Suggestions for Low-Cost Equipment for Physical Geography I: Laboratory Equipment

Patrick Pease, Scott Lecce, Paul Gares, and Mark Lange

Abstract

Fieldwork and laboratory experiences have always been important components of physical geography education, at universities as well as secondary schools. However, the rising cost of necessary equipment and dwindling education budgets of most universities and secondary schools have placed such experiences in crisis. This is the first of two papers that present lab- and field-based items we have designed and built for student research. The equipment is easy to construct and made from low-cost materials like PVC plumbing pipe. Photographs, construction notes, and costs have been included for each of the pieces of equipment, as well as measured schematics for the more complex items.

Keywords: *low-cost equipment, field equipment, lab equipment, student research*

Patrick Pease is an assistant professor at East Carolina University. He is a geomorphologist with research interests in aeolian transport of sediment, mineral dust, the use of geochemical data to identify sediment sources and transport histories in geomorphic environments.

Scott Lecce is an assistant professor at East Carolina University. He is a fluvial geomorphologist with research interests in hydrological processes, transport and storage of heavy metals in fluvial environments, and flood hydrology and geomorphology.

Paul Gares is an associate professor at East Carolina University. He is a coastal geomorphologist with research interests in coastal dunes, beach processes, and environmental management.

Mark Lange is a doctoral student at University of Southern California. He is a coastal geomorphologist interested in microtidal estuarine beaches and high energy beach morphology.

Introduction

Fieldwork and laboratory exercises are important components of teaching in physical geography and other natural science fields. However, many universities, colleges and high schools lack the funds to outfit field trips, field courses, and labs properly with necessary equipment. Many authors have pointed to decreasing funding and increasing enrollment as major impediments to field-based learning and have written extensively on what some see as the bleak future of field experiences for students (Clark 1996; Fuller et at. 2000; Higgitt 1996; Jenkins 1994; Kempa and Orion 1996; Kent and Gilbertson 1997; Nairn et al. 2000; Tinsley 1996). Equipment shortages are a significant issue in developed nations, but Sane (1999) points out that access to affordable equipment is one of the single most critical issues in science teaching in developing countries. Despite the considerable pedagogic and methodological attention that has been given to the importance and future of fieldwork, few papers have offered pragmatic suggestions to faculty and teachers regarding solutions to their equipment shortages. Two notable exceptions (Jernigan and Murray 1974; Wikle and Lightfoot 1997) have provided specific, detailed suggestions about effective equipment that can be constructed at low cost. We follow these examples in presenting illustrations of some low-cost field and lab equipment that we have designed and built and that we think might be useful to other instructors.

The development of a geomorphology research group at East Carolina University, the Tobacco Road Research Team, has fostered a spirit of innovation, as we have been involved jointly in several research-based teaching projects. Like many of our colleagues at other universities and high schools, we face problems in equipment acquisition that are related to the appropriateness and cost of various devices. In this paper, the first of two parts, we present four pieces of laboratory equipment that the members of the Tobacco Road Research Team have designed and built in response to both teaching and student research needs. In part II of this paper we will present examples of field equipment we have built. Photographs and construction information for each item are given, and measured schematics are included for the more complex pieces.

Building Equipment

Although we do not advocate trying to build everything you need, there are clear benefits to constructing some of your own equipment, including cost, availability, and education. The leading problem in acquiring equipment is money. In some cases, the desired device may be prohibitively expensive and constructing your own is the only way to obtain the item. In other situations, building low-cost versions of simpler items can free money to purchase equipment too complex to build. A second problem in equipment acquisition is that some items do not exist commercially, and is a key reason for the long tradition of "do it yourself" attitudes that are common in fields like geomorphology. Researchers and instructors are forced to design and build their own. We also believe that involving students in such projects, or encouraging them to build

Journal of Geography 101: 167-175

their own research equipment (when practical), can be valuable beyond the simple cost benefit. If students are forced to consider exactly what they want an instrument to do, and how it must operate in order to collect the data they want, students can develop a better understanding of the principles of data measurement as a technological and scientific process, and therefore be more aware of what their data mean.

Design is an important aspect of building equipment. We recommend that persons considering this course of action give it considerable thought, whether they are copying one of our items or working on their own creation. A good way to get started is to find an example of the desired item in a catalog, on the Internet, or in a store, and to copy it using materials that are readily available. It is probably difficult to duplicate the design exactly, but often its function can be replicated. Options for building materials are varied, but some serious consideration should be given to availability, cost, ease of use, and durability of the construction material. Wood can be easy to work with but tends to warp and must be well maintained to prevent decay. Metals are durable but require more sophisticated tools in the construction process and rust can create problems. Our most common raw material of choice is PVC plumbing pipe. PVC pipe is readily available at any hardware store; it is inexpensive yet durable, and it has a Tinker Toy-like quality that makes it versatile and easy to work with. Construction with PVC takes little skill, only simple tools, and the standardized sizes and connections help to ease design considerations.

The following four projects are examples of equipment we have made and used for laboratory analysis. Most measurements in this paper use English units because most of the construction materials used are sold in those units. Some items, however, are sold only in SI units, and we have used those measurements when appropriate. We welcome you to copy them and we hope they inspire additional new ideas that will solve some of your equipment needs.

Laboratory Equipment

Vacuum Filtration Manifold

The vacuum manifold (Figures 1 and 2) is used to filter solid particulates from multiple water samples simultaneously. The system consists of the manifold itself, a small vacuum pump, and a water trap to receive the leftover water after it has passed through the system. The pump represents the biggest hurdle in the development of this apparatus. New pumps are expensive, but they are commonly found in science laboratories, so used ones may be available. We salvaged ours from our medical school's surplus equipment. Any rigid container at least one gallon in size will work as a water trap. We use a five-gallon glass carboy (Figure 1).

Our manifold was designed with five ports. This decision was based on the size of our pump, but we also had limited counter space. Additional ports can be added easily if the pump is powerful enough. We installed valves on each of the filtration arms so that individual arms can be sealed when not in use, or when all of its water is drawn through, and, thus, a good vacuum can be maintained.

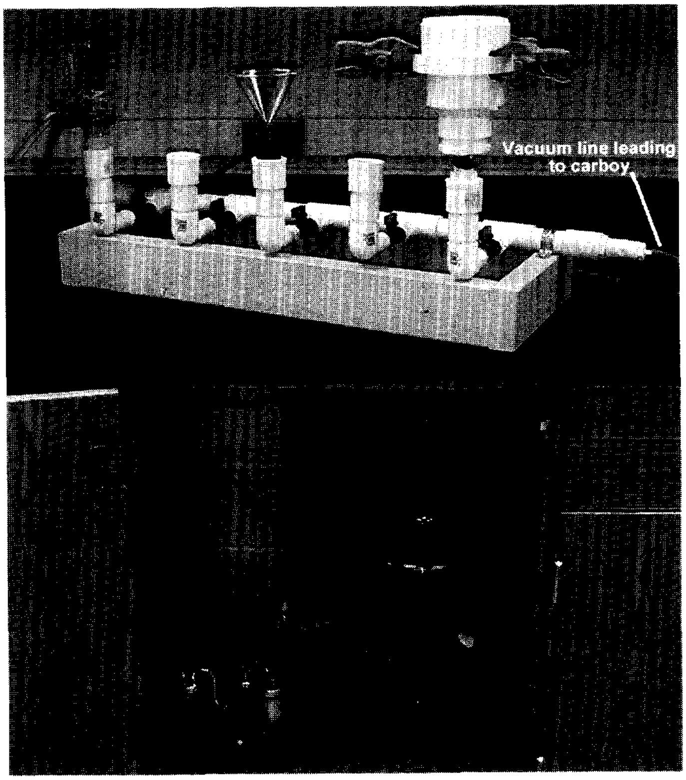

Figure 1. *Vacuum filtration manifold. Up to five samples can be filtered at once and valves can be closed to seal ports not in use. The glass carboy serves as a water trap and the other two bottles are dryers that came with our pump. We configured our system so the pump and traps are hidden in a cabinet below the manifold. The manifold base is made of scrap 2x4 lumber, painted to protect it from spilled water. Shown on the manifold are the three types of filter holders we have used, including the large PVC model shown in Figures 3 and 4.*

The manifold is built with PVC pipe and fittings to the specifications shown in Figure 2. Connections need to be properly glued and the threaded pieces need to the lined with teflon tape to ensure a good seal. The glassware is fitted to the manifold with a rubber stopper. We generally use either glass 47 mm filter holders or our own filter holders made out of PVC fittings (Figure 3; see description below) for large, 125 mm filters.

The vacuum filtration manifold is a particularly cost effective piece to build because the commercial versions are extremely expensive. The list price in a well-known scientific supply catalog for a six-position stainless steel manifold is $1,709, and $824 for a PVC model. Our version cost about $43. Granted, the commercial versions have a more streamlined appearance, but for a 1900 percent savings, we have been happy.

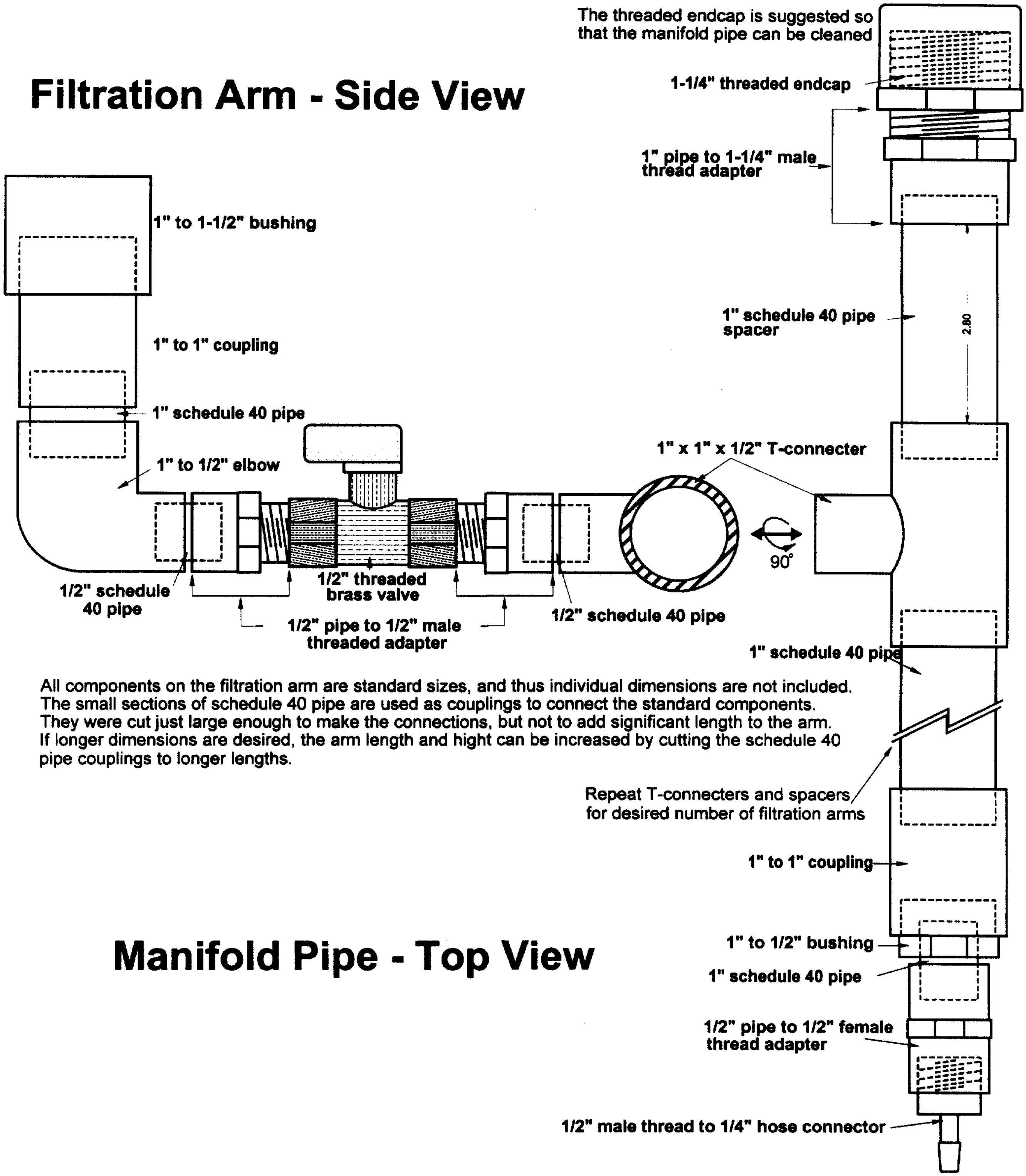

Figure 2. Drawing of the vacuum manifold port arm and the manifold pipe. Repeat the T-connecter for the desired number of ports.

Filter Holders

One of the problems with filtering suspended sediments from water is that even moderate concentrations quickly inundate the filter and dramatically slow the process. We have tried both funnels and filter holders in our manifold (see examples in Figure 1). When using funnels, a circular filter is folded into a cone and fitted into the funnel. This method, although less expensive, concentrates the flow of water and the sediment collected onto the small tip of the cone, which dramatically slows the process. We also have had difficulty with vacuum leaks around the filter cone. We have found that commercial filter holders, which hold a 47 mm filter paper flat and use the entire surface area, work better and are faster. These holders are readily available from scientific equipment supply companies in both glass and plastic versions. The drawback is that they are much more expensive than funnels (47 mm filter holders cost between $90 and $200 for glass and over S100 for plastic). We have also found filter inundation to be a major problem with some of our samples when running them through the 47mm filters. Using larger filters, such as 125 mm, can solve the problem by increasing the surface area of the filter, but commercial glass filter holders are common only in sizes up to 90 mm and are priced at over $300 each. Plastic versions are available for slightly less cost. However, we tried one, and found that the design, which drained water through holes in the base, caused sediment to concentrated at the holes and the entire filter surface was not used. Our solution was to construct large filter holder ourselves (Figures 3 and 4). The filter holders are more involved that most designs in this paper, and are also the most labor-intensive to construct.

The basic design follows those of commercial filter holders - a funnel system that sandwiches a filter - but ours is constructed mostly of PVC parts (Figure 3). The upper and lower parts of the funnel are spigot closet flanges, which are used in the installation of toilets. The lower flange fits into a series of reducers to achieve an end piece that fits into the opening of our vacuum manifold. The pieces were chosen for no reason except to get us from a 3-inch spigot flange to a 1-inch bushing. The lower, 3-inch flange has a recess inset into its larger open end, in which we opportunistically fit the filter platform. The filter platform was constructed in three parts. The PVC ring is cut as a spacer to get the wire mesh at a flush height with the lip of the flange. It was cut from the end of a 3-inch T-connecter, which was the only part we found that had an appropriate diameter. The plexiglas base serves as a rigid base on which the filter rests. This base is not sufficient, however, because like commercial versions, the flow would concentrate at the holes, and reduce the usable surface area of the filter. The wire mesh that sits over the plexiglas holds the filter off the disk enough that the filter paper does not get stuck to the plexiglas and therefore the entire surface of the filter is active. The holes in the plexiglas can be fairly large since the filter does not rest directly on the disk. The mesh must be flush with the lip of the spigot flange because the filter paper overlaps onto the flange lip, where it is sandwiched and sealed between the upper and lower flanges.

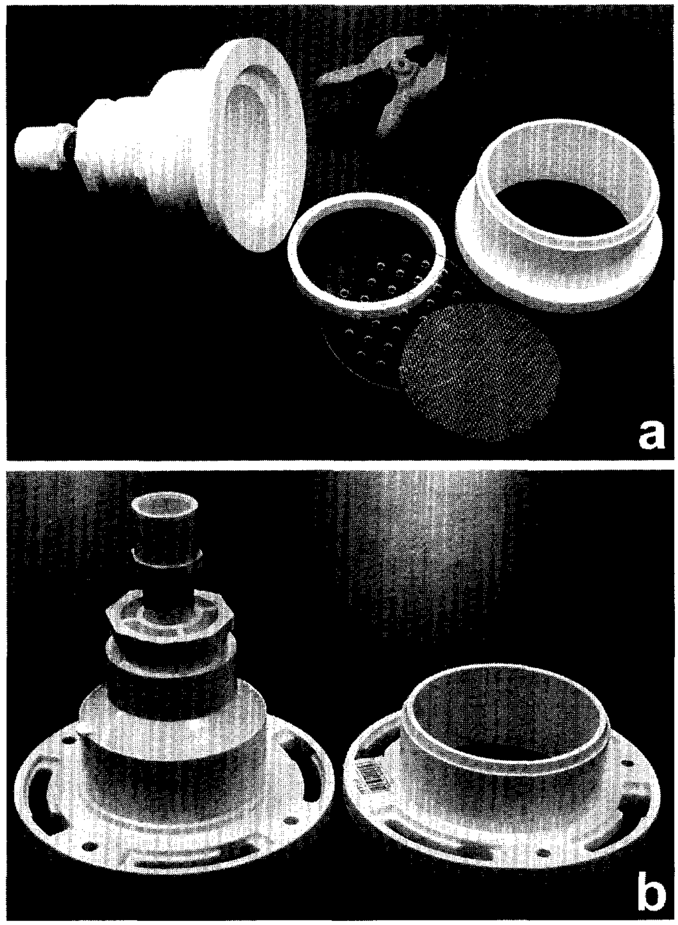

Figure 3. Large filter holder for 11 cm – 12.5 cm (4.3″ – 4.9″) diameter filters. Figure 3a shows the finished holder with all of the parts. Notice the recess in the bottom flange in which the spacer ring, plexiglas plate, and wire mesh fit. The pieces are held together with 3 or 4 hand clamps like the one shown. Figure 3b shows what the spigot flanges look like before the outer part of the flange lip was cut away (see text and Figure 4 for explanation).

The most labor-intensive aspect of the filter holder is the preparation of the spigot flanges. We cut away the outer portion of the flange lips (shown as dashed lines on Figure 4) to make the holders smaller and easier to work with. We made the initial cuts by freehand on a table saw and smoothed the cuts with a disk sander mounted in a hand drill. The most critical aspect of the filter holder is that the mating surfaces of the two spigot flanges must be sanded smooth to create a seal with the filter paper. When purchased, the surfaces are uneven and may have raised text. After we cut away the excess outer portion of the lip, we sanded the surfaces with a power palm-sander using 60-grit sandpaper. The sander leveled the surface but left deep scratches that were removed during two additional

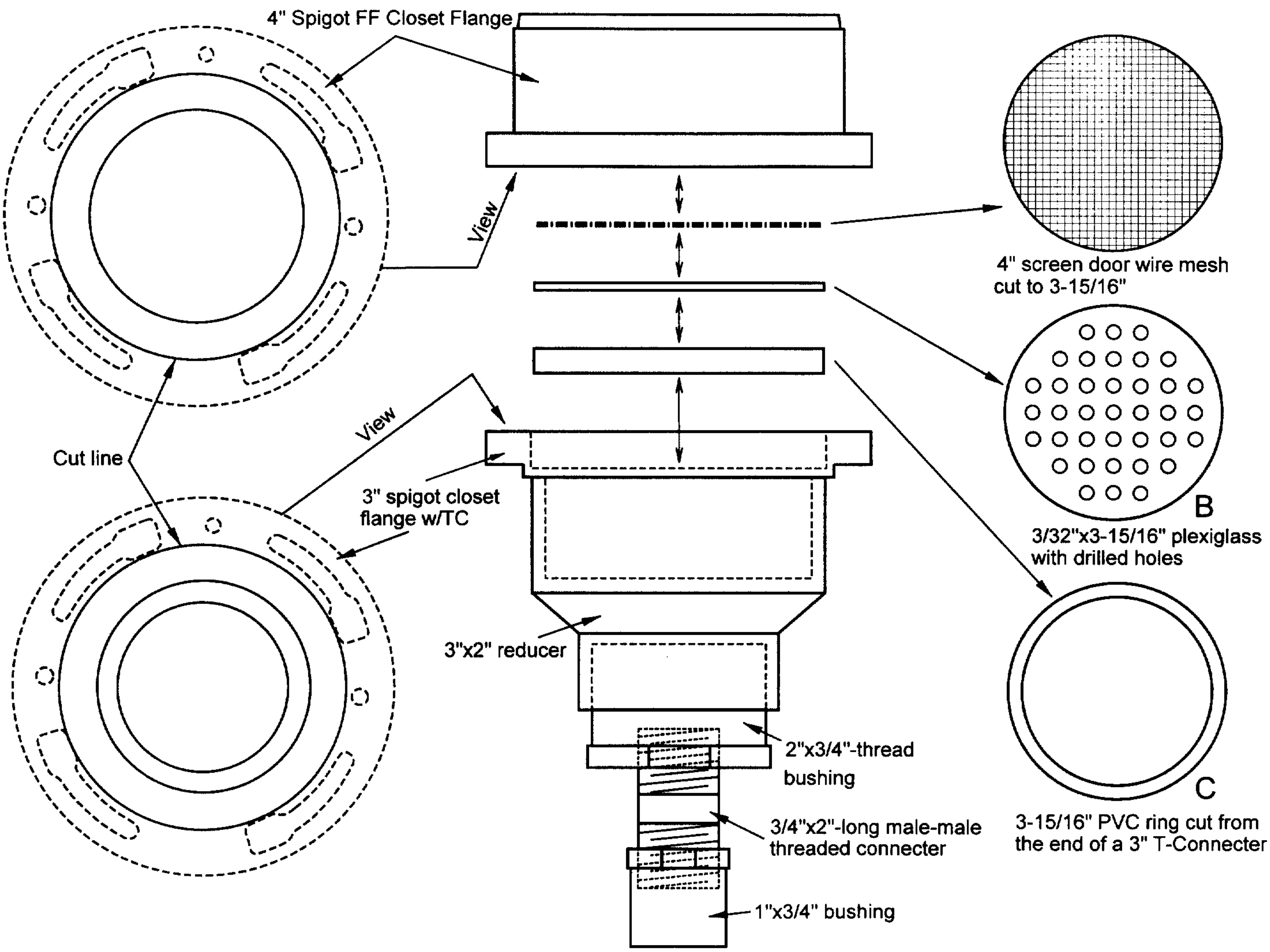

Figure 4. *12.5 cm (4.9") filter holder. The filter holder is constructed from spigot closet flange pieces. The lower flange has a recess in which we fit Plexiglas and wire mesh disks to support the filter paper. An explanation for the wire mesh is given in the text. The PVC ring in included to raise the Plexiglas disk flush with the flange lip. Small spring-loaded clamps hold the pieces together and seal the holder during filtering.*

sandings. To smooth the surface, a sheet of 100-grit sandpaper was placed on a flat, even surface (rough side up) and the flange was worked in a circular motion over the paper. The same process was used a second time with 220-grit paper. With careful and patient work, the two mating surfaces can be leveled to a very smooth fit. When ready for use, the filter holder is held together with three or four small, spring-loaded hand clamps (see Figure 1).

Although this filter holder can be made with hand tools, some power tools make the process faster, particularly when making several of them. A table saw was used to cut away the excess portion of the spigot flanges and to cut the PVC spacer ring. The plexiglas disk was cut with a hand jigsaw. A sanding disk mounted in a hand drill helped to smooth the edges of the flange cuts and the plexiglas disk. A random orbit palm sander made much quicker work of the initial leveling of the flange surfaces than hand sanding could have.

Darcy Apparatus

The Darcy apparatus was built as a teaching aid (Figures 5 and 6) to demonstrate the permeability of sediment. The apparatus consists of a main chamber is filled with a porous material (e.g., gravel) and three vertical tubes (manometers) protruding from the side of the chamber. Water is put into the chamber via a hose that is coupled to the top of the apparatus. With an empty chamber, water would rise to the same level in each manometer tub, but when filled with sediment, there is a progressive drop in head pressure, and thus water level (representing the piezometric gradient) in each manometer.

There are several things to consider when constructing this equipment. The only task of any difficulty was the construction of the manometer tubes that required splitting lengths of 1/2-inch PVC pipe. If you have a table saw or band saw, the process will be easy; otherwise a good hacksaw and a lot of patience will do. The 1/2-inch PVC pipe serves mostly as a support frame for clear vinyl tubing that is fitted within the split pipe. The tubing allows students to see and measure the change in head from one manometer to another. The tubing must fit tightly in the bottom of the PVC frame to prevent leaks. We used tubing with an outside diameter of 5/8-inch that fit tight enough that we did not have to use any sealant. We did not glue the manometers into the 90° elbows so that they can be removed for easier storage. The 3/4-inch threads at the top of the apparatus allow a garden hose to be used as the input, but other types of connections might be more appropriate, depending on your lab facilities. The upper valve can be used to control the inflow volume, and thus initial head pressure. Discharge can easily be measured at the outflow point by timing how long it takes to fill a container of known volume. The lower valve is useful because it can be closed at the start of an experiment and the chamber flooded to ensure the sediment is completely saturated, then opened for the experimental run. We used silk-screen cloth sandwiched between screen-door mesh at the lower end to keep sediment in the chamber. Small amounts of medium and fine sand are lost through the mesh, but we felt it was more important not to restrict flow. Although only two manometers are needed, we found the addition of the third to be useful. It allows us to fill the apparatus with two layers of different sediment and observe two different piezometric gradients. We also found that the size of this device makes it difficult to force water through such a long section of fine material. When we use sand we fill the chamber only past the middle manometer, reducing the column length. If you plan to use mostly low permeable material, we recommend you scale down the size of your apparatus to reduce the column length.

Although we are unaware of any commercial versions, brief Internet searches indicate we are not the first to build our own. Despite the rather complex drawing accompanying this piece, it's a simple and inexpensive item to construct, costing about $32.

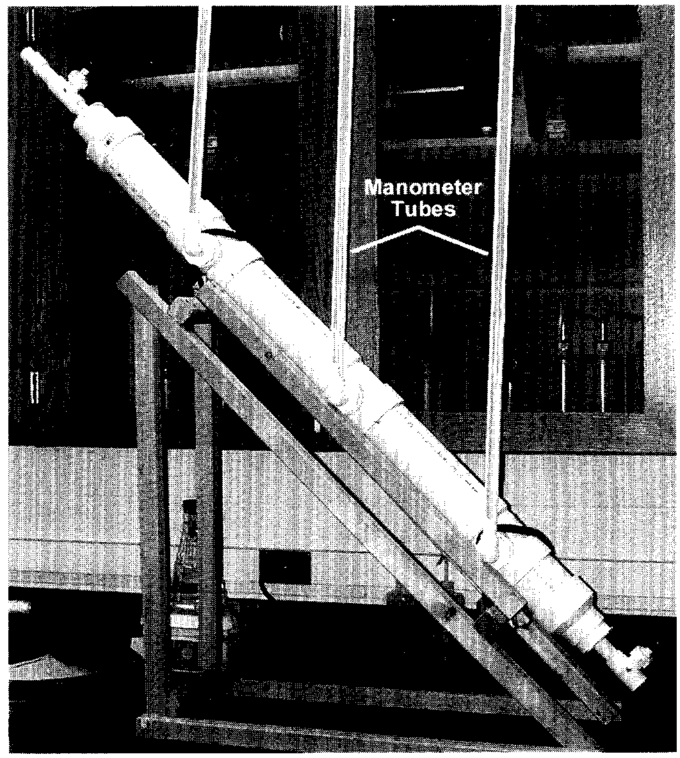

Figure 5. *Darcy apparatus. Shown here attached to a wood frame constructed of 2x2 lumber. The short wood strip is used to brace the PVC elbows and stabilize the device. A hose is attached to the top end and water discharges into a sink at the bottom.*

Equipment Protection and Maintenance

Chest Waders Dryer

Because students often bend over too far when standing in deep water, a dryer for chest and hip waders is useful. Although there are commercial versions available, we choose to build our own (Figure 7) largely based on cost and the ability to customize the design to our needs. The dryer splits an air supply into two tubes over which boots or waders are hung. The power source is a hair dryer and the legs are 1-inch and 2-inch PVC pipes and connectors mounted on a 2x6 lumber base. The legs were made long enough to dry chest waders as well as hip waders. The lower portion of the legs is thicker to add rigidity, and the upper parts are narrow to make it easier to fit the boots over them. The 90° elbows at the top are so the boots do not plug up the hole and so air is sure to circulate into the toe of the boot. The legs are not glued at the base so the unit can be disassembled and stored more easily. The wooden box forming the base protects the hair dryer from being kicked, and adds sufficient weight so the unit does not tip over. The PVC components cost about $12 and the single biggest factor controlling the cost is in the selection of a hair dryer or other air source.

Discussion and Conclusions

We have provided here several designs for equipment that can be used in projects for physical geography or earth science courses offered in high schools and colleges. We believe strongly in the value of experience-based projects in order to get students involved in the topics covered in these courses. There are two ways of providing this

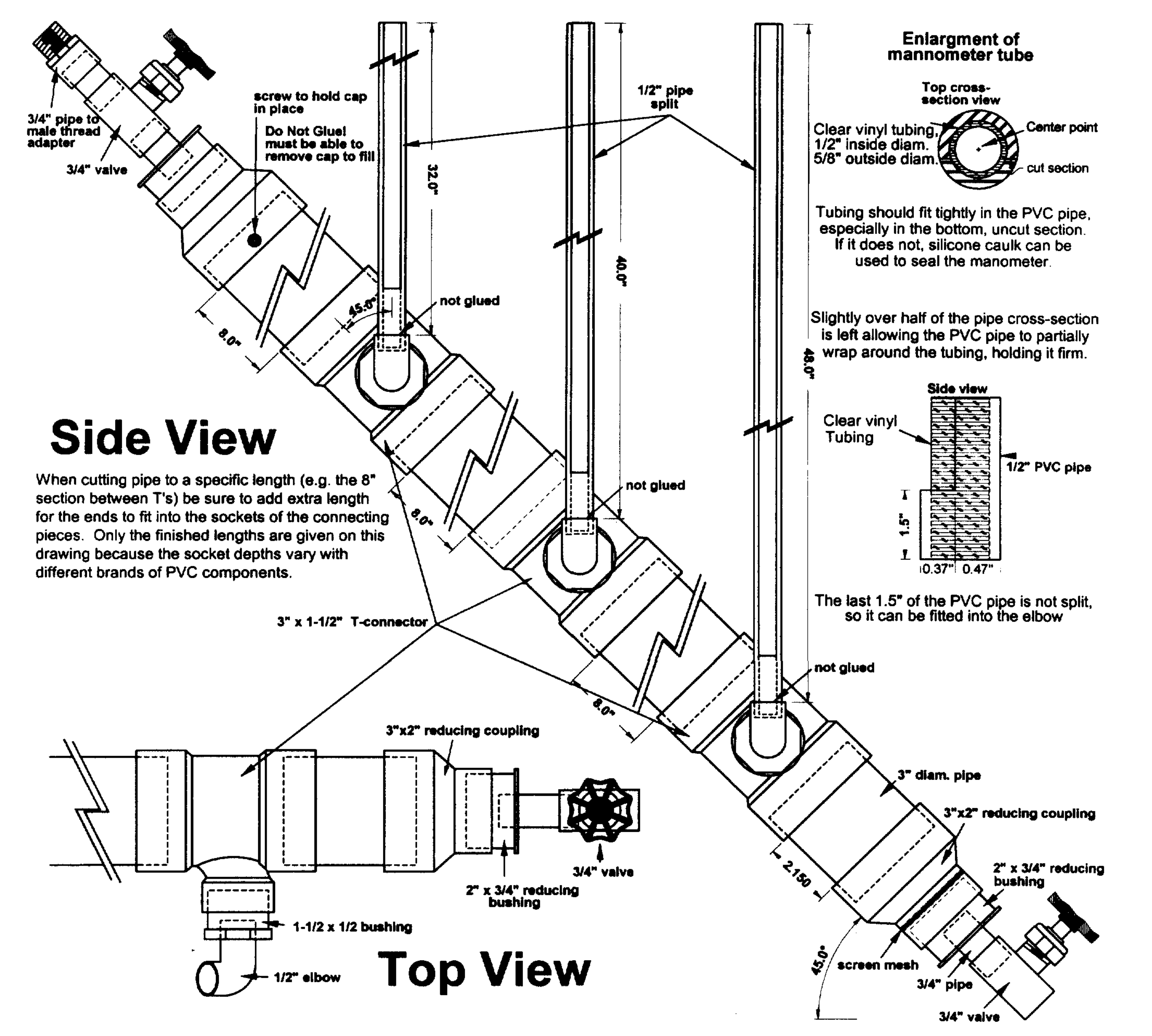

Figure 6. Drawing of the Darcy Apparatus. This model is designed to rest at 45° on a wood frame. The mesh at the lower end is held in place between the 2"x3/4" bushing and the 3"x2" reducer.

experience, through laboratory exercises that simulate the real world and through field research. One advantage of using exercises to accomplish this goal is that this provides students with an understanding of what scientific research is all about (Kent and Gilbertson 1997). However, it is often difficult to undertake research projects because of the lack of equipment or because the necessary equipment is too expensive. We believe that these problems can be overcome with creative self-built items that limit expense.

There are cases where laboratory demonstrations of physical phenomena provide the students with a better learning experience than they would get through an oral description. That experience, of course, has been the purpose of laboratories in physical science for ages. In geomorphology, it is difficult to replicate nature because of scaling issues, but things like stream tables have been used in physical geography lab demonstrations (Wikle and Lightfoot 1997), and flumes or wind tunnels are used for graduate student research (Nickling and McKenna-Newman 1997). The Darcy apparatus presented here also fulfills the role of a demonstration device, but like the flumes, it can be used in experiments to test certain conditions. We have developed a laboratory exercise around this device in which students solve the Darcy equation (see Bras 1990 or any groundwater hydrology text) for hydraulic conductivity for three sediment types and discuss the rea-

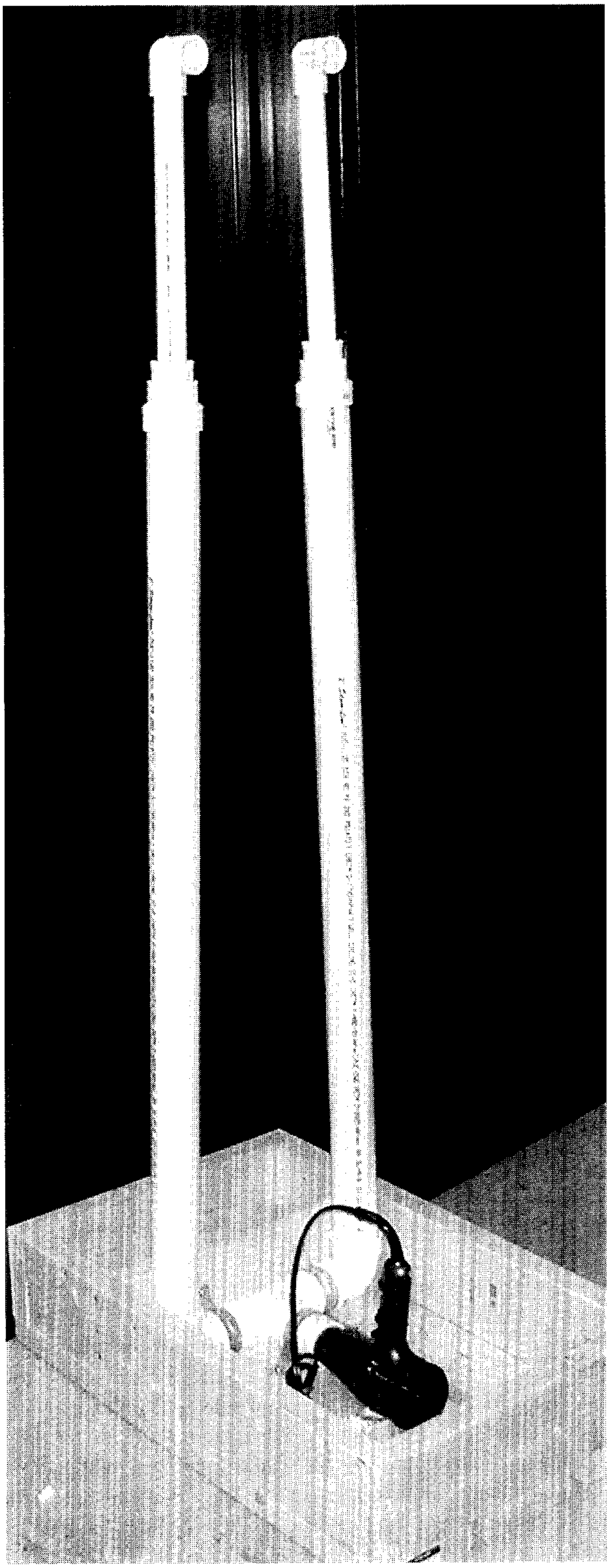

Figure 7. *Chest/hip waders dryer. This simple design is driven by a $12 hair dryer. Waders or boots are draped upside down over the legs.*

sons for the differences. They are also given the manometer and discharge values for a fourth, unknown sample and asked to characterize the sediment relative to what they learned about permeability in the earlier runs. We can imagine that there are other devices that could be similarly developed for laboratory demonstration around which exercises could be devised to give the students a feel for scientific experimentation.

Given the rising cost of field and laboratory equipment, and the dwindling budgets of most universities and secondary schools, we believe it is becoming increasingly necessary for instructors and researchers to find less expensive alternatives to many commercial products. We have presented design plans for four items that we have built to solve some of our equipment needs, and in a following paper in this journal we will present additional, field-based equipment ideas. If you do not find these projects of use, we at least hope they inspire ideas that will solve some of your equipment shortages. And if you come up with something good, please return and favor and let us know. We're always looking for new ideas ourselves.

Acknowledgments

Thanks to BJ Grieve for his significant contribution to the design and construction of the chest waders dryer. We thank Derek Alderman for initial discussions about the content of this paper and for subsequent improvements resulting from his review of an early draft. This paper is contribution number 54 to the Tobacco Road Research Team.

References

Bras, R.L. 1990. *Hydrology: An Introduction to Hydrologic Science*. Reading, MA: Addison-Wesley.

Clark, D. 1996. The changing national context of fieldwork in geography, *Journal of Geography in Higher Education* 20(3):385–392.

Fuller, I., S. Rawlinson, and R. Bevan. 2000. Evaluation of student learning experiences in physical geography fieldwork: Paddling or pedagogy? *Journal of Geography in Higher Education* 24(2):199–216.

Higgitt, M. 1996. Addressing the new agenda for fieldwork in higher education, *Journal of Geography in Higher Education* 20(3):391–399.

Jenkins, A. 1994. Thirteen ways of doing fieldwork with large classes/more students, *Journal of Geography in Higher Education* 18(2):143–155.

Jernigan, H. D., and J. P. Murray. 1974. Methods for providing and using field equipment, *The American Biology Teacher* 36(8):468–473.

Kempa, R., and N. Orion. 1996. Students' perception of co-operative learning in earth science fieldwork, *Research in Science & Technological Education* 14(1):33–42.

Kent, M., and D.Gilbertson. 1997. Fieldwork in geography teaching: A critical review of the literature and approaches, *Journal of Geography in Higher Education* 21(3):313–332.

Nairn, K., D. Higgit, and D. Vanneste. 2000. International perspectives on fieldcourses, *Journal of Geography in Higher Education* 24(2):246–254.

Nickling, W. G., and C. McKenna-Newman. 1997. Wind tunnel evaluation of a wedge-shaped aeolian sediment trap, *Geomorphology* 18:333–345.

Sane, K. 1999. Cost-effective science education in the 21st century – the role of educational technology, *Pure and Applied Chemistry* 71(6):999–1006.

Tinsley, H. 1996. Training undergraduates for self-directed field research projects in physical geography: Problems and possible solutions symposium, *Journal of Geography in Higher Education* 20(1):55–65.

Wikle, T., and D. Lightfoot. 1997. The stream table in physical geography instruction, *Journal of Geography* 96(1):23–30.