subcritical flow is reached. Maybe do the demo a few times to show this.
- You could also show how the systems respond to a newly increased flow after the air-blocks have reformed. Do this by pouring water into the intake works by way of the overflow. A system that is supercritical should increase its flow by flushing out some of the air, but a system that is subcritical will probably not show much change in flow.

# Head Loss Calculations and Natural Flow

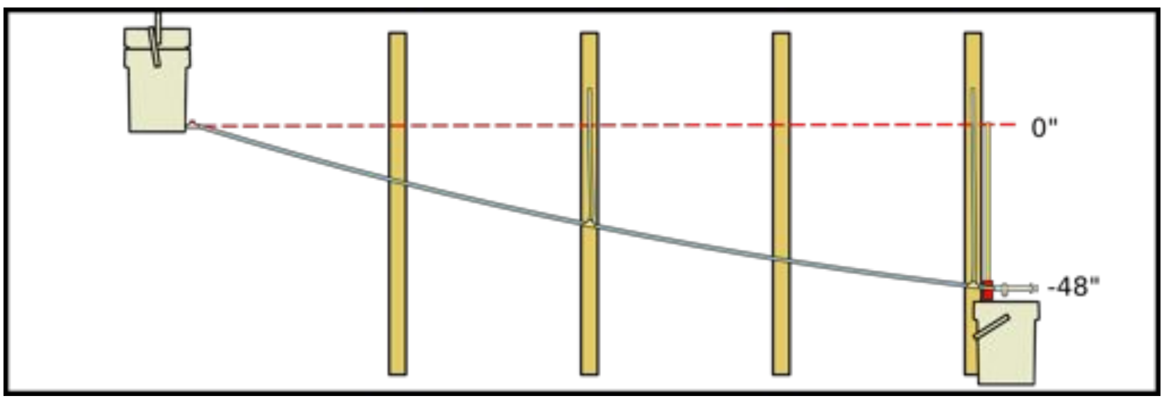
Using the head loss charts included, it is possible to teach basic head loss calculations. While not very useful for the average community member, this could be helpful for those who are learning or participating in aqueduct design.

**Objectives**
- Practice calculating the head loss for a given flow and pipe or combination of pipes.
- Practice determining the natural flow for a given pipe configuration

**Setup**

The setup for this demonstration is similar to the HGL demonstration. The only difference is that 2 of the vertical tubes are removed and there is a measuring tape so that the amount of head loss can be measured. The vertical tube in the middle of the line is there to verify head loss when acombination of tube sizes is used.

| | |
|---|---|
| **Flow at Source:** | 3 L/min. |
| **Tubing Size** | 3/8 in. and 1/4 in. |




**Doing the Demonstration**
1) Explain head loss and how the charts are used to determine head loss at a given flow.
2) Use the charts to calculate the expected head loss for a given flow and tubing size.
3) With the measuring tape in place, start the maqueduct. Open the valve at the end of the line until the measured head loss is equal to the result of the calculation.
4) Measure the flow to determine of your calculation was correct.
5) Repeat for various flows and tubing lengths, sizes. You could even have the audience choose the setup (within some limits of course).
6) Explain the meaning of natural flow and how to find it given pipe length and elevation change.

7) Determine the natural flow for a particular setup. As before you may have members of the audience choose what this is. (The calculations can be a bit more tricky for combinations of tube sizes)
8) Make sure to remove the vertical tubes and the valve from the line and check your calculations by measuring the natural flow.

**Talking Points**

- Are all head loss charts the same? (Pipe caliber, pressure loss, head loss per 100 ft, etc.)
- Minimum desired residual head for pipeline design
- Plotting the HGL
- How does the HGL change between the design flow and the natural flow?
- How could one use natural flow calculations to evaluate an existing pipeline?

**Tips**

- It can be difficult to adjust the valve to get the desired head loss. Over shoot it and then use light taps to bring the loss to where you want it.
- The calculations don't always come out perfect. The water level in the intake works might vary a bit. The couplings between the tubes (especially when coupling different sized tubes) may create turbulence and more head loss.

## Other Demonstration Ideas that You Could Develop…

- Pipe Basics: Open Channel Flow
    - A bit more focused
    - What does the HGL look like?
    - Happens any time the source yield goes below the natural flow.
- Multiple Sources
- Sedimentation Tanks
- Pressure Release Tanks
- Float Valves
- Multiple Tanks
- Advanced Distribution Systems
    - Flow calculations
    - Tabulated design

If you develop any new demonstrations, or make improvements on existing ones, please send an email so that the guide can be updated: mprogge@gmail.com

# Storage

After using the maqueduct it should be stored properly. Everything must be dried. When the maqueduct is stored wet, the vinyl tubes become white and mold begins to grow inside of them. Possibly rinse them with a little bleach water after each use. To dry the tubes disconnect them and set them out in a warm sunny place for a while. Make sure that all the parts are returned so that the next person to use the maqueduct doesn’t have a major problem when they find out that they are missing parts during their demonstration.

# Head Loss Charts

These head loss charts were derived from measurements made with the maqueduct. They are nothing official. There may be slight variations in tubing from different manufactures as well as slight differences between tubing of different wall thickness. It would be a good idea to verify that these tables work with your tubing before trying it out before an audience. If they don't it isn't too hard to produce your own.

| Head Loss for 1/4 in. Vinyl Tubing | |
|---|---|
| **Flow (L/min)** | **Head Loss ($f_h$/L)** |
| 0.10 | 0.002 |
| 0.20 | 0.006 |
| 0.30 | 0.012 |
| 0.40 | 0.021 |
| 0.50 | 0.032 |
| 0.60 | 0.044 |
| 0.70 | 0.059 |
| 0.80 | 0.076 |
| 0.90 | 0.094 |
| 1.00 | 0.114 |
| 1.10 | 0.136 |
| 1.20 | 0.160 |
| 1.30 | 0.186 |
| 1.40 | 0.213 |
| 1.50 | 0.242 |
| 1.60 | 0.273 |
| 1.70 | 0.305 |
| 1.80 | 0.339 |
| 1.90 | 0.375 |
| 2.00 | 0.413 |
| 2.10 | 0.452 |
| 2.20 | 0.492 |
| 2.30 | 0.535 |
| 2.40 | 0.578 |
| 2.50 | 0.624 |
| 2.60 | 0.671 |
| 2.70 | 0.719 |
| 2.80 | 0.769 |
| 2.90 | 0.821 |
| 3.00 | 0.874 |
| 3.10 | 0.929 |
| 3.20 | 0.985 |
| 3.30 | 1.043 |
| 3.40 | 1.102 |
| 3.50 | 1.163 |
| 3.60 | 1.226 |
| 3.70 | 1.289 |
| 3.80 | 1.355 |
| 3.90 | 1.421 |
| 4.00 | 1.490 |

| Head Loss for 3/8 in. Vinyl Tubing | |
|---|---|
| **Flow (L/min)** | **Head Loss ($f_h$/L)** |
| 0.10 | 0.000 |
| 0.20 | 0.001 |
| 0.30 | 0.002 |
| 0.40 | 0.003 |
| 0.50 | 0.004 |
| 0.60 | 0.006 |
| 0.70 | 0.007 |
| 0.80 | 0.009 |
| 0.90 | 0.012 |
| 1.00 | 0.014 |
| 1.10 | 0.017 |
| 1.20 | 0.020 |
| 1.30 | 0.023 |
| 1.40 | 0.027 |
| 1.50 | 0.030 |
| 1.60 | 0.034 |
| 1.70 | 0.038 |
| 1.80 | 0.042 |
| 1.90 | 0.047 |
| 2.00 | 0.051 |
| 2.10 | 0.056 |
| 2.20 | 0.061 |
| 2.30 | 0.067 |
| 2.40 | 0.072 |
| 2.50 | 0.078 |
| 2.60 | 0.084 |
| 2.70 | 0.090 |
| 2.80 | 0.096 |
| 2.90 | 0.102 |
| 3.00 | 0.109 |
| 3.10 | 0.116 |
| 3.20 | 0.123 |
| 3.30 | 0.130 |
| 3.40 | 0.138 |
| 3.50 | 0.145 |
| 3.60 | 0.153 |
| 3.70 | 0.161 |
| 3.80 | 0.169 |
| 3.90 | 0.177 |
| 4.00 | 0.186 |