

Water for Everyone, Step One: Test Water

In developing countries, water-related disease blights the lives of the poor.

-Gro Harlem Brundtland, WHO Director-General (2001)

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Introduction

Clean drinking water is essential for every human to live a healthy life. According to the World Health Organization, over one billion people around the world lack access to safe drinking water. Much of this water has been contaminated by fecal material and other waste products and can lead to diseases that cause severe diarrhea and even death. Many organizations worldwide, including MIT and past IDEAS Competition winners, are working to bring safe water to families in developing countries.

One essential step in providing safe drinking water is water quality testing. This is important for three main reasons:

1. Testing distinguishes safe water sources from contaminated sources.
2. Testing determines how well a water treatment method is working. Testing is also necessary for long-term routine monitoring of a treatment system.
3. Testing gives a diagnostic tool to scientists and public health workers.

One effective method for providing quantitative data about the level of bacterial contamination is membrane filtration, which will be described later. Our goal is to design an inexpensive and accurate membrane filtration device. Existing commercial systems have high initial capital costs, on the order of \$1,000. A first low-cost prototype (Zip Aqua I) was developed at MIT in the fall of 2003 but was too inconvenient for general use. Our water-testing device (Zip Aqua II) is about \$13 and easier to use than Zip Aqua I.

Having a good testing device is the first step to safe water. A cheap and reliable device will identify and then facilitate treatment of contaminated water, giving more people access to clean water worldwide. To this end, we believe that a cheap, easy-to-use and reliable water-testing device will have applicability for large organizations involved in disaster relief such as the Red Cross, World Health Organization and Center for Disease Control along with small organizations such as local technical centers.

An example of specific community in which this device will have immediate applicability is a small rural community in northern Honduras. Through the D-lab course, students went to a small community in Guadalupe Carney, Honduras in January 2004. This community has two sources of water. One source is a spring from the surrounding hills and the other is from boreholes drilled down to the water table. The residents believed the water coming from the spring was clean while the water coming from the ground was contaminated. In fact, MIT students determined that the opposite was true at the time. With a cheap, easy-to-use water testing device, the local technical NGO (Centro Technico San Alonso Rodriguez, CTSAR) in Tocoa will be able to monitor the water supplies and ensure that the community members are drinking safe water.

Technology Background

Membrane Filtration

Membrane Filtration (MF) tests allow direct numeration of bacteria present in a water sample. A water sample is pulled through a filter paper, which has pores small enough to trap any bacteria in the water. Water cannot simply be poured through the filter paper because its pores are so small that water will just sit on top. A filter holder assembly uses a vacuum to pull the water sample through the filter paper. Features common to all membrane filtration devices include a mesh to support the filter paper, gaskets or o-rings to make a good seal and prevent leaking, and a syringe to create the vacuum needed to draw the water through the filter.

The filter paper is then placed in a Petri dish with growth medium that feeds the bacteria. The dish is incubated until colonies of bacteria can be counted by the naked eye (Figure 1). The results are then expressed as the number of “colony forming units” (CFU) per 100mL of water.

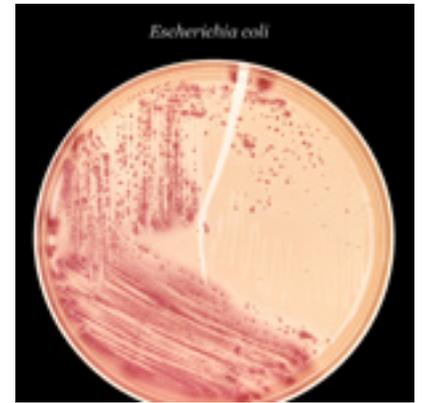


Figure 1. Petri dish showing bacteriological contamination

Image from Wikimedia Commons, <http://commons.wikimedia.org>. Courtesy CDC.



Figure 2: Millipore Field Apparatus

Commercial Water-Testing Systems

The Millipore Corporation manufactures a commercial device that is currently used by team member Brittany Coulburt and other students in the Environmental Engineering department at MIT. The stainless steel device is compact, and, thus, good for field-testing (see Figure 2).

Steps to membrane filtration using the Millipore assembly:

1. The lid is removed, inverted and placed on the bottom of the apparatus to collect water after filtration. An o-ring creates an airtight seal around the receiving cup.
2. A filter paper is placed on top of the mesh, and the funnel cup is snapped into place above the filter paper.
3. The water sample is poured into the top funnel cup.
4. A syringe is connected through a rubber tube to a hole in the side of the assembly.
5. The tester uses this syringe to apply a vacuum to pull the water through the filter paper.

This design is simple to use as all the parts easily lock together. It is very durable and works well for years if treated with care. All parts are metal, allowing for easy sterilization and minimal waste. The parts fit together ingeniously.

Unfortunately, this system is too expensive (\$1,063) for many users in developing countries. A second drawback is that it is time-consuming to sterilize because it must be sterilized before each test. This apparatus is sterilized by flaming methanol and allowing the resulting formaldehyde to reach all the surfaces of the device. The lid must be closed for 15

minutes to ensure proper sterilization by this chemical reaction. Thus, sterilization can serve as the limiting factor in determining the number of tests that can be performed in a day.

First Low-Cost Prototype (Zip Aqua I)

The first prototype (Zip Aqua I) of the low-cost device was comprised of common lab materials such as wash bottles, mesh and tubing. D-lab students took Zip Aqua I to India and Honduras for field-testing.

Steps to membrane filtration using Zip Aqua I (see Figure 3):

1. Water is collected in sterile Whirl-Pak bags.
2. The bag opening is then folded over the mouth of a bottle.
3. A filter paper is placed upon the bag opening.
4. A supporting piece of sterilized mesh and a water-sealing gasket are placed in the bottle cap. The mesh is pressed into the gasket so that it is held enough to be flipped onto the bottle/bag assembly.
5. The cap is flipped over and screwed onto the bottle and bag combination.
6. A rubber tube is attached to the spout on the cap.
7. A syringe is then attached to this rubber tube.
8. The entire assembly is inverted and the tester uses this syringe to apply a vacuum to pull the water through the filter paper.



Step 1

Step 2

Step 3

Step 4

Steps 6-8

Figure 3: Use of Zip Aqua I

Zip Aqua I is very cheap (about \$7) and minimizes waste but has several flaws. It is awkward and time-consuming to place the sample bag over the bottle/scaffolding; also, folding the bag over the mouth of the bottle gave an inadequate seal. Pressing the mesh into the gasket enough to flip the bottle cap over was an unreliable step, with the mesh often falling out of the lid, and needing to be re-sterilized. Screwing the cap onto the filter/bag/bottle assembly often caused the filter paper to tear.



Figure 4: D-lab students in Honduras guesstimating the sample size and working intently with tweezers

In addition, the sample bags that must be used with this design hold 350mL while the filtration test must be done with 100mL. Testers had to judge the size of the water sample by eye. Finally, the whole apparatus is cumbersome, requiring the assembly of many parts (see Figure 4).

Our Low-Cost Prototype (Zip Aqua II)!

Our device addresses all of the problems mentioned above. We drew ideas from both the Millipore system and Zip Aqua I during our design process. Our water receptacle is a sterile drop-in instead of the sample collection bag. Though this adds a cost of \$0.13 to each test (which costs approximately \$2 for any membrane filtration system), the drop-in gives a better seal and allows us to use accurately a 100mL sample. Our prototype (Zip Aqua II) does not tear the filter paper because there are no longer any shear forces; everything touching the filter paper rotates with the paper. Furthermore, the system is very cheap.

Our filter holder assembly design consists of inexpensive and readily available or easily manufactured parts. We use a baby bottle with disposable drop-in inserts as our base design. We chose to use baby bottles because drop-in inserts are sterile and a good tradeoff between

cheap and convenient. In addition, they produce little waste compared to other disposable filter assemblies because they are made of very thin plastic. The inserts allow for easy “drop-in” convenience and have a semi-rigid and smooth top lip, which allows the insert and filter paper to rotate freely when the lid is screwed on, avoiding shear forces. The apparatus is assembled with the bottle “upright” so that water does not spill out. The entire thing is then inverted after it is fully assembled so that the water rests on top of the filter paper.

A sketch of the Zip Aqua II design is shown in Figure 5. All of the components are laid out in Figure 6.

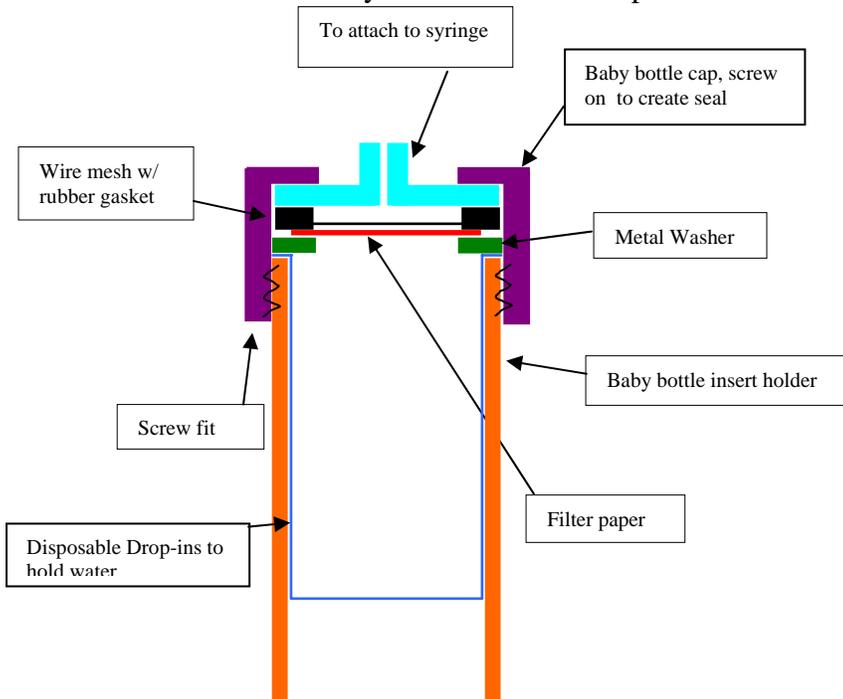
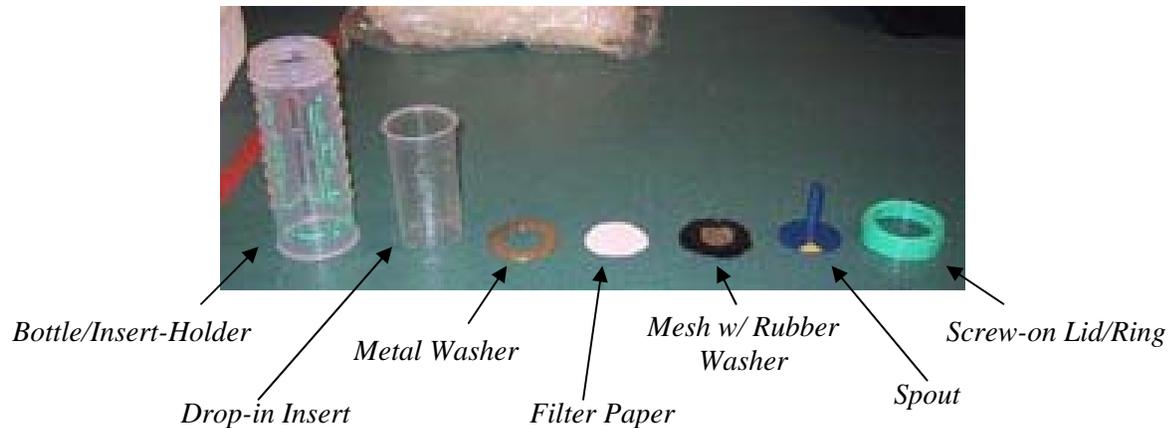


Figure 5: Design Schematic of Zip Aqua II

Figure 6: Components of Our Design



Steps to membrane filtration using our innovative design (Figure 7):

1. A sterile insert is dropped into the rigid plastic bottle/holder.
2. The water sample to be tested is poured into the disposable insert.
3. A metal washer is placed on top of the disposable insert.
4. The filter paper is then placed on top of the metal washer (the metal washer is necessary to prevent the filter paper from falling into the insert; the washer is flamed so that it is sterile).
5. A fine metal mesh is placed on top of the filter paper.
6. A rubber washer is placed on top of the mesh to create a tight seal between the washer, mesh, filter paper, and drop-in insert when the lid is screwed on the top.
7. The “lid” is actually a ring that screws on to the top of the bottle. A rubber nipple is usually placed inside this ring for feeding infants. Instead of this nipple, we place a plastic disk with a spout sticking out (made from a plastic wash bottle lid) through the bottle’s ring. It is through this spout where the filtered water will flow out. These two pieces are screwed tightly on to the top of the bottle, sealing the filtering mechanisms.
8. A rubber tube is attached to this spout.
9. A syringe is then attached to this rubber tube.
10. The entire assembly is inverted and the tester uses this syringe to apply a vacuum to pull the water through the filter paper.

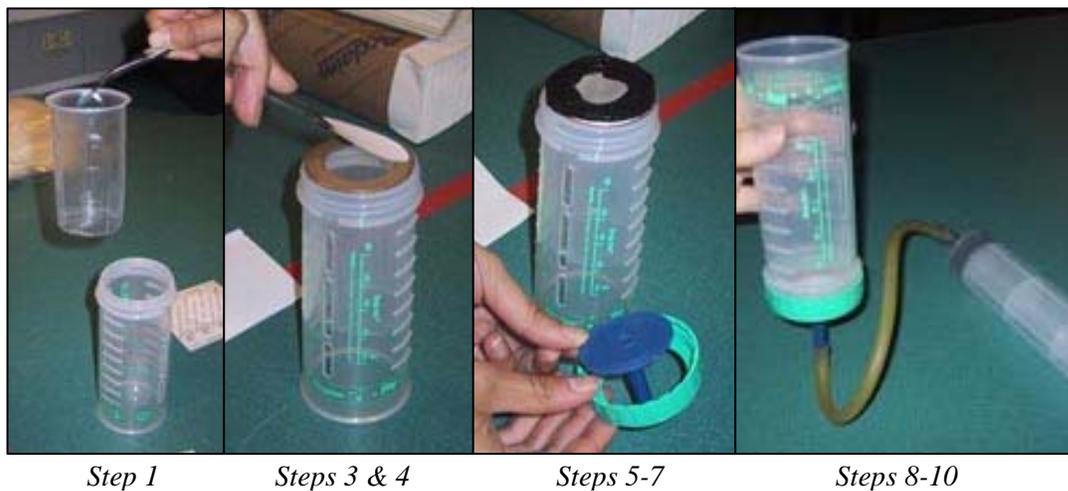


Figure 7: Use of Zip Aqua II

Between each test the insert is discarded and traded for a sterile one, and the mesh and metal washer are sterilized in alcohol and/or flame. A new filter paper is used for each test. The other parts of the assembly do not need to be sterilized because they do not touch the sample water before it touches the filter paper, nor do they touch the middle of the filter paper where the bacteria colonies will be grown. The metal mesh and rubber washer may need to be sterilized only at the beginning of each testing session (e.g. only once per testing day). This will be verified through further testing.

As with all membrane filtration tests, after the above steps are completed, the filter paper is removed from the assembly and placed in a Petri dish with growth medium that feeds any bacteria. The dish is incubated for 24 hours and the bacteria colonies are counted to identify the level of bacteria contamination in the water sample.

This design has gone through preliminary testing procedures and it works! We will continue to adjust the design as needed after further testing and feedback, but we are confident that our final product will successfully allow for accurate microbial testing of water samples.

Plan of Action

Table 1: TestWaterCheap Proposed Timeline for the Next Year

Timeline												
	2004						2005					
	March	April	May	June	July	August	Sept.	Nov.	Dec.	January	February	March
Design												
Design Alpha Prototype												
Test Prototype												
Design Machine-Manufactured Beta Model												
Manufacturing												
Assemble Alpha Models												
Manufacture Beta Models												
Implementation												
Deliver and Teach Comm. Partners in Latin America												
Use Product on D-Lab Trips												
Plan & Assemble Design for Further Dissemination												
Community Feedback												
Feedback from Comm. Partners in Latin America												
Feedback from MIT and Other Partners												

The above timeline in Table 1 gives our proposed schedule for design, manufacturing, implementation and feedback. We will continue to develop the alpha prototype by

experimenting with materials, looking for ways to further reduce cost, and streamlining the procedure. In addition to the creation of the actual device, we plan to write a manual to instruct testers in Zip Aqua II's use. The next important step is to conduct quality assurance tests of Zip Aqua II alongside the Millipore system. The Millipore system is certified as a standard apparatus. To interest scientists and researchers, we must be able to show that our device gives results comparable to the Millipore system. We plan to conduct over 100 water tests this summer to make sure that our product lives up to standards. Once we have finalized our design, we will build 30 alpha prototypes for our community partners, researchers at MIT and D-lab students.

Throughout our developing and testing phase in the summer, we will also look for contacts in large disaster relief organizations such as the Red Cross and the Center for Disease Control.

Brittany, Jin and Juhi will travel to Honduras and El Salvador in late June to field-test our alpha prototypes. This trip will be in conjunction with D-Lab students who have worked previously with our community partners in Honduras. We will deliver Zip Aqua II to Gines Suarez at CTSAR in Honduras and local NGO's in El Salvador through contacts of Luis Gonzales of TROCAIRE. With our community partners, we will test local water and teach local technicians how to use our product.

Through this field-test, we hope to receive feedback to direct the design of our beta prototype in late 2004 and early 2005. While on our site visits we will examine locally available materials for incorporation into our design. Though it is feasible for community partners to import our product as they do other lab equipment, locally available materials would give our design added flexibility. The beta prototype will be ready for the next D-lab trip in January 2005.

Based on feedback from our initial field test, we will determine the next step for our product. We might decide to mass produce the product and market it or keep it "in-house" for the purpose of D-Lab students and community partners. If we decide to mass-produce our product for the commercial market, we must look for additional funding from something like MIT's \$50K business competition and think about patenting our device. Some obstacles to taking the product commercial would be the reaction of competitors such as Millipore.

Community Contacts and Mentors

Support Network

Our current support group is made up of Amy Smith, other members of the DTM staff and classmates with previous contact with our community partners. We also receive support from community partners in Honduras (Gines Suarez from CTSAR), El Salvador (Luis Gonzales from TROCAIRE) and World Education (Barbara Garner).

Community Connection

Currently, our strongest community contacts are in Honduras and El Salvador. The partner in Honduras is Gines Suarez from Centro Technico San Alonso Rodriguez (CTSAR) in Tocoa. D-lab students met with Gines during their January 2004 trip to Honduras when they used Zip Aqua I in communities in and around Tocoa. CTSAR provides technical assistance with farming, building materials and water quality to local communities. The case study of the

spring water versus well water in the introduction occurred in a community connected with CTSAR.

The partner in El Salvador is Luis Gonzalez, Rehabilitation Officer in the NGO, TROCAIRE. TROCAIRE has partnered with NGO's, government and local communities in El Salvador to provide innovative and earthquake-proof houses and fund micro-enterprise. We will use Luis's contacts in El Salvador to partner with appropriate organizations.

One such organization is REDES Foundation. REDES Foundation built 24 tanks for an equal number of families in order to harvest 22,000 liters of rain water per tank. This provided enough water for consumption by the families during the dry season (6 months). Tanks were built one year ago and the REDES Foundation would like to know about the quality of water after storage. They found one out-of-country university able to carry out the tests, but had to wait several months for the results for the results. The cost for the service amounted to \$800.

Our device would provide organizations like Trocaire and CTSAR with a cheap and overnight system to test the quality of water. The impact of our device can be summed up in three ways. It would serve to:

- 1) Lower water testing costs dramatically.
- 2) Eliminate need for slow/expensive out-of-country services.
- 3) Decrease time needed to get results for tests.

If they had had access to our device, the people at the REDES Foundation could have done the testing in two days for under \$2 per test (with the initial capital cost of \$13). Not only would this save time and money, it would also permit REDES to monitor the water treatment method on a more consistent and long-term basis.

The magnitude of effect of our device will reach from the organizations with which we work down to the families who may have better access to clean water as a result of frequent testing. Organizations will rely less upon out-of-country testing services, and large-scale testing will be possible. With quantitative data sets, organizations may be able to draw more sponsors and sources of funding for local water treatment. By empowering organizations with our low-cost water testing device, people can be informed about the quality water they drink within a matter of days. Ultimately, water-borne disease can be reduced and lives may be saved.

Conclusion

There are few options for *inexpensive* and *quantitative* testing of water. We feel that our device fills a need that has no current solution. We have adapted an existing technology to meet a global need and exhibited the kind of creativity that we hope to fuel in our community partners. Furthermore, our product is certain to have an impact on at least two communities in the coming months, and we are confident that Zip Aqua II will benefit the health of people worldwide.

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EC.715 D-Lab: Disseminating Innovations for the Common Good
Spring 2007

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