Rainwater Harvesting for Domestic Water Supply in Developing Countries: A Literature Survey

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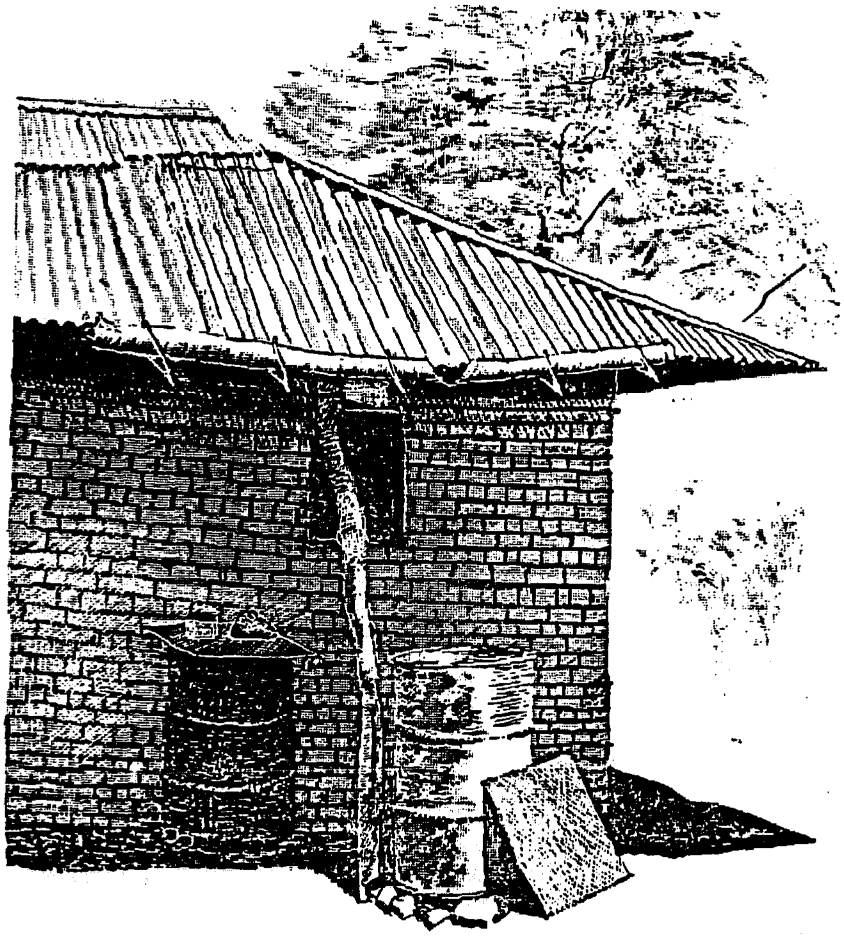

Drawing from White et al, 1972, by permission

RAINWATER HARVESTING FOR DOMESTIC WATER SUPPLY IN DEVELOPING COUNTRIES: A LITERATURE SURVEY

ABSTRACT

Interest in rainwater harvesting ("RWH") for water supply in developing countries has grown with interest in supporting locally organized and implemented efforts to meet basic human needs. RWH is an attractive way of increasing the quantity of water available for household use in areas with water shortages. Catchments using existing roof structures and surfaces, in combination with self-help built storage containers, represent a particularly promising approach. The literature is reviewed; publications most useful to prospective designers and implementors of RWH projects are identified. Feasibility and costs assessment guidelines for simple RWH systems are given. Construction of selected catchment and storage technologies is described. When a small existing roof is used for catchment, several gallons per day could be provided for at least part of the dry season in central Africa, at a cost (for self-help construction of the storage tank) of under US$ 100. Costs of tanks with effective covers may be reduced by applying or modifying traditional storage techniques or planning storage into construction of new buildings.

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1. Introduction

Effective rainwater harvesting (RWH") techniques have been known and practiced for thousands of years in many areas of the world. Today there is a rapid increase in interest in the potnetial of RWH for water supply, as development assistance groups devote more and more attention to small-scale, locally-implemented projects for meeting basic human needs.

This high level of interest should not be surprising. As an option for development of water resources, RWH presents a number of advantages. It is a way to increase the quantity of water available to households on an incremental basis; it does not require mobilizing vast quantities of resources, all at once, to import the materials and expertise involved in planning and building large complex systems. In combination with sanitation or other projects, RWH planning and construction can serve as the focus for community organization efforts. RWH relies and builds upon local skills and experiences in construction, water consumption, and rainfall patterns. And when proven techniques are combined imaginatively with local structures and materials, RWH systems can be relatively low in capital cost. For example, in southern Chad, * an existing sheet metal or tile roof with a plan area of 30 m^2, guttering made and hung with local wood and fiber, and three tanks made of traditional baskets and cement mortar, could be built at a cash cost of about US$ 80 (assuming

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* see section 4.1

self-help labor)**. This system would provide several gallons of water per day for much of the year, substantially improving a family's water supply situation during at least a part of the dry season. Use of locally-available containers to replace or supplement the cement mortar tanks might reduce costs a great deal. And if water storage could be planned and built into a new public facility such as a school or health center, a much larger supply might be developed for a relatively small increment in construction costs.

Finally, RWH may be the only way to increase availability of water where ground and surface supplies cannot be developed further.

Why has the great potential of RWH only recently come to the attention of an international audience of development planners and practitioners? Answers to this question lie in the traditional structure and administration of development assistance. International assistance bodies and national development planning authorities, each striving for broad-scale impact within the short term, have tended to devote their resources to water supply technologies and projects they can design centrally and implement regionally or nationally. While a history of failures indicates that this is not the most effective strategy for meeting water needs, it has nevertheless been the tendency if not the rule. Successful RWH programs, on the other hand, would clearly depend

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**assuming a cement price of US$ 5.00 and less than 10% of total expenditures for sand and gravel. See section 4.2.

on local considerations: climate, participation of users, building styles, materials, and skills.

Another reason for the historical lack of interest in RWH is that the systems are simple, requiring neither the imported technology nor experts which international development assistance organizations are set up to provide.

These characteristics of RWH, however, are precisely the features which have aroused the interest of individuals and groups committed to supporting locally-organized efforts with concrete, acheiveable goals. While providing planning assistance and funds for such projects will present challenges for many organizations, the potential benefits--in increased quantity of convenient, clean water for people in many areas--call for a close look at the range of RWH techniques. The rest of this paper is an attempt to survey the field by reviewing literature and identifying published accounts of greatest value for planning and assessing RWH systems. An additional objective is to identify and describe the construction of a few of the most promising and widely applicable of the catchment and storage techniques identified in the literature survey.

2. OVERVIEW

2.1 The Range of Rainwater Catchment Technique

Rainwater harvesting -- like any other kind of water supply -- is a means of taking water out of the hydrologic cycle for some human or productive use. Most water supply strategies interrupt the cycle after the water is on or in the ground, diverting water out of streams or pumping it up from below the surface. In rainwater harvesting, the water is intercepted as it falls.

Rainwater harvesting is an attractive alternative for water supply in many areas where other sources are in short supply, but it would seem to make particular sense in arid regions where most rainfall is lost to any kind of use because it is held only briefly in parched soil and evaporates, returning directly to the atmosphere. (Myers, 1962).

Rain is a diffuse source of water in the same way that sunlight is a diffuse source of energy; but, also like sunlight, it is (usually) relatively clean, and it can be collected and stored until it is available in useful quantities.

The range of water harvesting approaches and applications is tremendous, spaning a broad spectrum of technologies and a considerable reach of human history. Furrows in the soil surface were used in ancient Israel and are used today in Australia (now called "road catchments") to provide water for agriculture. In Roman times, cisterns varying in capacity from 30 to 3,000 m^3 were excavated out of soft limestone and filled with surface water diverted off of hillsides (Davis, 1963). Certain tree trunks, when hollowed out, can hold a considerable volume of water caught from flow down the tree branches.

In general, rainwater harvesting can be defined as "the process of collecting natural precipitation from prepared watersheds for beneficial use" (Currier, 1973). In practice, most RWH schemes can be understood as systems with two basic components: 1) a surface or "catchment" for collecting rain and channeling a flow of water, and 2) some kind of reservoir for receiving the water from the catchment and holding it for use or distribution. There are many possible ways of classifying and organizing RWH systems for purposes of description and analysis. Systems can be classified according to the broad type of catchment surface employed: untreated soil, treated soil, or artificial sheet material. Often RWH systems are called "ground catechments" or "roof catchments" according to the elevation of the catchment surface. Sometimes it is useful to distinguish between systems in which the surface of stored water is below the ground (e.g. in a buried tank) or, alternatively, above the ground (as in a jar). These categories often overlap and intermingle in practice. For example, rooftop catchment surfaces may feed above-ground tanks, buried tanks, open ponds, or all three; and conversely, underground tanks may collect water from treated or untreated soil surfaces or, on the other hand, from some kind of roof.

2.2 Implications of Type of Use for Choice of Techniques

Survey of the literature on techniques and applications suggests that establishing categories of intended use (e.g. domestic use vs. agricultural use) is helpful. The nature and requirements of the use then indicate certain techniques as preferable to other alternatives. For example, agricultural uses--water for stock watering or for irrigation -- call for large quantities of water, with quality less of a concern. Clearly large catchment areas are required and the ground surface is the obvious choice. Since color and clarity are not important, any of a wide variety of physical and chemical soil treatments, easily applied over large expanses of ground, may be considered. Tanks without covers will often be chosen to reduce costs.

On the other hand, water for domestic use should be cleaner and more convenient than agricultural water. Roofs are an obvious choice for a catchment surface as their elevation protects them from many of the sources of contamination and damage which plague ground surface catchments. Tanks built into or adjacent to homes and public buildings mean that the distribution point is convenient. Public health considerations usually dictate some kind of cover for tanks, which reduces evaporation and means they can be built smaller yet support thesame rate of consumption provided by larger, uncovered tanks.

Thus the nature of domestic use indicates rooftop catchments and tanks in or near buildings, for RWH schemes for domestic water supply. Obviously this will not always be true, and this report will describe domestic supply schemes with ground-surface catchments and open/underground tanks (e.g. Maikano and Nyberg, 1980; Ionides, et al., 1969). In many areas, lack of suitable roofing materials will stand in the way of rooftop catchment, at least until alternativeroofing is available. But where suitable roofs exist -- and few areas are entirely without some impermeable roofing, at least atop public facilities -- the catchment structure and surface are paid for, and available cash and effort can be invested in adequate guttering, foul flush systems, and tanks for storage. Additionally, rooftop catchment systems do not involve the all-out mobilization of labor required by most community ground-surface catchment systems (Farrar and Pacey, 1974; Grover, 1971). Village water supply can improve incrementally with catchment systems, each requiring a small up-front cash outlay, undertaken one at a time.

2.3 Rooftop Catchments for Household and Small Community Water Supply in Developing Countries

This report, then, will focus on rooftop catchment systems which have been used in developing countries. Ground-surface catchment techniques will not be ignored; rather, they will be surveyed and considered for their potential applications for low-cost domestic water supply.

In addition to scarcities of capital and lack of access to many kinds of modern industrial expertise, here are listed conditions, some of which are prevalent in many developing countries, relevant to RWH as a local-level water supply option:

a. tropical and subtropical climates: marked wet and dry seasons; rainfall coming in short, torrential bursts; very high potential evaporation rates, often exceeding 2 m per year (Grove, 1978).

b. soils which dry out and crack during sustained dry periods, reducing the capacity of soil horizons to absorb and retain water and limiting groundwater recharge (Myers, 1962); satisfactory groundwater sources often too deep to develop using available human or animal power, and too expensive to develop using imported engine-driven pumps.

c. dangers of waterborne and other infectious diseases wherever water is ponded or stored in the open.

d. rural proverty with corresponding nutrition deficits; lack of experience in organizing for community public works.

3. LITERATURE REVIEW AND BIBLIOGRAPHY

3.1 Broad Concerns and Basic Constraints in Rainwater Harvesting

3.1.1 Rainfall patterns

Rainfall is random and even sporadic in occurrance. This is especially true in continental climatic regimes; (Grove, 1978) notes that for Africa as a whole, rainfall totals will be within 10% of averagfe in only about 4 of 10 years. In effect, this means that there is some likelihood during any given year of at least moderate drought. Grove (1978) says that observers in East Africa contend that most of the rain in that area falls "in a few spells lasting about a week". Thus, even during the rainy seasons, there may be dry periods of considerable length.

Even in climates moderated by nearby bodies of water, the amount and frequency of rainfall during any given month or year can beexpected to depart from the norm represented by averagfe precipitation statistics.

What does this imply for water supplies from simple rainwater catchment systems? At a minimum, an addition of relatively clean water during rainy periods can be expected. In areas with high rainfall totals and short dry seasons, having rainwater for household use in some kind of simple above-ground container may be a significant advance over using groundwater polluted by interaction of near-surface wastes and high water table.

With investments in storage capacity, water could be provided during periods of rain and some water would be available during parts of dry periods. Larger investments in storage (and possibly catchment area as well) could make water available throughout dry periods, although this would be impracticably expensive in many rural areas (see section 4.1, "Using Rainfall Data to Design a RWH System").

3.12 Needs

The value of achievable improvements in water available through RWH must be measured against local water needs. It could be that during wet months, there is agreement that water is adequate in quantity, quality, and convenience. In such a case there would be little to be gained by channeling water from rooftops into small containers; real gains would only be made if larger storage tanks could provide for more water during the dry months.

Local peoples' perceptions of their needs may also differ with those of outside evaluators. For example, it could be that from a public health point of view, abundant water in puddles and ponds should not be drunk, and that rainwater collected in jars would be preferable. Local people, on the other hand, may be accustomed to water from open sources and see little point in investing in cleaner drinking water.

3.1.3 Costs and comparisons with alternatives

Implicit in the above discussion is the need to calculate the costs of a proposed RWH system, and examine those costs and related benefits in light of the feasibility of other kinds of water supply improvements. Discussion of benefit/cost comparison techniques for water supply is outside the scope of this report, but a few basic observations can be made. White et al (1972) have generalized that construction and financing costs of individual RWH systems are substantially higher, on a per head basis, than simple community improvements such as standpipes and community wells. They estimate a per capita construction cost of US $15 for cisterns, as compared with US $7 per capita for community wells (East Africa, 1972). However, White et al (1972) also point out that greater dispersion of settlement and aridity of climate each tend to work to raise the per capita costs of any kind of water supply improvement: "The range of costs is (decreasing) from arid dispersed environments to humid nucleated areas" (page 88). Thus in many climatic and settlement regimes the cost advantege of standpipes and wells may disappear; and indeed in some areas there may be no practicable means for providing such community improvements.

Parker (1973), Farrar and Pacey (1974), and Grover (1971) have each made observations as to the conditions which favor simple RWH systems in comparison with alternatives. RWH will be relatively attractive:

a. where the barriers to organzing and providing large amounts of labor (for self-help community systems) are high;

b. where capital for water supply improvements can be made available only in small amounts;

c. where the community organizational infrastructure does not exist to arrange financing, construction, or maintenance of community sytems;

d. where settlement patterns are dispersed;

e. where impervious roofing surfaces are in use.

In a particular situation the cost advantage of simple RWH systems over other alternatives will also depend on availabilities of materials, skills, cash, and/or financial assistance. Actual costs of catchment and storag depend on what existing structures (such as roofs) can be used, the local prices of the building materials which must be purchased to build the remaining parts of the system, and expenditures for labor (although in this report, discussions of costs will assume self-help labor). Specific cost estimates for storage and catchment technologies are included in the following sections, and rough materials cost estimates for a proposed system can be calculated using the guidelines in section 4. It is worthwhile, though, to make some general observations:

a. most of the materials cost involved in building rooftop catchment systems goes into providing storage (the term "tank" will be used in this report) which does not leak and protects water quality. The most common materials used are combinations of cement, sand, gravel, bricks, stones, steel rod or wire, and steel netting ("chickenwire").

b. the costs of storage in tanks, as measured in materials cost per cubic meter (m^3) of water capacity, vary widely. Among the tanks included in this report, cost/m^3 ranges from under US $ 1.00/m^3 for a proposed salt-lined open reservoir system in Mali (Cluff, 1975) to US $30.00/$m^3$ or more for manufactured "tin" tanks for rooftop catchment in Eastern Africa (White et al, 1972).

c. as tanks increase in volume, their ratio of wall and cover area to capacity decreases. Thus larger tanks will tend to have lower materials costs per m_3 of capacity.

d. however, large tanks built with manufactured or imported materials may cost more per m^3 than smaller tanks built with locally available materials (see chart, page 59).

e. "family-sized" tanks, built with cement mortar and a variety of other materials, can be built for costs of US $8.00-15.00/$m^3$ (1982) in developing countries.

3.14 Maintenance and Public Health

The objective of maintenance, of course, is to keep the system working (collecting rainwater) and, at the same time, see that the quality of the water provided is as high as possible. Achieving these goals requires attention to each of the processes which transmit water from the atmosphere to the user: contact with the catchment surface, transport in some kind of channel to the tank, residence in the tank, and delivery.

Rooftop catchment surfaces collect dust, vegetable matter, and bird droppings which can clog transport channels to the tank, cause rapid sediment buildup on the tank bottom, and in some cases) contaminate the water stored in the tank. Gutters and downpipes (used to transport water from the edge of the roof to the tank) must be cleaned frequently so that they will not overflow during heavy rain. A bigger problem is consistently diverting the dirty water which "washes" the roof at the beginning of each storm so that it will not contaminate stored water in the tank, and subsequently allowing clean water to flow into the tank. In Java, where steel-reinforced cement motor tanks are being built by the hundreds (Winarto, 1981; Pompe et al, 1982), the bamboo trough from the gutters to the tank inlet is propped away from the inlet hole until after the first few minutes of rain. When the roof is clean, it is moved into position over the inlet screen by a child. This scheme has no mechanism to break down, and the household is always aware of the precise time of the beginning of the rain because washed clothes hanging out to dry must be brought indoors. A variation on this simple but effective strategy, when smaller tanks are used without downspouts, is to move the tank into position or uncover it after the roof is clean (see the drawing on the cover sheet).

Other arrangements have been devised which require some kind of addition to the trough or downpipe from the gutters to the tank. These include a tipping funnel mounted under the gutter outflow (UNEP, 19079), "butterfly valves" (Dooley, 1978) which are turned manually after the roof is cleaned, and "roofwashers", in the first "foul flush" is collected in a container. These various devices all require cleaning and repair, and moving the flow of water into position when the roof is clean often easier and almost always cheaper. Techniques for fastening downpipes and a variety of "foul flush" devices are described in more detail in section 3.2.3.

Filters of sand, gravel and charcoal are often suggested as a way of keeping sediment and contaminants out of large cisterns (e.g. Office of Water Programs/EPA, 1974; VITA, 1977). The designs usually show a small concrete box atop the cistern cover, which in turn has a removable cover for cleaning. Such filters require frequent inspection and flushing to prevent dangerous bacterial buildup on the filtering grains. Because of this high maintenance requirement, Henderson et al (1973) recommend against use of a filter with cisterns and suggest that an effective "foul flush" system be installed in the downpipe instead. Farrar and Pacey (1974) question the effectiveness of sand as a filter when the flow of water through it is intermittent. Our conclusion is that it is better to invest available resources and effort in keeping the "foul flush" out of the tank than in filters.

The maintenance requirements of the tank itself will depend to a large extent on the effectiveness of roof, gutter, and downpipe cleaning, as well as the practicality of the "foul flush" system. The other important factor in tank maintenance is the quality of the tank cover and screening on any inlet and outlet holes. If sunlight reaches the water its temperature rises and algae grow.

Unprotected openings bring mosquito breeding, particularly dangerous in malarial areas where tanks are located near homes. But regardless of the quality of the cover and screening, all tanks need to have sediment scooped out and walls scrubbed. "Heaven's water..." (1980) suggests vinegar, baking soda, and chlorine bleach solutions as cleaning agents. Any cleaning material can be used to remove scum from tank walls as long as it would not contaminate the new charge of water.

Any tank's access hole or tap area must be kept clean and well drained. Cracks in mortar should be replastered after each cleaning of the inside surface.

A pump, if used to lift water out of a tank, has substantial maintenance requirements of its own.

The maintenance requirements of ground surface catchment systems are broadly similar to those of rooftop catchment systems. "Foul flush" devices are not used; sometimes sedimentation basins near the outflow of the catchment area (e.g. Maikano and Nyberg, 1980) are used instead. Ground surface catchments are vulnerable to contamination and damage caused by human and animal traffic. Ionides et al (1969) and Grover (1971) propose fencing catchment areas to keep all such traffic off the surface, but this would be expensive and ineffective in many areas. Maikano and Nyberg (1980) say that traditional grain threshing floors used a catchment surfaces in Botswana could be fenced inexpensively, possibly using tree branches.

A general point to be made about the maintenance of ground surface catchment systems which serve a group of families is that some degree of community organization is required. By contrast, maintenance of household rooftop catchment systems requires no such commitments.

A summary of key maintenance considerations follows:

1. Any RWH system has catchment, channeling, storage, and delivery components which must be given frequent attention.

2. Community systems require community organization for effective maintenance; household systems require a correspondingly smaller scale of organization.

3. Rooftop catchment surfaces have the advantage of not being vulnerable to human and animal traffic which causes contamination and damage to ground suface catchments.

4. A procedure or device for keeping the "foul flush" out of the tank deserves particular attention.

5. Gutters and downpipes must be inspected and cleaned especially carefully.

6. Any tank needs periodic cleaning. Its design should take this fact into account.

3.1.5 Publications and how to obtain them +++

Commission on International Relations/NAS, 1974, More Water for Arid Lands: Promising Technologies and Research Opportunities, book, 154 pages, mention name of your group or insitutional affiliation when requesting a free copy from BOSTIC (JH215), Office of the Foreigh Secretary, National Academy of SCiences, 2101 Constituion AVenue, Washington, D.C. 20418, USA.

Still useful and provocative after 8 years in print, this overview is divided in two halves, "water supply" and "water conservation". Topics: runoff agriculture, reuse of water, reducing evaporation from water and soil surfaces, trickle irrigation, selecting water-efficient crops, and others. The chapter on rainwater harvesting dislcusses techniques and research in Australia, Zimbabwe, and the western U.S., as well as the ancient gravel mounds and strips used to harvest rainwter from hillsides in the Negev 4000 years ago. Includes good photographs of the "sand-sausage" tanks described in Ionides et al (1969) and Farrar and Pacey (1974), and section 3.3.4 (below).

Frasier, G.W., and Myers, L.E., (?), in preparation, a handbook on rainwater harvesting with parts devoted to domestic water supply. Will be published as a USDA handbook, available from the Superintendedt of Documents, Washington, D.C., in 1983. For further information contact Dr. Frasier (see section 3.2.4).

Hofkes, E.H., ed., 1981, Small Community Water Supplies, Technical Paper no. 18, IRC/WHO, book, 413 pages, request a free copy from IRC, P.O. Box 5500, 2280 HM RIJSWIJK, The Netherlands.

"A handbook/source document on technology of small community water supply systems". This useful overview contains a 12-page section which is probably the best short published summary of rainwater as a source of domestic water supply that we have seen. Includes good drawings of an underground rainwater storage well (as used in China) and a venetian cistern. Bibliography of 12 items.

IRC says that the editor is currently working on a "design manual for RWH systems".

+++here, as in sections 3.2.4 and 3.3.6, much of the access information has been taken from Darrow and Pam (1976) and Darrow et al (1981).

ITDG, in preparation, "a practical manual describing rainwater harvesting techniques as an option for water supply." This book will probably not be available until late 1983, but the consistens quality of ITDG publications leads us to believe that it will be well-researched and useful to a broad range of workers. "The emphasis will be on low-cost systems for small communities and the scope will cover the provision of water for domestic and agricultural purposes. The manual is intended for use by project holders and field workers and consequently is planned to include, wherever possible, practical information derived from experience in the field. In order to achieve this objective ITDG is anxious to make contact with field personnel who would be willing to share something of their experiences--successes and failures." (personal communication, Adrian Cullis, ITDG.) Write to Ms. Cullis at: Applied Research Section, Shinfield Road, Reading, Berkshire RG2 9BE, United Kingdom.

White, G.F., Bradley, D.J., and White, A.U., 1972, *Drawers of Water: Domestic Water Supply in East Africa*, book, 306 pages, US$16 (clothbound) from University of Chicago Press, 11030 S. Langley, Chicago, Illinois 60628 USA.

An effective, carefully assembled overview of domestic water supply in the developing tropics, of interest to a broad range of workers involved in the formulation of water supply strategies. Of particular interest: analysis of basic types of water improvements and their varying applicability over the range of environments and settlement patterns in East Africa, where the authors studied from 1965-68. A key source for planners, containing lessons and insights relevant to much of the developing world.

3.2 Catchment technologies

3.2.1 Surfaces and materials.

Roofing materials. In many areas where rooftop rainwater catchment might be an attractive option, existing roofs with clearly suitable surfaces are rare. This section outlines some of the most promising of recent developments in low-cost, impervious roofing for developing countries.

The "conventional" materials of choice for impervious roofs in developing countries are usually corrugated galvanized metal sheet (variously called "tin", "galvanized", "iron sheet", "zincpan", etc.) , fired tile, and "asbestos" sheet. Manufactured metal sheet is light in weight, easy to install, and sheds water better than the other alternatives; it is also, however, expensive or altogether unavailable in many isolated areas where rooftop catchment might be most appealing. Tile is fairly impervious but its manufacture requires a source of good clay soil and fuel for firing; it is also substantially heavier than most other materials. Manufactured corrugated asbestos sheet is strong and light in weight, but like metal sheet, expensive and often practically unavailable (Hofkes, see section 3.1.5, suggests that certain asbestos roofing materials may shed asbestos fibers into the runoff).

"Traditional" materials may have some potential as rain-shedding surfaces for roofs which can be guttered. McDowell (1976; see section 3.3.6) reports that thatched roofs have been guttered with polyethylene and that the water from the roof is potable (some sources question the potability of water collected from thatch surfaces). Hall (1981; see section 3.2.4) discusses thatching materials and techniques, emphasizing the cost-effectiveness and broad potnetial of a traditional technology. The durability of thatch has been widely questioned; public-health-minded investigators often express concern over thatch as a breeding place for insects and even rhodents.

The fabrication of rain-shedding shingles from coconut tree trunks is an example of the use of local materials which might fit well in a rooftop catchment system.

Fibre reinforced cement ("FRC") corrugated sheets, and processes for local-level fabrication in developing countries, have received considerable attention (UNIDO, 1978; Parry, 1981; I.T. Building Materials Workshop; see entries in section 3.2.4). UNIDO estimates that at a cement price of US$5 per 50-kg bag, FRC sheets reinforced with sisal fibers could be fabricated for a materials cost of about $\$0.90/m^2$ in many developing countries (1978). Parry (1981), reporting on the pioneering work on small-scale manufacturing technologies for FRC sheet, says that "By comparison with the conventional alternatives, if production labour costs are counted, fibre cement roofing components generally turn out to be: 1) Between one-third and one-quarter the cost of asbestos cement roofing sheets and requiring a similar roof structure. 2) Slightly more expensive than locally-produced traditional clay tiles but requiring a mcuh simpler and cheaper roof structure. 3) About three-quarters the cost of galvanized corrugated iron sheets and requiring similar or slightly more expensive roof structures. 4) About the same cost as medium quality traditional thatch where materilas have to be bought commercially by house builders, but with a similar roof structure. If made and supplied on a self-help basis with labour costs not counted, the FRC roofing products would frequently work out as the cheapest roofing of all."

Parry also emphasizes the importance of proper tools and adequate training in the methods for successful manufacture. FRC sheets (made under carefully controlled conditions) in natural exposure tests show no deterioration after four years.

A variety of natural fibers, which are usually mixed with the cement or placed manually as the sheets are cast, can be used in FRC sheets. Coconut hull fibers ("ijuk") are being tested in Indonesia at the Development Technology Institute, Bandung (Anshori Jausal, personal communication). Crushed bamboo culm is apparently another alternative.

The mechanical forming of waste fiber into boards, which are then soaked in an asphalt bath, is one of many techniqeus being investigated in India.

NAS (1974; see Roofing in Developing Countries , section 3.2.4) provides an overview of new roofing technologies. Development of more effective low-cost roofing is one of the keys to the broad-scale feasibility of rooftop catchment schemes in developing countries.

Ground Surfaces. Grover (1971, page 52) offers a useful list of the range of ground surface catchment tecnologies:

> "a. Clearing sloping surfaces of vegetation and loose material,
> b. Improving vegetation management by changing ground cover,
> c. Mechanical treatments, such as smoothing and compacting the surface,
> d. Reducing soil permeability by the application of chemicals,
> e. surface-binding treatments to permeate and seal the surface,
> f. Covering the catchment with a rigid surface, and
> g. Covering the catchment with a flexible surface."

With its emphasis on rooftop catchment, this report will devote relatively little space to ground surface catchments. We hope to indicate the range of possibilities and the kinds of investigations into a very broad and widely-researched topic.

The lowest-cost alternative in ground catchment is, of course, a traditional one--the diversion of runoff from completely unprepared ground surfaces. This is how "hafirs" fill in the Sudan; Ionides et al (1969) describe a strategy for locating "sand-sausage" tanks in Botswana which took advantage of the collecting effect of road tracks. The "efficiency" (ratio of collected runoff to rainfall) of unprepared ground surfaces may be no more than about 5% (Lauritzen, 1961; Cluff, 1974).

A variety of materials and treatments can improve efficiency of ground-surface catchments. Myers (1974, page 3) provides a list of "desirable characteristics for materials for catchment aprons...:

1. Runoff from the structure must be nontoxic to man and animals.
2. The surface of the structure should be smooth and impermeable to water.
3. The structure should have high resistance to weathering damage and should not deteriorate because of internal chemical or physical processes such as crystallization.
4. The structure need not have great mechanical strength but should be able to resist damage by hail or intense rainfall, wind, occasional animal traffic, moderate flow of water, plant growth, insects, birds, and burrowing animals.
5. The materials used should be inexpensive, on an annual cost basis, and should permit minimum site preparation and construction costs.
6. Maintenance procedures should be simple and inexpensive."

AVailable materials and treatments meet some (and fail to meet others) of these specifications. Steel (Lauritzen, 1967) has the obvious drawback of great expense; butyl (Lauritzen and Thayer, 1966; Bradley, 1967) is also expensive and may impart a noticeable, if harmless, color to water. Paraffin may be "the most promising of all the chemical treatments tested. Paraffin is cheap, easily applied, and its life expectancy is at least five years when applied to a sandy soil" (Eshenaur, 1982). Application of sodium salts, to reduce seepage on catchment surfaces and in reservoir banks (e.g. Cluff, 1975) is low in cost but relatively short-lived and dependent in effectiveness on soil composition. Sprayed asphalt has been widely considered and proposed (Frasier, 1975; see section 3.2.4). Asphalt, after weathering, also tends to impart a dark coloring to water which might be eliminated by spraying with one of a variety of treatments. Grover (1971) proposed such a sprayed asphalt catchment for a community rainwtaer harvesting scheme in Kenya.

The University of Arizona, U.S.A., has been a center for research into ground surface catchments, although the emphasis of the research has been to develop catchments for agricultural uses. Cluff (1974) describes a range of approaches being investigated there including "compacted earth" , "compacted earth sodium treated", "gravel covered plastic", and a sequence of layers, "asphalt-plastic-asphalt-chipcoat" (see Frasier, 1975 section 3.2.5). As described, the treatments are heavily dependent on large, expensive machinery; however, some of them might be adapted for application using labor-intensive methods.

The organization Christian Care (Farrar and Pacey, 1974, see illustration in section 3.3.4) suggests a concrete apron to collect water for their underground tanks. Maikano and Nyberg (1980) describe a pilot rainwater catchment project in Botswana which makes use of traditional grain threshing floors as catchment surfaces. These floors are plastered with a mixture of clay and cow dung and the project is monitoring the water collected for chemical and pathogen concentrations.

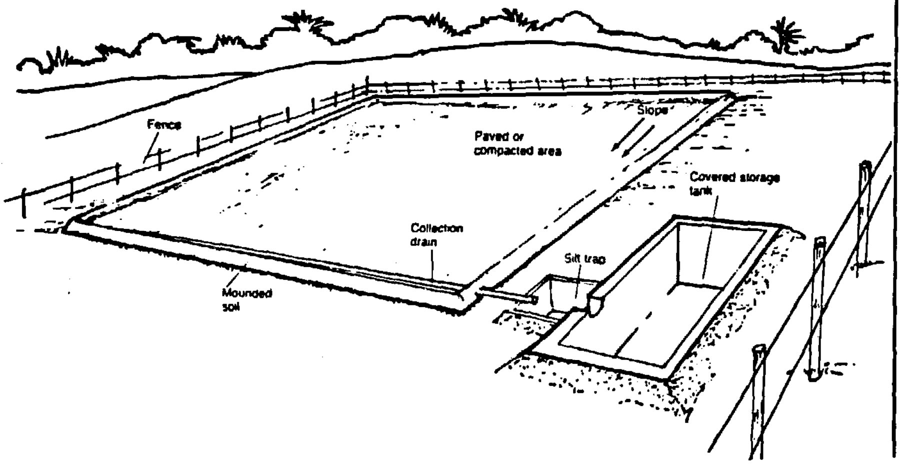


Figure 4. Ground Catchment

Institute for Rural Water, 1982c (draft) by permission

3.2.2 Guttering systems

Clearly, effective guttering is a key to rooftop catchment systems; water can be neither stored nor consumed if it is not channelled efficiently from the roof to the tank. Yet the materials and techniques for construction of effective gutters is a topic that is omitted from almost all accounts. Technically, guttering is far less challenging than construction of cost-effective water storage, and its cost is usually a relatively small part of tltal costs. Possibly guttering has been largely ignored in published accounts for these reasons.

General considerations. How big do gutters need to be? Size needs will obviously vary with the intensity of local storms and the ground area covered by the roof. Ree (1976), investigating runoff yields from sloping metal roofs, used sheet metal gutters 20 cm wide by 10 cm deep, each with a downpipe 15 cm in diameter. Each of these gutters had a capacity of twice the greatest runoff rate recorded from half the 12 x 18 m area of roof over a period of one year in Oklahoma, USA. Thus gutters half as wide or half as deep would have handled the year's heaviest rain from that roof. In general, gutters and downpipes with a cross-sectional area (width x depth) of 100 cm^2 will probably be big enough to handle all but the most torrential rains from most roofs.

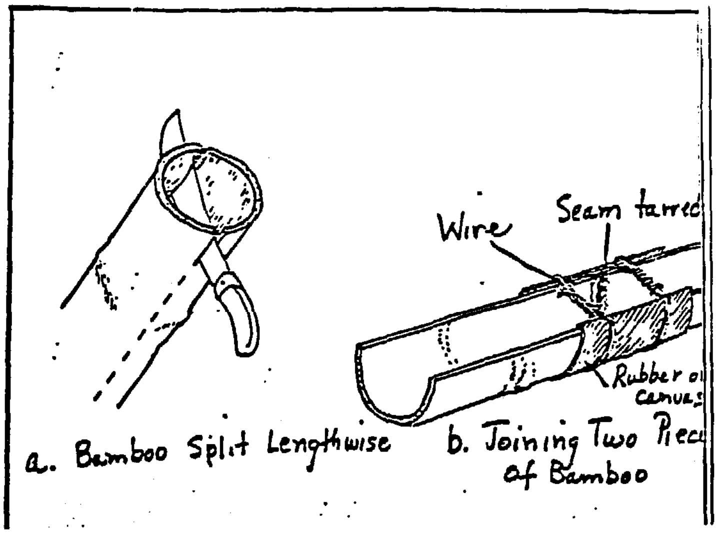
A greater problem than gutter size is probably hanging gutters securely so that they do not sag or fall during heavy rainfall, and keeping them positioned so that they catch both gushing flow and dripping flow from the edges of the roof. Ensuring adequate slope for the entire system, so that water does not stand and damage gutters or attract mosquitoes, is equally important.

Manufactured metal gutters. Aluminum or galvanized sheet metal guttering is the technology of choice in most areas in developed countries. The gutter sections are joined with sepcial brackets and hung with metal straps or long spikes with sleeves which are driven through the upper part of the gutter's width and into wood backing. As of this writing, in the U.S. aluminum guttering and downpipe sections cost about US$1.85 / m (galvanized sheet is slightly less expensive but tends to corrode more quickly unless coated with high-quality rust-resistant paint). Hardware for joining and hanging the system costs another $0.60 per meter. This would make the materials costs of guttering and downpipe for a building 6 m long approximately $30 (1982, US). Higher cost or complete unavailability are likely to eliminate manufactured metal gutters as possibilities in most rural areas of developing countries.

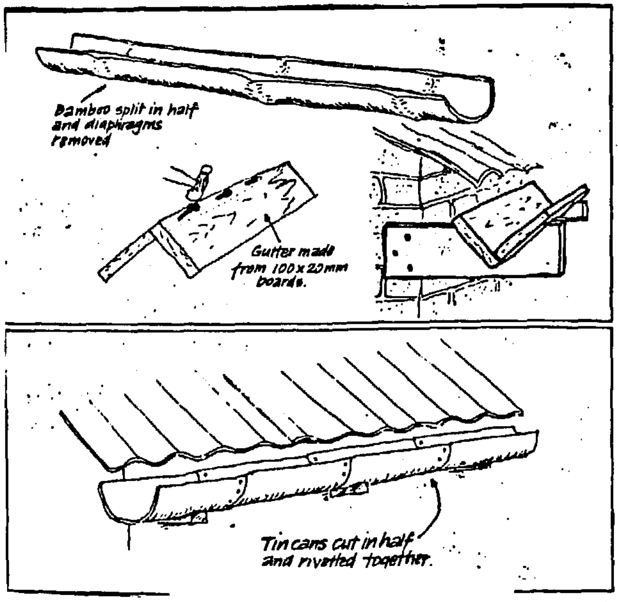
Alternatives using local materials. McDowell (1976, page 33) observes:

> "It is noticed that, in many areas, houses will have a short length of roughly fashioned guttering fixed under the eaves just above the door, and that water from this will be collected in an old oil drum or other container. It seems that this type of device is used more for the purpose of preventing water from running in through the doorway of the hut than as a serious approach to water collection. However, the existence of this "technology" could provide the link point for development of simple but effective roof catchment systems."

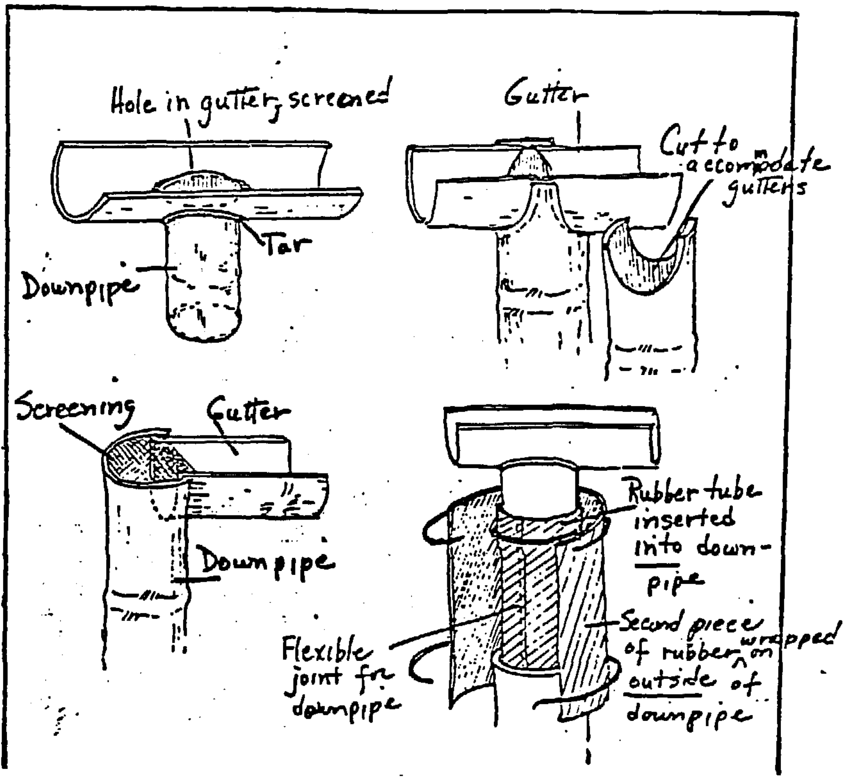
McDowell also reports on the use of split bamboo culms with joints removed, and "V"-shaped gutters made by nailing two boards together at right angles edge-to-edge. This construction seems likely to leak but the "V" might be



Institute for Rural Water, 1982 (draft), by permission

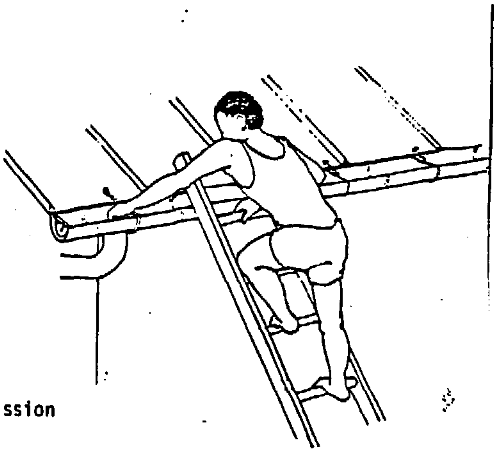


Basics, October 1978, page 4



Joining Gutters and Downpipes
(Institute for Rural Water, 1982, by permission)

sealed with tar, pitch, or some local gum. Institute for Rural WAter (1982; see section 3.2.4) provides good ideas for joining sections of bamboo guttering with iwre and some flixible sheet material such as rubber or canvas, and joining gutters and downpipes with similar materials (see figures). Institute for Rural Water also suggests hanging gutters with twisted wire or local fiber, wrapped around the gutter and tied to holes in roof sheeting or to the ends of roof supports (see figure below).

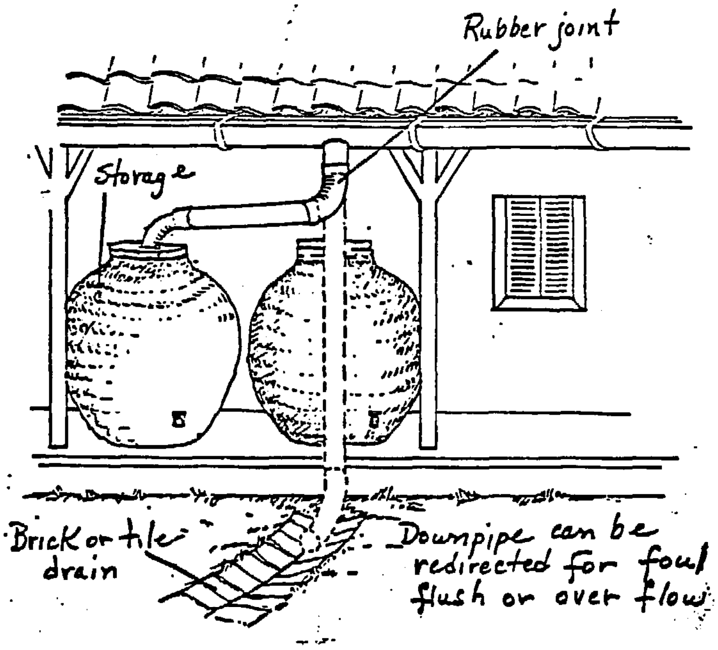


INstitute for Rural Water, 1982b (draft), by permission

3.2.3 Diverting the "foul flush"

The crucial importance of some routine or technique for keeping dirty water, flowing off a roof at the beginning of a storm, out of the stroage tank has been discussed above in section 3.1.4. In general, there is more to be gained by devising an effective "foul flush" method than by investing in filters, which clog and contaminate quickly (e.g. Midwest Plan Service, 1979). There are two kinds of foul-flush devices, those which require the flow of water to be switched manually from waste to the tank after the appropriate interval, and those which are "automatic".

Manual systems. Usually lower in cost and easier to devise, these will be the obvious choice in most poor areas. An attractive and simple approach is to attach the downpipe so that it can be propped in the "waste" position, then propped in the tank inlet after the roof is clean. Open trough downpipes like split bamboo can be suspended beneath the outflow of the gutter with wire or local fiber; closed downpipes with a flexible joint can be moved in the same manner (see figure below).

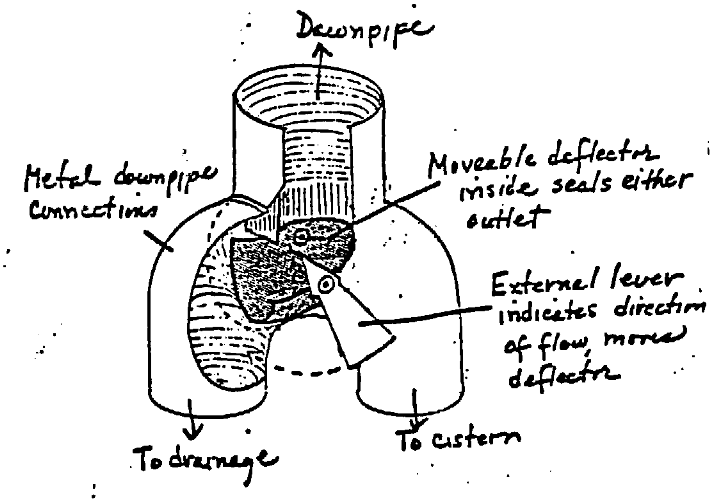


INstitute for Rural Water, 1982 (draft), by permission

The task of moving the downpipe can be performed consistently by a child; people in developing countreis tend to be conscious of the precise moment fo the start of rainfall because drying laundry must be brought under shelter.

Another simple technique for tanks with small covers is to leave the cover on, blocking the flow of water into the tank, until the roof is clean. A similar approach (for very small containers like jars) is to move the container into position under the downpipe only after an appropriate interval. Both these routines may be objectionable from a public health point of view: they cause mud and pools of standing water at the tank. Nevertheless, they may be the method of choice where a more complex downpipe and foul flush arrangement is impracticable.

Bypass valves built into metal downpipes may be an option in some areas. Often referred to as "butterfly" valves, they require sheet metal working capability, and thus would be expensive or impossible to fabricate in many situations. It might be possible to devise a similar valve for downpipe arrangements made of other materials, but a movable downpipe will probably be the cheaper, more functional alternative.



Institute for Rural Water, 1982b (draft), by permisssion

Automatic systems. Automatic roof cleaning devices are available commercially only in a few areas, but they may be fabricated from local materials in some situations. One simple automatic device is a container or receptacle for dirty water called a "roofwasher" (Midwest Plan Service, 1979; see figure below). After the roofwasher receptacle fills up with the foul flush, water begins to overflow into the storage tank. A screen is usually attached between the downpipe and the foul flush container as shown in the figure to keep our leaves and other large pieces of debris that would float on the water in the receptacle and clog the overflow pipe to the tank. Oil or fuel tins, used for hauling water in many areas, might be converted to roofwashers. Midwest Plan Service (1979) recommends about 10 liters of roofwasher receptacle capacity for every 30 m^2 of building area. Other sources (e.g. Dooley, 1978) say a roofwasher should be big enough to hold the first 20 minutes of runoff.

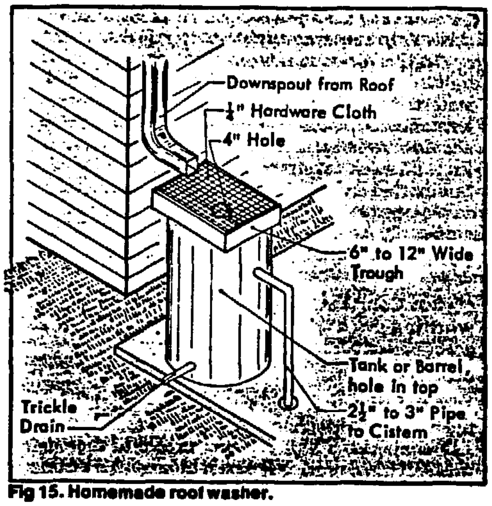
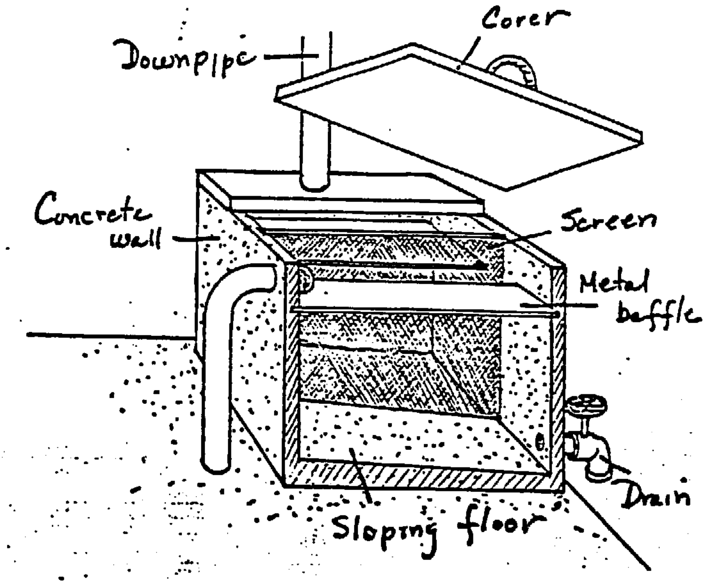


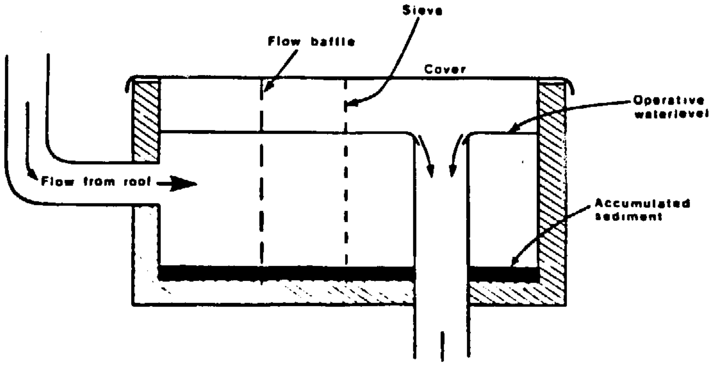
Fig 15. Homemade roof washer.

Midwest Plan Service (1979)
by permission

A problem with such a simple device is that when the beginning of a rainstorm is torrential, water will pour vigorously into the roofwasher from the downpipe, stirring dirt and bird droppings so that they are carried through the overflow pipe into the tank instead of settling at the bottom of the receptacle. Modification: a baffle mounted crossways, inside the roofwasher to inhibit this stirring action, and/or a vertical screen dividing the



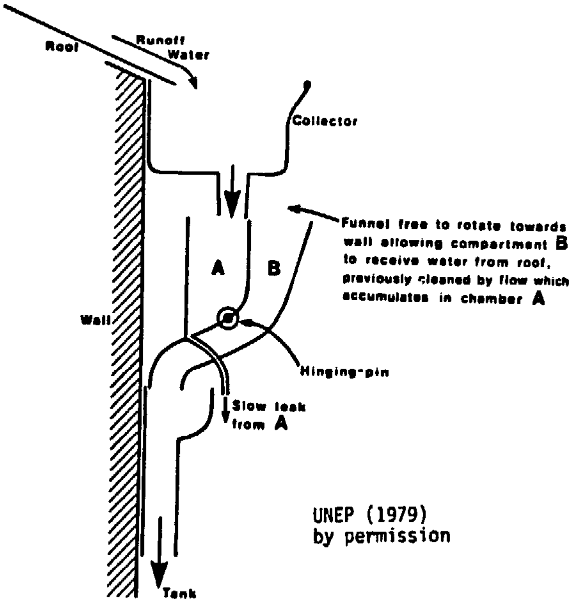
Institute for Rural Water, 1982
(draft) by permission



UNEP (1979)
by permission

downpipe side from tank inlet side (see figures above). Roofwashers must have a drain and removable cover so that they can be cleaned after each rain.

More complicated "automatic" foul flush devices tend to require more attention and stronger structures with more hardware for mounting in the downpipe. Reported in use in Australia, "swing funnels" are made of sheet metal, with a large inflow side divided into two compartments, and hinged on a horizontal pin (see figure below).



UNEP (1979)
by permission

At the start of a storm, water pours from the gutter into the first compartment. As the weight of the assembly increases, the funnel swings so that water pours from the gutter into the second compartment which leads through the downpipe into the tank. Such a funnel would have to be quite large to hold the recommended volume of foul flush. Mounting and hingepins would also have to be quite strong. This particular device is unlikely to be the most attractive of foul flush options in most places, but it is an interesting idea.

3.2.4 Publications and how to obtain them

Frasier, G.W., ed., 1974, Proceedings of the Water Harvesting Symposium, Phoenix, Arizona, March 26-28, 1974, Agricultural Research Service/USDA report no. ARS-W-22, 323 pages, currently out of print. Request infomration from the editor, Southwest Rangeland Watershed Research Center, 442 East 7th Street, Tucson, Arizona 85705, USA.

A wide-ranging compilation of 40 papers and reports on rainwater harvesting. Much of the material is quite technical and most of it concerns development of systems for agriculture. It is , however, a fine overview of the specturm ov developments in ground surface catchment. Of particular interest: "Engineering aspects of water harvesting research at the University of ARizona" (Cluff, 1974, pages 27-39) and "Storage systems for harvested water" (Dedrick, 1974, pages 175-191).

Hall, N., 1981, "Has Thatch a Future?", Appropriate Technology, London, Vol. 8, no. 3, December 1981, pages 7-9, £ for the issue with Air Speeded Post from Intermediate Technology Publications, Ltd., 9 King Street, London WC2E 8HN, United Kingdom.

"Thatch is currently out of favour almsot everywhere. It is veing replaced by modern sheet materials or expensively manufactured tiles. However, as the essential ingredients of modern building become more and more costly with the rising price of raw materials and the fuel required to process them, it is undoubtedly worth re-appriasing traditional materials." The author, who is studying thatch and has found little information available on the topic, presents a concise summary of thatch grass types and methods of thatch ing roofs, highlighting Balinese "prefabricated" techniques. No mention of guttering thatch roofs for rainwater catchment.

The author's address: Open University, Walton Hall, Milton Keynes, Bucks, United Kingdom.

Institute for Rural Water, 1982, "Constructing, Operating, and Maintaining Roof Catchments". Water for the World technical note no. RWS.1.C.4, USAID, request from the Development Information Center, Agency for International Development, Washington, D.C., 20523 USA.

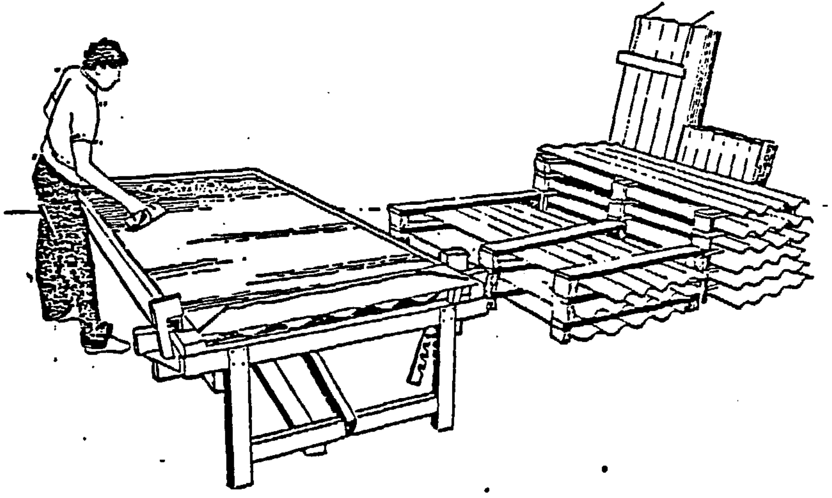
A good overview of simple rooftop catchment systems, discussion roofing and gutter installation, foul flush disposal, and maintenance. ABout 4 pages of text, the remainder figures, several of which are reproduced with permission above.

Request "Evaluating Rainfall Catchments (RWS.1.P.5), "Designing Roof CAtchments" (RWS.1.D.4), "Designing a Household Cistern" (RWS.5.D.1), and "Constructing a Household Cistern" (RWS.5.C.1_), from the same source.

I.T. Building Materials Workshop, "Production and Installation of Corrugated Roof Sheet made from Fibre REinforced Cement: Basic Operating Manual for Honduras and Guatemala", 19 pages, request from I.T. Building Materials Workshop, Corngreaves Trading Estate, Overend Road, Larley, West Midlands, B64 7DD, United Kingdom.

Describes, in good detail and with excellent line drawings, the tools, sheetmaking table and molds, and techniques for FRC sheets outlined in Parry (1981, below). "This manual describes the basic production and application techniques for the roofing products. Modifications have been incorporated to suit local circumstances in Honduras and Guatemala...The document is intended as a namual for the assistance of groups who are already in possession of the

Ideal Deployment of Sheetmaking and Curing Equipment



I.T. equipment to make corrugated roof sheets and ridge tiles, and have received first hand training from an experienced operator".

NAS, 1974, Roofing in Developing Countries: Research for New Technologies, book, 57 pages, give name of group or institutional affiliation when requesting a free copy from BOSTIC (JH215), Office of the Foreign Secretary, National Academy of Sciences, 2101 Constitution AVenue, Washington, D.C. 20418, USA.

A useful overview of the range of possible low-cost roofing materials relying on local materials and/or new techniques. Includes appendices on low-cost roofing research in India.

Parry, J.P.M., 1981, "Development and tEsting of Roof Cladding Materials Made from Fibre Reinforced Cement", Appropriate Technology, London, Volume 8, no. 2,September 1981, pages 20-23, £ 1.50 for the issue and Air Speeded Post from Intermediate TEchnology Publications Ltd., 9 King Street, London WC2E 8HN, United Kingdom.

A summary of the I.T. Building Materials Workshop findings on fibre-reinforced cement sheeting for use in the manufacture of roofing components. "The final outcome of the development work was a complete low-cost roofing system involving a new corrugated cladding panel which has the coverage of a one metre sheet but which is fitted like an extremely large but lightweight tile." Manufacturing processes for implementation on a small scale in developing countries (see I.T. Building Materials Workshop, this section) are outlined. The author believes that FRC sheets were being made at the combined rate of about 2,000 a month by several production teams in at least seven countries in April 1981. Cost and roof structure requirements comparisons are made with coventional materials; cost advantages hinge on the lifetime of the new sheets: "only time will tell the eventual lifespan of the FRC products, but the development has now reached the point where it can be considered as a viable alternative to conventional materials and one which is especially appropriate because of its facility to be produced labour-intensively, on a small scale, in virtually any urban or rural situation."

3.3 Storage Technologies or "Tanks"

3.3.1 General considerations

As has been noted in other sections, the water storage facility or "tank" is usually the most expensive part of simple RWH systems, and at the same time the most difficult to construct so that it will perform satisfactorily over a long period. An adequate tank must not leak; it must be structurally strong enough to support thegreat load of the water it will hold; and it must be covered, to keep out sunshine, dirt, insects, and (if the tank is buried) dirty surface water.

As far as users are concerned, the tank is also the focus of the system; it is usually both the storage and distribution point, requiring cleaning and maintenance to ensure both these functions.

In fact, a tank which addresses storage needs and performs well is the key to a rooftop catchment system. It is for this reason that this section on tanks is the bulkiest part of this report.

Tanks can be categorized by their applications into three groups:

1. tanks used with individual household rooftops, mostly above ground
2. tanks used with larger rooftops or several rooftops--community centers, schools, etc; above, partially buried, and below ground.
3. tanks used with surface catchments.

Within each of these three groups there are many different kinds of tanks, each with its own construction methods, materials costs, and labor requirements. Each of these factors, along with the capacity needed (see technical note on using rainfall data to design a RWH system, section 4), enters into decisions about what kind of tank to build. These key aspects of tank designs are described as fully as space permits in the subsection below; see also section 3.1.3 on costs and the technical note on section 4 on costs of materials. Here, a few general comments about choice of tanks design will be made.

The tank's function--as an individual household source or source for a group of families--is probably the single most important determinant of tank sizing and design. This choice can be made only in close consultation with the people who will build and use the tank; without their participation growing out of genuine support for the idea, a tank-building effort has little prospect of success. In their comments on the slow progress of open tank construction for irrigating school gardens in Botswana, Farrar and Pacey (1974) note:

> "In any community where a tank programme is contempleted, it would seem important to enquire into the 'felt needs' of the people. To which category of water use do they give highest priority?
> a) drinking water: for home or school use?
> b) washing water
> c) water for gardens: again, at home or at school?
> In most parts of southern Africa, water for school gardens would be given the lowest priority."

Whether to build an above-ground tank or an excavated (underground) tank deserves considerable thought. Watt (1978) notes,

> "Storing water in tanks built on the surface has many disadvantages when compared with storage tanks excavated into the ground. Besides avoiding the need for laborious excavation which is almost impossible in some hard dry soils, the tanks can be observed for leaks and easily repaired by trowelling a layer of mortar onto the inside of the empty tank. In addition, although the stored water is likely to become hotter in the sun, the risks of polluted material falling into the tanks are reduced. Water stored above ground can flow out under its own weight whereas it has to be pumped out of a ground tank."

The main advantage of underground tanks, on the other hand, is that the earth supports the tank lining and contents, making it possible to build deeper tanks with thinner walls. This means that building materials can be conserved and used to make leakproof wall surfaces instead of structural wall reinforcement.

Underground tanks do not always require a pump. Figures in Section 3.3.3, (below) shows how a concrete block tank supported with earth embankments can be fitted with a tap.

Larger tanks require fewer materials per unit of water storage capacity than smaller tanks, which tend to give them a cost advantage. Constructing smaller tanks, though, tends to require less expertise and preparation, fewer tools, and less cash "up-front". Large tanks may bring with them structural problems; for example, large areas of flat plastered wall are more vulnerable to cracking than smaller walls (e.g. Maikano and Nyberg, 1980). Thus, in many cases smaller tanks, or groups of smaller tanks, will be chosen in preference to a single larger one.

Different kinds of tanks demand different standards of workmanships in construction. Ferrocement and other tanks made with mortar plaster will crack and leak if mortar is not made with clean components in proper proportions, and applied properly to the reinforcing framework. A prototype made by people who have never made one before may not perform satisfactorily; a failure should be planned on or experience sought.

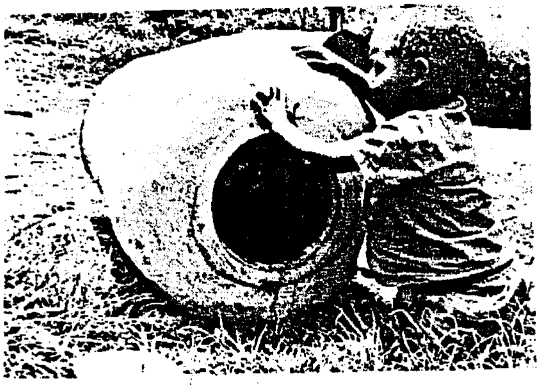
The walls of underground tanks must be built carefully, especially if they are of brick or masonry. Cairncross and Feachem (1978) say these tanks should only be built by an experienced builder (and indeed, local masons should always be involved). Individual Water Supply Systems (Office of Water Programs/EPA, 1974) emphasizes the importance of high-quality workmanship and recommends against "unskilled labor". Bricking, plastering, and curing are all part of a tank with a long life which will not leak.

3.3.2 Tanks used with individual household rooftops

Recycled, used containers. A wide variety of locally-available containers can be used to catch water flowing from guttering or sim ply dripping off the edge of roofing. White et al (1973) dscribe the use of steel petrol drums with one end cut out in West Africa (see picture at the front of this report). These drums hold about 0.17 m^3 and cost about US $2.50 (1969); they can be covered with a board and a rock. Watt (1975) notes that Thais collect rainwater from roofs in large pottery jars. He reports a price of about US $5.00 (1975) for a 0.3 m^3 jar.

Cement mortar jars. Apparently first devised in Thailand (Watt, 1975), these jars have been enthusiastically built in other parts of southeast Asia and Africa (McDowell, 1976). Cloth sacking filled with rice hulls or some vegetable waste is used as a jar-shaped mold, onto which cement mortar is plastered. McDowell (1976) says that jars can be constructed with capacities up to 3 m^3 using this method; the author has seen prototypes of even larger models, made with soil-cement, in Java. A great attraction of this method of storing rainwater is its low cost. Watt (1975) reports materials costs of US $0.50 per 0.25 m^3 jar; that entire sum is for cement.

Most jars of this type are apparently made in the size range of 0.15-0.5 m^3, as larger jars lacking reinforcement tend to crack where the wall meets the base. See section 4 for Watt's instructions on making a 0.25 m3 jar.



cement jar

McDowell (1976)
both by permission

plastered basket

Jim Bell (personal communication) reports on a variation of this method for making water jars of about the same size widely practiced in Liberia. A hole, the shape of the jar is excavated in the soil: wire netting ("chickenwire") is pegged to the walls of the hole, which are then plastered with cement mortar. After the jar has cured, it is dug out of its earthen "mold".

Traditional baskets plastered with cement mortar. Originating in Thailand, this technique has been used to build hundreds of tanks in Kenya, Burundi, Rwanda, Swaziland, Tanzania, Lesotho, and Zambia. The usual technique is to plaster a granary basket which is set into a cement or concrete foundation.

"In Kenya, the basket frame is made from sticks cut from woody shrub which grows throughout the country. In Rwanda and Burundi, the frame is made from bamboo, presumably provided that the material is strong, the basket could be made from any number of shrubs or sticks which can be woven into basket form. The basket is constructed on the ground by weaving the sticks into round shapes. The actual shape does not seem very important, but it is recommended that the bottom be omitted so that the sides can bond with the base" (UNICEF, Eastern Africa Regional Office, 1982).

Apparently tanks up to 7.5 m^3 in capacity have been constructed by reinforcing the basket frame with bands of straight wire or wire mesh. The more common size, requiring no metal reinforcement, is about 1.5 m high and has a capacity of about 2.3 m^3. Assuming a cement price of $7.14 per 50-kg bag, (rural Zaire, 1981), and allowing about 20% of total materials costs for sand, gravel and outlet pipe, a 2.3 m^3 tank of this type could be built for about US $42.00 (1981). See section 4 for detailed notes on construction as carried out using a "Ghala" basket in Kenya (UNICEF East AFrica Regional Office, 1982).

Cast concrete ring tank. Relying on thin unreinforced concrete rings, poured between concentric steel forms, these tanks have been promoted by the Thai Ministry of Health for use at schools in a country where many buildings in rural areas have galvanized sheet metal or tile roofs (Watt, 1978 b). The rings, which are about 1.5 m in diameter and 0.6 m high, can be stacked to give tank capacities of up to 7 m^3. Watt estimates materials costs of US $40.00 (1977) for a tank of this size, not including the cost of the forms. Watt points out that forms could be used again and again in a tank construction project and suggests central production of the rings under skilled supervision. The cured, high-quality rings could then be transported by truck to the tank location for placement on their concrete foundations.

Brian Grover (personal communication) reports that the Thai Ministry of Health and the Population Development Association of Thailand, in collaboration with the U.S. Peace Corps, are building similar tanks with bamboo staves cast into the rings for reinforcement.

Ferrocement tanks. These tanks are built using a techniques in which cement mortar paste is applied by hand to a reinfocing wire mesh. "True" ferrocement has much more steel reinforcement than called for in the tanks described here. Still the principle is the same: metal reinforcing strands distribute loads evenly through the cement mortar, preventing the cracking that would occur in unreinforced materials of similar thickness (Office of the Foreign Secretary/NAS, 1973). Tank walls 4 cm thick are strong enough to hold 2 m depths of water above ground. Thus walls require much less total material than conventional concrete walls. (Briscoe (1981) notes that ferrocement tank walls do not necesarily require less cement than concrete walls.)

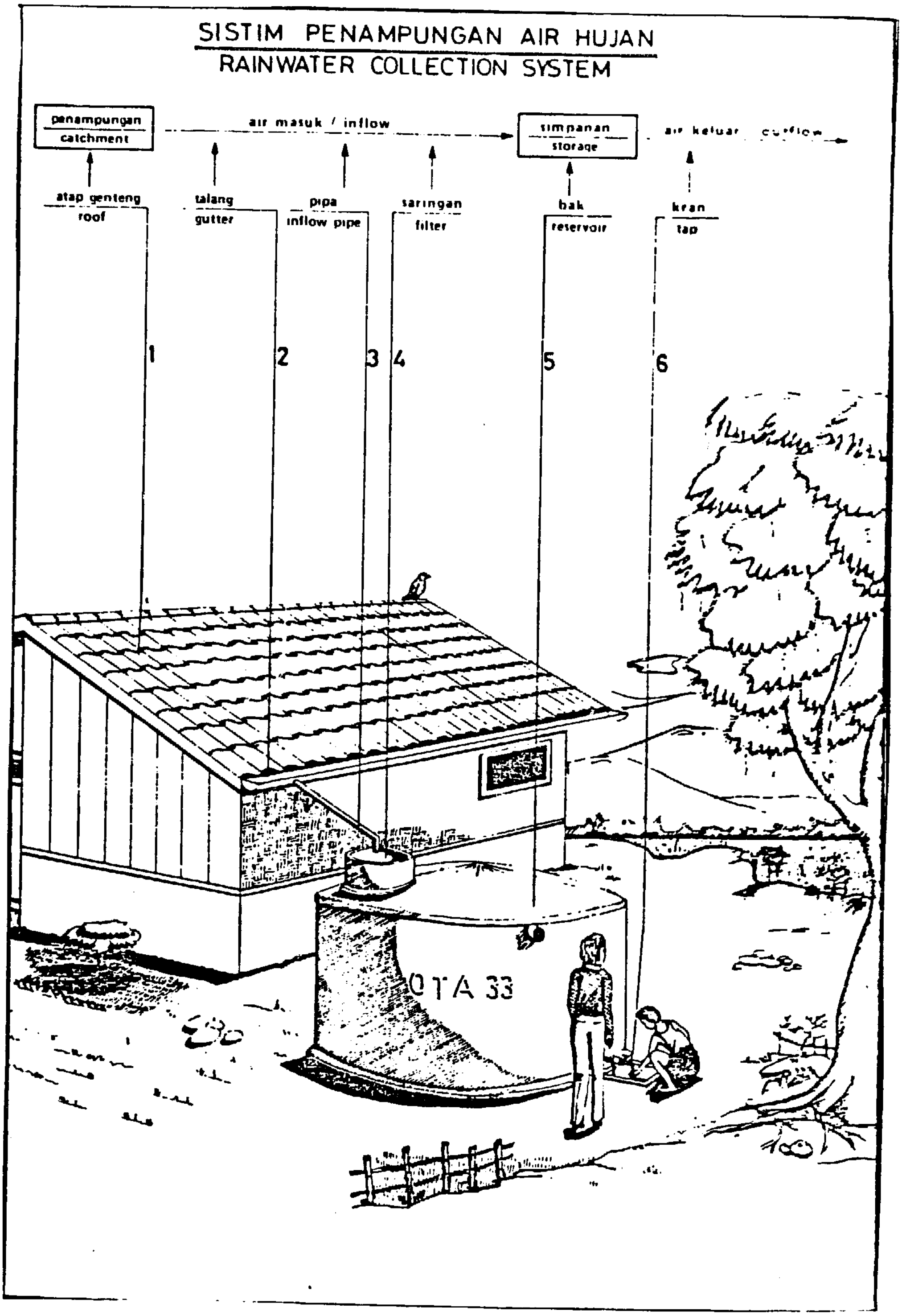
In his handbook for field workers (Watt, 1978, Ferrocement Water Tanks and Their Construction, see section 3.3.6 below), Watt notes:

> "The main advantages...of this material over other tank construction materials, such as galvanized corrugated iron, are its cheapness and easy working using the minimum of expensive materials, equipment and skills. It is, in addion, very durable. Some of the tanks described in the manual have been inconstant use for over 25 years with only a few instances of failure--due in the main to poor workmanship in construction."

Watt goes on to say that ferrocement techniques are particularly suited for low-income rural areas because 1) they use commonly available materials (cement, sand, water, and wire); 2) only simple skills ar needed: "...untrained people can make satisfactory tanks after only a few days supervision..."; 3) users of the tanks can help in construction; 4) only simple hand tools are required.

Clearly an important advantage of ferrocement tank construction is that it can be taught and learned readily. Early development of these techniques was done at the Friends Rural Training Center, Hlekweni, near Bulawayo, Zimbabwe. Roy Henson of the Center reports training of a half-dozen craftsmen and construction of 210 9 m^3 tanks in Matabeleland in 1971-72 (Farrar and Pacey, 1974). At the Asian Institute of Technology in Bangkok, trainings are held for field workers fromn developing nations who, in turn, train local craftsmen in the techniques. AIT-trained field workers in Central Java make modified ferrocement tanks and have begun using woven bamboo staves to reinforce smaller tanks. They and their trainees have reportedly built 1,400 tanks up to 10 m^3 in capacity (Winarto, 1981). And in West java, two separate programs are planned to construct a total of 650 tanks made using the Central Java techniques (Pompe et al, 1982).

Ferrocement tanks are typically built one of two methods. In the first layers of wire netting ("chickenwire") are attached to a grid framework of 6 mm (or larger) steel rod. Mortar is trowelled directly onto this framework from the outside (Sharma and Gopalaratnam, 1980) or against a sheet of woven bamboo mat



Ferrocement tank installation in Java
Pompe et al, 1982 , by permission

tied temporarily against the inside of the framework wall to act as a "form" (Winarto, 1981; Pompe et al, 1982). When reinforcing the vertical rods are continuous from the floor through the wall and into the cover, cured tanks can be moved on makeshift rollers. The materials costs for a 1.2 m^3 tank of this type with integral floor and cover were estimated at US $33.00 (Thailand; Sharma and Gopalaratnam, 1980).

In the second construction method, no reinforcing framework of steel rods is used. Wire netting and plain straight wire are wrapped around a sturdy inner cylindrical form and plastered with thin coats of cement mortar (Watt, 1978; Watt, 1977; Farrar and Pacey, 1974; see <u>Ferrocement Water Tanks and Their Construction</u>, and "Catchment Tanks in Southern Africa: A Review", section 3.3.6). Like tanks with steel rod reinforcement, these tanks are installed on a concrete foundation; but unlike them, they must be built in place. Materials costs are usually substantially less than for tanks of the first type because a single layer of wire netting and plain wire cost less than the steel rod framework. Assuming a cement price of US $7.14 per 50-kg bag, wire netting price of $1.00 per m^3 tank described by Watt (his construction steps are presented in section 4) could be built for about $150.00. Similar tanks of 9 m^3 capacity built at the Friends Rural Training Center, Hlekweni, cost $62.50 including gutters (1973, Zimbabwe; Farrar and Pacey, 1974).

These costs do not include money spent on materials for the cylindrical inner forms around which the wire and netting are wound. Calvert and Binning (1977) report using mats woven from wood and bamboo, pitpit, or wildcane for forms in the New Hebrides. However, the forms recommended by Roy Henson and Watt, made of sections of corrugated iron sheet roof bolted together make it much easier to plaster to a uniform wall thickness and build consistently good tanks. If

FIGURE 9 A paste of mortar is forced into the layers of mesh by hand . . . (Smith Kampempool, Applied Scientific Research Corporation of Thailand)

FIGURE 10 . . . or trowel. The mortar is dry enough to remain in place when applied; a formwork is not needed. (Noel D. Vietmeyer, National Academy of Sciences)

Office of the Foreign Secretary/NAS, 1973
by permission

corrugated iron sheeting costs US \$2.20 per m_3, this kind of form for a 10 m^3 tank would cost \$50.00 plus costs of angle iron, hardware, and fabrication. The form will, in some areas, cost as much as the materials for one tank. However, the form is portable and can be used to build many tanks. Where a large number of tanks are to be built in one area, this technique should be considered.

In New Zealand, ferrocement water tanks are manufactured by a number of firms using method similar to those described by Watt. With a welded grid of 10 mm rod in the floor, tanks with capacities of 0.7 m^3 to 18 m^3 are portable (hauled from factory to farms in trucks) and often guaranteed for 25 years (Office of the Foreign Secretary/NAS, 1973).

Manufactured "Tin" or corrugated sheet metal tanks. These tanks have been used for many years in many areas. Farrar and Pacey (1974) report that in parts of southern Africa, most foreigners have "tin" tanks alongside their homes. The costs of these tanks are high and extremely variable, depending on distance from point of manufacture. Farar and Pacey give the cost of a 9 m^3 version as US \$112.00 (1973, Zimbabwe); White et al (1973) say that "tin" tanks of 1.4 m^3 capacity cost \$39.00 to \$84.00 in East Africa (1972). The corrugated metal from which these tanks are fabricated may not last longer than 5 years in a damp climate, even then galvanized. Calvert and Binning (1977) report that in the salt-laden atmosphere of New Hebrides, 16 gage tanks fail after 3 or 4 years.

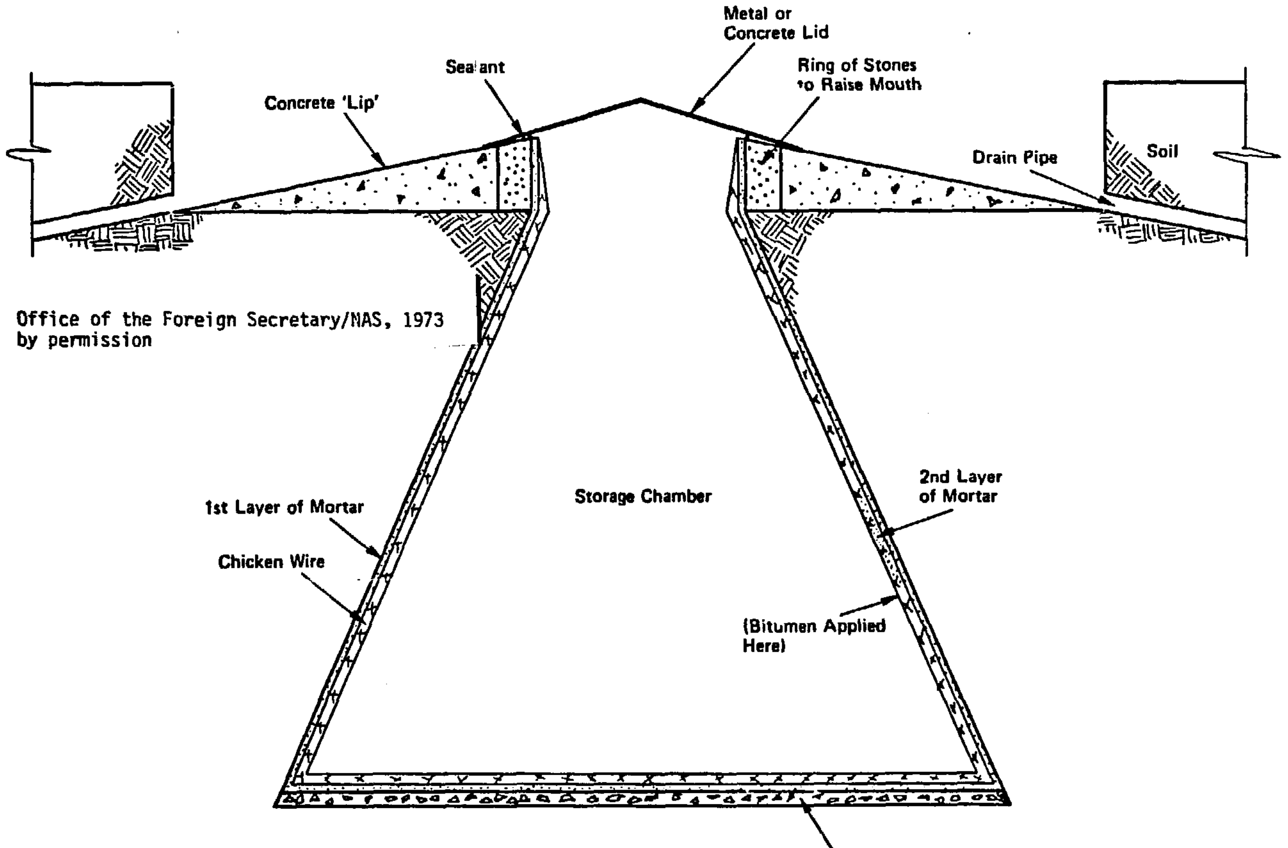
3.3.3 Tanks used with larger rooftops or several rooftops

Underground ferrocement tanks. Most tanks of this type are basically an earthen pit lined with wire-reinforced mortar. As with other underground tank designs, structural strength is provided by the confining earth walls, meaning that the ferrocement lining can be made only a centimeter thick. A further advantage of these tanks is that their construction requires neither the steel rod framework nor forms needed to build aboveground ferrocement tanks.

Calvert and Binning (1977; see "Low Cost Water Tanks in the Pacific Islands", section 3.3.6) describe an innovative design complete with reinforced cover, 3.5 in diameter and 2 m deep, volume 15-20 m^3. First a circular concrete foundation or "footing" is poured; soil from the footing trench is used to make a gently sloping earthen dome in the center of the circle. A 5 cm layer of cement plaster reinforced with wire netting and steel rod is laid over the dome, and two 0.6 m holes were left near opposite edges. After this forrocement dome cures, digging begins through the holes and the tank is excavated beneath. 2 layers of wire netting are used to strengthen the plaster applied to the earth walls.

The authors believe that these tanks should not cost more than about US $250 (1976, New Hebrides). They suggest that the design is suitable for "collecting a village's water supply drained from the roof of a large public building." While fabrication of cover which will not crack may require some experimentation, the approach seems promising. Maikano and Nyberg (1980) report trails of similar covers for underground tanks in Botswana.

A ferrocement-lined underground-grain storage bin suitable for storing water has been documented in the Harar Province of Ethiopia (Office of the Foreign Secretary/NAS, 1973; Sharma et al 1979; see Ferrocement; applications in developing countries and "State-of-the-art Review on Ferrocement Grain Storage Bins", section 3.3.6). Traditional grain pits, conical in shape with sides sloping inward to a narrow mouth at the surface, are lined with plaster reinforced with wire netting and given a concrete floor. A small cover is needed, and provision made so that surface water will run away from the mouth of the pit. Ferrocement linings have been installed in pits of this type with depths of up to 3 m and floor diameters of 4 m.



Office of the Foreign Secretary/NAS, 1973 by permission

FIGURE C-3 Cross-section of ferrocement underground storage pit.

Soil type will affect smoothness of earthen walls and the ease with which plaster can be applied to the sides of an excavation. Calvert and Binning (1977) say that their tanks should be dug out in "soft" soil. Sharma et al (1979) say that traditional grain pits have been lined successfully in all the major soil types of the Harar province of Ethiopia.

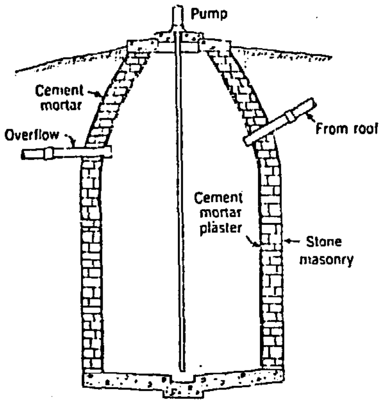
The linings of traditional dogon granaries with ferrocument pioneered by Hans Guggenheim and described by Watt (1978), represents an interesting above-ground version of the Ethiopian scheme. Existing adobe-brick granaries, about 2.4 m high and 2.6 m in diameter, are lined with plaster reinforced with wire netting and covered in the Traditional manner with timbere-reinforced adobe. The flat roofs of the adjacent houses are already equipped with water spouts to drain the torrential (if infrequent) rains. The system seems to be an extremely inexpensive and elegant way to provide a rooftop catchment system with storage capacity of about 13 m^3. Clearly only very sturdy adobe walls would be suitable; Watt noted that trouble can begin when adobe walling begins to erode in the rain.

Buried and partically buried brick and masonry tanks. Stones and bricks have been used all over the world to build structures to hold water. Stones or bricks laid with mortar have great strength under compressive loads, but lask strength to resist loads from the side. This means that the lower parts of walls in deep tanks, where the water pressure is greatest, tend to buckle outward if they are not built strongly enough. This fact, in turn, is the principal motivation for buying (or partically burying) this type of tank: the deeper parts of the walls are supported by earth. Brick and masonry tanks when covered properly also tend to keep water cooler than above-ground tanks, and can be built in to a basement or share a foundation wall.

Buried brick and masonry tanks have their disadvantages, however. Cracks and leaks, which allow stored water to escape and contaminated ground and surface water to enter are harder to detect and in many cases harder to repair. If a pump is used to raise water, the tank must be fitted with a strong (and expensive) cover that will bear human traffic safely. A pump, in itself, may bring with it serious maintenance problems.

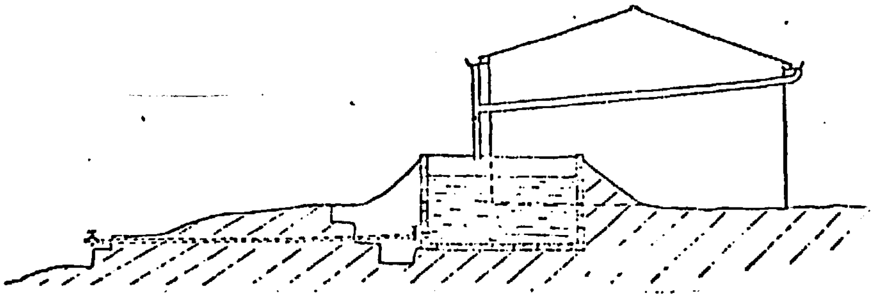
A wide variety of shapes and sizes is possible. Rectangular tanks are easy to design and can be readily incorporated into a building. Circular and elliptical tanks require less wall surface (and hence less material) per unit volume of storage capacity. The walls of circular and elliptical tanks are also stronger, and there is a shorter zone of weakness where mortar cracks are most likely to develop along the line where the wall meets the floor (Maikano and Nyberg, 1980; Cairncross and Feachem, 1978; see Small Water Supplies, section 3.3.6). Cairncross and Feachem say, in fact, that stone and masonry tanks more than 2 m acorss should be circular.

We have found few accounts of brick and masonry tanks in use, probably because their construction is nothing new or noteworthy. Wright (1956) shows a drawing of an underground tank "...walled up with stone or bricks and mortar and plastered with cement mortar".



Wright (1956)
by permission

In Southern Africa, "...the occasional large buildings in rural areas--schools, churches, halls, etc.--can provide a water supply to the community on about the same scale as that from 'beehive' tanks (45-90 m^3, see section 3.3.4 below, ed.)...Four or five 9,000 liter tanks would be needed for many school buildings, though a more usual method of providing this capacity is to build a single large tank of concrete blocks. The difficulty is that tank walls built in this way are ill-suited to resist the sideways pressure of the water, so concrete block tanks are usually built in shallow excavations with piled earth used to buttress the sides. (The figure) illustrates a tank of this kind, showing how the tap may be placed so that water can be drawn off by gravity flow."



Farrar and Pacey, 1974 by permission

(Farrar and Pacey, 1974, see "Catchment Tanks in Southern Africa: A Review", section 3.3.6). In this same paper, a 71 m^3 tank of this type built in Ghana (parker, 1973) is said to have cost US $260.00 (1973). At $3.63/$m^3$ (1973) of storage capacity, this would be one of the cheaper tanks (in cost/m^3 of storage) we have seen documented.

Many of the cisterns built into the basements of residences in Bermuda, where provision for rooftop catchment and storage is required by building codes, are made of concrete block plastered with cement mortar. Volume of these cisterns varies with the size of the dwelling, but most fall within the range of 50 m^3 to 90 m^3 (John Sands, Solar Engineering Technology, personal communication).

One of the strongest arguments for considering tanks of this type is that they can readily bve designed and built into or alongside new public buildings for a relatively small increment in procurement and labor costs. See the discussion of construction details of stone and masonry tanks in section 4.

Underground concrete tanks. These tanks have been widely used for rainwater storage in the developed countries. In the United States they are usually referred to as "cisterns" and are frequently built into or alongside basements with capacities ranging from 10 m^3 to 50 m^3. Properly reinforced with steel rod, concrete is probably the strongest material for walls for water storage. It is resistant to cracking and leaking, and its cover can be cast with an inspection hole so as to effectively seal out contaminants from the surface. The great disadvantage of underground concrete tanks is their expense: they require large quantities of cement, gravel, sand, and steel; and materials for forms, and expertise in the methods, are often also expensive and scarce in rural areas of developing countries.

This type of tank or "cistern" is widely documented in literature published in U.S. textbooks on rural water supply and sanitation. Salvato (1958) and Wright (1959) describe a cistern with simple sand filters, overlapping manhole covers and hand pumps, and "butterfly" valves in the downpipe for diverting dirty water from the roof at the beginning of a rain. Both sources give simple guidelines for matching cistern size to roof area in light of the water needs of farming households in the U.S. Wagner and Lanoix (1959) give simple sizing guidelines and discuss location: tanks shjould be higher than and at least 3 m from any sewage disposal installation. They also emphasize the need to keep gutters clean and sloping evenly toward the downpipe to prevent setting water. VITA's Using Water Resources (see section 3.3.6) gives tools and materials lists, and quantitites, proportions, and procedures for constructing a cistern and sand-grael filter. (Village Technology Handbook (VITA, 1973; see section 3.3.6. gives detailed information on building with concrete. The sizing guidelines given for matching cistern volume to roof area assume that the cistern should hold a full year's water supply for the family using it. See the note in section 4 on using rainfall data to plan a rooftop catchment system.

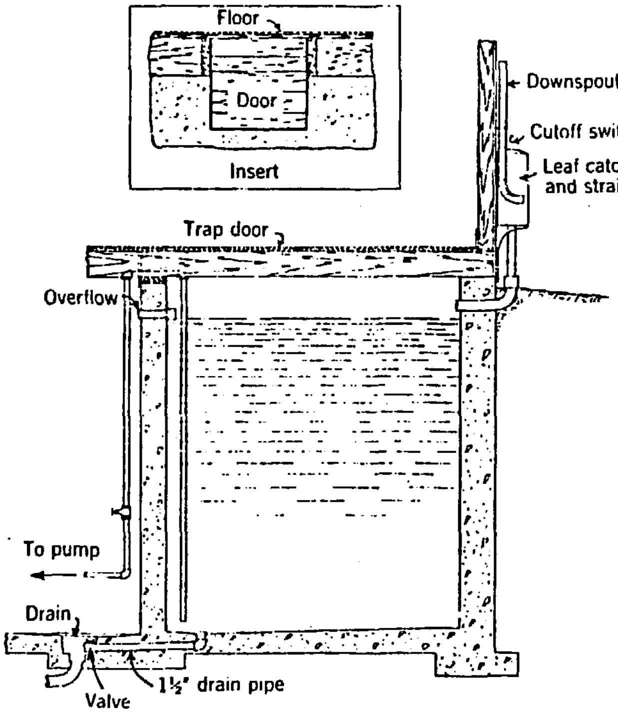
The Manual of Individual Water Systems (Office of Water Programs/EPA, 1974), originally published by the US Public Health Service in 1950, presents the text and cross-section drawings of a cistern which are referred to an appear in Salvato (1959), Wagner and Lanoix (1959), and VITA (1973). Henderson and Smith (1973; see Planning for an Individual Water System, section 3.3.6) and Midwest Plan Service (1979) are two more recent books published by government extension programs in the US for rural applications. They give similar information on cisterns, with useful color sketches and cross-sections. Midwest Plan Service recommends against use of filters for the water from the downpipe, noting that they can quickly become contaminated. They suggest, instead, an adequate "roofwasher" system (see the note on gutters and foul flush devices, section 4).

"Heaven's Water: in Rural Places, Cisterns Gather the Rain" (1980) is a useful presentation of the pros and cons of cistern systems as seen by users in Indiana, U.S., written for a popular audience. The users emphasize the importance of some kind of a "roofwasher" system, discussing several alternatives. This article also relates some of the potential problems with rooftop catchment systems in industrialized countries: "'Rainfall itself carries dust and even chemicals. Near Highways, there is probably a significant lead content in the air. Downwind from industrial plants, there will be a problem with pollution. You need to be site-specific with cisterns.'"

Also mentioned are cleaning solutions for yearly scrubbing of the insides of cistern walls: 3 parts vinegar to one part water; 1 kg baking soda dissolved in 8 lkiters of water. This is the only source we have seen which recommends against the addition of chlorine to water being stored in a tank, saying that it can interact with impurities to form chloroform. A chlorinator which treats the water as it is pumped to the house, or iodine solution or pasteurization, is recommended instead. Other sources recommend periodic chlorination of the water in the tank.

Dooley (1978) discusses cisterns for the rural U.S. in another popular journal. She uses chlorine bleach to disinfect cistern water and describes a chlorine level test using hydrochloric acid. Dooley also recommends scrubbing the inside of the cistern with bleach to disinfect it every two or three years.

Even in the U.S., where the materials are readily available, concrete cisterns are expensive. Dooley (1978) estimates materials costs of a 36 m^3 underground reinforced tank at about US $1,000 (U.S., 1977). Such a tank would be impossible to build in most situations in rural areas of developing countries. The discussion of underground reinforced concrete tanks is included here because elements of their design may be useful when large rectangular tanks are built into public buildings. Wright (1959) shows a design in which one wall of a cistern is the wall of a building foundation or basement.



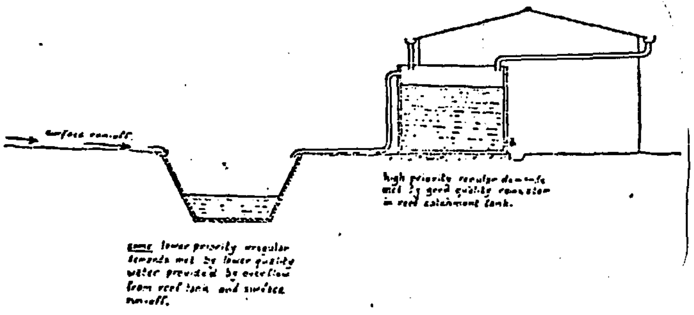
Wright (1956)
by permission

Fig. 3-27. A cistern suitable for a basement. The foundation wall serves as one or more sides of the cistern, the other walls being constructed of concrete. Note that the cistern is entirely enclosed to keep out dust and rodents and that a leaf catcher and strainer is provided on the down spout. Entrance to the cistern for cleaning and repairs may be through a trap door, as shown, or through a special door in the side between two floor sills as shown in the insert.

3.3.4 Tanks Used with surface catchments

As noted in the section on catchment surfaces, ground level catchment systems have been used primarily to harvest rainwater for irrigation, stockwatering, or some other agricultural purpose. In some situation in developing countries, rooftop catchment systems will be more attractive for domestic supply because of the reduced organization and cash reqirements of rooftop systems, not to mention problems related to acquisition of land and protection of ground-level catchment surfaces.

Nevertheless, tanks used with ground surface catchment represent a possible improvement upon the practice, established in many areas, of using water which collects in natural surface depressions. Some designs offer low materials costs per unit of water storage capacity. Additionally, some of the tanks which have been proposed for use with ground catchments might be used with a rooftop catchment instead, or used as overflow storage in combination with another, smaller rooftop catchment tank.



Farrar and Pacey, 1974 by permisssion

One particularly interesting scheme involves tanks used with traditional threshing floors in Botswana (Maikano and Nyberg, 1980; see *Rural Water Supply in Developing Countries*, section 3.3.6). The tanks are about 2 m deep, 2.5 to 4 m in diameter, and hold 10-25 m^3 of water. The first of these tanks were rectangular, but circular ones have been recommended to the pilot project because their wall area is less for an equal storage capacity, and the finished walls should be less likely to crack. Water is channeled into the tanks through a short length of PVC pipe from a shallow settling basin in one corner of floor, where some sedimentation occurs. A brick curb is built around the perimeter of the tank to keep out surface water and provide a foundation for the cover, made of lengths of tree trunk or precast concrete slabs reinforced with barbed wire. Domed cement covers, plastered over wire mesh on an earthen mold, are also being tried. These covers are allowed to cure and then lifted into place on the curb. The construction of the cover seems to be much like the method of Calvert and Binning (1977). Inside the excavation a "thin layer" of cement mortar plaster is applied on wire netting pegged to the sides. Again the approach seems to be much like that of Calvert and Binning (1877), who splashed a liquid cement mixture on the soil walls and plastered cement mortar onto that surface. The materials costs of the tanks appear to be fairly low: for a 25 m^3 tank, the authors estimate about US $135.00 for cement, chicken wire, and PVC pipe (Botswana, 1980). It is not clear if this amount includes the cover.

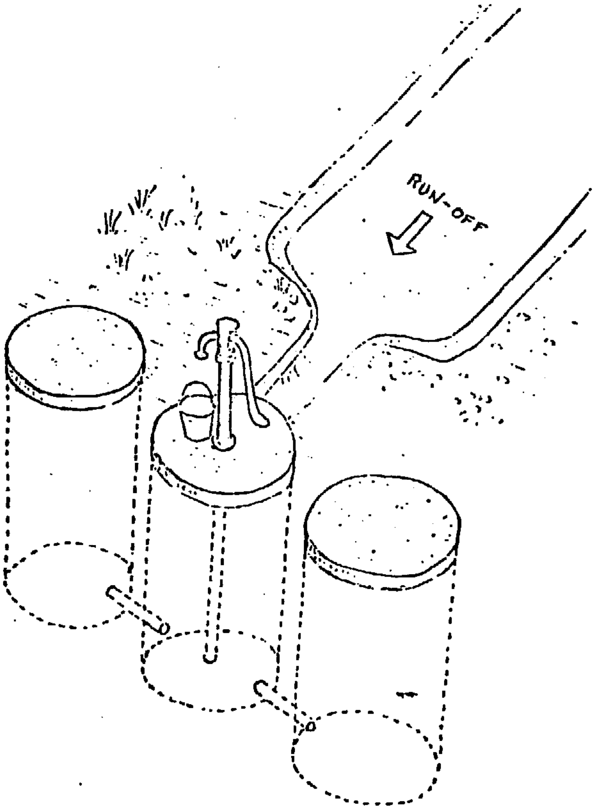
The tanks are intended to provide water for people and cattle. Maikano and Nyberg (1980) note that "The cistern will require cleaning before the beginning of the next rains. Plastering of the tank and cover may have to be done as cracks are noticed."

Most widely known of recent community rainwater harvesting schemes in Africa is, without doubt, the pilot project for providing water to irrigate school gardens in Botswana (Ionides et al, 1969). Large excavations were lined with alternating layers of polythene, mud, and "sand-sausages" (thin plastic tubing about 15 cm in diameter, filled with a mixture of 14 parts sand to one part of cement and soaked briefly in water before placement in the liner). The hardened "sand-sausage" provided low-cost wall strength and were also used to build "beehives", which were essentially well casings in tanks filled with sand in the manner of an artificial aquifer. A technical problem with the lining chosen for popularization (several configurations were considered) was building the inflow side of the tank strong enough to withstand the erosive force of rushing water during a storm. Another likely problem seemed to be rodents eating through the polythene sheet layers of the lining.

Materials costs for the sand-sausage tanks were very low: Farrar and Pacey estimeted US $75.00 for a 45 m^3 tank (1973), Botswana). The technique for lining the excavations seemed to have promise, as well. Still, the tanks have not been widely adopted. School gardens and vegetables for the children were, like the tank, ideas originating substantially from the outside. A second reason may be the great labor requirement of these tanks combined with poor nutrition, reducing peoples' capacity and enthusiasm for manual labor (Farrar and Pacey, 1974; see "Catchment Tanks in Southern Africa: a Review", section 3.3.6).

The "beehive" design, using the liner describe design, using the liner described and filled with sand to reduce evaporation (water is drawn through beehive-shaped wells), may have promise for community domestic water supply efforts: "The performance of the 'beehive' tanks that have been built has generally been satisfactory, and from a technical point of view, we would regard this type of catchment tank as a highly attractive approach to the water supply problems of semi-arid areas."

Farrar and Pacey (1974) also give a brief description of the "Water Harvester", built by the Christian CARE Organization in Zimbabwe: "The cylindrical holes are dug to about 2 meters depth, lined with brick or stone, then plastered with cement to make them water proof. Concrete lids are made to keep the water clean." The system shown uses three tanks linked underground with pipe, so that only one pump is needed. The rough estimate of the cost of these linked cylinder tanks is US $75.00 for 9 m^3 of storage (1973, Zimbabwe).



Farrar and Pacey (1974) by permission

Research into the use of synthetic asphalt, plastic, and rubber liners to water proof large excavations or "hafirs" (a traditional name for a depression where water collects during wet months in the Sudan) goes back at least as far as the early 60's. Thorsky (1961) and Ellsperman (1962) present methods for lining hafirs with capacities in the range of 7,500 m^3 with sprayed asphalt and PVC sheet. Their reports describe experimental work, and no indication of implementation for community water supply is given.

Grover (1971) supervised construction of a 270 m^3 tank excavated into coral on an island off the coast of Kenya. The tank was lined with 0.8 mm thick butyl rubber sheet. This prototype effort was sufficiently promising that Grover proposed 3 similar tanks (each with a volume of 2,300 m^3) to meet the storage requirements of a ground catchment system for the farm and domestic needs of 200 families on another coral island. These proposed tanks would have been covered with a floating sheet of the same butyl material, reducing evaporation to a negligible level. The cost of butyl (about 3.7/m^3, 1969, in Kenya) made the cost of each of Grover's proposed tanks about US $18,000 (Kenya, 1970) including pumps. The cement stabilized, asphalt---sprayed catchment surface was expected to cost an additional $15,000.

Cluff (1975) points out that evaporation of 2-3 ma/year in Mali causes existing ponds or "mares" to disappear during the dry season, and proposes constructing embankments to make deeper reservoirs adjacent to the mares. This would reduce the surface/volume ratio of the storage (reducing evaporation) and might provide enough capacity to meet the domestic water needs of groups of several thousand people. In one case Cluff proposed an 80,000 m^3 system, lined with salt to reduce seepage, and estimated that its capital cost (including the cost of earthmoving and an imported engine-driven pump to move water from the mare to the reservoirs) would be less than US $1.00 per m^3 of storage (1975, Mali).

None of these huge open tank systems has been built, but Cluff used precipitation records, local watershed characteristics, demand figures and labor costs in his analysis and proposals for several villages. His report is provocative.

3.3.5 Costs of materials, costs/m^3 of water storage

On the following pages is a tabular summary of most of the materials cost information in section 3.3. The tanks are listed in sequence from smallest in storage capacity to largest. Differences in local materials prices and dates of documentation call for extreme care when making comparisons. The figures do, however, show that:

1. In general, large tanks (e.g. 12, 14, 15 below) can be built at lower cost/m^3 of storage than small tanks.

2. Some small tank options (e.g. 2 below) may be among the cheapest of all tanks.

3. Tanks built with similar methods, but to meet different engineering standards, may vary greatly in cost (compare 4, designed at a university, and 10, developed "in the field").

4. "Household-sized" tanks can be built for materials costs of under US$18/$m^3$ (2,6,7,10 below).

See section 4.2.1 for direct comparisons of materials requirements of tanks 6, 10, and 12.

3.3.5 Costs of materials, costs/m^3 of water storage (continued)

TANK (C: cover, P: pump, G: gutters)	MATERIALS	MATERIALS$^+$ COST (US$)	COST/M^3 $^{++}$ (US$)
1. 0.17 m^3 steel drum, East AFrica (White et al, 1972)	manufactured	2.50	14.90 (1969)
2. 0.25 m^3 cement mortar jar, Thailand (Watt, 1975)	cement mortar, concrete	0.50	2.00 (1974)
3. 0.3 m^3 pottery jar, Thailand (Watt, 1975)	purchased locally	5.00	16.70 (1973)
4. 1.2 m^3 ferrocement tank (C), Thailand (Sharma and Gopalaratnam, 1980)	cement, sand & gravel, steel mesh & rod	33	28 (1980)
5. 1.4 m^3 "tin" tank, East Africa (White et al, 1972)	manufactured	39-84	28-60 (1969)
6. 2.3 m^3 plastered "Ghala" basket, East Africa (UNICEF, 1982)	cement, sand & gravel	42*(est)	18 (1982)
7. 7.0 m^3 cast concrete ring tank (C), Thailand (Watt, 1978 b)	cement, sand & gravel	40 (1)	5.70 (1977)
8. 9 m^3 ferrocement tank (C,G) Zimbabwe (Farrar and Pacey, 1974)	cement, sand & gravel, steel netting and wire	62.50 (1)	6.90 (1973)
9. 9.0 m^3 galvanized corrugated iron tank, Zimbabwe (Farrar and Pacey, 1974)	manufactured	112	12.50 (1973)
10. 10 m^3 ferrocement tank (C) (Watt, 1978)	cement, sand & gravel, steel netting and wire	150*(est)	13 (1982)

\+ author's figure unless indicated otherwise
++ my calculations, not those of authors
* assumes US$ 7.14 (Zaire, 1981) per 50 kg bag of cement; other materials estimated. See text
(1) excluding costs of metal forms

3.3.5 (continued)

	TANK (C: cover, P: pump, G: gutters)	MATERIALS	MATERIALS+ COST (US$)	COST/M^3 ++ (US$)
11.	15-20 m^3 underground ferrocement (C), New Hebrides (Calvert and Binning, 1977)	cement, sand & gravel, steel netting and rod	250	12.50 (1976)
12.	25 m^3 underground ferrocement tank, Botswana (C?) Maikano and Nyberg, 1980)	cement, steel netting, PVC pipe	135	5.40 (1980)
13.	36 m^3 buried reinforced concrete cistern (C,P?) USA (Dooley, 1978)	cement, sand & gravel, steel rod, materials for forms	1000	27.50 (1978)
14.	45 m^3 "sand-sausage" open tank, Botswana (Farrar and Pacey, 1974)	cement, sand, plastic tubing	75	1.67 (1973)
15.	71 m^3 partially buried concrete block tank (C, G), Ghana (Farrar and Pacey, 1974)	cement, sand, concrete block	260	3.70 (1973)
16.	2,300 m^3 butyl-lined tank (C,P), Kenya (Grover, 1971; proposed only)	0.8 mm butyl sheet, cement, hand pumps	18,000 (2)	7.83 (1970)
17.	80,000 m^3 NaCl-lined earth reservoir system, Mali (Cluff, 1975; proposed only)	NaCl, engine-driven pump	not enumerated	under 1.00 (1974)

(2) not including cost of sprayed asphalt catchment surface, estimated at an additional $15,000

3.3.6 Publications and how to obtain them

-- Cairncross, S., and Feachem, R., 1978, Small Water Supplies, book, 78 pages, £1.50 from the Ross Institute, London School of Hygiene and Tropical Medicine, Keppel Street (Gower Street), London WCIE 7HT, United Kingdom.

This book is a compact presentation of basic information on building small-scale water supply systems. Discussions include sources of water, watrer treatment, water lifting, and storage and distribution. Contains 2-page section on building water tanks of bricks and masonry. No diagrams, but text gives guidelines for wall, footing, and floor thicknesses; plastering and waterproofing; cleaning and maintenance; inlets, outlets, overflows, screening, and covers; and drainage. In some cases the construction specifications given provide for more strength, and use more materials, than necessary.

-- Calvert,R.C., and Binning, R.J. 1977, "Low Cost Water Tanks in the Pacific Islands", article, 3 pages, in Appropriate Technology magazine, Vol 4, no. 3, November 1977,£0.75 for the issue including Air Speeded Post, from Intermediate Technology Publications, Ltd., 9th King Street, London WC2E 8HN, United Kingdom.

Describes fabrication of ferrocement cover on an earthen dome, excavation of tank from beneath the cover, and plastering of ferrocement lining for 15-20 m^3 tanks built in "soft" sdoil in the New Hebrides. The authors believe the tanks can be built for under US $250.00. They also describe a method for building above-ground ferrocement tanks using locally available wood and reed materials for forms.

-- Farrar, D.M., and Pacey, A.J., 1974, "Catchment Tanks in Southern Africa: A Review", Africa Fieldwork and Field Technology Report no. 6, 13 pages, request

Farrar and Pacey 74 (cont)

from Paul Sherlock, OXFAM, 274 Banbury Road, Oxford OX2 7DZ United Kingdom.

An excellent critical description and evalution of open and "beehive" "sand-sausage" ground surface catchment tanks, ferrocement roof catchment tanks, and combinations of these designs in Swaziland, Botswana, and Zimbabwe. The authors give the most complete construction cost information we have seen, and also discuss manual labor requirements as a barrier to completion of some of the technically sound "sand-sausage" tank projects. Step-by-step instructions for making a 7.5 m^3 version of the ferrocement tanks built in the hundreds around the Friends Rural Center, Bulawayo.

Anyone considering a rooftop catchment system or project in Africa should try to read this report.

-- Henderson, G.E., Jones, E.E., and Smith, G.W., 1973, Planning for an Individual Water System, book, 156 pages, $5.00 from American Association for Vocational Instructional Materials, Engineering Center, Athens, Georgia 30602, USA.

A well-written book on conventional water installations for rural and farming families in the U.S. Includes good color drawings of cisterns, roofwashers, and a filter. Better pictures, but less construction detail, than in Using Water Resources (below)

-- Maikano, G.J., and Nyberg, L., 1980, "Rainwater Catchment in Botswana", paper, 5 pages, in the book Rural Water Supply in Developing Countries: Proceedings of a Workshop on Training held in Zomba, Malawi, 5-12 ? August 1980. Ask for a free copy of the book from International Development Research Center, Box 8500, Ottawa, Canada K1G 3H9.

Bibliography and access information for section "Storage Techniques"

An account of a pilot program for popularizing underground ferrocement tanks to store water caught on traditional grain threshing floors. Rainwater harvested using these systems is for families and cattle, and should allow farmers to move to their land and begin plowing 17 days earlier in the rainy season than otherwise. Not many construction details are given, but domed ferrocement covers and poured concrete covers reinforced with barbed wire are mentioned. Maintenance of the tank and catchment floor are emphasized. "Today, the pilot project has about 10 underground tanks built and more are under construction. In all it is hoped to have 80 completed by the end of 1980".

-- Office of the Foreign Secretary, 1973, Ferrocement: Applications in Developing Countries, book, 91 pages, mention your institutional affiliation or name of your group when requesting a free copy from: Board on Science and Technology for International Development (JH215), Office of the Foreign Secretary, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418, USA.

A basic book on the range of ferrocement techniques and potential applications, sidely referred to throughout the literature on the topic. Chapters cover ferrocement for boatbuilding, food storage facilities, fooe-processing equipment, low-cost roofing, and the basics of construction of shells and walls. Appendixes include diagrams construction steps, and cost breakdowns for food-storage silos in Thailand and Ethiopia which can be used for storing water. (These silos are also described in the article by Sharma, et al, below).

-- Pompe, C., van Kerkvoorden, R., and Siswoyo, H., 1982, "Ferrocement Applications in the West Java Rural Water Supply Project", article, pages 51-61 in Journal of Ferrocement, Vol. 12, no. 1, January 1982. Ask for a reprint or xeroxed copy at ~~cost~~ from International Ferrocement Information Center, Asian Institute of

$.20 per page plus $ 2.00 per request

Technology, P. O. Box 2754, Thailand.

An overview of the project which plans to construct hundreds of 5 m^3 and 10 $,^3$ ferrocement tanks, as well as a reservoir and community water supply system built largely of ferrocement. Presents a chart comparing costs of various rainwater storage tanks in Java, including gutters and labor costs of Rp 1000 (US$1.60) per man-day. Also includes good drawings showing construction details of the 10 m^3 tank and 2.5 m^3 bamboo-cement tank.

-- Sharma, P.C., Pama, R.P., Valls, J., and Gopalaratnam, V.S., 1979, "State-of-the-art Review on Ferrocement Grain Storage Bins", article, pages 135-150 in Journal of Ferrocement, Vol 9, no. 3, July 1979. Reprint or xerox copy at $0.20 per page plus $2.00 from International Ferrocement Information Center, Asian Institute of Technology, P. O. Box 2754, Bangkok, Thailand.

Describes construction techniques and costs for four ferrocement grain storage structures "...developed in different parts of the world that have been extensively field tested satisfactorily." An above-ground conical bin which has been called the "Thailo", holding 4 tons of grain or 9.5 m^3 of water and an undergound pit silo lined with reinforced plaster are two maodels which h.ave been used to store water. The authors give the cost of a 9.5 m^3 underground plastered pit built in India, at US $62.00.

-- UNICEF East Africa Regional office, 1982, "From Kenya--How to Make Plastered basket tanks for storing water", article pages 7-8 in Appropriate Technology magazine, Vol 8, no. 4, March 1982. £ 1.50 from Intermediate Technology Publications, 9 king Street, London WC2E 8HN, United Kingdom. Also available from UNICEF, East African

Regional Office, P. O. Box 44145, Nairobi, Kenya.

Describes activities and gives background of the Karen Appropriate Technology Unit outside Nairobi. Cement mortar jars (like those described by Watt, 1975, below) and a PVC bag suspended in a thatch-covered bamboo-lined pit are two tank designs tried at the center. Also mentions other ideas in passing: "It is noticed that, in many areas, houses will have a short length of roughly fashioned guttering fixed under the eaves just above the door, and that water from this will be collected in an old oil drum or container...(this) could provide the link point for development to simple but effective roof catchment systems." And, "Collection of water from grass roofs, even on circular huts, is possible by using a polythene film guttering or by simple guttering made from split bamboo or from two planks joined to give a "V" section." Many other ideas for food production/storage/preparation, and effective institutional involvement in village technology activities.

--VITA, 1977, Using Water Resources, book, 143 pages, $5.95 from Volunteers in Technical Assistance, 1815 North Lynn Street, Suite 200, Arlington, VA 22209 USA.

This is a reprint of a part of VITA's Village Technology Handbook, available for $10.00 (387 pages) from the same address, and including excellent sections on concrete and bamboo construction as well as health and sanitation, agriculture, and food processing and preservation. Using Water Resources contains a good 6-page piece on planning and building a conventional US-type concrete cistern with a capacity of 10 m^3 or more, including drawings of a filter and a "roofwasher".

Bibliography and access information for section "Storage Techniques"

The book as a whole is good basic reading for anyone consideriong construction of a small water supply.

-- Watt, S.B., 1978, Ferrocement Water Tanks and Their Construction, book, 118 pages, £ 2.95 from Intermediate Technology Publications, Ltd., 9 King Street, London WC2E 8HN, United Kingdom.

For those considering a rooftop catchment system, this book may be the single most useful publication listed here. Gives straightforward guidelines for design, descriptions of materials, and tools required, and a detailed, step-by-step summary of methods for building the ferrocement tansk (using metal forms) which have been "used successfully for over 25 years in different parts of the world" (see technical note in section 4). Also describes construction of several variations on the basic method, including small jars of unreinforced mortar (see technical note in section 4), 1-25 m^3 manufactured tanks in New England, a 6 m^3 tank built without formwork in the U.K. 10 m^3 ferrocement-lined traditional adobe grain storage bins in Mali, a 40 m^3 roofed tank built with makeshift formwork in Zimbabwe, and a 150 m^3 open tank built with makeshift formwork in Arizona, USA.

Lists amounts of materials required for each design, and gives a brief discussion of using rainfall data to plan a rooftop catchment system (see technical note, section 4).

-- Watt, S.B., 1978, "Rainwater Storage Tank in Thailand", article, pages 16-17, in Appropriate Technology magazine, Vol 5, no. 2, August 1978, £ 0.75 for the issue including Air Speeded Post, from Intermediate Technology Publications, Ltd., 9 King Street, London, WC2E 8HN, United Kingdom.

Bibliography and access information for section "Storage Techniques"

Describes construction of tanks made out of stacked ureinforced concrete rings, cast in 1.5 m. diameter cylindrical stee forms. The 60-cm-high rings can be stacked up to four high and have low materials costs (US $40.00 for a 7 m^3 tank) but the inner and outer steel forms would be expensive. Watt suggests that high-quality rings could be cast centrally under supervision and trucked to location for assembly.

-- Winarto, 1981, "Rainwater Collection Tanks Constructed on Self-Help Basis", article, pages 247-253 in Journal of Ferrocement, Vol 11, no. 3, July 1981. Ask for a reprint or xeroxed copy at $.20 per page plus $2.00 per request from International Ferrocement Information Center, Asian Institute of Technology, P. O. Box 2754, Bangkok, Thailand.

An account of the adaptation of standard ferrocement tank methods to the materials availabilities of rural Java. Detailed verbal instructions for building a steel rod reinforced 9 m^3 tank with integral floor and cover. Bamboo mats are used as plastering forms. Some pictures; construction could be attempted with basic knowledge of the techniques in <u>Ferrocement Water Tanks and Their Construction</u> (Watt, 1978). Also describes construction of smaller tanks built with bamboo (instead of steel rod) reinforcement cages. The steel rod and bamboo cage designs presented here have been adopted by the West Java Rural Water Supply Project (Pompe et al, above).

4. Technical notes describing planning and construction of promising rooftop catchment and storage technologies

4.1 Using rainfall data to design a rooftop catchment system +++

The principal factors affecting the design of a rainwater catchment system are a. local rainfall patterns; b. area of the rainfall catchment; c. volume of the container the water is stored in; and d. the amount of water to be provided by the system for consumption. The first of these factors is the most important and, at the same time, the one we can do the least about. So the amount of rain that fall, and the periods of time between rains, are the basic natural facts which should shape the combination of the other three factors in a rainwater catchment system.

This section, then, will show how to think about:

a. area of rainfall catchment;
b. volume of storage; and
c. amount of water to be provided for consumption,

given available information on rainfall.

In rich countries the usual aprpriach in water supply is to start with an amount for consumption, and then to design storage and catchment to provide that amount of water even during dry periods. In this approach, maximum emphasis is placed on convenience and reliability. In developing countries, on the other hand, concerns about convenience and reliability must nearly always take second place to concerns about costs. In these situations it often makes sense to start with available resources--existing physical structures, cash, local materials, and labor--, and then to work out a plan for

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+++ methods in this section are extracted and modified from Watt (1978, pages 109-112), VITA (1977, page 111), and Hardenbergh and Rodie (1960, pages 103-104).

expending those resources in such a way as to come closest to a target for water consumption. We will take this latter approach in this section.

Rainfall data. The degree of detail of rainfall data varies widely. Obviously we would like to know how much rain falls during storms, and how much time separates the storms. This would allow us to determine of a catchment and storage combination would take all the water from a storm or waste some of it; we could also easily determine whether the storage would hold enough water to last until the next storm would be expected to occur. In practice, rainfall data this detailed are very hard to get. In many areas, the best data available are month-by-month rainfall totals. These figures can be obtained from weather bureaus, airports, and sometimes from agricultural research or extension stations. The data should have been taken over several years.

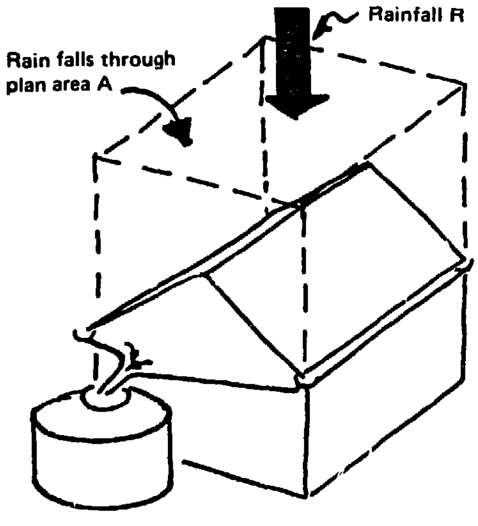
In many places it may be impossible to find month-by-month rainfall totals. The next best alternative, then, is to find out monthly average totals for your area. The last and least desirable alternative is to find out yearly average totals for your area. Average totals are less useful because it is impossible to tell from them how often, and how extreme, are the deviations. (We noted in section 3.1.1 that there is less than a one-in-two chance of rainfall totalling within 10% of the yearly average, for any particular year, for the continene of Africa. We can expect that monthly deviations from the average would be at least as great.) This means that a system planned using average rainfall totals might provide water as expected only about two thirds of the time. For thie reason, VITA recommends (Using Water Resources, see section 3.3.6) that average rainfall totals be multiplied by 2/3 to give an estimate of the minimum rainfall. We can be much more certian that actual rainfall in the future will meet or exceed this minimum rainfall estimate.

In any case, whether you use month-by-month rainfall totals or average totals, it is important to try to get information which has been collected over several years. Here is part of a table (van der Leeden, 1975, page 442) showing monthly averages (for data collected over 3 years) for Am Timan, Chad.

TABLE 7-2. TEMPERATURE AND PRECIPITATION DATA FOR REPRESENTATIVE WORLD - WIDE STATIONS (continued)

OUNTRY AND STATION	LATITUDE	LONGITUDE	ELEVATION	TEMPERATURE											AVERAGE PRECIPITATION													
					Average Daily								Extreme															
					JAN.		APR.		JULY		OCT.																	
				Length of record	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Length of record	January	February	March	April	May	June	July	August	September	October	November	December	YEAR
	° '	° '	FEET	YEAR	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	YEAR	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.	IN.
ameroon:																												
Ngaoundere	07 17N	13 19E	3,601	9	87	55	87	64	82	63	82	61	102	46	10	•	•	1.1	5.5	7.0	8.4	10.6	9.6	9.2	6.3	0.5	•	57.2
Yaounde	03 53N	11 32E	2,526	11	85	67	85	66	80	66	81	65	96	57	11	0.9	2.6	5.8	6.7	7.7	6.0	2.9	3.1	8.4	11.6	4.6	0.9	61.2
ntral African Republic:																												
Bangui	04 22N	18 34E	1,270	5	90	68	91	71	85	69	87	69	101	57	5	1.0	1.7	5.0	5.3	7.4	4.5	8.9	8.1	5.9	7.9	4.9	0.2	60.8
Ndele	08 24N	20 39E	1,939	3	99	67	98	73	86	69	90	68	109	58	3	0.2	1.3	0.6	1.7	8.4	6.1	8.3	10.1	10.7	7.8	0.6	0.0	55.8
ad:																												
Am Timan	11 02N	20 17E	1,430	3	98	56	105	68	89	70	96	67	113	43	3	0.0	0.0	0.1	1.2	4.3	5.0	7.3	12.3	5.8	1.2	0.0	0.0	37.2
Fort Lamy	12 07N	15 02E	968	6	93	57	107	74	92	72	97	70	114	47	5	0.0	0.0	0.0	0.1	1.2	2.6	6.7	12.6	4.7	1.4	0.0	0.0	29.3
Largeau (Faya)	18 00N	19 10E	837	5	84	54	104	69	109	76	103	72	121	37	5	0.0	0.0	0.0	0.0	•	0.0	•	0.7	•	0.0	0.0	0.0	0.7

Figuring runoff. The amount of runoff, or water available for storage in a tank, is related to the horizontal area covered by the catchment surface. (As we work this example, we will assume that we plan to use the roof of a building for a catchment surface. This seems to be a sensible use of existing resources in many areas. The procedure used in the example could equally well be used for a variety of catchment surface sizes and types.) For a building, this area is the ground area covered by the roof., as shown in the figure.



Watt (1978) by permission

Let's assume that the ground area covered by the roof is 30 m^2 (the area of a 5 x 6 meter building). The amount of runoff which could be collected from the roof is:

$$R = \text{area} \times \text{rainfall} \times 0.9^*$$
$$= 30\ m^2 \times \text{rainfall} \times 0.9.$$

Runoff or "R" can be figured for any kind of rainfall total. Using monthly average rainfall totals would give monthly average R; using a yearly minimum estimate would give a yearly minimum estimate R.

Using runoff totals to plan storage capacity. The amount of water in storage should come as close as possible to providing for water needs during dry periods. Take, for example, a family of five, each of which needs a minimum of 20 liters of water per day over a dry period of one month. Their water needs during the month would be:

$$\text{needs} = 5 \text{ people} \times 20 \text{ l./day} \times 30 \text{ days}$$
$$= 3{,}000 \text{ liters.}$$

This means that to supply this need for water, a storage tank would have to contain at least 3 m^3 at the beginning of the dry period. A tank containing 2 m^3 (2,000 liters) would provide most, but not all, of the family's minimum needs.

Simple graphical method. If you can compute monthly runoff totals, cimple graphs can help show dry periods and wet periods and indicate the need for storage. We will work out an example using the data for Am Timan (above).

The first step is to calculate runoff totals for each month. The rainfall data available for Am Timan are monthly average totals, so multiplying

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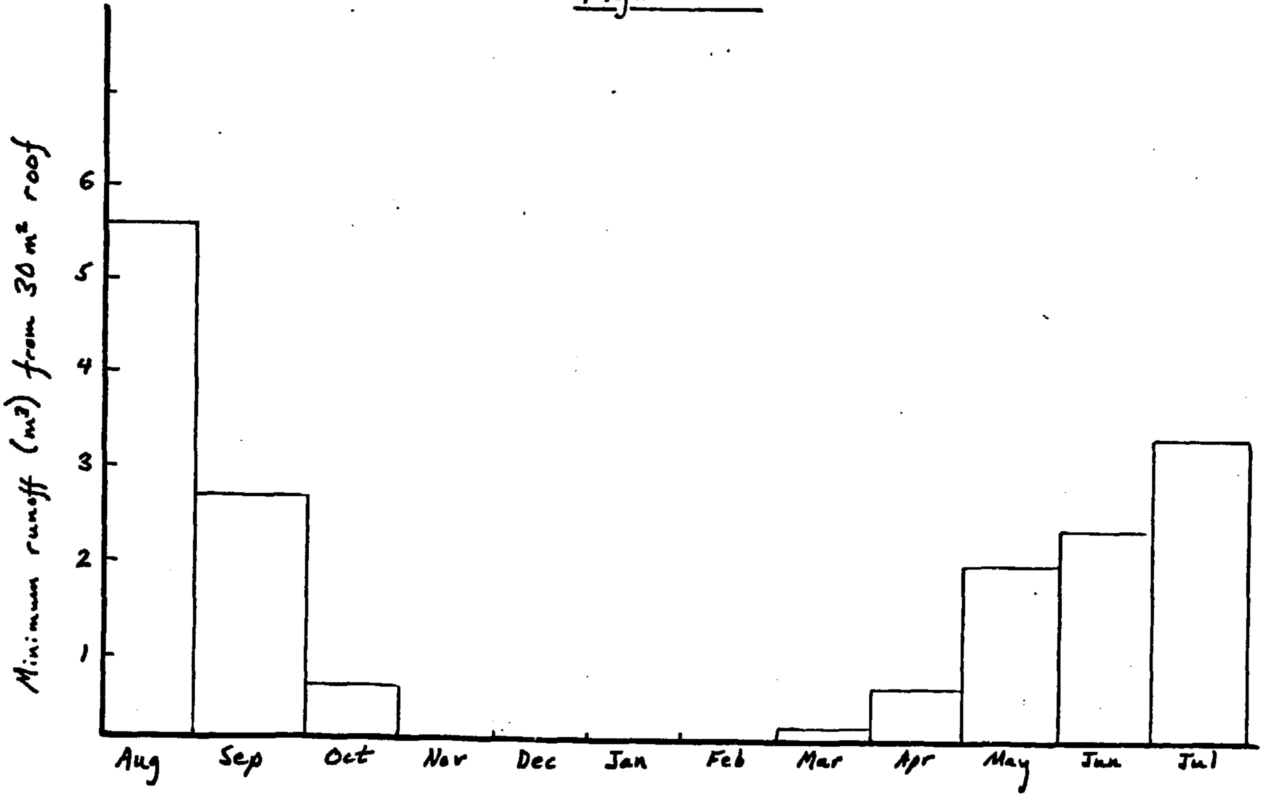
* Ree (1976) says that a sheet metal roof with good guttering is about 90% efficient. Other materials may be less efficient.

each of these by the roof area gives monthly average runoff. Then, to get a minimum runoff, the product is multiplied by 2/3. Here is the calculation for October (average rainfall in October, from the table above, is 30.5 mm):

$$\begin{aligned} R_{(Oct)} &= \text{area} \times \text{rainfall}_{(Oct)} \times 2/3 \times 0.9 \\ &= 30\ m^2 \times 0.0305\ m \times 2/3 \times 0.9 \\ &= 0.55\ m^3. \end{aligned}$$

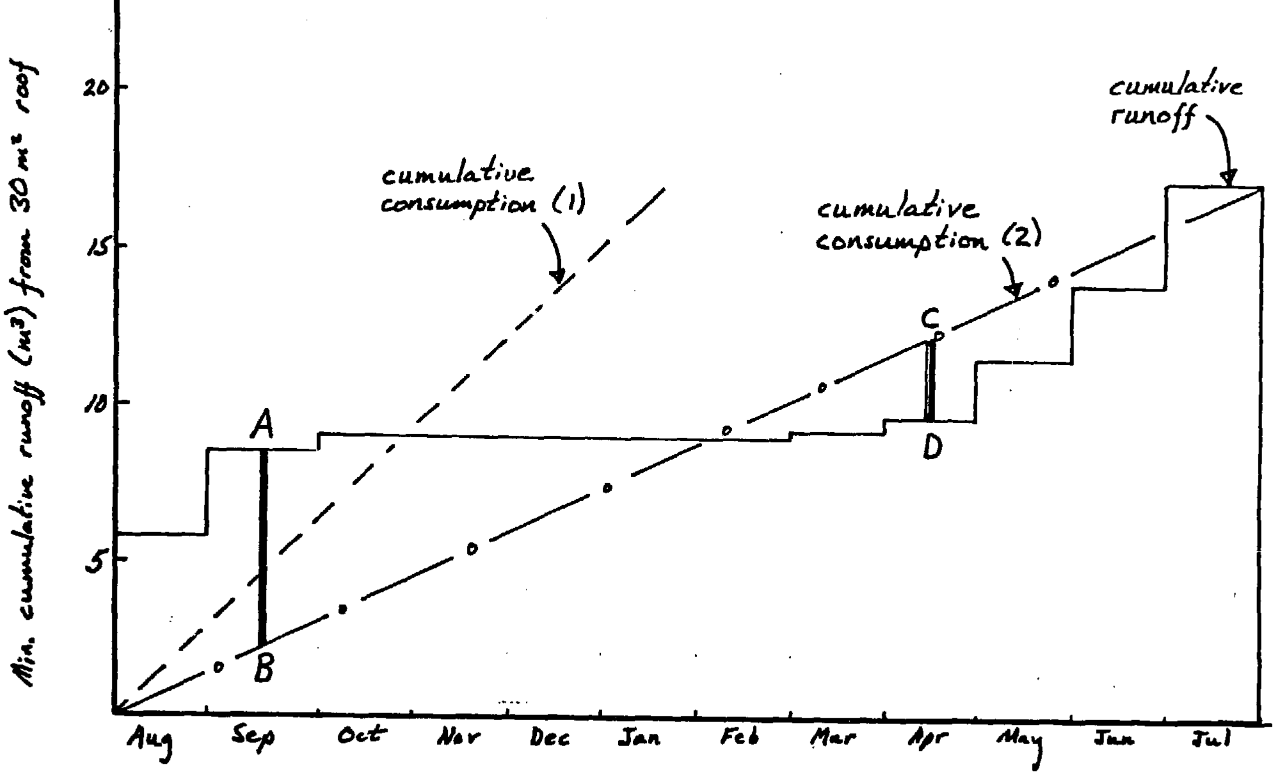
This calculation is performed for each month. These minimum runoff totals are shown on the following graph, figure 1, with the peak month of the wet season at the far left (this makes the procedures below more straightforward):

Figure 1.



The second step is to show "cumulative" runoff--that is, each monthly total from figure 1 above is added to the total of the previous months. Thus the graph shows the sum of all runoff, which increases or remains the same throughout the year. For October, for example, the graph will show the sum of the runoff totals for the months of August, September, and October. The solid line of the following graph shows minimum cumulative runoff ("minimum" because we have multiplied each monthly runoff figure by 2/3):

Figure 2.



Note that the line is horizontal for the months with rainfall and runoff totals of zero: for these months, there is no increase in the cumulative runoff. At the end of a year the cumulative runoff is 17.2 m^3. This means that a tank with a capacity of 17.2 m^3 could theoretically hold all the water collected over an average year's time from our 30 m^2 roof in Am Timan.

The final step is to show cumulative water consumption on the graph along with cumulative runoff. Take, for example, the family of five, each member consuming 20 l. per day. At the end of one month the family will have used 5 x 20 l. x 30 days = 3,000 l. or 3 m^3; at the end of two months they will have used another 3 m^3 for a total of 6 m^3, and so on. This cumulative consumption is shown as the dashed line on the graph above, figure 2. The dashed line runs below the cumulative runoff line until October, but rises above it after that. This shows that the 30 m^2 roof cannot provide enough water to support this rate of consumption.

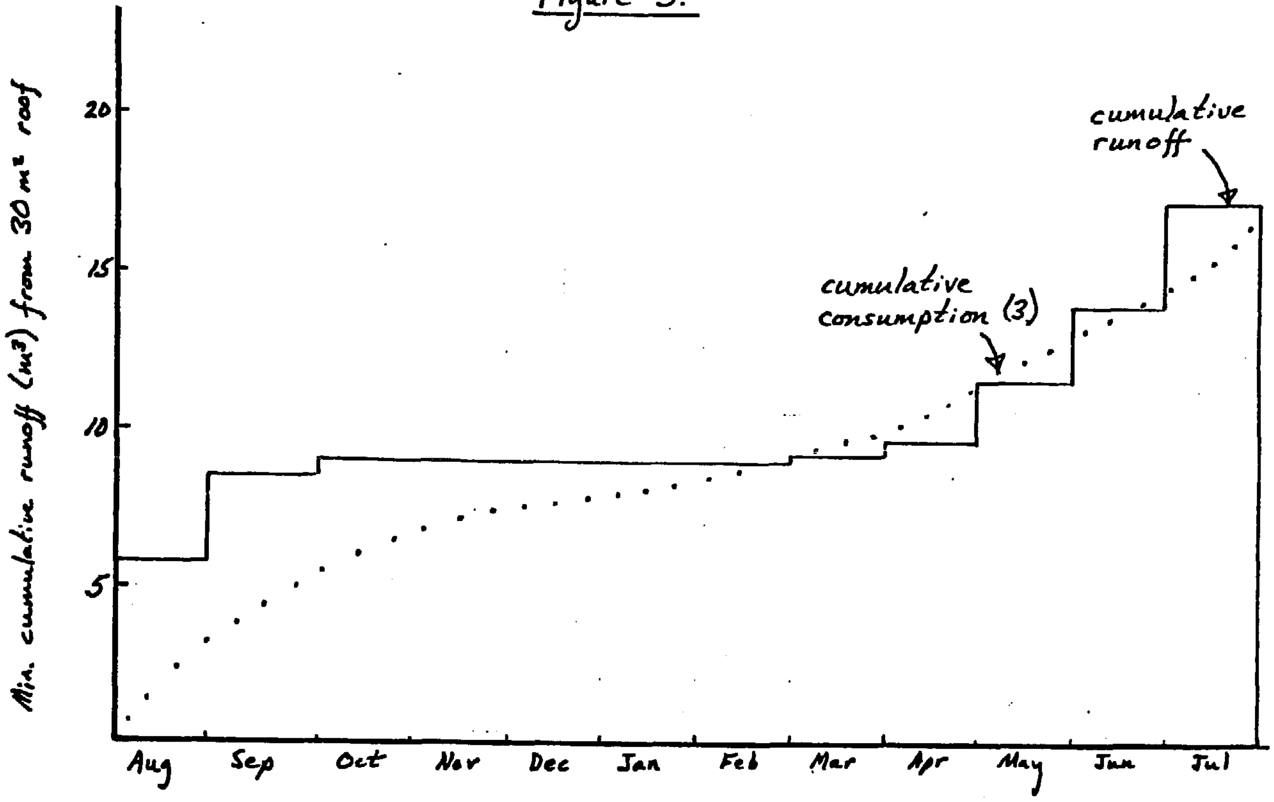
What rate of consumption can the 30 m^2 roof provide? We can determine this by drawing a second consumption line (the dashed line with dots, figure 2) so that is meets the runoff line at the end of the year (on this graph, in the middle of the wet season). Thus cumulative consumption equals cumulative runoff for the year. Runoff increases faster than consumption for August and September, but then the runoff line levels off and consumption increases faster than runoff from October to June. Then in June and July runoff again increases faster than consumption.

The volume of storage required to provide this rate of consumption, and use all the runoff from the roof, can also be dtermined from the graph. This volume is the sum of the greatest vertical distance from the runoff line above the consumption line to the consumption line (distance AB in figure 2, which represents about 6 m^3), and the greatest vertical distance from the runoff line below the consumption line to the consumption line (distance CD in figure 2, representing about 3 m^3). So a tank which could store about 6 + 3 = 9 m^3 could theoretically hold enough runoff from the 30 m^2 roof to provide the steady consumption rate indicated by the dash-dot line (2). This line rises at the rate of about 1.4 m^3 per month; 1.4 m^3 (1,400 liters) divided by 5 people, divided again by 30 days gives a consumption rate of a little more than 9 liters per day for each member of the family.

Water rationing and storage. Most families in areas with water shortages tend to consume more water during wet months and less water during dry months. Thus a line representing cumulative consumption on a graph like the ones above would not be straight (like lines 1 and 2) but instead tend to curve, following the cumulative runoff line. The graph in figure 3 (below) shows a curving consumption line (3); using the method for calculating storage above, it is easy to show that much less storage volume is needed to provide for this rate of consumption which changes with the seasons.

The technique described in this section is a useful tool for making an educated guess at how much water could be provided by a proposed system. It is best, however, to bear in mind the words of Watt (1978, page 112) in his discussion of system size: "In the real world the climate is unlikely to be uniform enough to allow these steps to give more than a rough indication of tank size".

Figure 3.



4.2 Costs of construction

4.2.1 Materials quantities for 4 tanks

The following page compares the materials inputs for construction of tanks discussed in section 3.3 and listed in table 3.3.5. Using this kind of information, local prices can be applied to roughly determine costs and make cost-based judgements about the relative attractiveness of different designs.

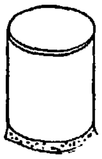
"Trade-offs" are evident: for example, the cement mortar plastered basket (UNICEF, 1982) requires more cement / m^3 of storage than any of the other three, but meeds no metal reinforcing material and little gravel.

The subsequent section (4.2.2) gives guidelines and examples for roughly calculating amounts of cement needed to build a variety of tanks.

4.2.1 (continued) Materials quantities for 4 tanks

Ferrocement Tank with foundation (no cover) (after Watt, 1978)
10 m3

cement	:12 bags (50 kg. each)
sand	: 1 m3
gravel	: 0.5 m3
chickenwire	: 16 m2



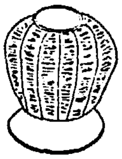
materials per m3 storage:

1.2 bags cement
0.1 m3 sand
.05 m3 gravel
16 m2 chickenwire

plus: straight wire, use of forms

Cement mortar plastered basket with foundation (no cover) (after UNICEF, 1982)
2.3 m3

cement	: 5 bags
sand	: .13 m3
gravel	: .04 m3

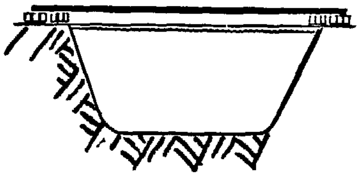


materials per m3 storage:

2.2 bags cement
.06 m3 sand
.02 m3 gravel

Reinforced cement mortar plastered underground tank (after Maikano and Nyberg, 1980)
20 m3

cement	: 12 bags
sand	: 1 m3
chickenwire	: 32 m2

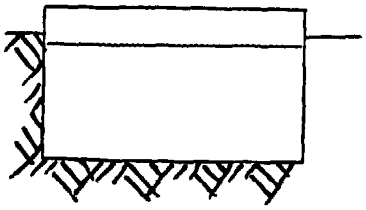


materials per m3 storage:

0.6 bag cement
.05 m3 sand
1.6 m2 chickenwire

Underground concrete tank with cover
12 m3

cement	: 13 bags
sand	: 1 m3
gravel	: 1.4 m3



materials per m3 storage:

1.1 bag cement
.08 m3 sand
.12 m3 gravel

plus: reinforcing rod, material for forms

4.2.2 Calculating costs of materials

The following discussion on figuring costs shows how to obtain rough amounts for some of the amin materials needed for construction of roof catchment systems. The procedures are simple, and computations like them can be used to get an idea of whether materials for a proposed catchment are affordable, and to compare the costs against the costs of alternatives. They do not take many important questions into account: they ignore the time required for delivery, and any costs of labor, for example.

Here is a summary of the computations of materials costs:

$$\text{cost of cement (for concrete)} = \text{volume of concrete} \times \frac{7\ \text{bags cement}}{\text{m3 concrete}} \times \frac{\text{price}}{\text{bag}}$$

$$\text{cost of cement (for mortar)} = \text{volume of mortar} \times \frac{10\ \text{bags cement}}{\text{m3 mortar}} \times \frac{\text{price}}{\text{bag}}$$

$$\text{cost of roofing material (sheet)} = \text{area of roof} \times \frac{\text{price}}{\text{m2}}$$

The first two examples are worked out for materials that would be needed for construction of the $10\ m^2$ ferrocement tank described in section 4.3.2 (see also table 3.3.5, no. 10,and section 4.2.1). Other materials, in addition to the ones mentioned here, would be needed--sheet metal for forms, for example. The final example concerns cost of sheet metal for roofing. See section 4.1 for how to think about how much rainwater a given roof can collect.

Cement in concrete floors, footings, and foundations of tanks

1. Figure the volume of concrete needed. For a 2.8 m diameter floor which will be 7.5 cm thick,

$$\begin{aligned} \text{area} &= \pi r^2 \\ &= 6.2\ \text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{volume} &= \text{area} \times \text{thickness} \\ &= 6.2\ \text{m}^2 \times 0.075\ \text{m} \\ &= 0.47\ \text{m}^3. \end{aligned}$$

2. Figure the amount of cement needed to make the concrete. Concrete mixed in the proportions 1:2:3, cement:sand:gravel, is plenty strong for self-help floors, footings, and walls when made with clean materials and cured properly.* Concrete mixed 1:2:3 contains about 7 bags (@ 50 kg per bag) per m^3. Using this information, we can figure the number of bags needed:

$$\begin{aligned} \text{bags of cement} &= \text{volume of concrete} \times \frac{7\ \text{bags}}{\text{m3 concrete}} \\ &= 0.47\ \text{m}^3 \times \frac{7\ \text{bags}}{\text{m3 concrete}} \\ &= 3.3\ \text{bags}. \end{aligned}$$

3. Figure the cost, using the price of a bag of cement in your area. For example,

$$\begin{aligned} \text{cost} &= \text{\# of bags} \times \text{price per bag} \\ &= 3.3\ \text{bags} \times \$7.14\ (\text{US\$, Zaire, 1981}) \\ &= \$23.49. \end{aligned}$$

---

* determined using the "concrete calculator", VITA (1973). You many decide to use a lower porportion of cement. The "concrete calculator" shows how to adjust the volumes of the other materials.

Mortar for plastering floors, walls, and roofs of tanks

1. Figure the volume of mortar needed. For a floor plastered with 5 cm. of mortar, 2.5 m in diameter,

$$\begin{aligned} \text{area} &= \pi r^2 \\ &= 4.9\ \text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{volume} &= \text{area} \times \text{thickness} \\ &= 4.9\ \text{m}^2 \times 0.05\ \text{m} \\ &= 0.25\ \text{m}^3. \end{aligned}$$

For a cylindrical tank with walls 2 m high, plastered with a total of 4 cm of mortar,

$$\begin{aligned} \text{area} &= 2\pi r\ (\text{height}) \\ &= 15.7\ \text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{volume} &= \text{area} \times \text{thickness} \\ &= 15.7\ \text{m}^2 \times 0.04\ \text{m} \\ &= 0.63\ \text{m}^3. \end{aligned}$$

So the total volume needed, for walls and floor, is $0.25\ \text{m}^3 + 0.63\ \text{m}^3 = 0.88\ \text{m}^3$.

2. Figure the amount of cement needed to make this volume of mortar. Mortar mixed 1:3, cement:sand, is recommended for waterproof walls. This mix contains about 10 bags (@ 50 kg) per m^3 (always check with local masons and collect opinions on mixes, if you are inexperienced). So:

$$\text{bags of cement} = \text{volume of mortar} \times \frac{10 \text{ bags}}{\text{m3 mortar}}$$

$$= 0.88 \text{ m}^3 \times \frac{10 \text{ bags}}{\text{m3 mortar}}$$

$$= 8.8 \text{ bags.}$$

3. Figure the cost of the cement, using the price of a bag of cement in your area. For example, in Zaire,

$$\text{cost} = \text{\# of bags} \times \text{cost per bag}$$

$$= 8.8 \text{ bags} \times \frac{\$7.14}{\text{bag}}$$

$$= \$62.83.$$

Roofing material (corrugated metal sheet)

1. Figure the area of roof to be covered with the metal sheet. Allow for overhang, and consider where gutters will be hung, when making measurements. A building 8 m long with a pitched roof might have 2 roof surfaces of equal area:

$$\begin{aligned} \text{total area} &= 2\,(\text{length} \times \text{width}) \\ &= 2\,(8\text{ m} \times 3\text{ m}) \\ &= 48\text{ m}^2 \end{aligned}$$

2. Using this area, figure the cost, using the price of metal sheet in your area. For example,

$$\begin{aligned} \text{cost} &= \text{area} \times \text{price per m}^2 \\ &= 48\text{ m}^2 \times \frac{\$2.20}{\text{m}^2} \quad \text{(Monrovia, 1981, US\$)} \\ &= \$105.60 \end{aligned}$$

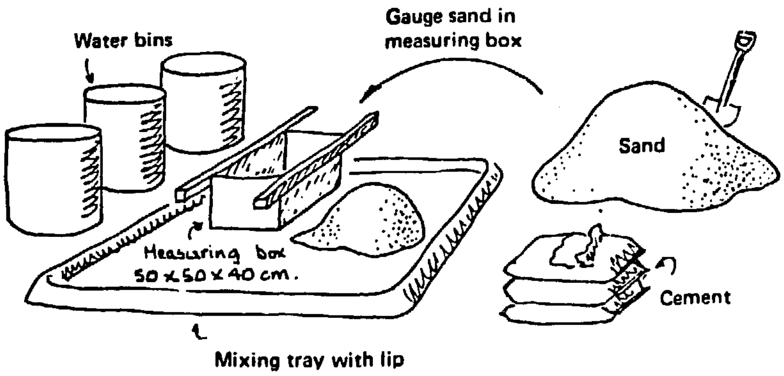
This is only a rough figure, because it ignores the size of the individual sheets and how much they must be cut to fit the roof surface. Also, the sheets must overlap a little to shed water properly. This means that the actual area of sheet needed, and the cost, may be 15-20% more.

If gutters are to be made with the sheet material, this may increase the cost again. Sometimes sections of gutter and hanging straps can be made with pieces cut when the sheets are fit to the roof.

4.3 Building Water Tanks

The construction information in this section is for three of the most widely docemented of the tanks outlined above in section 3.3.2. Here we intend to give the interested reader detailed information on the materials, tools, and skills involved in their construction; some readers with confidence in their manual skills would be able to attempt construction from the information given. We do not mean to imply that these are the three "best" tank designs for household rooftop catchment; in fact, each of these three tanks requires a relatively great amount of cement per m^3 of storage (see, for example, section 4.2.1). They are, however, three of the most "teachable" of the designs documented. See section 3.3 for a more complete discussion of water stroage alternatives.

Each of the tanks described in this section is made with cement mortar, which is a mixture of sand and cement and water. It is always important to make mortar with the cleanest available materials, and to keep soil and other contaminants out of the mortar mixture . Watt (1978) suggests using a mixing board or making a small concrete pad on a layer of gravel. The board is probably a better choice where the tanks or jars will be built far from each other.



Watt (1978) by permission

The mortar mixtures used for the following tanks and jars contain proportions of cement:sand ranging from 1:2 to 1:3 (measured by volume). Mixtures with more cement are easier to plaster with and may be stronger and more waterproof for the surfaces of smaller jars with littel reinforcement. For larger containers, a 1:3 cement:sand mixture is strong enough and less likely to crack when curing.

Sand for mortar should be clean. A range of sand grain sizes is OK, but sand with lots of fine silt should be avoided because it causes mortar made with it to flake off. Sand and any other materials to be used in construction should be gathered before any work strats. Study the list of materials preceeding each of the tanks, and read through the instructions carefully beginning.

Clean water should be added to the cement and sand after they have been thoroughly mixed together with a trowel or shovel. Make a hole in the pile of cement/sand mix and pour the water in, a little at a time. While a mix that is too "dry" will be difficult to apply, a "wet" mix will not be as strong when cured. Use as little water as possible to obtain a workable mixture. STart with an amount of water that is half the volume of the cement, and add water sparingly.

Do not mix more mortar than can be applied to the tank or jar in about 1/2 hour! After about this amount of time, mortar begins to set and cannot be applied properly (Watt, 1978).

Concrete is used instead of mortar for the foundations of most tanks and jars because it contains gravel or small stones and is less likely to break or weaken under the load of a heavy tank and its contents. The gravel used in concrete ideally contains a range of sizes, and the stones should not be flat. Like sand, gravel m ust be clean, or the concrete will be weak.

Concrete used for foundations can be mixed in proportions ranging from 1:2:3 to 1:3:6. Regardless of the proportions, concrete should be made with as little water as possible and mixed in a clean place. Containers like those shown in the figure above can be used to measure the proportions of materials in mortar and concrete mixes. REsist the temptation to estimate proportions or use the blade of a shovel to measure with; this will result in a weaker mix.

The Village Technology Handbook (VITA, 1973; see section 3.3.6) includes an excellent section on selecting mixes, preparing, and building with concrete.

4.3.1 0.25 m^3 cement plaster jar

Unlike the other water containers in this section, this jar is built entirely of mortar. It contains no strengthening fibers nor wires. The mortar is applied to a " mold" which is usually made of sacking material (like burlap) filled with something heavy enough to plaster against.

Because these jars have no reinforcing material, they are made with a mortar mix which is "rich" in cement. The proportions of materials recommended in the following instructions (copied by permission from Watt, 1978, see section 3.3.6) are 1:2, cement:sand (measured by volume). Watt does not mention the proportion of water to be used. He says instead that the mortar should be mixed as "dry" as possible, for highest strength. Refer back to the discussion of making mortar above.

The following instructions are for construction of a small jar which holds about 0.25 m^3. Watt says that people with no experience have been taught to make the jars in less than two days. Much larger jars, which have screens, lids, and taps, have been constructed using this method. Subsituting soil and lime for some of the cement and sand in the mortar has also been tried.

MATERIALS: 1/2 bag of cement (less than this should be required)

clean sand

clean water

burlap, "gunny cloth", or other strong sacking material

sand, grain husks, or sawdust to fill the sacking

TOOLS: needle and thread, or other tool for sewing the sacking

mixing board or pad and containers for measuring and mixing mortar materials

trowel and wooden stick

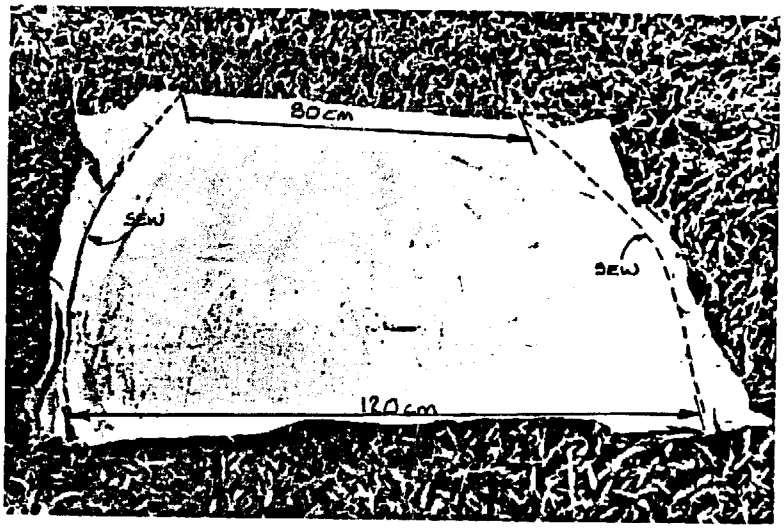
STEPS IN CONSTRUCTION REQUIRING SPECIAL CARE:

Making sure that the material used to fill the sacking (step 2.4) is heavy enough to keep its shape during plastering. It is a good idea to try filling the sack on the ground before beginning contruction.

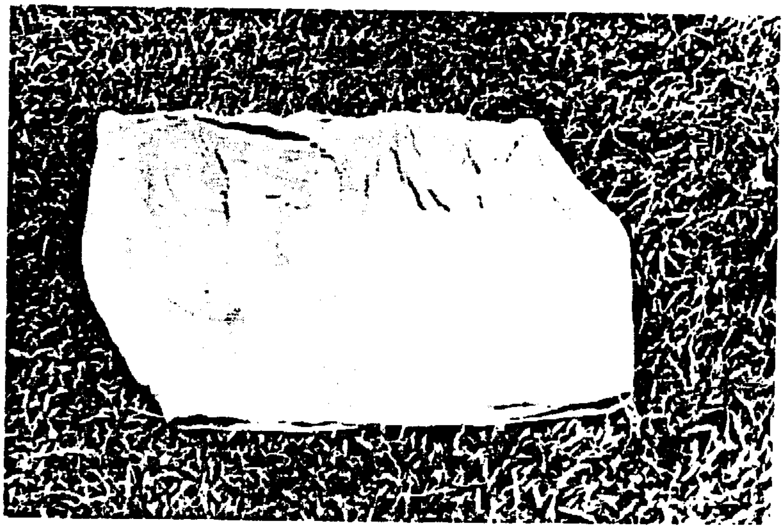
Making the mortar. Do not make the mortar for applying to the mounl until you are actually ready to begin (step 2.8). This should allow you to work with a "dry" mortar mixture for maximum strength. Mixing the cement and sand well, before adding the water, is especially important.

Curing the new jar (step 2.10).

*Photo 2 Making a small water jar: 250 litres. Thailand***

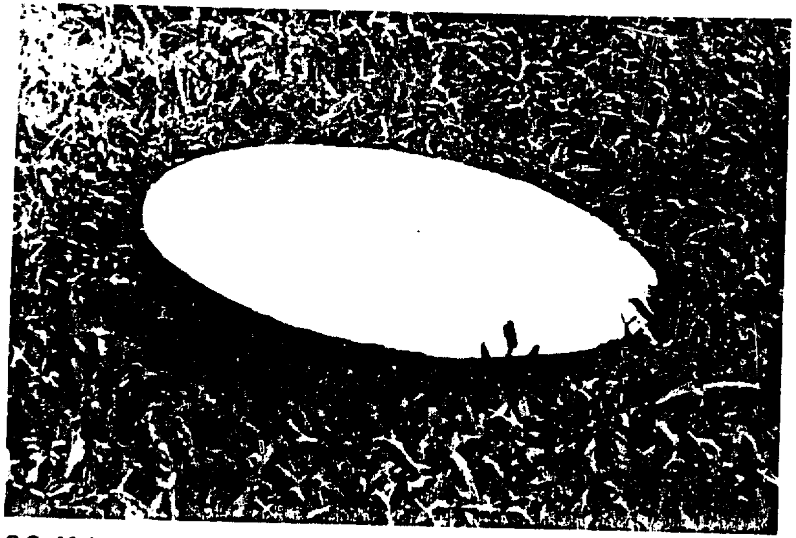


2.1 *Place two pieces of gunny cloth (hessian sacking) 125cm by 110cm together and mark out. Sew the two pieces together along the curved lines leaving the top and bottom open.*



2.2 *After sewing, turn the sack inside out.*

** copied from Watt, 1978, by permission, ITDG

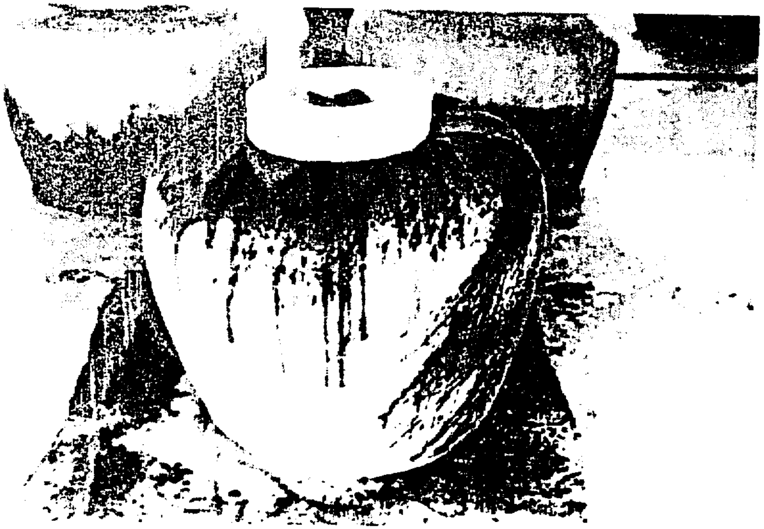


2.3 *Make a precast mortar bottom plate, 60cm in diameter and 1.5cm thick. Make the mortar from a mix of 1:2 cement:sand by volume as dry as possible consistent with easy trowelling.*

2.4 *Place the sack on the bottom plate with the smaller opening downwards and fill the space inside with paddy husk, sawdust or sand. The weight of the fill will hold the lower edge of the sack firmly on the bottom plate. Make sure that the mortar bottom plate sticks out from under the sacking.*

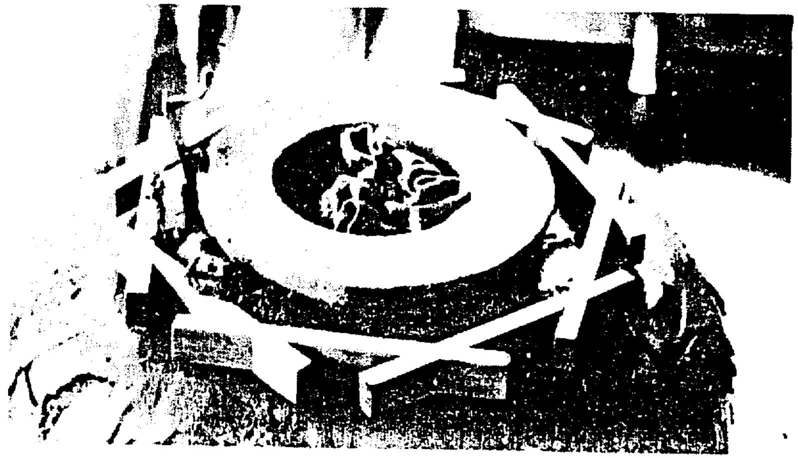
2.5 *When the sack is filled up, fold the top and tie it into the shape of a traditional water jar. Use a piece of wood to tap on the mould to make it round and fair.*

2.6 *Spray some water on the mould before plastering to make it damp.*

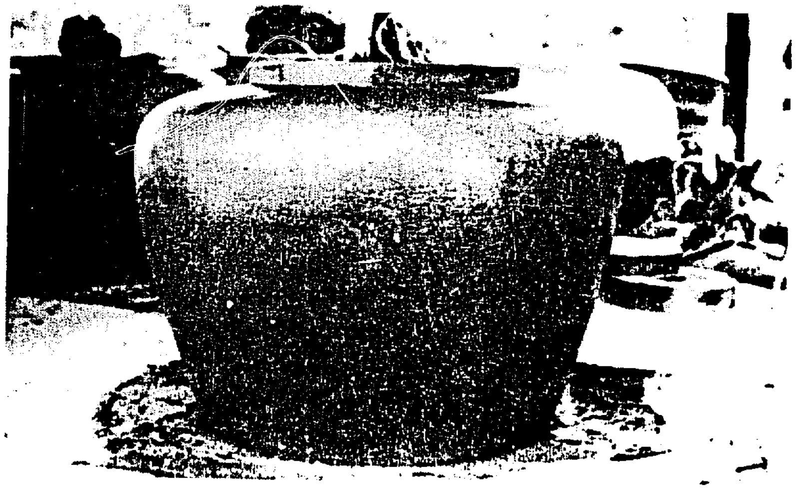


2.7 *Place a circular ring on the top of the sack to make a mould for the opening of the jar. This can be made of wood or precast mortar.*

2.8 *Trowel a first layer of mortar onto the mould to a thickness of about 0.5cm.*



2.9 *Plaster the second layer of 0.5cm in the same manner as the first layer. Check the mortar layer for thickness by pushing in a nail: any weak or thin spots should be built up with an extra layer of mortar. Build up the opening.*

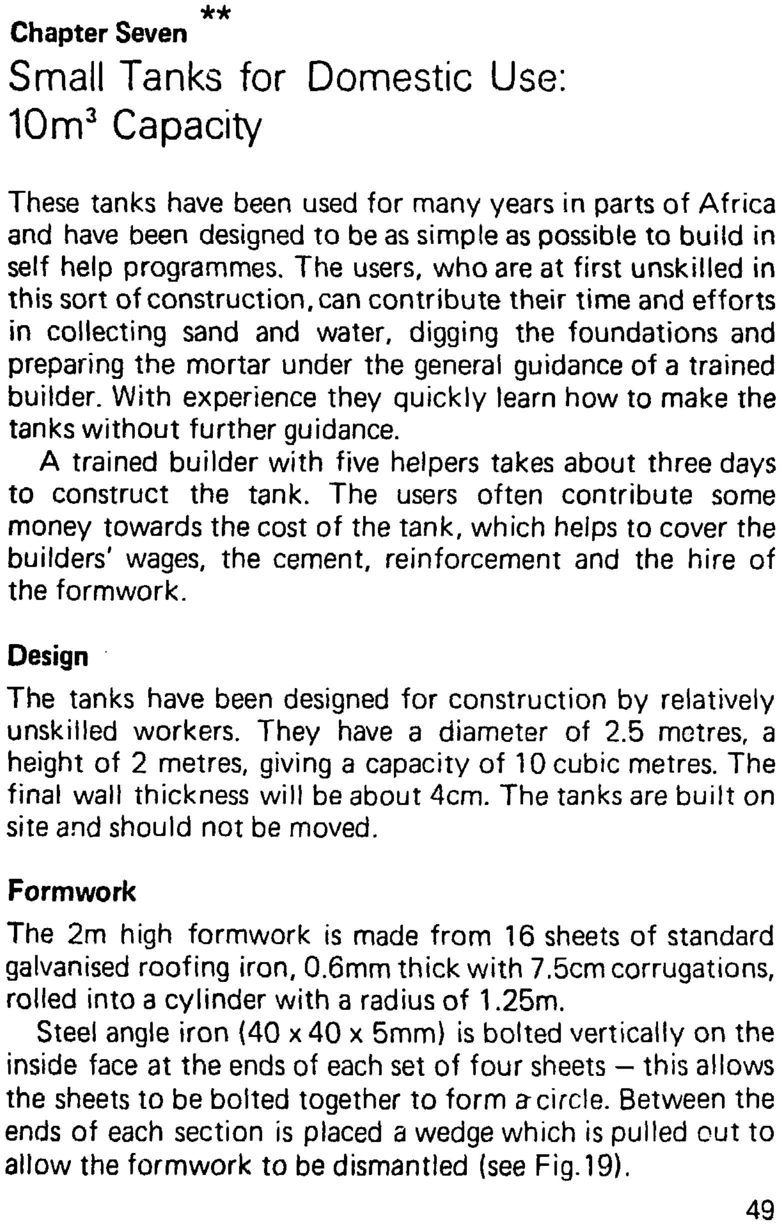


2.10 *Remove the contents of the gunny bag and the bag 24 hours after the jar has been made. Check the jar for any defects and correct these with mortar; the inside of the jar should also be painted with a cement slurry. Cure the jar out of sunlight and drying winds, preferably under damp sacking or plastic sheet for at least 2 weeks.*

This technique has been used with great success in Thailand and pots of up to 4000 litres (approx 1000 galls.) capacity have been made in this way.

4.3.2. Ferrocement tank, 10 m^3

The following description and instructions have been copied from Ferrocement Water Tanks and their Construction (see section 3.3.6). This tank design is based, in part, on years of experience with the construction method in Zimbabwe; other versions are being built in Thailand and Indonesia. See section 3.3.2 for more information on ferrocement tanks.



Chapter Seven **

Small Tanks for Domestic Use: 10m^3 Capacity

These tanks have been used for many years in parts of Africa and have been designed to be as simple as possible to build in self help programmes. The users, who are at first unskilled in this sort of construction, can contribute their time and efforts in collecting sand and water, digging the foundations and preparing the mortar under the general guidance of a trained builder. With experience they quickly learn how to make the tanks without further guidance.

A trained builder with five helpers takes about three days to construct the tank. The users often contribute some money towards the cost of the tank, which helps to cover the builders' wages, the cement, reinforcement and the hire of the formwork.

Design

The tanks have been designed for construction by relatively unskilled workers. They have a diameter of 2.5 metres, a height of 2 metres, giving a capacity of 10 cubic metres. The final wall thickness will be about 4cm. The tanks are built on site and should not be moved.

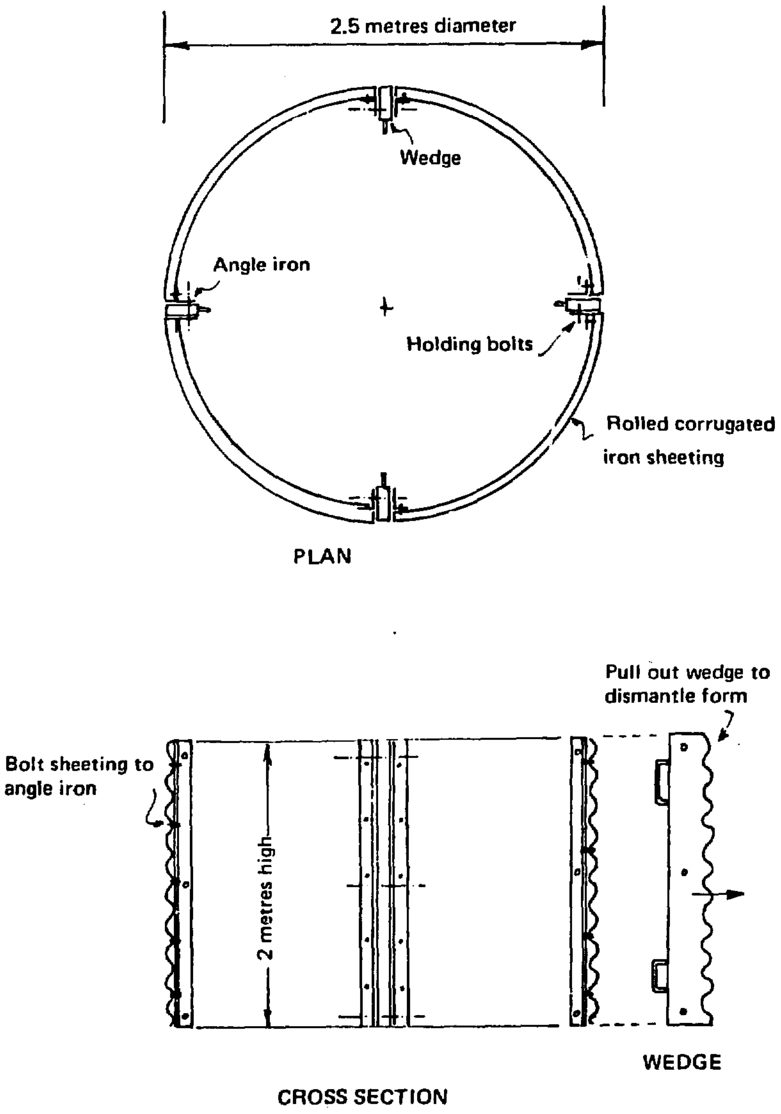
Formwork

The 2m high formwork is made from 16 sheets of standard galvanised roofing iron, 0.6mm thick with 7.5cm corrugations, rolled into a cylinder with a radius of 1.25m.

Steel angle iron (40 x 40 x 5mm) is bolted vertically on the inside face at the ends of each set of four sheets – this allows the sheets to be bolted together to form a circle. Between the ends of each section is placed a wedge which is pulled out to allow the formwork to be dismantled (see Fig.19).

** copied from Watt, 1978, by permission, ITDG.

Fig.18 Standard formwork to make $10m^3$ tank



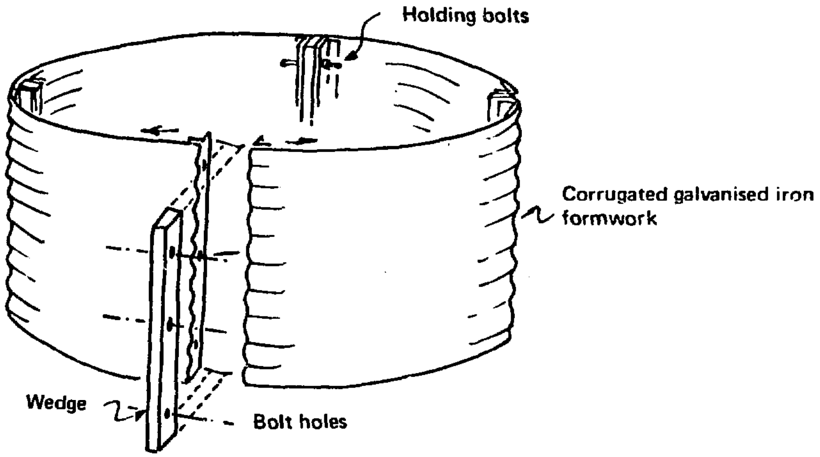


Fig.19 Assembling the formwork

Construction

A circular area 2.8m in diameter is cleared at the required site for the tank and excavated down through the loose topsoil. A 10cm layer of sand and gravel is laid evenly over the excavation and a 7.5cm layer of concrete laid on top of this; the concrete mix of 1:2:4 (cement:sand:gravel by volume) will form the foundation slab under the tank.

Into this concrete foundation is cast a 1m length of 20mm bore steel water pipe with a tap on the outside end. The pipe is curved so that it projects 10cm above the floor of the tank; a piece of wire is threaded through the pipe to act as a pull through after the tank has been built (see Fig.20).

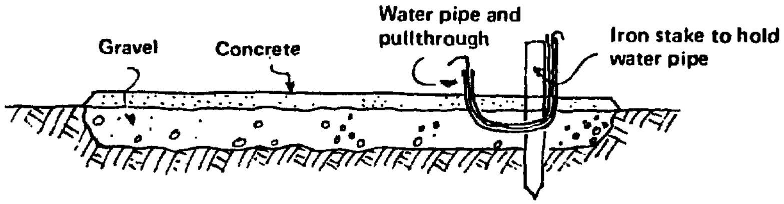


Fig.20 Foundation of tank

When this concrete floor slab has hardened the formwork for the tank is erected. The bolts passing through the angle iron and wedges are tightened to provide a rigid cylindrical form. This is cleaned free from cement and dirt, oiled and the wire netting wrapped around it to a single thickness and tucked under the forms. The netting has a 50mm mesh, and is made from 1.0mm wire (see Fig.21).

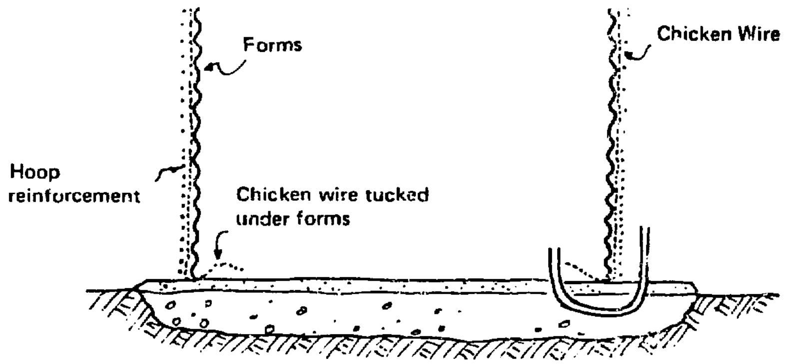


Fig.21 Erect formwork and wind on reinforcing wire

To form the hoop reinforcements, the 'straight' galvanised iron wire, 2.5mm diameter, is wound tightly around the tank from the base at the following spacings:—

2 wires in each corrugation for the first eight
1 wire in each corrugation to the top
· 2 wires on top corrugation.

About 200m of 2.5mm diameter wire will be needed, weight 8 kg. The netting provides vertical reinforcement to the tank and also holds the hoop wire out of the corrugations.

The outside is then plastered with a layer of mortar made from a mix of 1:3 (cement:sand by volume) and as soon as this has begun to stiffen a second mortar layer is trowelled on to cover the reinforcing wires to a depth of 15mm. The surface is finished smooth with a wooden float.

After a day or so the formwork is dismantled by removing the holding bolts and by pulling out the wedges which will leave the shuttering free to be stripped away from the inside mortar wall. The sections are lifted clear of the tank to be thoroughly cleaned of any mortar or cement.

A 20cm length of 8cm diameter downpipe is built into the wall at the top of the tank to act as an overflow and the inside of the tank is plastered with mortar to fill up the corrugations. When this has hardened sufficiently a second final coat is trowelled onto the inside and finished with a wooden float.

A 5cm thick layer of mortar is next laid onto the floor of the tank and the junction with the floor and the walls built into a coving.

The floors are unreinforced and these tanks would fracture if they were moved.

Take care that the mortar does not block up the outlet pipe. Before the mortar on the floor has stiffened, form a shallow depression in the middle; this will allow the tank to be cleaned at a later date — the sediment can be brushed into the hole and cupped out (see Fig.22).

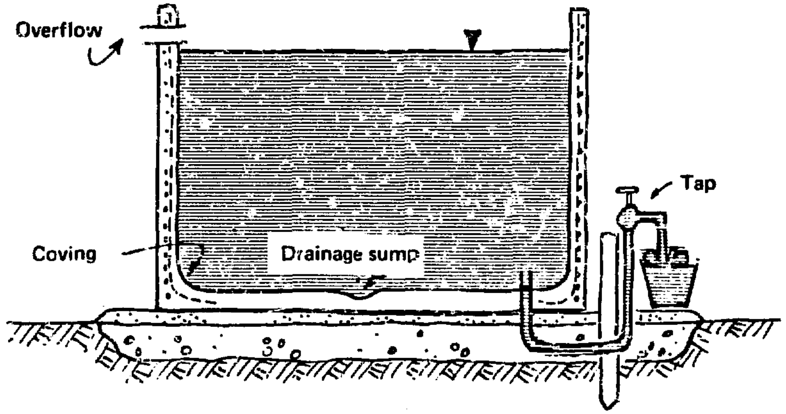


Fig.22 The completed tank

The inside of the tank is painted with a thick cement slurry to seal the tank, a small volume of water is allowed to stand in the bottom of the tank and the tank is covered and cured for seven days.

Roof

The tank is covered with sheets of 0.5mm galvanised sheeting supported on two lengths of angle iron. Alternatively, a reinforced mortar roof may be built in the ways described in Chapter 10. Building a mortar roof is not difficult but it requires extra sets of formwork.

Materials required for 10m3 tank with galvanised iron roof

Cement	600 kg.
Plain wire 2.5mm diameter	200m
Chicken mesh 1m wide	16m
Water pipe 20mm bore	1m
Water tap	1 No.
Overflow pipe	20cm of 8cm dia. iron or concrete pipe
Galvanised iron sheet and angle iron for roof	
Sand	$1.0m^3$
Gravel	$0.5m^3$

4.3.3 THE GHALA TANK

This tank is made by plastering a sturdy basket for holding grain. While this design comes from Kenya, the idea could be used to make similar tanks out of baskets made from a wide variety of indigenous materials. Most of the information and the drawings for these instructions come from an article in the Magazine APPROPRIATE TECHNOLOGY, March 1982 (see Section 3.3.6).[**] The authors say that ghala-type tanks can be built as large as 7,500 liters and should last ten years. Most of these tanks have been built closer to the size of the tank described here, which has a capacity of about 2,300 liters.

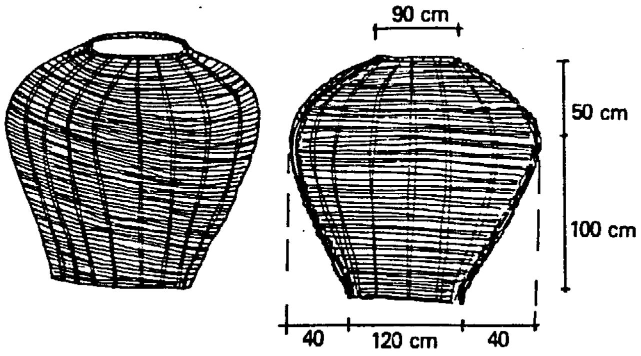


Fig. 1 Ghala basket constructed without a base.

[**] figures reproduced from UNICEF East Africa Regional Office, 1982; by permission, ITDG

GHALA TANK (cont.)

MATERIALS:

- 5 bags of cement (50 kg each).
- 12 wheelbarrows of clean sand.
- 4 wheelbarrows of clean gravel. Most pieces of this gravel should be about 1.25 cm in diameter.
- clean water.
- enough small rocks to build the foundations. See step 1 below.
- 2 m of water pipe about 1.25 cm in diameter, with 90° elbow (see fig. 2).
- tap to fit the water pipe.
- one ghala-type basket, woven without a base (fig. 1).

TOOLS:

- mixing board or pad, and containers for measuring proportions of mortar and concrete materials.
- shovel and trowel.
- pipe threader.

STEPS IN CONSTRUCTION REQUIRING SPECIAL CARE:

--- Compacting the foundation until it is solid enough to support the weight of concrete, tank, and water (step 1).

--- Mixing mortar "dry" enough that it will not fall off the overhang of the inside of the basket, yet wet enough that it can be worked into the weave of the basket walls (steps 6 and 7 below). If you can, make a small quantity of mortar and try applying it to the basket before beginning construction.

--- Plastering the inside of the bottom of the basket to give a strong, leak-proof bond to the foundation (step 7).

--- Curing: keeping the walls damp while the newly constructed tank strengthens, before it is used.

GHALA TANK (cont.)

CONSTRUCTION:

--- 1. Lay the rocks for the foundation, in a circle about 2 m diameter and 20 cm deep (fig. 2).

--- 2. Spread a mixture of soil, sand and gravel over the rocks and stamp or pound down to a 1.5 cm thickness (fig. 2).

--- 3. Prepare concrete as described above. Use proportions 1:2:4, cement:sand:gravel (measured by volume). This concrete is to be laid on the foundation; making the mix with about 20 l. of cement should yield enough concrete for a layer about 7.5 cm thick.

--- 4. Spread about 1/3 of the concrete on the foundation. Place the water pipe and tap in the wet concrete as shown in fig. 2.

--- 5. Spread the remaining concrete on the foundation. Immediately place the basket in the center and work its lower part into the concrete. Work some of the concrete up against the basket wall (fig. 2) to make sure the basket is firmly anchored.

--- 6. After the concrete is set, prepare mortar as described above. Use proportions 1:3, cement:sand (measured by volume).

--- 7. Apply the mortar by hand or with a trowel to the inside of the basket walls, starting from the bottom of the basket. This layer of mortar should be about 1.25 cm thick. Use a little extra mortar where the bottom of the basket meets the concrete of the foundation; fill and smooth this area so that the bond will be strong.

--- 8. While the first layer of mortar is stiffening, prepare mortar for the second layer. Use proportions 1:2, cement:sand (measured by volume). Apply to the inside of the basket and smooth into a layer about 1.25 cm thick with a trowel. Then apply any remaining mortar to the outside of the basket. This may help protect the original basket materials and will help strengthen the tank.

--- 9. As soon as the second layer of mortar sets, cover the tank with wet sacks or cloths. (These covers should be kept wet for about a week. It is much easier to keep the covers damp for proper curing if the tank can be shaded from the sun.) After about 12 hours, fill the tank about 1/4 full with water; this keeps the inside damp.

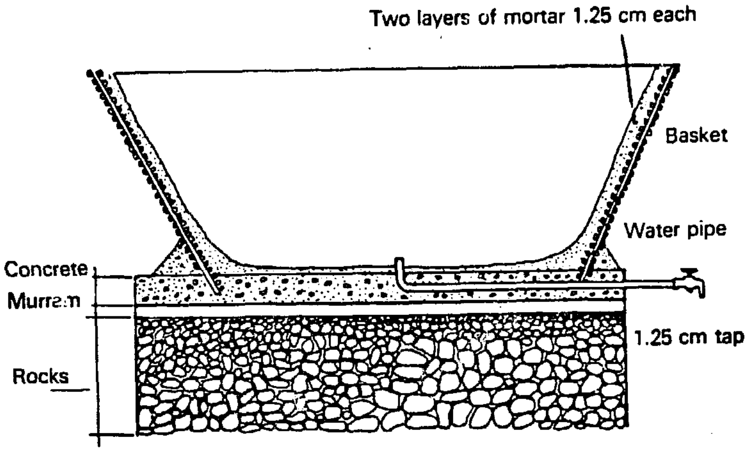


Fig. 2 Construction of the foundation and positioning of the basket.

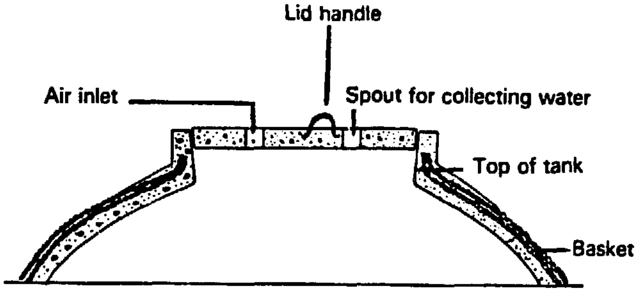
GHALA TANK (cont.)

--- 10.Make a lid. A concrete lid can be poured into a 3 to 5 cm deep circular hold in the soil, carefully cut to match the diameter of the opening at the top of the tank (fig. 3). Line the hole with sand so that the lid can be pulled out easily; using soil or some other material, carefully make mounds in the hole for air and water holes. A handle can also be placed in the concrete as it stiffens. See the details of figs. 3 and 4.

The authors of the article in APPROPRIATE TECHNOLOGY note that lids can be made out of wood or other materials.

However the lid is made, its holes should be screened to keep out mosquitoes and dirt.

Fig. 3 Construction of the lid.



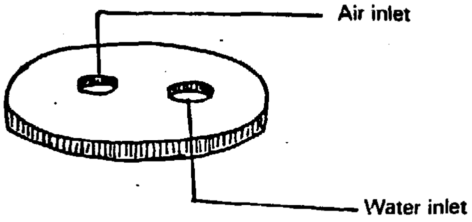


Fig. 4 Detail of the lid.

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