RAINWATER COLLECTION ACTIVITIES IN INDONESIA AND THAILAND

September, 1984.

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From the office of

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I.R.C.
The Hague

A copy of "Rainwater Collection in Indonesia and Thailand" is enclosed for your information .

It is a report on the study conducted during 1983.

B. Latham

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Report to

Canadian International Development Agency

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5528

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ABSTRACT

A study is done of the technical aspects of rainwater collection programmes operated by agencies in Indonesia and Thailand. For each agency, a description of the regions where the rainwater tanks are being built is given, the construction technique for the tank is described and the tank's design is analysed for its structural strength. It was found that many of the tank designs in Indonesia were similar to each other and, for the most part, are sufficiently strong in theory. However, the 9 m^3 tank built by Yayasan Dian Desa may require a second layer of chicken wire mesh to increase its strength. In Thailand, the tank designs are adequate but they vary considerably in type and strength. The tank of the Population and Community Development Association appears to be slightly under-reinforced while that of the Appropriate Technology Association may be over-reinforced. Further mutual sharing of the expertise of different groups in the theory and practice of tank construction is recommended. Construction of the popular Thai Jumbo Jar is described.

Next, there is a review of the hydrologic methods used to determine the level of demand that a particular size of tank can sustain. Estimates of possible demands are compared and evaluated using a computerized model based on actual rainfall data. Hydrologic design curves are prepared for regions of greatest rainwater collection activity. It is shown that tanks containing 5 cubic metres should be able to supply a minimum level of 5 litres/capita/day (lcd) to a family of 5. The necessity of a proper analysis of the amount of water collected is highlighted by one estimate that failed to do this.

A discussion of the use of bamboo as a reinforcing medium concludes that bamboo is unsuitable at present in most cases and that studies on its use in water tanks are needed.

Finally, the costs of the tanks described are presented for comparison.

ACKNOWLEDGEMENTS

The assistance of the Scholarship Committee of the Canadian Intenational Development Agency and the project officer Fernand Boivin is gratefully noted. The work would not have been undertaken without their financial assistance.

The assistance and patience of those people in Canada, England, Indonesia and Thailand whom I visited and talked to were remarkable. Although everyone was of great help, I must particularly mention Dr. Thamrong Prempridi of Chulalongkorn University, Bangkok for his extreme generosity.

Thanks is also given to the many villagers who allowed another foreigner to examine their houses.

- Brian Latham

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PREFACE

This is a report on a study of existing and functioning projects that are delivering low-cost rainwater collection systems to villagers in Southeast Asia. It was designed to be a study of some of the practical aspects of rainwater collection in order to complement a more theoretical work, namely a Civil Engineering thesis "Rainwater Collection Systems: The Design of Single Purpose Reservoirs" written by the author for a Master's degree at the University of Ottawa, Canada. This thesis concentrated on computer modelling of a rainwater collection tank's operation to produce estimates of required tank volumes. The resultant model is used in Part III of this study to verify more informal size estimation methods. The emphasis in this study is on the technical construction techniques that can deliver low-cost systems. Since the major component is the tank, various methods of building this are examined.

The approach used is anecdotal in that the various programmes visited are reported on separately as case studies. This should not imply that the groups undertaking the projects do so in isolation from others, although this may be the case at times. Cooperation and consultation between groups may occur at informal meetings and conferences and may be formalized as well. Where a sharing of knowledge has occurred or is suspected, it is noted.

The funding for the project came from a scholarship grant from the Canadian International Development Agency. Initial work began in late 1982 and early 1983 when contacts were made with agencies in Indonesia and Thailand who have been operating successful programmes in the field of rainwater collection. The study tour, during which most of the data and experience included in this report were obtained, took place from July 27, 1983 to October 5, 1983 and involved visits to a number of agencies in both countries. A visit was made to the Intermediate Technology Development Group of London in late July, 1983 in Reading, England, where the considerable literature at ITDG's Rainwater Collection Group was reviewed. An additional visit was made to the Bali region of Indonesia in March, 1984.

INDONESIA AND THAILAND: CONTRASTING SITUATIONS

The contrast between Thailand and Indonesia in the level of acceptance of rainwater as a water source is striking. In Indonesia, the number of tanks in use may total 10,000 or 20,000 if one were to make a very optimistic estimate. Most of these have been built in the ferrocement or bamboocement style by development agencies in a few select areas. There has been very little apparent commercialization of tank building, so the agencies must train builders and provide considerable financial support for almost all tank programmes. Moreover, the agencies have to mount education programmes to convince owners of the tanks that the rainwater is safer than the traditional surface water that people's tastes have become accustomed to.

In Thailand, on the other hand, the situation is much different. Agencies and research groups engaged in the promotion of rainwater collection work in a milieu that is very favourable to this form of water source. Taste for water is very particular with people strongly preferring one type of water over another. Although the desirable attributes of the preferred water vary from village to village and are not quantifiable, it is generally accepted that rainwater has the purest or sweetest taste and is preferred above other sources for drinking water. In short, in many areas, rainwater is a traditional source of water. Education centres on hygiene rather than on acceptance of the water.

As a result of this different public attitude, rainwater collection is more developed in Thailand. The number and variety of water-storing devices are increasing rapidly. Traditional small jars are being replaced by the newer Jumbo Jars that are being built commercially at the many local factories dotted throughout dry areas such as Khon Kaen. Tanks can be the squat ferrocement or jar type or taller poured concrete ones. Because of all this rainwater collecting activity, the number of tanks is hard to estimate but is high.

PART I
INDONESIA

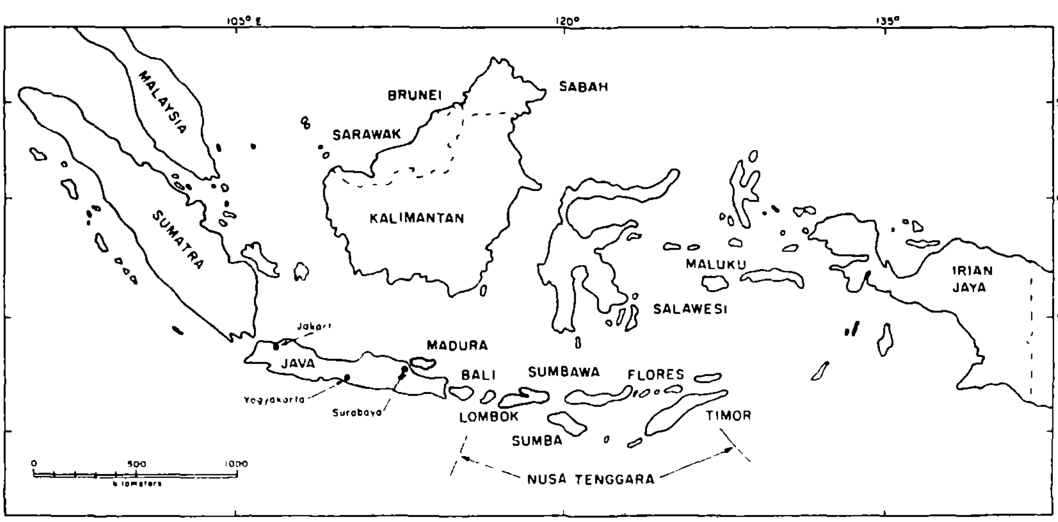


Figure 1: Indonesia

Chapter 1

INTRODUCTION

1.1 OVERVIEW OF RAINWATER COLLECTION IN INDONESIA

Rainwater collection in Indonesia is entirely based on roof collection and primarily involves individual family tanks. Rainwater collection systems are used in Java, Bali, Lombok, the islands of Nusa Tenggara Timur (NTT) and other eastern islands. These areas may have high annual rainfalls but long periods of drought. Although without other economic water sources for part of the year, surprisingly, they do not have a tradition of rainwater collection. Thus, there is considerable resistance of potential users to switch from traditional strong-tasting, turbid surface water sources to the near tasteless but safe rainwater.

The most common, if not the only, type of tank used is constructed by plastering a rich cement and sand concrete mix on a reinforcement network. The network may be made of wire mesh and reinforcing bars (ferrocement), bambooo strips (bamboocement) or a combination of the two.

The dominant influence in this field of water supply in Indonesia is provided by Yayasan Dian Desa (YDD), a non-government organization in Yogyakarta which has conducted a number of programmes of its own as well as administering a number of programmes for international and domestic agencies. As a result, their tank design has been used in smaller programmes run by other NGO's and some government groups. A government programme has been in development in West Java since 1978 but has not proceeded much past the demonstration stage. Other agencies engaged in rainwater collection are Foster Parents Plan, Oxfam and CARE. All programmes are restricted by the high cost of the systems and are dependent on substantial subsidies from the government or external aid groups. Little, if any, commercialization of the provision of rainwater collectors has taken place.

All aid agencies contacted follow a similar support plan. Funding is given for training village construction supervisors (YDD calls them 'cadres') who assist in construction. Materials and transport are provided free as are the services of an agency overseer during the

construction but labour is supplied by the owner of the tank. In the case of bamboo tanks, the owner must also supply the bamboo.

1.2 OUTLINE OF STUDY IN INDONESIA

Preparation for the visit began in late 1982 and early 1983 when contact was made with YDD by mail and a review of documents concerning their work was done. This was assisted by the help of Jeff Ramin of the Unitarian Service Committee of Canada who was a project officer for a rainwater collection programme they were sponsoring with YDD. In England, en route, the author was briefed by Dr. Marilyn Carr of Intermediate Technology Development Group on aspects of YDD observed during an earlier visit.

The major visit for this study was made August 10-30, 1983. On arrival in Jakarta, contact was made with a number of people - Mr. S.T. Malling and Dr. U. Kuruppu of UNESCO, Mr. R. Soeharsono of the World Bank, Mr. Z. Karim and Ms. L. Tunggal of UNICEF, Ms. H. Morris of the Canadian Embassy and Dr. Srimoerni Doelhomid of the University of Indonesia.

In Yogyakarta, Mr. Anton Soedjarwo, Dr. Winarto, Mr. Didik Prijono, Mr. Dyoko Srihono and Mr. Hari Susanto, all of YDD, were interviewed. A one day visit to the villages of Ngestirejo and Jeruk in the Tepus area of Gunung Sewu was arranged. Ngestirejo was the first village to receive bamboo-reinforced tanks under YDD programmes [21]. The firm of Sir M. McDonald and Partners was contacted and background information on ground and surface water resources in Gunung Kidul was obtained in an interview with Adrian Young.

Contacts were also made with Foster Parents Plan (PLAN), Yogyakarta where Richard Thwaites, Markus Sudjawad and Suparmadi were interviewed and a visit to Bendogede, Ponjong and Karangmojo, other villages in the Gunung Kidul, followed. A later visit to PLAN's Bali rainwater project was made in March, 1984. Peter Whiticar, Janet Parry and Purnama Wijana were interviewed and a tour of their project area near Amlapura in Karangasem was given by Mr. Wenton.

In addition, during the major visit, several types of rainwater tanks were observed in a tour of villages in West Java arranged by IWACO/Unisistem of Bandung, who are Dutch water supply consultants for the Indonesian government. Mr. R. van Kerkvoorden and Mr. C. Pompe of IWACO were interviewed.

Chapter 2

YAYASAN DIAN DESA

2.1 THE AGENCY

Yayasan Dian Desa is an Indonesian non-government agency engaged in rural development activities. Largely centred around its founder and leader, Anton Soedjarwo, the agency handles water supply, agricultural and economic development projects in Central Java, Madura, Nusa Tenggara Barat (NTB - the islands of Lombok and Sumbawa), Nusa Tenggara Timur (NTT - the islands east of NTB), and Sumatra.

Yayasan Dian Desa is made up of engineers and technical people from Gadja Madah University in Yogyakarta but is attracting dedicated people with administrative training.

Support for YDD comes from a wide variety of sources: Oxfam, Ford Foundation, World University Service (WUS), Canadian International Development Agency (CIDA), Unitarian Service Committee of Canada (USC), International Development Research Centre (IDRC) and USAID.

Within Indonesia, YDD has developed a training programme on village development. Materials for this were developed with a grant from IDRC [31]. People from areas other than Yogyakarta are given seven months of training. Formation of new local organizations similar to YDD is encouraged. This approach has been taken because YDD recognizes it lacks both the staff to handle the increasing number of programmes and also the familiarity with local areas (such as Madura) that is such a major factor in a successful programme [31]. Government and NGO (Non-Governmental Organization) people are also being trained for specific projects. For example, six villagers were trained for three weeks on ferrocement tank construction for PLAN and government workers were trained for a World Bank Project [25], [17].

2.2 LOCATION OF RAINWATER COLLECTION PROJECTS

2.2.1 Gunung Kidul

Gunung Kidul was the first and, until recently, was the major area for YDD's rainwater collection programme. Gunung Kidul (The South Mountain) is an elevated area southeast of Yogyakarta in south-central Java. The area can be divided geologically [32] into two regions:

1. the Wonosari Plateau composed of limestone, which is a good aquifer and gives wells of manageable depth (5 to 25 m) and;

2. the Gunung Sewu ('One Thousand Hills' in Javanese), an area with little or no groundwater.

At a maximum elevation of 500 m, Gunung Sewu is about 800 square kilometres of limestone karst that is well-fractured, resulting in a rock structure with poor water-holding properties. The result of such a porous rock is that rain neither runs off the surface for any appreciable distance nor is it held in any aquifer. Thus streams do not exist and wells are exceedingly deep. With effectively no groundwater and few alternative water sources, the area is extremely dry during the dry season and water of any quality is difficult to obtain. This lack of water greatly limits the economic development of the area.

The surface of Gunung Sewu is distinguished by small (50 m or less in height) hills of mostly bare limestone with pockets of terra rosa (a red limestone soil) [12]. There is very little level ground for agriculture or construction of towns. Roads are long, winding and of poor quality, farm plots are small and villages take up scarce agricultural land [33], [34].

The area has a population of 225,000 and an average density of 260 people per km². The area's economy is based on rainfed cropping (cassava, cattle, tobacco [33], [34], [11]). Because of poor soil, incomes are very low. Gross household income is about $100 US per year.

Rainfall is negligible in all areas from June to September (May to October in Bantul). Droughts (periods with less than 5mm daily rainfall, i.e. the evaporation rate) of 5 to 6 months are not rare and 1982 had 200 days of drought [13]. On the other hand, average annual rainfall is 1800 to 2000mm and monthly depths in January to March in all areas are greater than 200 mm. The climate of the area is therefore one of extremes. Very high annual rainfall is concentrated in 6 to 8 months of intense rain which are followed by 4 to 6 months of complete drought [13].

2.2.1.1 Water Sources in Gunung Kidul

On the Wonosari Plateau, groundwater is available at depths of 5 to 25 m. There is about one well for every four households. These may dry up in prolonged drought but surface water and other wells are usually available within one kilometre [23].

In Gunung Sewu, groundwater is nearly non-existent as the watertable drops to sealevel at the edge of the plateau. Present water sources there are:

1. telagas or water holes that are traditionally the main source of water in the dry season. There are about 250 [11] of these naturally-sealed water collectors but water is lost from them due to leakage and evaporation so most will dry up in the dry season [11]. When in use, they will be used by villages as far as 10 km walking distance away for all water purposes: drinking, bathing, washing and livestock watering and cleaning. Water for drinking and cooking is carried on foot to the village. Telaga water quality is very poor (more than 1000 bacteria/cm³ [24]) and water is muddy and green from algae. Pollution by animal wastes and soap is unavoidable.

   Improvement of telagas is difficult because of their comparatively large size and the rock structure as the bottom must be perfectly sealed to be effective.

2. rainwater collection. This is as yet a small water source and, due to the costs involved, will never supply full water requirements. Rainfall of 1800 to 2000mm per year is heavy but is poorly distributed over the year. A long dry season (up to 6 months) requires large storage volumes to meet even minimal demands. Tanks at present are small compared to the number of users and can go dry in only ten days of dry weather [11], although others may last through a prolonged dry season such as that of 1983 [33].

3. wells that may operate during the wet season with depths of about 10m but these are low in quality and dry up in about 10 days of dry weather [11]. Groundwater otherwise is at 100 to 200m [32].

4. village water holes or improved reservoirs built of stone masonry in major villages. They are small and open and therefore quickly run dry. Problems with maintenance of these community ponds are reported [11].

5. a small number of caves and sinkholes in the area with limited amounts of water in them from local underground storage [12]. Sinkhole water is muddy [12] and cave water is either contaminated by the water gatherers [32] or is inaccessible. Some minor improvements of the cave situation have been carried out.

6. trucked water. At the end of the dry season, water is trucked in from wells near Wonosari. Costs vary with the distance travelled but in bad years, villagers may have to sell cattle to cover the cost [34]. Development of wells at the edge of the plateau could cut transport costs to Gunung Sewu [32].

7. springs located mostly along the southern coast of Java, the major one being at Baron. A distribution system is impossible in this area because the costs of pumping and construction in the Gunung Sewu terrain are above the ability of the people to pay.

The future sources of water appear to be rainwater collection to supply high qulaity water for drinking and cooking, and telagas for other uses [32]. The water problem in the area is clearly one of availability first and foremost. Quality is seen as important by most people interviewed but was a secondary goal at this time.

2.2.2 Nusa Tenggara Timur

The NTT is a string of islands stretching east of Sumbawa. It is one of the driest provinces of Indonesia with inconsistent rains and a dry season of 4 to 5 months. Annual mean rainfalls are from 950 to 1500 mm. Low water tables or brackish groundwater make hand-dug wells inappropriate although salt water from them may be used by necessity. Banana plants are cultivated especially for cutting the stalk to obtain the plants' juices for drinking water [22]. Springs can be up to 5 kilometres from settlements and may dry up before the rains come [6].

The installation of piped gravity systems is restricted by local disputes about water rights. Pipes may be sabotaged by villagers near the sources. YDD has built both bamboocement and ferrocement tanks here [6].

2.2.3 Madura

Madura is an island to the Northeast of Java and is more or less east of Surabaya.

2.2.4 Lombok

Lombok is one of two islands in the NTB. Located immediately east of Bali, it has an area of 4,595 km² and a population of 1.6 million (1971) for a density of 344 people per km².

2.3 HISTORY OF YDD'S TANK PROGRAMME

YDD has been contracted by UNICEF from the start of its programmes to do the design, sizing, training, construction and maintenance for tanks built with UNICEF money but the direction of the projects has been through the Indonesian Department of Health [9]. A World Bank project which began in 1983 to build 5000 10m³ ferrocement tanks is similarly handled but was conditional on the supervision by YDD [9].

Here, then, is a short history of YDD's programme. Prior to 1978, very little rainwater collection was practiced. Some water may have been collected by the villagers for minor use such as handwashing but no organized collection was done [34]. This seems extremely hard to believe in water-short areas like Gunung Kidul but few water vessels were seen [33], [34]. Some large tanks of masonry had been built but were cracked and not repaired. The government had built about 180 large (50m³) reinforced concrete tanks in the Gunung Kidul area but these were not successful as they leaked and there was no control on their use.

YDD began building tanks in 1978/79, starting with 10m³ ferrocement ones [31] but UNICEF says that their first tanks in 1978/79 were 18m³ ferrocement ones for shared use by 5 families and a few tanks with more than 190m³ steel tanks for village use [9]. YDD built one bamboo reinforced tank of 10m³ but it was not successful, so they went to the 4.5m³ size. A pilot project of 85 bamboo tanks was done in Sidohargo, Gunung Kidul, in 1978 with funds from the Canadian International Development Agency (CIDA). By March 1981, there were 2240 9m³ tanks in Gunung Kidul [21] and by mid-1983 [11] YDD had built over 4000 tanks there [22]. Eight hundred of these were 4.5m³ bamboocement ones built in 1979/81 but the rest were ferrocement [31]. The bamboo tanks were sponsored by UNICEF -- 300 in Sidorejo and other villages -- and the Unitarian Service Committee/Canadian

International Development Agency (CIDA) -- 500 in Sidorejo and Ngestirejo. UNICEF has sponsored 300 other tanks in the Yogyakarta area. In 1983/84, the World Bank has provided funding for 5000 tanks, 3000 in the Yogyakarta area and the rest elsewhere.

On Madura Island, YDD has built about 400 tanks [22], mostly ferrocement. These were supported by UNICEF and, it is believed [17], by the World Bank.

In NTT, in the Kupang area of East Timor, YDD has built over 300 tanks [22], [6] which were built with help from USAID, the Indonesian Department of Health, Oxfam, BKKBN (the Indonesian Family Planning Board) and UNICEF. Of these tanks, about 135 were ferrocement of the YDD design, 2 were ferrocement of the IWACO design and the rest were bamboocement. USC will sponsor 1000 ferrocement tanks in Kewapantai sub-district of Sikka, Flores in 1983-84 [6].

YDD has built smaller numbers for UNICEF in East Java, Samarang (Central Java), Grobangen, Southeast and South Sulawesi and Bali.

2.4 TECHNICAL DETAILS IN GUNUNG KIDUL

2.4.1 Roofs

Roofs in the Gunung Kidul are of clay tile [33], [34]. The tiles may be bought but they are often made by the villagers. Roofs are generally large as there are wide eaves and a good sized living area. Nine metres by seven metres (63m²) is very common but a 12m x 8m one was seen [33]. In addition, there may be barns and sheds approximately 6m x 7m close to the houses.

Roofs are low. Generally the lowest part is about 2.2m above the ground although the roofs have a characteristic two-stage design with a steeply pitched central portion surrounded by wide gentle eaves. The bottom of the central portion would be no more than 0.75m above the lowest part of the eaves.

2.4.2 Gutters and Downpipes

Gutters are simple. They are usually made of galvanized roof sheeting bent into a simple V-shape and attached at the edge of the roof. Many of those observed were rusted through although replacement with new sheeting was observed in one case. Downpipes are similar in construction to gutters. They appear to be a temporary feature which is put in place during the rainy season.

2.4.3 Filters, Foul Flush and Cleaning

The YDD tank uses a combined manhole/filter box arrangement as a water inlet. It was difficult to assess the effectiveness of this filter as examples were seen in the dry season and most of them were in poor condition or not in place. One tank was seen with no manhole cover [33].

There was no mechanism for collecting the initial roof runoff (foul flush, bypass storage) as it was felt that once the rainy season began, none was needed. However, villagers were instructed to wait for several rains before filling the tank [23].

Cleaning of the tank was supposed to take place every year at the beginning of the wet season and villagers were instructed to let water run in with the sump pipe open [23]. How common this is in practice could not be determined with one visit.

2.4.4 Taps

Water is obtained from the tank by a brass globe tap. A box large enough to hold a pail (50 cm x 50 cm x 50 cm) is built under the tap as part of the tank construction.

2.4.5 Overflow Pipes and Contents Gauges

The 2 inch diameter overflow pipe is located about 10 cm from the top edge of the tank. Wire screening has been put on it using a gear clamp. However on most of the tanks seen, the wire screen had been broken, possibly by children. Thus, the effectiveness of the screen is minimal in practice and consideration should be given to placing the screen on the inside of the tank or leaving it off altogether.

To encourage conservation, a contents gauge was installed on YDD's first tanks. This consisted of a float, a string attached to it that passed through the roof over a pulley and was attached to an indicator that would move up the tank wall as the water level fell. None of those seen was in operation (again because of children?). New tanks are not built with these as they are useless.

2.5 YDD RAINWATER TANKS

YDD builds two sizes of tanks - a 4.5m³ bamboocement one and a 9m³ ferrocement one.

The concrete mortar used in both cases is made from 1 part cement and 2 parts sand. The most difficult aspect of concrete mixing is the amount of water added as this determines the watertightness. The drier the mix, the more watertight. The consistency is hard to explain [23] and should be experienced. YDD suggests the use of 0.4 parts water per part of cement by weight [10], but measuring is only a rough guide as water in the sand will decrease the amount required. The concrete plaster is about 3 cm thick for bamboo and 4 cm for ferrocement, the difference being related to tank size [9], [23], [31].

YDD organizes the collection of materials for the tanks. Cement is bought and transported to the site. Sand is also supplied as it is usually not available close to the villages in Gunung Sewu or may be unsuitable such as in East Java where the sand is contaminated with salt [31]. The villagers provide all construction labour and for bamboocement, must also supply the bamboo.

2.6 THE YDD FERROCEMENT TANKS

The first type of tank built by YDD and, as it is turning out, the most enduring, is the ferrocement tank. The standard model now has a volume of 9m³ but it can be built up to 18 m³. The original version had a large 150 cm by 180 cm opening in the flat top covered by a sheet of corrugated iron but this has been replaced by a complete curved ferrocement top that is part of the tank. Water enters and access is gained to the tank by an inlet box with a removable screen that is covered with gravel and palm fibre filter materials.

The dimensions of the two ferrocement tanks built by YDD are given in Table 1 and were obtained from [4] and [30]. Plans of the tanks are in Figures 2 and 5, which may have minor dimensional differences from the tabled dimensions. Active volume is defined as the volume of water that can actually be withdrawn from the tank.

TABLE 1

Dimensions of the YDD Ferrocement Tanks

	$9m^3$	$18m^3$
Diameter (m)	2.5	3.52
Height to top cover (m)	1.85	1.85
Volume (m^3)	9.08	*18.00*
Active vol. (m^3)	8.17	16.25
Wall thickness (cm)	2-3	3
Base Thickness (cm)	5	5-6
Horizontal reinforcement	4.5mm bar at 15-20cm centres	6mm bar at 20 cm centres
Vertical reinforcement	4.5mm bar at 20 cm centres	6mm bar at 20 cm centres
Wire Mesh	1 layer	1 layer overall 2 layers on bottom and lower half of walls.

Note:
Active volume is calculated using a radius equal to half of the diameter minus half the wall thickness and a height equal to the height minus the 2 inches diameter of the overflow pipe (see the bamboocement drawing) minus 10 cm which is the height of the outlet pipe above the floor of the tank.

2.6.1 The 9 m^3 YDD Ferrocement Tank

2.6.1.1 Verification of Strength

This calculation follows the method used by Tuinhof in [27] and is a somewhat simple analysis, although it will indicate the ability of the concrete/reinforcement combination to withstand the static pressure of the water. The graphs needed from Tuinhof are in Figures 3 and 4.

D - Diameter = 2.5 m
r - radius = 1.25 m
h -height = 1.85 m
t - wall thickness = .02 m

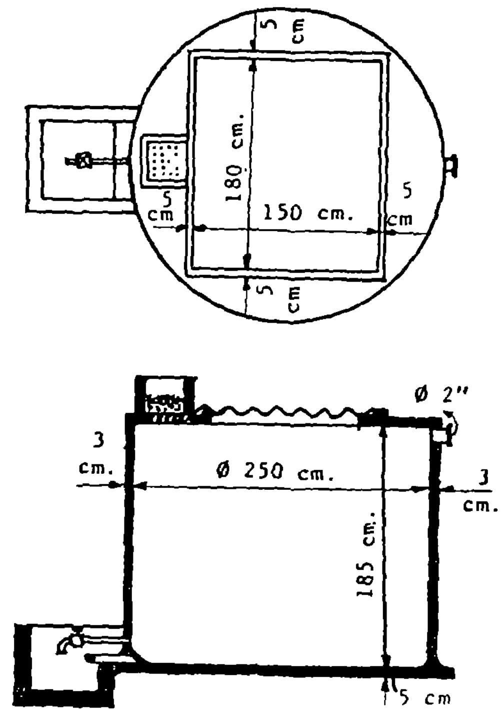
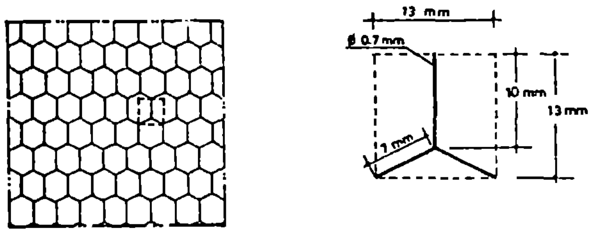


Figure 2: The Dian Desa $9m^3$ Ferrocement Tank



Wire mesh **repeating section**

Figure 3: Dimensions of Chicken Wire

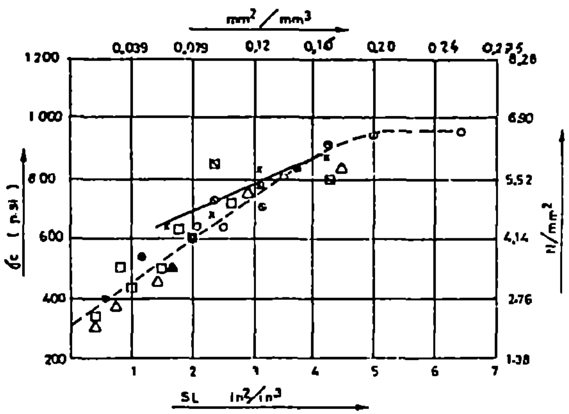


Figure 4: Observed Specific Surface Ratio vs. First Crack Composite Stress

P = water pressure (assumed maximum at base)
= γh

$$= \frac{9800 \times 1.85}{1000}$$

= 18.13 kPa

Hoop stress σ_h = Pr/t
18.13 x 1.25 / .02
= 1133 kPa
Assume a safety factor of 2
σ_d - design stress = 2266 kPa

$$\text{Specific Surface, SL} = \frac{\text{surface area of reinforcement}}{\text{volume of composite}}$$

Assume that wire mesh is similar to Tuinhof (see Figure 3) but with a diameter of 0.65 mm.
Then

$$SLw = \frac{n(\pi \times 0.65 \times 10 + 2\pi \times 0.65 \times 7)}{13 \times 13 \times t}$$

where n = number of wire mesh layers
t = mortar thickness (mm)
= 29n/t (1/mm)
Assume 1 layer
SLw = .29/20 = .0145 1/mm

SL for reinforcing wire rod

$$= \frac{Dw}{Ht}$$

where Dw = wire diameter = 4.5mm
H = distance between wires
For horizontal, H= 150-200mm (assume 200 - the worst case)

$$Slh = \frac{\pi \times 4.5}{200 \times 20}$$

= .00353
For vertical, H = 200mm
Slv = SLh = .00353

For 1 layer of rod and chicken wire
SL = Slw + SLh +SLv
= .0145 + .00353 + .00353
=.02156 1/mm

From Tuinhof (see Figure 4)

Composite stress, $\sigma_c = 2.76 \times 10^3$ kPa

Es - reinforcement modulus of elasticity

$= 2.0 \times 10^8$ kPa

Em = concrete modulus of elasticity

$= 2.2 \times 10^7$ kPa

At 0.01% strain, i.e. $\varepsilon = 10^{-4}$, the proof stresses are

for reinforcement $\sigma_s = Es \times 10^{-4}$

$= 2.0 \times 10^4$ kPa

for concrete $\sigma_m = Em \times 10^{-4}$

$= 2.2 \times 10^3$ kPa

$$\frac{As}{Ac} = \frac{\text{area of reinforcement}}{\text{cross-section area of concrete}}$$

$$= \frac{n\ 0.25\ \pi\ d^2}{13\ t} \quad \text{for wire mesh (Tuinhof [27], p. 4.5)}$$

$d = 0.65$mm $\quad n = 1$

$= .001276$

For reinforcing wire

Horizontal

$$\frac{As}{Ac} = \frac{1/4\ \pi\ Dw^2}{H\ t}$$

$$= \frac{1/4\ \pi\ (4.5)^2}{20 \times 20}$$

$= 0.03976$

Vertical

$= 0.03976$ (same)

Now, σ'_c = first crack stress

$= \sigma_c\ (As/Ac)^{1.1} + \sigma_m$

$= 2.0 \times 10^4\ (0.001276 + 2(.03976))^{1.1} + 2.2 \times 10^3$

$= 3456$ kPa

Check

1) $\sigma_d < \sigma'_c$?

i.e. design stress less than first crack stress

2266 < 3456 YES OKAY

2) $\sigma_d < \sigma_c$?

i.e. design stress less than composite strength

2266 < 2726 YES OKAY

Conclusion

This indicates that the tank wall is strong enough but only just. A second layer of wire mesh might be advisable. A later version was made with 6mm rod [6]. For this case

$\sigma_d = 2266$ kPa

SLw = 0.0145

SLh = SLv = 0.004712

SL = .0145 + 2(.004712) = 0.02392

$\sigma_c = 2800$ kPa

Thus $\sigma_d < \sigma_c$ OKAY

As/Ac for wire = 0.001276

$$\text{for rod} = \frac{1/4\ \pi\ 6^2}{20 \times 20}$$

$= 0.07069$

$\sigma'_c = 2.0 \times 10^4\ (.001276 + 2(.07069))^{1.1} + 2.2 \times 10^3$

$= 4548$ kPa

Thus $\sigma_d \ll \sigma'_c$

This is an improvement, but a second layer of wire mesh would still be advisable.

2.6.1.2 Construction of the 9 m³ Tank

The 9 m³ ferrocement tank construction is described below [6].

1. Prepare 8 hoops of 6mm reinforcing rod and 2 hoops of 8 mm rod by bending them around ground stakes 20 cm apart on a circle of 250 cm diameter. Each rod is 800 cm long and the ends are tied with wire.

2. Prepare the floor reinforcement by first tying two 900 cm rods of 8 mm diameter at right angles at their centres and then making a network of 6 mm rods. All intersections are tied with wire. An 8mm hoop can be used at the edge of the base.

3. Space four to six vertical bamboo poles of length 2m along the edge of the hoops and drive nails into them at 20-cm intervals.

4. Place the hoops on the nails. The 8 mm hoops are at the bottom and top.

5. Bend the 8 mm base rods vertically to shape the walls and bend them again at the top edge to form the roof. Tie these to the hoops with wire.

6. Bend the 6mm rods along the sides and over the top. Cut off the excess and tie them at all intersections.

7. Leave a hole (approximately 60 x 60 cm) at the edge of the top for the manhole/inlet.

8. Apply hexagonal chicken wire to the inside of the top, bottom and walls of the tank. The wire should follow the contours closely and not bend or bow out from the frame. Tie it into place and join different parts of the wire mesh by overlapping and intertwining it.

9. Prepare the tank's site by excavating a square 15 cm below grade that is 20 cm greater than the tank diameter, i.e 2.7 m square. Backfill this with 2-3 cm of sand and cover it with paper from the cement sacks.

10. Cover the outside walls with solid woven bamboo matting and tie it in place with rope loops. Leave holes for the overflow pipe at the top and the delivery and clean-out pipes at the bottom. Install these pipes with anchors.

11. Make up a mortar of 1:2 (cement, sand), wet it with 0.4-0.5 parts water (by weight) and mix it uniformly.

12. Cover the base paper with a 2 cm layer of mortar.

13. Place the wire and mesh framework and attached bamboo onto the mortar and, using hands and rubber gloves, add 2 cm of mortar or enough to cover the framework. Be sure that all air spaces between the rod and chicken wire are filled. Allow this to harden for one hour.

14. Apply one cm of mortar to the inside walls using gloves. Be sure to cover all rods and chicken wire. Build up the bottom joint with extra mortar. Let dry one-half hour. Finish plastering using a trowel. Let dry one-half hour again. Seal the wall with a cement/water mix (no sand) applied with a brush.

15. Let the mortar dry for 6 hours minimum or until the walls can stand external plastering. Remove the bamboo matting.

16. Apply a 1-cm layer of mortar with a trowel and smooth it carefully to give a good appearance. Seal it as with the interior.

17. For the roof, carefully and completely prop the bamboo matting into place with poles from the inside. It should be supported well enough to hold wet concrete and workers.

18. Apply a layer of mortar with rubber gloves, smooth it with a trowel and seal it. After four days, remove the interior framing, plaster the inside, smooth it with a trowel and seal it.

19. A water level indicator may be installed using a bobber and weight connected by a string going through the roof of the tank and over a pulley. (Note from the author: this was originally applied to the tank but was later abandonned because children broke it. A better indicator is a length of clear plastic pipe attached to the tap and held up against the tank. When the tap is opened, the water will rise to its level. This mechanism was not seen in Indonesia.)

20. A box for the filter/manhole is fashioned so that there is a lip left at the bottom of it. A square of concrete the same size as this hole with a pattern of pencil-sized holes and a handle is poured. When placed in the manhole, it is covered with palm fibre and small pebbles to act as an inlet filter.

21. Cover the tank to protect it from direct sunlight. Splash the surface of the tank with water at least twice daily. After three days, water should be put into the tank to keep the inside damp. This curing process should continue for ten to fourteen days.

2.6.2 <u>The 18 m³ YDD Ferrocement Tank</u>

2.6.2.1 Verification of Strength

See the 9 m³ YDD ferrocement tank case for an explanation of terms.

Diameter, D (m)	3.52
Radius, r (m)	1.76
Height, h (m)	1.85
Wall thickness, t (m)	.03

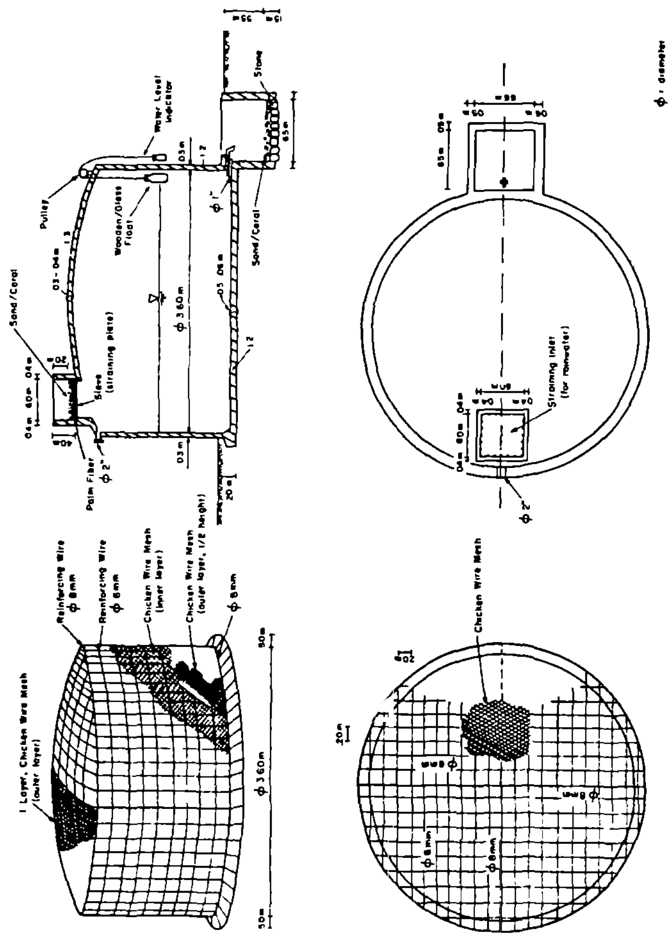


Figure 5: The Dian Desa 18m³ Ferrocement Tank

Pressure, P (kPa)	18.13
Hoop stress, σ_h (kPa)	1063
Safety factor	2
Design stress, σ_d (kPa)	2126

SLw = 0.29n/t (1/mm)
Assume 2 layers
SLw = 2 x .29/30 = .01933 1/mm

SL for reinforcing wire rod

$$= \frac{Dw}{Ht}$$

where Dw = wire diameter = 6.0mm
H = distance between wires
For horizontal, H = 200mm

$$Slh = \frac{\pi \times 6.0}{200 \times 30}$$
$$= .003142$$

For vertical, H = 200mm
Slv = SLh = .003142

For 1 layer of rod and chicken wire
SL = Slw + SLh +SLv
= .01933 + .003142 + .003142
=.02561 1/mm
From Tuinhof (see Figure 4)
Composite stress, σ_c = 3.12 x 10³ kPa

Es = 2.0 x 10⁸ kPa
Em = 2.2 x 10⁷ kPa
At 0.01% strain, i.e. $\varepsilon = 10^{-4}$, the proof stresses are
σ_s = 2.0 x 10⁴ kPa
σ_m = 2.2 x 10³ kPa

$$\frac{As}{Ac} = \frac{n\ 0.25\ \pi\ d^2}{13\ t}$$ for wire mesh (Tuinhof [27], p. 4.5)

(d = 0.65mm n = 2)

= .002553

For reinforcing wire

Horizontal

$$\frac{As}{Ac} = \frac{1/4\ \pi\ Dw^2}{H\ t}$$

$$= \frac{1/4\ \pi\ (6.0)^2}{20 \times 30}$$

$= 0.047124$

Vertical
$= 0.047124$ (same)

σ_c' = first crack stress

$= \sigma_c\ (As/Ac)^{1.1} + \sigma_m$
$= 2.0 \times 10^4\ (2(0.04712) + .002553)^{1.1} + 2.2 \times 10^3$

$= 3733$ kPa

Check

Design Stress, σ_d	2126
Composite Stress, σ_c	3120
First crack stress, σ_c'	3733
Check	
$\sigma_d < \sigma_c$?	OK
$\sigma_d < \sigma_c'$?	OK

Conclusion

The 18 m³ tank is stronger than the 9 m³ one. However, note that the concrete alone guarantees a minimum safety for first crack stress.

2.6.2.2 Construction of the 18 m³ Tank

The construction process for the 18 m³ tank is similar to that of the 9 m³ one except that

1. on the bottom half of the tank, a second layer of chicken wire is added.

2. the total thickness of the tank walls is 3 cm minimum.

3. other dimensions are changed to meet the specifications.

2.7 THE YDD BAMBOOCEMENT TANK

From experience, YDD has found that the largest tank that can be safely built with bamboo reinforcement is 9m³ so they use bamboo only in the 4.5m³ tank [23], [30]. Ferrocement is used if tanks are larger than this or if adequate supervision is not available.

The dimensions of the tank are in Table 2.

TABLE 2

Dimensions of the YDD 4.5 m³ Bamboocement Tank

Diameter inside (m)	2.0
Height to Top Cover (m)	1.6
Volume (m³)	5.0
Active volume (m³)	4.2
Wall thickness (cm)	3-4
Base thickness (cm)	5
Reinforcement	Bamboo strips 1.5cm by 2mm with 3cm spaces (4.5cm centres)

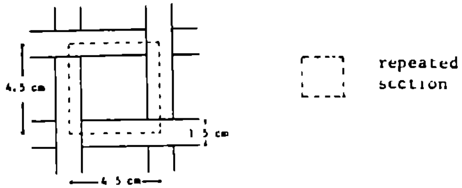
NOTE:
Active volume is calculated with the given height to top cover minus 10 cm to the top of the overflow pipe minus the diameter of the overflow pipe (2" = 5 cm) minus 10 cm from the floor to the bottom of the outlet pipe. Effective height is 135 cm.

2.7.1 Verification of Strength

See the 9 m³ YDD ferrocement tank case for an explanation of terms.

Diameter, D (m)	2.0
Radius, r (m)	1.0
Height, h (m)	1.6
Wall thickness, t (m)	.03
Pressure, P (kPa)	15.68
Hoop stress, σ_h (kPa)	523
Safety factor	2
Design stress, σ_d (kPa)	1100

Worst Case cross-section



Total area =	4.5 x 4.5	=	20.25 cm^2
Less centre =	3 x 3	=	9.00 cm^2

Area			11.25 cm^2
Both sides area			22.5 cm^2
Plus edges 18 x .2			3.6 cm^2

Total			26.1 cm^2 = 26 cm^2

Volume of composite = 4.5 x 4.5 x 3 = 60.75 cm^3

SL = 26/60.75 = 0.428 (1/cm) = 0.043 (1/mm)

Thus, σ_c = 3.3 x 10^3 kPa = 3300 kPa

σ_s = 1.4 x 10^3 kPa for bamboo

σ_m = 2.2 x 10^3 kPa for concrete

As/Ac = 1.5 x .2/(4.5 x 3) = 0.022

Then, σ_c' = 2221 kPa

Design Stress, σ_d	1100
Composite Stress, σ_c	3300
First Crack Stress, σ_c'	2221
Check	
$\sigma_d < \sigma_c$?	OK
$\sigma_d < \sigma_c'$?	OK

Conclusion

Note that the first crack tensile strength is only slightly greater than the proof strain of the concrete alone. In other works, nearly all of the strength is in the concrete. The bamboo contributes little to strength although it may prevent cracks by distributing stresses throughout the concrete.

2.7.2 Construction of the Bamboocement Tank

The basic construction method for bamboocement tanks built by YDD is outlined in "From Ferro to Bamboo" [10]. A drawing of the bamboocement tank is in Figure 6. Bamboocement is similar to ferrocement in production, except that bamboo strips are used as reinforcement. Since bamboo is an organic material, much more care is required in using

it than steel reinforcement. Drying and proper covering with concrete are crucial to the life of the tank. As a result, the need for close supervision is greater than in ferrocement construction which appears to be more tolerant of minor mistakes. The proper concrete/water ratio is a major factor in watertightness, which also affects the rate at which the bamboo will decay. Use of bamboo as a reinforcing medium requires experience and care to make it effective. A discussion of its use is in Part III.

The bamboo used is Gigantochloa apus or G. bolong (called bambu apus and bambu bolong in Indonesian) [31]. These are recognized by their dark green colour and medium distances between nodes. Preparation is important. The bamboo, cut from plants at least two years old, must be dried for two to three days so that it is not green but is not so dry that it is inflexible. Bamboo has a tough outer shell and a pulpier interior. Only the outer 1.5mm skin is used and this is cut into strips 2 cm wide. About ten bamboo poles are needed for each tank [23]. The spacing of the strips (4.5 cm centres or 3 cm space between strips) is a compromise between strength and adequate space for the mortar [1]. Bond strength is increased by weaving and alternating the strips outer part up/outer part down [22]. No coating is put on the bamboo to keep it waterproof as this was thought to reduce the bond strength [22]. It does not appear that tests have been carried by YDD out to measure the effect of these arrangements on the bond strength.

The concrete mortar is the same as for ferrocement, ie. 1:2:0.4 (cement, sand, water) and the walls are 3 to 4 cm thick. Complete covering of the bamboo with concrete plaster is essential to prevent the entry of termites and rot. A single point left exposed can result in the eventual loss of the entire bamboo framework.

The construction proceeds as follows:

1. Bamboo is cut into 1.5 cm wide strips and the outer 1.5 to 2mm of each strip is separated from the rest. The following quantities are needed:

No. of pieces	Length (cm)
35	640
155	155
100	120

2. A reinforcing framework for the walls is created by laying the 35 longest pieces out parallel at 4.5 cm centres, alternatively skin up, skin down and weaving the 155 cm pieces between them. Again, the skins are alternated. The edges are secured with a bamboo rope (two narrow bamboo strips interwoven through the strips).

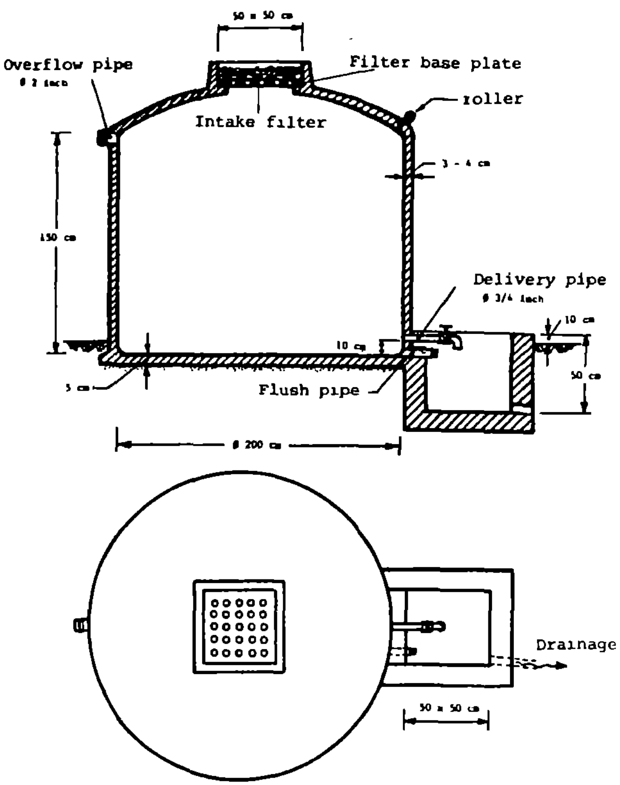


Figure 6: The YDD Bamboocement Tank

3. This framework is rolled into a cylinder and the ends secured.

4. Using the 120 cm strips, two square nets are similarly made for the base and roof reinforcement.

5. The top, bottom and the cylinder are woven together. The cylindrical shape is maintained by a 2 m diameter ring of stakes set in the ground at 10 cm distances. The base grid is perpendicular to the walls but the top is made in a dome shape.

6. A 50 x 50 cm square is cut from the top reinforcing net for the inlet.

7. Loose strands are carefully burned off all of the bamboo framework in order that they do not protrude through the surface of the concrete and allow water to leak out.

8. The site is excavated to 15 cm, levelled and covered with 2-3 cm of sand or gravel and paper from the cement bags is used to cover the sand.

9. The walls of the framework are covered with a bamboo mat and this is tied in place.

10. Concrete (1:2:0.4, cement, sand, water) is prepared and a 2.5 cm layer is laid on the cement bags and sealed with a cement/ water paste. This foundation is allowed to set for 15 minutes.

11. The framework is placed on the foundation and the pipes are secured in place on the walls.

12. A 2 cm layer of concrete is applied to the base inside the tank and a thin layer to the walls. Additional concrete is applied to the bottom corner.

13. This is allowed to set for 30 minutes and a second coat is applied using a mason's trowel. The total inside thickness is 2 cm. The walls are sealed with cement/sand paste and are smoothed carefully and sealed.

14. After 2 hours, the outside bamboo mat is removed and the concrete is allowed to dry for one more hour.

15. An outer layer of 2 cm is applied, the wall is smoothed, sealed and smoothed again.

16. The tank is allowed to set for 12 hours.

17. A supporting formwork for the roof is constructed and small concrete spacers (3 x 4 cm) inserted between the top reinforcing mesh and the support.

18. The concrete mix is applied to the roof and sealed.

19. A mould for the inlet hole is made, placed over the hole and its walls filled with concrete plaster.

20. The mould for the inlet is removed when the concrete has hardened sufficiently but the roof support should remain in place for 3 to 4 days. The inside of the roof is then finished and sealed.

21. Curing continues for 10 days during which water is splashed on the tank and 10 cm of water is kept in it.

22. A sunken box below the tap and a coarse filter plate to fit in the bottom of the inlet hole can be made from concrete.

Chapter 3

FOSTER PARENTS PLAN (PLAN)

3.1 THE AGENCY

Foster Parents Plan (PLAN) has two offices in Indonesia - one in Yogyakarta and the other in Bali. Each of these runs a cubang (literally 'tank') programme for the collecting of rainwater. Besides aiding villages through sponsorship of children by donors, PLAN has undertaken many programmes of wider scope which have included regional water systems, irrigation and rainwater collection where appropriate.

Funding comes through PLAN International which, in turn, receives public and government donations.

3.2 GUNUNG KIDUL

In Java, PLAN has helped to build about 100 rainwater systems in the Ponjong, Bandogede and Nglipa areas of Gunung Kidul as a support for their family programmes [25]. The tanks are the 9 m³ ferrocement YDD type. They have been built by village workers ("cadres") trained and supervised initially by YDD. There was some reservation about the filter [25] as it was thought that the palm fibre allowed insects to breed and get into the water, although the use of the filter was not discouraged [34].

The water in them is shared by three families of 5 each. The motivation for the programme seems to be for health improvement in most cases. In the village visited, the waterhole or telaga was only 800 m from the village but was very polluted. In Gunung Kidul, PLAN began by arranging and transporting materials but now leaves that up to the villagers [25], although how payment is handled was not noted.

3.3 BALI

The information in this section has been obtained from [29].

Bali is an island just east of Java. The population is 2.5 million, 85% of which is rural. Karangasem is a district or regency in eastern Bali in which PLAN presently operates its rainwater projects. Its population is 314,000. Annual per capita income is 28,600 Rp or $46 US (1981 survey) and is based on farming and crafts. It is the poorest regency in Bali. Water shortage is most acute in the dry season in dryland farming areas and upland areas where water quickly runs off. Groundwater is apparently unavailable and springs are highly seasonal especially in the high areas around Gunung Agung, Bali's volcano. Drinking water in the area has usually been carried, with 69% of the families going over one kilometre, and 7% over six kilometres.

Gravity systems have been installed by PLAN in lower areas but in the higher areas the population is too sparse and the risk of earthquake and flood damage is too high to make this possible. Water sources for family use in 1979 are shown in Table 3 which shows that rainwater collection was in use before PLAN's cubang programme. Traditional rainwater storage was done in partially buried open stone mortar tanks.

TABLE 3

Traditional Water Sources in Karangasem, Bali

(subject to seasonal variation)

Wells	14% of families
Spring	50% " "
Rainwater	24% " "
River	11% " "
Irrigation Channel	1% " "
Pipe	0% " "

Rain in the area is heavy at 1300 to 2000 mm annually but it falls generally from December to April, leaving up to 7 months of drought. The areas with the longest dry season have the lowest groundwater levels as well. A summary of the drought months is in Table 4.

TABLE 4

Number of Months With Less Than 10mm Rain, Karangasem, Bali

Village	Year 78	79	80	81	82
Bebandem	0	1	1	0	5
Seraya	0	3	4	1	5
Abang	0	1	4	1	2
Culik	0	3	3	NA	5
Kubu	NA	5	5	3	7
Tianyar	2	6	7	5	7

Source: reference 29.

In 1980-83, PLAN built about 700 tanks. Many of these tanks are part of a package which includes a standard 6 x 4 m house with a galvanized roof. Some tanks in the North Deta area are as large as 38 m^3 but these are fed by roofs on community buildings. The water in these is used by 20 families (100 people). Another 300 tanks have been built by the Indonesian government and other NGO's [36].

The design for the tank was obtained from a rainwater collection programme in Lombok - the island immediately east of Bali. Balinese villagers were trained in construction by a builder from this project. The Lombok project is described elsewhere in this report.

3.3.1 The PLAN Bali Tank

The tank built by PLAN is similar to the YDD 9 m^3 ferrocement tank but is constructed with a metal form. Its dimensions are in Table 5.

The water inlet is a 50 x 50 cm filter box with a concrete perforated bottom. A survey of tank users showed

TABLE 5

Dimensions of the PLAN Ferrocement Tank

Diameter (m)	2.4
Height (m)	2.5, 2.0 bottom to overflow
Volume (m^3)	9.0
Active volume (m^3)	8.2
Wall thickness (cm)	4
Reinforcement	8mm rods for frame, wire at 15cm centres, covered in chicken wire.
Wire mesh	One layer (estimate)

NOTE: Active volume is calculated using the diameter given minus 4cm for the wall thickness and using the height to overflow minus 5 cm, an assumed distance from the base to the bottom of the outlet pipe.

that 68% used palm fibre as a filter medium and for the rest no material was used in the box. There is a separate circular manhole with a concrete cover. A gate valve tap is installed over a sunken box for obtaining water and a sump drain is attached for cleaning the tank.

The base is shown in drawings as only supporting the tank edges but those seen on the study visit appeared to have a full base.

3.3.1.1 Tank Contruction

The method of tank construction is not fully described in [29] and no construction project was observed by the author during his visit [36]. Hence, the details of construction are not described here. However, it is assumed that construction is similar to YDD's ferrocement tank with the exception that sets of forms are used as backing to hold the concrete plaster in place for drying. The convex forms are meant as an internal framework.

Some tanks had steps built alongside to aid in checking the water level and to give access to the filter and manhole. This seems to be an item of great expense for very little use that could be fulfilled with simpler materials.

The sand/cement mix is:

Foundation	1:6
Walls	1:2.5
Floor	1:2
Manhole cover	1:3

A roof to shade the tanks is shown in the drawings but it was not observed in the field.

3.3.1.2 How Durable are the Tanks?

A survey [29] of 170 of the tanks with an average age of 22.8 months showed that 32% of them had cracks but these were minor. One tank could not hold water and another was seeping water through a crack. Cracking was more prevalent in tanks built in the dry season and left empty and in those not in the shade. Further surveys of the tanks as they get older will be needed to determine their expected life.

3.3.2 Special Note on Taps

Through their experience with community taps, PLAN Bali has settled on a robust gate tap. The Japanese-made Kritz tap coupled with an oversized pipe elbow has outperformed others and is installed on the rainwater tanks as well as in the public gravity water tapstands. Its cost is considerable at 7500 Rp ($7.50 US) in 1983.

Chapter 4

IWACO

4.1 THE COMPANY

IWACO (International Water Supply Consultants) is a Dutch engineering company that is funded by the Dutch government to work for the Indonesian government in west Java on water projects. They have worked on the West Java Water Project, codenamed OTA-33, to provide water in a number of areas near Singakerta which is located on the north coast of Java about 100 kilometres east of Jakarta. The coastal plain in the area has very shallow groundwater which is often brackish.

Based on designing to meet a minimum demand of five lcd, a 10 m³ ferrocement tank was examined for the use by 4 families and a 2.5 m³ tank of concrete reinforced with various materials including bamboo for use by individual families. The research and building programme in rainwater collectors began in 1978 and was essentially finished by 1982.

Thirty tanks (10 m³ ferrocement and 2.5 m³ bamboocement) were built in 1979/80 by a contractor [15] and 500 more were planned for 1981/82. Cost for the 10 m³ ferrocement tank serving 4 families was $400 US. Up to 1983, IWACO had built 58 tanks in Singakerta serving 150 families in 92 houses. Most of these are ferrocement [35].

A series of reports [7], [20], [27] detailed the work done which included optimizing the tank size based on a computer analysis of rainfall and optimizing the tank dimensions for lowest cost of construction materials. The tank design has also been used by the Indonesian Department of Health in projects sponsored by them in Sikka, NTT [6].

4.2 THE IWACO BAMBOOCEMENT TANK

The IWACO project is most known for its 10 m³ ferrocement tank. In its research programme, however, it built its non-ferrocement tanks out of a wide range of materials and in a number of sizes. Construction details for these tanks are not readily available from IWACO but were recorded by Hans Roolos [19] for the 2.5 m³ and 10 m³ sizes although he failed to acknowledge IWACO's assistance. The dimensions are shown in Table 6 and plans are in Figures 7 and 8.

TABLE 6

Dimensions of the IWACO Tanks

Source: [19]

	2.5m³	10m³
Diameter (m)	1.40	2.8
Height to top cover (m)	1.6	1.6
Volume (m³)	2.46	9.85
Active vol. (m³)	2.19	8.77
Wall thickness (cm)	3	3
Base Thickness (cm)	8	8
Horizontal reinforcement	Bamboo with 3.5-4 cm spaces	
Vertical reinforcement	Bamboo with 3.5-4 cm spaces	
Bamboo strips	1-1.5 cm wide	1-1.5 cm wide
Roof	Bamboo-reinforced with 55 cm diameter hole in centre.	

NOTE: Active volume is calculated with height given minus tap height (10 cm), roof thickness (3 cm), 1 inch overflow pipe and a roof/overflow space (2 cm).

Note that both tanks are shown without a tap but with a siphon pipe in the top. IWACO's Caspar Pompe [35] explained that this feature was an interesting preliminary idea but a physically impractical one because one has to suck on the tube to prime it. Besides being somewhat unhygienic, it is not possible for the body to draw water up a tube longer than one metre.

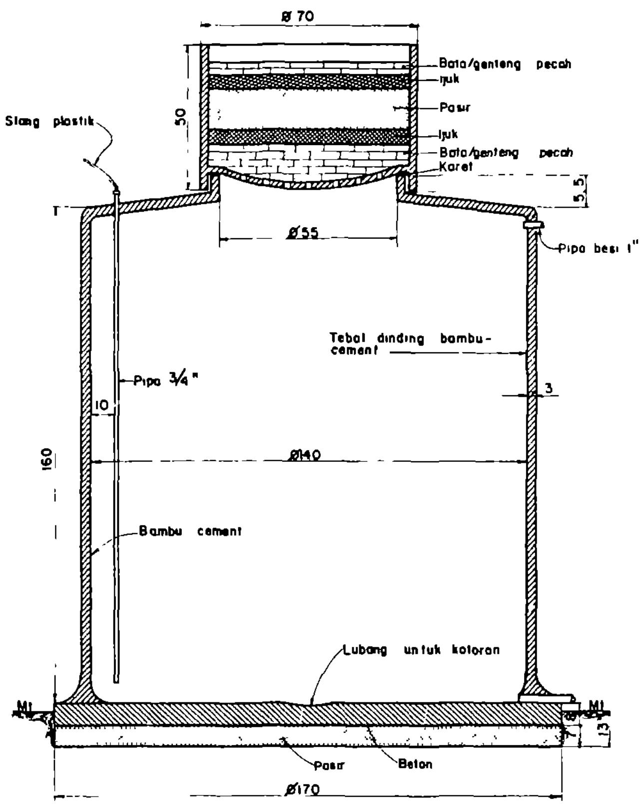


Figure 7: The IWACO 2.5 m³ Bamboocement Tank

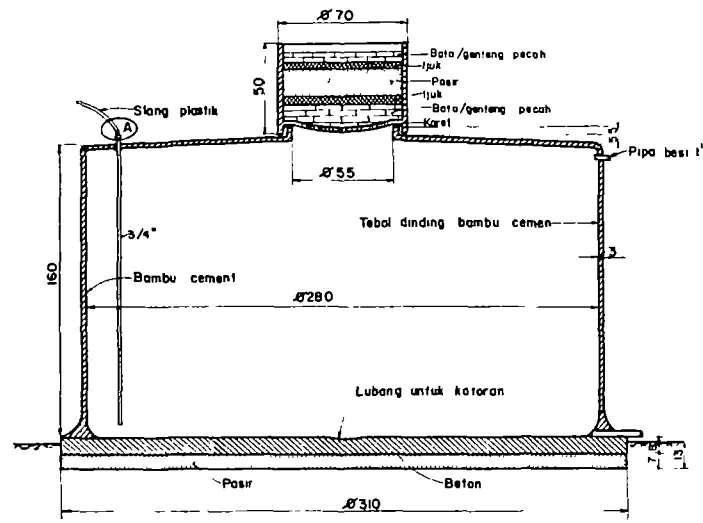


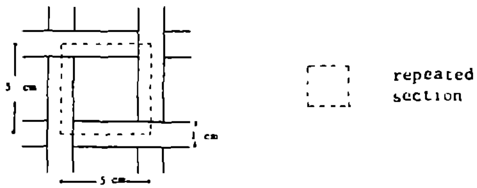
Figure 8: The IWACO 10 m³ Bamboocement Tank

4.2.1 Verification of Strength

This analysis is the same as for previous tanks. The terms are explained in the section on the YDD ferrocement tank.

	2.5 m³	10 m³
Diameter, D (m)	1.4	2.8
Radius, r (m)	.7	1.4
Height, h (m)	1.6	1.6
Wall thickness, t (m)	.03	.03
Pressure, P (kPa)	15.68	15.68
Hoop stress, σ_h (kPa)	366	732
Safety factor	2	2
Design stress, σ_d (kPa)	732	1464

Worst Case cross-section



Total area =	5 x 5	=	25	cm²
Less centre =	4 x 4	=	16	cm²
			--	
Area			9	cm²
Both sides area			18	cm²
Plus edges 16 x .2			3.2	cm²

Total			21.2	cm²

Volume of composite = 5 x 5 x 3 = 75 cm³

SL = 21.2/75 = .2827 (1/cm) = 0.02827 (1/mm)
Thus, σ_c = 2.89 x 10³ kPa = 2890 kPa

Now, σ_s = 1.4 x 10³ kPa
σ_m = 2.2 x 10³ kPa
As/Ac = 1 x .2/(5 x 3) = 0.0133
Then, σ_c' = 2212 kPa

	2.5 m³	10 m³
Design Stress, σ_d	732	1464
Composite Stress, σ_c	2890	2890
First crack stress, σ_c'	2212	2212
Check		
$\sigma_d < \sigma_c$?	much less OK	OK
$\sigma_d < \sigma_c'$?	much less OK	OK

4.2.2 Construction of the Bamboocement Tank

The construction of this tank is not as well detailed as the ferrocement one, but from the drawings in [19] and by the tanks' appearance, it appears that a number of techniques were tried out on the bamboocement tank that were later discarded. Some of the tanks seen by the author had only a galvanized iron sheet for a cover and on others, the top was formed separately and put in place rather than being formed in place.

In general, construction is similar to the ferrocement tank.

4.3 THE IWACO FERROCEMENT TANK

Although IWACO studied and built prototypes of the 2.5 m³ and 10 m³ ferrocement tanks, (both of which are described by Rolloos [18]), which are nearly identical in appearance to the bamboo models above, only the 10 m³ model has been popularized. A complete construction manual is available [8]. The dimensions of the tank are given in Table 7 and a plan is in Figure 9. The design calculations for the tanks were carried out by Tuinhof [27].

4.3.1 Verification of Strength

This analysis is the same as for previous tanks. The terms are explained in the section on the YDD ferrocement tank.

Diameter, D (m)	2.85
Radius, r (m)	1.42
Height, h (m)	1.6
Wall thickness, t (m)	.025
Pressure, P (kPa)	15.68
Hoop stress, σ_h (kPa)	891
Safety factor	2
Design stress, σ_d (kPa)	1782

TABLE 7

Dimensions of the IWACO 10 m³ Ferrocement Tank

Diameter inside (m)	2.85
Height to edge (m)	1.6
Volume (m³)	10.2
Active volume (m³)	9.7
Wall thickness (cm)	2.5
Base thickness (cm)	5 (estimated)
Horizontal reinforcement	5mm wire in spiral with separation of 5-30 cm. 2 layers.
Vertical reinforcement	Hoops at base. See Figure 10.
Wire mesh	2 layers

NOTE:
Active volume is calculated with the given height less the diameter of the overflow pipe (2" = 5 cm) less 3 cm from base to tap.

Calculation of composite stress

For chicken wire, diameter = 0.7mm (see YDD tank)

$$SLw = \frac{n(\pi \times 0.7 \times 10 + 2\,\pi \times .7 \times 7)}{13 \times 13 \times t}$$

$$= 0.31\ n/t = 0.31 \times 2 / 25\ (1/mm)$$

$$= .025\ (1/mm)$$

$$SL \text{ for rod} = \frac{\pi \times Dw \times n}{H \times t}$$

H = 150mm (average)
Dw = 5mm
n = 2

SL(rod) = 0.0084

SL = SLw + SL(rod) = 0.033
Then, σ_c = 3150 kPa

$$\frac{As}{Ac} \text{ for wire} = \frac{0.03\ n}{t} = \frac{0.03 \times 2}{25} = 0.0024$$

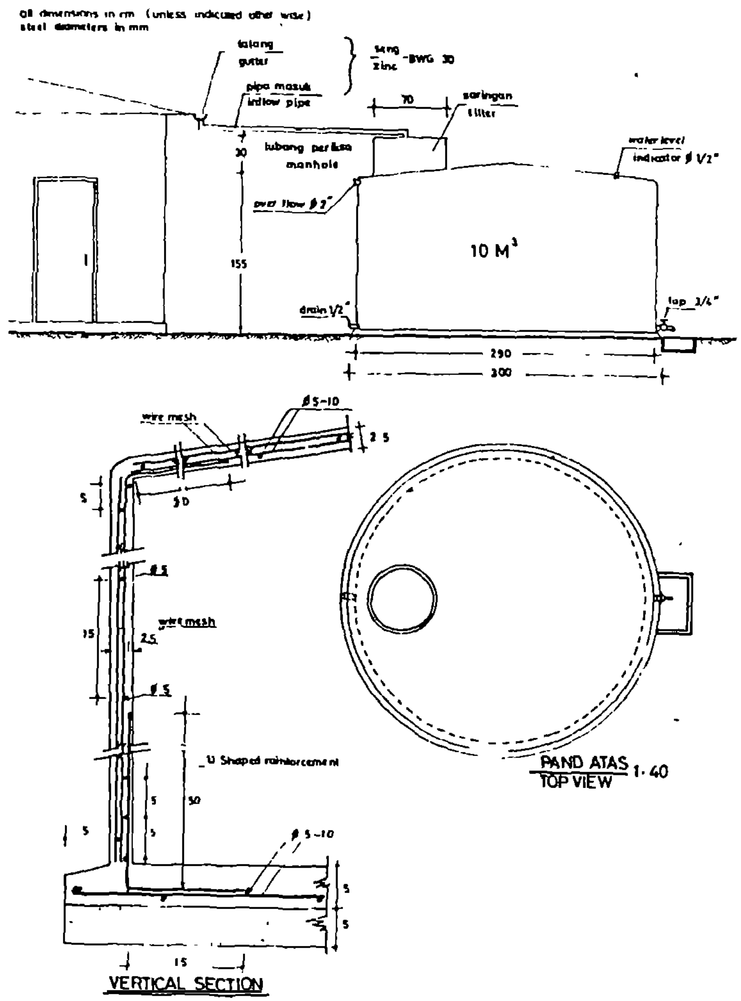


Figure 9: The IWACO 10 m³ Ferrocement Tank

$$\frac{A_s}{A_c} \text{ for rod} = \frac{.79\ n\ D_w^2}{t\ H} = 0.0105$$

$$\frac{A_s}{A_c} \text{ for combination} = .0105 + .0024 = .0129$$

Thus $\sigma_c' = 2367$ kPa

Design Stress, σ_d	1782
Composite Stress, σ_c	3150
First Crack Stress, σ_c'	2367
Check	
$\sigma_d < \sigma_c$?	OK
$\sigma_d < \sigma_c'$?	OK

4.3.2 Construction of the IWACO Ferrocement Tank

The construction technique is similar to that of the YDD ferrocement tank discussed before with the following changes:

1. An internal mould of steel rings covered in plywood is used. It was estimated that this was more economical than bamboo matting if more than eleven tanks were built with it.
2. A 5 cm layer of sand in a 10 cm deep excavated hole is used as a base. Edge bricks are used to hold the mould in place.
3. A layer of chicken wire is put on the mould and intertwined to hold it in place.
4. 45 U-shaped (see Figure 10) pieces of wire are placed at the bottom edge for extra support there.
5. A layer of rod is applied in a spiral at separations of 5-10-15-30-30-30-20-15-5 cm.
6. A second layer of chicken wire and rods is put in place and fastened.
7. A layer of mortar is applied to the outside wall and floor and the walls are covered in plastic.
8. The roof reinforcement is put in place and a bamboo mat put under it.

9. The inside walls and floor are wetted with a slurry and a 1-cm layer is put on.
10. The tank is covered in plastic for four days.
11. The bamboo mat is removed and the roof plastered on the inside.
12. 40 cm of water are added to the tank every day and it is covered with plastic for 37 days for curing.

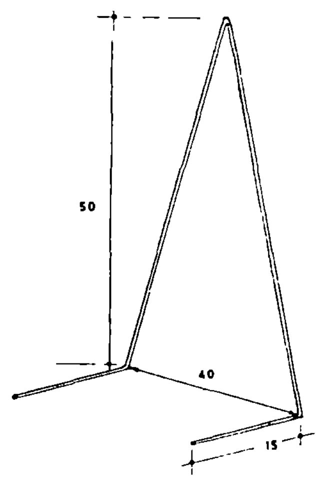


Figure 10: Bent Wire Rods Used at Base of IWACO Ferrocement Tanks

Chapter 5

OTHER AGENCIES

5.1 OXFAM

Oxfam has been engaged in rainwater tank construction in Nusa Tenggara Timur through joint projects with Dian Desa. The first project in 1982/83 built 14 bamboocement tanks in the Sikka district of NTT in a training programme for local artisans. In 1983/84, they paid for the non-local materials for 32 further tanks built by the villagers themselves in the same area [6] to match a similar number (i.e. 32) built by the villagers.

5.2 CARE

N. Truscott reported [26] in 1981 on a study of different types of tanks built on Lombok by Ben Young of CARE. Details of the tanks' size are in Table 8. Bamboo matting is used as a form for plastering. The bamboocement tanks have only the bamboo reinforcing network. The bamboo strips are 1 cm wide, 2 mm thick and at 4cm centres. In the bamboo/ferrocement tanks, chicken wire is applied to the outside of the bamboo framework on the walls and is carried around the top and bottom joints. Some tanks had chicken wire only on the lower half. A 1:2 sand/cement plaster is used and the walls are 4 cm thick. The roof is a galvanized sheet. A bamboo mat is used as a form.

The ferrocement tank uses a metal form on the interior. Reinforcing rod 1/4" (6 mm) in diameter at 30 cm centres reinforces the base, walls and roof. This is similar to YDD's ferrocement tank. Chicken wire is put on the outside of the rods and held in place by wire spiralled around the tank at 5 cm intervals. The roof does not have the large galvanized iron covered opening but only a small access hole in a ferrocement roof that is part of the tank. This is most likely the design used by PLAN Bali.

TABLE 8

Dimensions of the CARE, Lombok Tanks

	BAMBOO	BAMBOO/WIRE	FERROCEMENT
Diameter (m)	2.5	2.5	2.5
Height to Top Edge (m)	1.8	1.8	1.8
Volume (m^3)	8.8	8.8	8.8
Active volume (m^3)	8.1	8.1	8.1
Wall thickness (cm)	4	4	4
Base thickness (cm)	5	5	5
Reinforcement	Bamboo strips 1cm by 2mm at 4cm centres		6cm rod, 30cm centres. Wire spiral at 5cm in walls
Wire Mesh	-	One layer. May cover all bamboo or lower walls.	One layer.

NOTE: Active volume is calculated with diameter given minus wall thickness and the given height minus 10 cm (5 cm from the top of the tank to the top of the overflow pipe and 5 cm for the diameter of the overflow pipe - both measurements estimated from photographs).

PART II

THAILAND

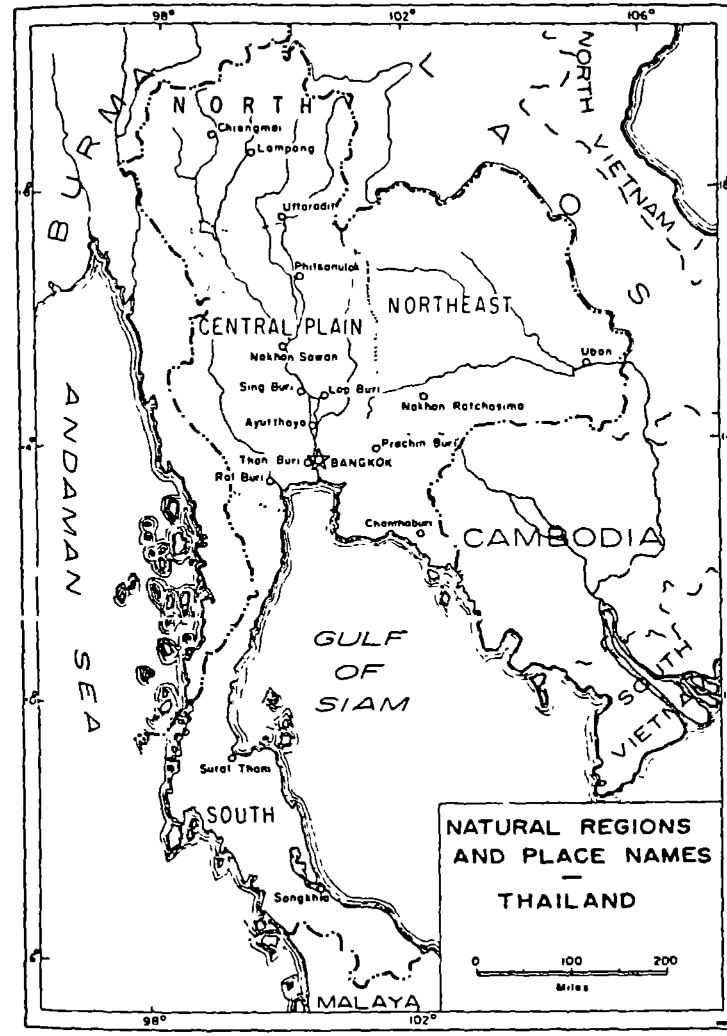


Figure 11: Thailand

Chapter 6

INTRODUCTION

6.1 OVERVIEW OF RAINWATER COLLECTION IN THAILAND

Although most villages use shallow dug wells for drinking water, rainwater collection is a very popular source of water in Thailand as there is a traditional bias towards it. A number of agencies, private and public, are working to improve the quality and quantity of water from this source for villagers. Most programmes are located in the Northeastern region, the poorest in the country.

The non-commercial, aid agency tank programmes are dominated by one group, namely PDA, the Population and Community Development Agency, which is centred in Bangkok and has developed a sophisticated market-oriented technique to train and support villagers in building its marginally bamboo-reinforced poured concrete rainwater tanks. This group has popularized a previous government-designed tank and has raised the credibility and level of sophistication of rainwater collection in general.

The other groups, however, have not copied PDA's approach but have pursued their own programmes. The government, private industry and other aid agencies have seldom stuck to one type of tank or one method of distribution. There are tanks of poured concrete, bamboo- and ferrocement, and jars and Jumbo Jars in a wide range of sizes. There are building programmes and training courses for owners, village artisans and potential entrepreneurs.

The structural features of the tanks have usually been well-designed but the size of the tank is less carefully considered, with tanks being built with set volumes which are usually overly large in order to be on the safe side.

6.2 OUTLINE OF STUDY IN THAILAND

Work for this study began with the establishment of contacts with Thai agencies by mail in late 1982 and early 1983. Mr. Brian Grover of R.L. Walker and Associates of Ottawa was interviewed as was Dr. Jaroslav Kukielka of London, England, former WHO team member in the Department of Health in Bangkok.

The major visit to Thailand was made September 1-26, 1983. In Bangkok, meetings were held with Ms. Sansaneya Kosinja of the Canadian Embassy, Dr. Suban Panvisavas, Dr. Nongluk Tunyavanich and Dr. Santhat of the Faculty of Social Science, Mahidol University, Bangkok, Dr. Thamrong Prempridi of Civil Engineering, Chulalongkorn University, Dr. Chanchai Limpiyakorn of ATA, Gerald Van Koeverden of CUSO, and Dr. Lilia Austriaco of the Ferrocement Institute of AIT.

Through the kind help of Professor Thamrong, various villages with rainwater collectors were visited in the Chaiyapum and Khon Kaen areas. Meetings were held with Dr. Sacha Sethaputra, Dr. Nipon Thiensiripipat, Chayatit Vadhanavikkit and Wirote Chaiyadhuma of the Civil Engineering Department, Khon Kaen University. A tour of the Department's study and demonstration projects was arranged. Through the help of Jean-Rene Rinfret of CUSO and the Small Scale Water Resources Project at KKU, visits were made to other villages and a Jumbo Jar factory in the area. Three days were spent with Mr. Prasong Lertpayub, Ban Pai district manager of PDA. Following general information sessions, participation in construction with PDA and village teams was arranged in two villages in Ban Pai and Channabot districts south of Khon Kaen.

6.3 THE WATER SITUATION IN THAILAND

In the small villages of Thailand, the percentage of the population that has improved water supplies is not known exactly. The National Economic and Social Development Board reports that 44% of the rural population has been provided with water at some time, but many of these systems have not been maintained. These could have been shallow and deep wells, metal and concrete storage tanks, ponds or piped systems. A 1978 WHO assessment of water supply reported that only 10% of the rural population had access to safe water [55].

In general, the proliferation of improved water systems is hampered, if not in other ways, by a lack of a central authority. In one way or another, rural water supplies are the responsibility of no fewer than eleven different government departments and agencies: The Royal Irrigation Department (RID); Department of Land Development (DLD); Department of Agricultural Extension (DOAE); Ministry of the Interior (MOI); Department of Local Administration (DOLA); Office of Accelerated Rural Development (ARD); Community Development Department (CDD); National Energy Authority (NEA); Department of Mineral Resources (DMR); Department of Health (DOH); and the National Central Security Command (NCSC) [40], [47]. Any government programme for water supply has had to be divided among the various departments and implementation is not effective without considerable co-ordination. Some of this splintering of power was reduced in 1979 when the new Provincial Water Works Authority under the Ministry of the Interior combined the Rural Water Supply Division of the Ministry of Health and the Provincial Water Supply Division of the Ministry of the Interior [55].

The only government money put into rural potable water in the current five-year plan (1982-86) is under the Ministry of Public Health and is detailed in Table 9. Some of this will go to supply rainwater containers to deprived areas [67].

6.4 AREAS OF USE

6.4.1 Northeastern Thailand Background

The rainwater collection system development and promotion programmes are mostly located in the Northeastern Region. The provinces with major projects are Khon Kaen and Maha Sarakam but tanks have been proposed in Buriram [55], Surin and Si Sa Ket [50] as well. In the Northeast Region, a survey in 1976 [68] showed that 85% of the households were in villages where the total household income was 15,600฿ or 2,600฿ per capita (22 ฿ = $1 US) but cash income was only 1,355฿. Per capita income was 5460 ฿ (1981) compared to 17,200 ฿ nationally [67]. In Khon Kaen province, for example, 94% of the people live in rural areas [42].

A summary of some statistics is presented in Table 10.

6.4.1.1 Khon Kaen

A major district for rainwater collection is Khon Kaen in the centre of the Northeast. The Khon Kaen area is mostly plateau land with some areas that slope towards the Mae Khong River. There are plains areas in the north. The old natural resource in the forests has been destroyed by deforestation. Local soils are a silty sand variety and are

TABLE 9

Thai Government Plans for Potable Water

	1981-2	1982-3	1983-4	1984-5	1985-6	Total
Target Villages	3,000	3,000	3,000	3,000	1,683	13,533
Small water works	500	500	500	500	500	2,500
Rainwater Tanks 3 cu.m.	3,000	3,000	3,000	3,000	1,663	13,633
Water Jars 1 cu.m.	3,000	3,000	3,000	3,000	1,683	13,683
Other components such as water purifications, latrines, economic stoves, training etc.						
Annual Budget (M. Baht)	31.72	31.72	47.73	54.73	42 47	208.37
Small Water Works	17.50	17.50	17 50	20.00	22.50	95.00
Rainwater Tanks	10.50	10.50	10.50	12.00	7.57	51.07
Water Jar	0.75	0.75	2.40	3.00	1.68	8.58
Other Components	2.97	2.97	17.33	16.73	10.72	53.72

Total 5 years budget for the Rural Poverty Eradication Programme is 8,593.38 M.baht

Source: Reference 55.

poor for agriculture and for holding water. There are many small creeks but these are emphemeral, being fed by the rains. With an average of 1200mm of rain per year, which falls mostly in the five months from May to September, the streams are dry for seven months a year.

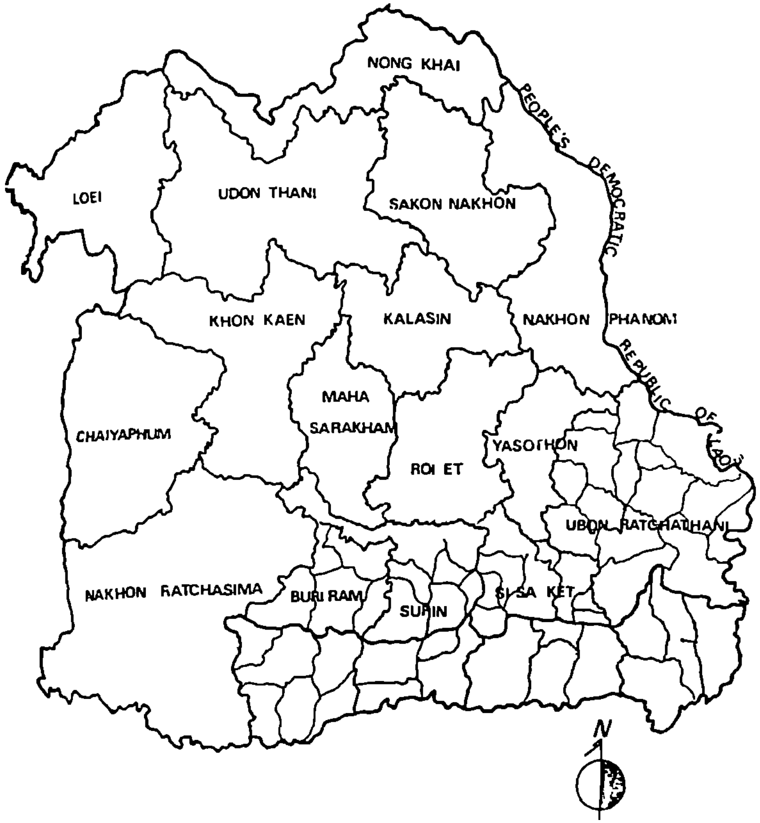


Figure 12: The Northeast Region of Thailand

TABLE 10

Statistical Summary for Parts of Thailand

	Area (km^2)	Population (1980) millions	Population per sq. km.
Thailand	513,115	46.96	92
Northeast	168,854	16.1	95
Khon Kaen	10,866	1.35	124
Maha Sarakam	5,292	0.76	144
Si Sa Ket	8,840	1.08	122
Surin	8,127	1.04	127
Buriram	10,322	1.13	110

Source: Statistical Summary of Thailand 1981. [59]

6.4.1.2 *Maha Sarakham, and others*

Other districts were not visited by the author and details on the areas were not obtained.

Chapter 7

THE POPULATION AND COMMUNITY DEVELOPMENT ASSOCIATION (PDA)

7.1 THE AGENCY

The Population and Community Development Association (PDA) is a private, non-profit, non-governmental organization in Thailand which was founded by its very visible leader, Mechai Viravaidya, a Harvard graduate who has pursued previously unorthodox methods in promoting family planning and village development.

PDA, which now has 300 staff, 16,200 volunteers in as many villages [55] and operates out of a multi-storey office complex in Bangkok, is made up of a number of divisions but it began in 1974 as a family planning organization. This function is now handled by the Community Based Family Planning Service (CBFPS) which is also engaged in the general health field in villages. Other divisions are: The Asian Centre for Population and Community Development, founded in 1975 as a training centre; the Community Based Appropriate Technology Development Service (CBATDS), founded in December, 1978 to improve village produce marketing and to promote appropriate technology including rainwater tanks; and the Community Based Emergency Relief Service, founded in 1979 to do family planning and administer foreign relief aid to refugees in Thai camps.

Funding for the PDA rainwater collection programme has come from German Agro Action (Deutsche Welthungerhilfe) since 1981 but other money has come from the Appropriate Technology Institute, Canadian International Development Agency, International Development Research Centre, the Ford Foundation, German Relief Association, the New Zealand embassy and others.

7.2 HISTORY OF PDA'S TANK PROGRAMME

Rainwater collection was chosen as one of the first projects of CBATDS. The Northeast Region was chosen for this work because of its dry climatic conditions, poor groundwater, and low economic state. However, the entire rainwater project is still an adjunct to the family planning programme as shown by the finished tank. PDA's name and logo are spray-painted on it and a number of red symbols corresponding to the level of permanence of the family's birth control method encircle it. Also reductions in the cost of tanks are given to an owner if birth control methods are used.

CBATDS ran a pilot rainwater collection project in two villages in the Ban Pai district of Khon Kaen province [42] and other villages in Maha Sarakham province in 1980. Fifty-one tanks were built in different sizes and of different materials (ferrocement, bamboo-reinforced concrete and pre-cast sewer pipe) and a village payment and revolving fund scheme was tested [49]. From this project, a standard poured concrete tank with minimal bamboo reinforcing framework was chosen as the model for future programmes.

Since the pilot project, several thousands of tanks have been built and many more are proposed under projects with the name Tung Nam (Tung = tank, Nam = water, in Thai). The numbers of tanks and the costs involved for each stage of the project are shown in Tables 11 and 12. These numbers are nearly all projected. Actual cumulative numbers of tanks built to date, excluding those of the pilot project, are in Table 13. Of those existing at the time of the study, about 1500 have been built with the assistance of German Agro Action and 1200 from the PDA revolving fund [44]. It is proposed to build 8,900 tanks in 1983-87.

7.3 THE PDA RAINWATER TANK

The PDA tank was not invented by the PDA study team nor PDA officials. Similar types of tanks were built before the PDA pilot project at schools and temples under short-term government employment programmes. In fact the forms used in the pilot project were borrowed from the Public Sanitation Department [42] and the basic design was also from them.

However, after an initial study of different construction methods, a model that PDA could confidently stand behind was set upon. Quality standards were set, a streamlined construction method was developed and a building programme was then launched.

TABLE 11

Workplan of Tung Nam Projects

Source: Reference 55.

YEAR	TUNGNAM 1	TUNGNAM 2	TUNGNAM 3	TUNGNAM 4	TOTAL
81-2	1000				1000
82-3	600	1000			1600
83-4	600	600	1500		2700
84-5	600	600	900	1500	3600
85-6	600	600	900	900	3000
86-91	3000	3000	4500	4500	15000
TOTAL	6400	5800	7800	6900	26900

TABLE 12

Cost Analysis of Tung Nam Projects

Source: Reference 55.

All costs in 1000's of Baht.
(22฿ = $1 US - 1983 rate)

YEAR	COSTS				
	Material	Admin&Opn	Total	Revolving Fund	Other
81-2	3500	700	4200	3500	700
82-3	5600	1120	6720	3500	3220
83-4	9450	1890	11340	5250	6090
84-5	12600	2520	15120	5250	9870
TOTAL	19810	6230	26040	17500	8540

TABLE 13

Cumulative Number of Tanks Built by PDA

Date	Number Completed	Reference
May 1981	0	
October 1981	450	50
April 1982	1004	51
August 1982	1500	52
January 1983	2000	53
April 1983	2772	54

PDA's major contribution to rainwater collection is its programme of dissemination of its tanks. Construction is standardized, tank quality is guaranteed, financing is arranged, payments are scrupulously recorded and transactions are done fairly. Given these conditions, villagers are willing to build, pay for and use the tanks.

7.3.1 Collection Mechanism

7.3.1.1 Roofs

In the areas that were visited in this study that used rainwater collection, the roofs were generally of galvanized iron sheeting. This may indicate that middle class villagers have the knowledge and funds to have a rainwater system. Roofs were generally large which again may be due to high family incomes.

7.3.1.2 Pipes and Gutters

These varied widely from professionally-made gutters with downpipes with swivels to move the rainwater flow away from the tank to gutters and pipes made by bending cut galvanized sheets into V-shapes to split bamboo. These items seem to be more of an indication of income level than other features such as the tank which is considered crucial to the system.

7.3.1.3 Roof Flush

The PDA tank is distinguished from other tanks in Southeast Asia by its roof flush device. This consists of a PVC section 3 inches in diameter and 2 m long with a tee at the top and a cap at the bottom. See Figure 13. Approximately nine litres of the first water coming from the roof are caught in this pipe before water begins to flow to the tank. Theoretically, after each rain, the cap should be removed and the water allowed to run out in preparation for the next rain. In practice, however, the effectiveness of the device is substantially reduced because the cap is attached to the pipe's bottom by friction. With a tight fit required, it is difficult to remove the cap to release the water. In one case [69], the back of a machete had to be used to carefully pound the cap off. In the process, mortar covering the brackets holding the pipe to the tank cracked and fell off, and the water flowed out at an uncontrolled rate, splashing the owner and anything else in the vicinity. There was still the problem of the technique of refitting the cap and further damage to the brackets.

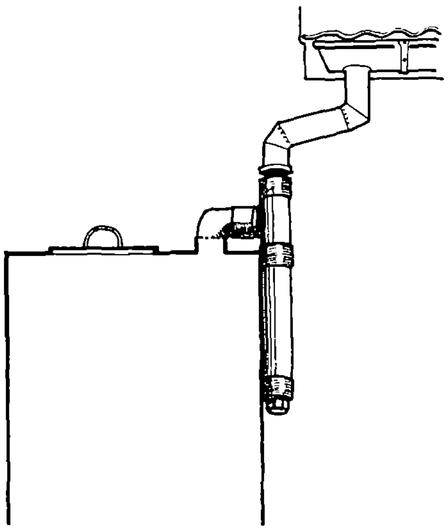


Figure 13: PDA Roof Wash Device

With this amount of difficulty involved in the operation of the roof flush, it is doubtful that the water is ever removed from the pipe. A serious assessment of the device's usefulness should be undertaken to either improve or eliminate it.

7.3.2 <u>The Tank</u>

7.3.2.1 Dimensions

The PDA tank is a tall, thick-walled cylinder with a concrete roof. It is set on a concrete base and reinforced with whole bamboo strips, not just the stronger outer layers as in the YDD tank. This tall shape is suited to the Thai village house which occupies nearly all of its lot, leaving little space for a wide-bottomed tank. The specifications for the tank are given in Table 14.

TABLE 14

Dimensions of the PDA Tank

Diameter inside (m)	2.0
Height to edge (m)	3.6
Volume (m^3)	11.3
Active volume (m^3)	9.6
Wall thickness (cm)	10
Base thickness (cm)	25 cm stone, 15 cm concrete, 2.5m x 2.5m reinforced with bamboo at 20cm centres.
Horizontal reinforcement	Bamboo hoops at 30cm centres.
Vertical reinforcement	20 bamboo uprights at 30cm centres attached to the base.

<u>NOTE</u>:
Active volume is calculated with the given height less the 45 cm from base to tap less the distance of the overflow from the top (10cm).

The bamboo used is not of a specific type except that it was "construction type bamboo" but it must be at least two years old and straight. It is cut into strips 2 cm wide and 0.5 cm thick and is dried for two days before construction. The following pieces are needed;

length(m)	No. of pieces
7.5	13
4.2	20
2.4	50

7.3.2.2 Strength of the Tank

The analysis used before is restricted to ferrocement so is not applicable here. However, a report done by Dr. Nipon Thiensiripipat of the Civil Engineering Department, Khon Kaen University [60] for UNESCO suggests that the amount of bamboo reinforcing should be 10 cm^2/m both horizontally and vertically. This means that there should be 10 cm^2 of reinforcing material area for every metre of concrete. In other words:

$$\frac{100wd}{c} = 10 \quad \text{or} \quad c = 10wd$$

where w = width of bamboo strips (cm)
d = thickness of bamboo strips (cm)
c = centre-to-centre separation of strips (cm)

For the PDA tank,

w = 2.0 cm
d = 0.5 cm
and thus c = 10 cm

Since PDA now uses 30cm centres, it appears that the amount of reinforcement is too little. However, in the construction case observed in the visit, the bamboo strips were thicker than 0.5 cm and were more likely 1 cm. Moreover, Dr. Nipon's guidelines are probably a bit conservative in the case of this tank as they are based on analysis of a larger tank . Despite these adjustments, it appears that the PDA tank could be improved by additional bamboo strips to reduce the distance between strips to 20-25 cm. The additional cost for this would be minimal.

7.3.2.3 Constructing the PDA Tank

PDA builds 15-20 tanks at a time in a village to make the most use of its technicians and forms and to get quantity discounts on materials delivered to the site by suppliers. The bases for all tanks are done first and then each tank is

poured in one day using six rings of forms. This single day of pouring prevents leaks at borders between one day's work and the next that were seen on older government tanks and earlier tanks built in PDA's pilot project.

The following brief outline of the construction procedure for the PDA tank was followed very closely in the several days of construction that the author engaged in [70]. This description is adapted from a PDA project proposal [49].

1. A site 2.5m x 2.5m x 25cm deep is dug and its edges lined with boards.

2. The site is compacted, covered with 15cm of gravel or crushed brick and enough sand to give an even surface, and compacted again.

3. 26 pieces of bamboo 2.4 m long are used to construct a reinforcing framework at 20 cm centres. The joints are secured with wire.

4. 16 bamboo strips 4.2 m long are bent into an L shape 50 cm from one end by beating them at the bend with a hammer. These are tied with wire onto the framework with the bends at the circumference of a circle of 2.05m diameter.

5. The bamboo framework is supported 5 cm from the sand in the excavation. A drainage pipe (1.25m of 1.5" PVC pipe with an elbow on one end and a steel connector and plug on the other) is set on the bamboo framework so that the elbow is at the centre.

6. 15 cm of concrete (1:3:5, cement, sand, rock) are poured for the base and let stand for 24 hours. An alternate method [44] is to put the reinforcing at the bottom of the site and work it up partially through the wet concrete.

7. 3 bamboo strips 7.5 m long are tied in hoops around the outside of the vertical strips at 10, 30, 50 cm above the floor.

8. The base is cross-hatched where the wall will contact it. The forms are oiled and assembled on the base with 10 cm between the inner and outer rings. The rings are arranged so that the vertical bamboo strips are in the middle of the space between them and the edges of the forms carefully levelled using a clear hose with water in it.

9. The floor is moistened and sand is packed around the base of the forms. Piping for the tap is inserted in special holes in the first ring.

10. Concrete with a 1:2:3 (cement, sand, rock) mix is poured into the forms and is tamped.

11. The next ring of forms is assembled on top of the first. A cement/water paste is used at first on top of the first pouring and pouring of the next ring proceeds. This continues until the 6 rings are poured. The top ring is different because the inner ring has spaces cut into it to take lumber that will support the roof while it is drying.

12. The concrete is allowed to dry for one day and the forms are removed.

13. After the tank has dried for another day, a platform of wooden planks is built on the wood at the top. PDA supplies pieces cut so that they fit the circular shape. A hole 50 cm in diameter is left for a manhole and a hole of 15 cm diameter is located 30cm from the edge of the tank for the roof flush pipe. A light metal ring, 10 cm high, provided by PDA, is attached to the top edge of the tank.

14. A bamboo framework of diameter 2.1 m is made up and supported so that it is 4 cm above the base of the roof.

15. The roof is poured 10 cm thick using a 1:2:3 concrete. This is allowed to harden for 3 days and the forms are removed.

16. Using a cement grouting (1:1 cement, sand), holes inside and outside the tank are repaired.

17. A final coating of the inside and outside is done with a cement slurry (water and cement only) to seal and finish the tank. This is usually done by the technician.

18. The tap is attached to the pipe which is protruding 30 cm from the wall. A special form is used to pour a support box for the tap. The concrete for it is the same as for the walls.

19. The roof flush is supplied assembled by PDA and is attached to the tank sides with brackets.

20. The manhole is made by pouring a 2 cm lip around the outside of the hole with 1:1 (cement, sand) concrete. A cover is poured 5 cm thick using concrete as for the walls.

21. The tank is cured for 21 days by covering it with burlap and keeping this wet. Water may also be kept in the tank. This curing time is not supervised strictly so some strength is lost, but this can be minimized if the tank is built in the wet season.

22. The tank is usually allowed to fill with water and then flushed out to remove any residue and taste before it is used.

Chapter 8

KHON KAEN UNIVERSITY RESEARCH GROUP

The Department of Civil Engineering, Khon Kaen University (KKU) is carrying out a wide-ranging research project into many aspects of rainwater collection. This is financed by several external agencies such as IDRC and UNESCO. As outlined in [62], the work has involved a study of water quality, roof types, concrete, construction materials and tank designs. Several demonstration tanks have been built and are being tested. However, there is apparently no programme plan at present to build tanks on a large scale in villages.

8.1 THE KKU FERROCEMENT TANK

Studies in tank construction have examined ferrocement tanks [64] that were 2.5 m in diameter, 2.5 m in height and tanks 2 m diameter, 3 m height with a wall thickness of 4 cm. Use of a 1:3:0.4 (cement, sand, water) concrete and a square grid wire of 25 mm spacing and 1.4 mm wire diameter (no. 16 gauge) allowed the tanks to be made without a form. Note that the cement used is silica cement - a 3:1 mix of Normal Portland cement and finely ground sand. This gives concrete that is weaker but slower to dry and hence easier to work with. Moreover, the square grid mesh was both stronger and cheaper than the hexagonal chicken wire mesh. Since the stresses were below the tensile strength of unreinforced mortar, the stiff reinforcement was chosen partly as an aid to construction. Specifications of the tank are given in Table 15 and plans are shown in Figure 14.

Because of the stiffness of the square wire mesh, the wire reinforcement is assembled differently than in other tanks but other construction details are similar to other ferrocement tanks. Construction proceeds in the following way [64]:

1. The bottom outer layer of mesh is formed so that 35 cm of it is on the base and the rest on the wall.

2. Steel hoops are installed on the inside at the bottom corner and at the top edge using one of the mesh wires as a guide. Vertical wires are installed and tied to the mesh and are adjusted to fit the mesh.

TABLE 15

The KKU Ferrocement Tank

Diameter inside (m)	2.5
Height to edge (m)	2.5
Volume (m^3)	12.3
Active volume (m^3)	11.5
Wall thickness (cm)	4
Base thickness (cm)	10 cm of concrete with stones.
Reinforcement	All bars are 9mm diameter - 16 vertical bars, 8 extend over full base diameter and half of roof diameter, 8 bars vice-versa. 2 hoops in base and roof, 3 hoops in walls at spacings from base of 22, 22, 24 inches.
Wire mesh	2 layers, 25mm square wire mesh.

NOTE:
Active volume is calculated with the given height less the less 10 cm from base to tap less 2.5 cm for overflow pipe diameter less 4 cm from the top of the wall to the top of the overflow pipe.

3. The outer mesh is applied to the bottom layer and tied in. The mesh is tied so that the two layers do not separate more than 20 mm.

4. The next outer layer of wire mesh is overlapped on the first so that individual wires are aligned. The steel rods are adjusted and tied and the inside mesh layer fitted and tied in place.

5. The foundation is compacted soil with a 30mm base of 3/4" stones. The form is put in place and 5 cm of 1:2:4 (cement, sand, stone) concrete applied. A coat of cement paste seals the base.

6. Wall mortar of 1:3:0.4 (cement, sand, water) is applied between the layers of mesh.

7. After one day's drying, inside and outside layers of 0.5-1 cm of concrete are applied and finished with a cement paste.

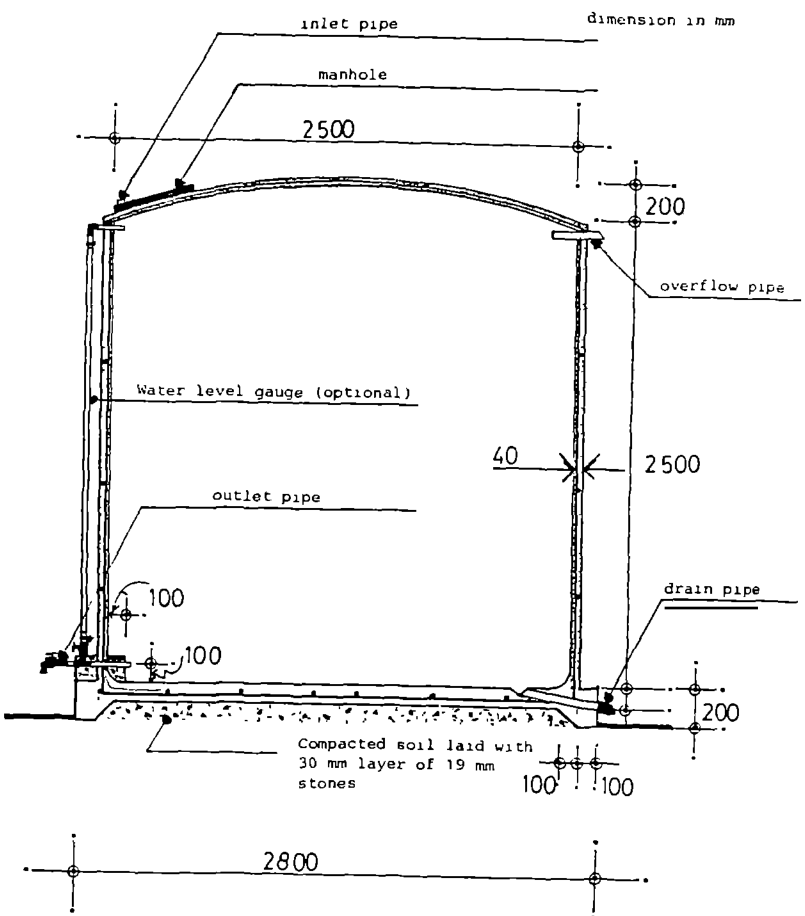


Figure 14: The KKU Experimental Ferrocement Tank

8. The roof is plastered using a piece of 1/4" plywood board to hold the mortar.

9. All joints at the base and wall and between the wall and pipes are sealed with a cement paste,

10. The tank is covered in PVC sheeting and cured for 14 days.

8.2 THE INTERLOCKING BLOCK TANK

This is a new development by KKU and uses a special interlocking brick that can be assembled to produce an unreinforced circular tank. Its major advantage is its low cost [63]. It is still being tested for durability and as of 1983, it was not proven for general use.

For a tank 2.5 m in diameter and 2.5 m high, the required brick is shown in Figure 15. The area of the shear plane A must be more than 1/5 of the area of the tension plane B. Joints of 3 mm are allowed for. Two types of brick are needed: one for the base and top rows and another for the rest of the walls. The bricks are made from 1:3 (cement, sand) concrete with 0.4 (by weight) of water that is tamped into the moulds. The ratio of ingredients is crucial, especially the amount of water. A cement paste (1:0.3 cement, water) is used as the joining compound.

The construction plans are in Figure 16. The base and roof are the same as in the ferrocement tank. Tanks with a diameter of 2 to 3 m can be made with the bricks for the 2.5 m diameter although construction is more difficult.

Construction is straightforward with these special features:

1. The bricks are soaked in water for 15 minutes before being used.

2. Each layer is laid out before mortar is used to check for irregularities.

3. A cement slurry (1:0.5, cement, water) is applied to the edges before applying the cement paste mortar.

4. Laying of the bricks is done in a way so that cement paste is squeezed from the joints as much as possible to ensure full joints.

5. The inside of the wall is covered with cement slurry to increase watertightness.

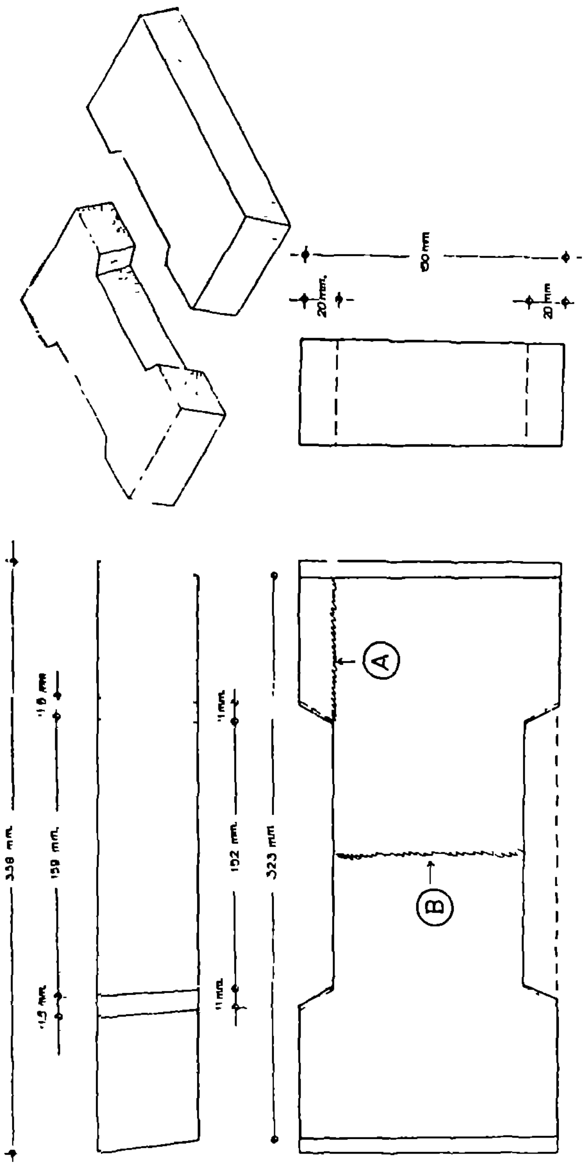


Figure 15: The KKU Interlocking Brick

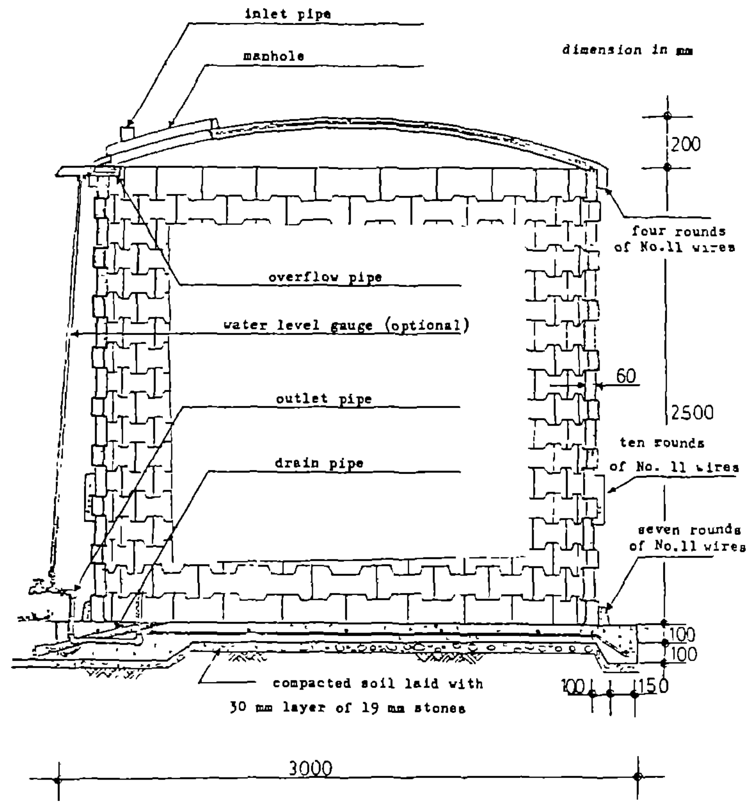


Figure 16: Plan of the KKU Interlocking Brick Tank

6. Three wire belts are applied - one at the bottom, top and around 1/4 of the height. The region for the belts is prepared with a cement slurry, mortar is plastered on, wire is wound around the tank at 4 cm centres, pulled tightly and the ends tied. Finally, the wire is covered with 1 to 1.5 cm of mortar. In the demonstration tank built [71], the central belt was not seen.

8.3 OTHER KKU TANK CONSTRUCTION METHODS

8.3.1 Brick

This tank is basically a ferrocement type that saves on cement by using bricks for most of the walls' thickness [65].

A plan for the tank is in Figure 17. Roof and base reinforcement are similar to the ferrocement tank with 1:2:4 concrete (cement, sand, stones) for the base and 1:3:0.4 (cement, sand, water) for the roof. The walls are built with bricks and mortar completely filling the spaces between them. Galvanized wire (diameter of 2.7-3.3 mm) is wound around the outside of the bricks at 40 to 100 mm intervals (increasing as the top of the tank is approached) and a thin 1 cm layer of mortar is applied. The inside of the wall is strengthened with light, 12.5 mm hexagonal chicken wire mesh nailed to the wall and covered with mortar mixed 1:3:0.4 (cement, sand, water) as before. Curing is 14 days under PVC sheeting.

Due to the generally poor quality of local low-cost bricks and their tendency to shrink, these tanks are not expected to be as durable as other types and will probably not see widespread use.

8.3.2 Bamboocement Tank

Dr. Nipon Thiensiripipat of Civil Engineering, Khon Kaen University has done a detailed calculation [60] of stresses and moments related to small tanks and applied the results to a bamboo reinforced tank. He concluded that there should be about 10 cm² of reinforcement cross-section per metre of concrete wall both horizontally and vertically. This is satisfied by 1 x 2 cm strips at 20 cm centres.

Construction for a tank 3 m high and 3 m diameter is similar to that of the PDA tank but with the following differences:

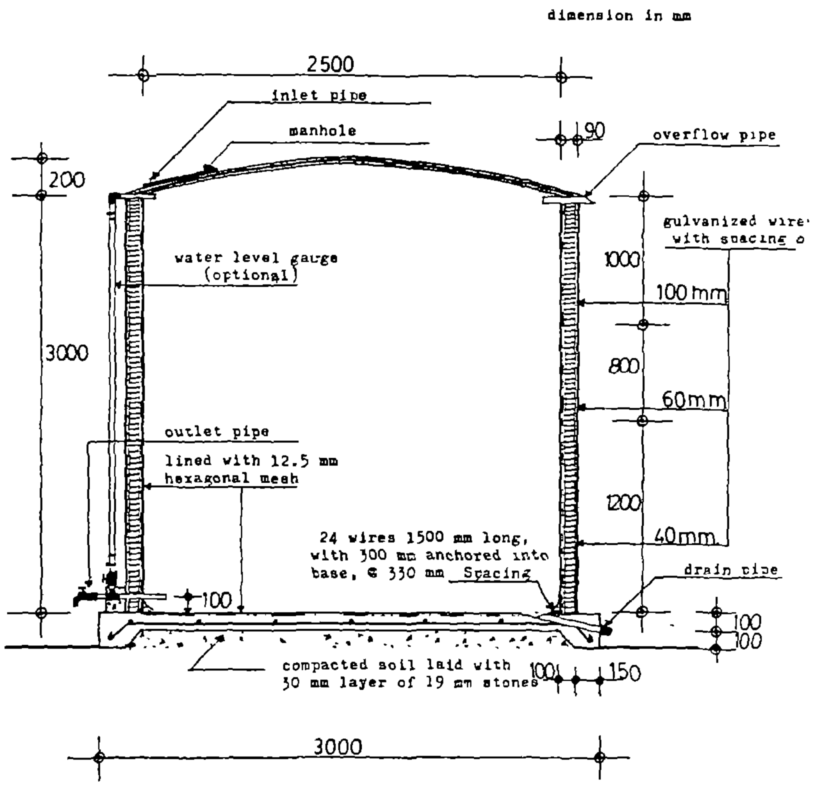


Figure 17: The KKU Brick Tank

1. The bamboo is not dried but is covered with "dammar" - a wood resin or similar sealant.

2. Bamboo strips are at 20 cm centres.

3. A single set of ring moulds is used with a new rise being poured every day.

4. The concrete mix is 1:2:3 (cement, sand, stone)

This tank is essentially the same as the PDA tank and both groups would benefit from a sharing of ideas about their respective tanks. PDA would gain by a more detailed analysis of the mechanics of reinforcement and KKU would benefit by seeing how improvements in construction such as using a full set of forms instead of one, can reduce the cost of the tanks in the field while improving their quality.

Chapter 9

OTHER RAINWATER COLLECTION GROUPS

9.1 APPROPRIATE TECHNOLOGY ASSOCIATION

9.1.1 The Agency

The Appropriate Technology Association for Development (ATA) is a training and demonstration group in Bangkok. It is very closely connected with the Working Group on Appropriate Technology at the Faculty of Engineering, of Chulalongkorn University, Bangkok. Dr. Thamrong Prempridi of Civil Engineering is on the board of directors and Dr. Chanchai Limpiyakorn of Mechanical Engineering is its head. In the two years to 1983, ATA had run ten workshops in Northeastern Thailand, mostly at temples in Khorat, Buriram, and Pachang and also in Bangkok.

In rainwater collection, ATA has developed plans for rainwater tanks in bamboocement, poured concrete and Jumbo Jars. However, the poured concrete type was found to be unsuitable for village-level training because a mould is required. The use of a mould means that more organization and infrastructure is required to make it worthwhile. This can seriously inhibit independent artisans from building tanks on their own.

9.1.2 The ATA Bamboocement Tank

This tank, designed by Dr. Panitai of Civil Engineering, Chulalongkorn University, is distinguished by a very high ratio of bamboo to concrete compared to other bamboocement tanks in this report. The size is somewhat variable from 6 to 8 m^3 but common measurements were 2m diameter and 2m height. A tank of this size, 6 m^3, was intended for one family. Figures 18 and 19 show some of the construction sequence.

The bamboo used is Thyrsostachys Siamensis (4-6 cm diameter) or Bambusa Blumcana (7-10 cm diameter, yellow colour) or T. Oliveri in Northern Thailand. The bamboo used must be at least one year old. This is cut into 1.5-2 x 1 cm strips and is either dried or soaked in water for 24 hours and covered with Flintkote tar.

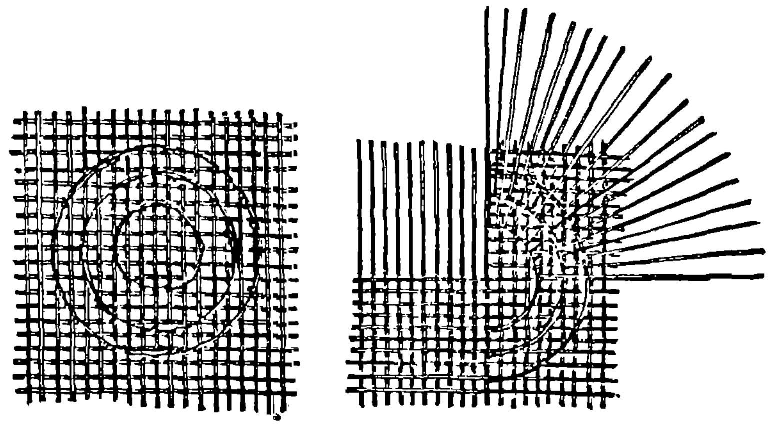


Figure 18: Construction of the ATA Bamboocement Tank

The base reinforcement is a grid at 12 cm centres (estimated from drawings in [38]) and 3 concentric hoops. As with the PDA tank, the wall verticals are attached to the base and bent to the vertical. Two horizontal spirals, one inside and one outside, are attached to these uprights to reinforce the walls. These are spaced at 5 cm. Concrete on the walls is 4-6 cm thick and is mixed at 1:2:0.4 (normal Portland cement, sand, water). This is applied in two equal layers each 3 cm thick and covered with a rich sealing coat. The first layer is made with sand finer than no. 8 mesh and the second layer with sand finer than no. 18 mesh (very fine). Tanks are cured for 5 days and kept in the shade for 14 days with 30 cm of water in them.

The roof has a reinforcing grid augmented by short diagonal strips around a central manhole. A manhole cover must be removed to let water into the tank. Because of this, there is no overflow pipe.

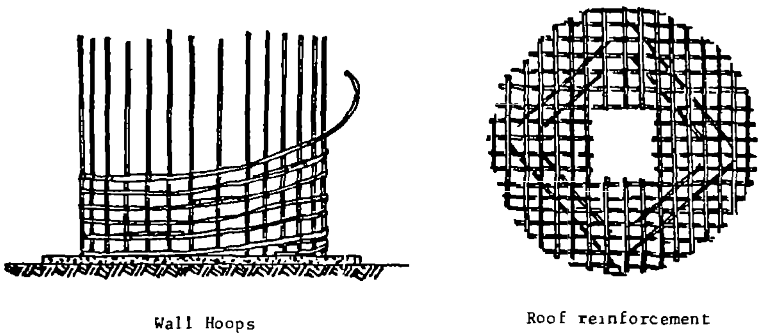


Figure 19: Construction of the ATA Bamboocement Tank

Building a tank takes 5 days of work for ten people. Approximately 50 of the tanks have been built, most in Ban Lok Don village near Khon Kaen.

9.1.2.1 Strength of the Tank

Using the analysis of Dr. Nipon, [60] with a width of 1.5 cm and a thickness of 1 cm for the bamboo strips, the centre-to-centre distance should be 15 cm. This is the same for both horizontal and vertical reinforcing. Since the actual centres measurement appears from drawings to be 6.5 cm horizontal and 9 cm vertical, there is certainly enough bamboo in these tanks. One is moved to question whether or not there is too much and if there is enough space for the concrete mix to form a continuous medium.

An interesting feature is the tarring of the green bamboo to seal it from shrinkage. It is claimed that this eliminates problems with the bamboo's changing shape and also improves the bonding strength between the bamboo and the concrete.

Further monitoring of this tank is needed as the 50 tanks built to date get older and begin to show any flaws. Some of the tanks have developed horizontal cracks 5-8 cm long at a height of 1 m. This has been ascribed to poor curing [45]. The tanks are expected to have problems that have been seen elsewhere, such as Indonesia, where the bamboo is destroyed by fungus and termites, although this effect may be reduced by the Flintkote tar. However, the high reinforcement ratio is expected to weaken the structure somewhat because the tensile strength of bamboo is low in relation to concrete.

9.1.3 <u>ATA's Jumbo Jar Programme</u>

ATA also conducts training sessions on building the Jumbo Jar (see the next chapter for details) in conjunction with the Siam Cement Co. which has developed a temporary brick form method to simplify construction. The method is suited to tanks in the 1.5-2 m^3 size but for smaller traditional Thai jars, a form made from a burlap bag filled with sand is easily made [66].

9.2 <u>THE IRON, IODINE AND CLEAN WATER PROJECT</u>

This 15-person group at the Faculty of Medicine at Siriraj Hospital of Mahidol University, Bangkok is led by Dr. Romsai Suwannik. They are mainly concerned with projects to correct iron and iodine deficiencies in villages but have used rainwater collection as a vehicle for these trace elements because rainwater is accepted by a majority of the people.

The tank used is the Jumbo Jar which has been built in sizes from the 200 l traditional factory jar bought in the market to demonstration jars of 5 to 7 m^3. A 5 m^3 jar is 1.9 m high and 2 m in diameter at the base. The construction method is the Siam Cement brick form method (see the next chapter).

The larger tanks are made in place and have poured bases, a tap and a hose attached to the tap pipe that serves as a contents gauge.

9.3 ASIAN INSTITUTE OF TECHNOLOGY

The Asian Institute of Technology (AIT), a technical university on the outskirts of Bangkok, is the home of the International Ferrocement Information Center, which has prepared a construction manual on ferrocement tanks [57] and publishes the Journal of Ferrocement which has had a number of articles on tanks that could be used for rainwater storage. A test of the construction instructions in the manual has been carried out with unskilled labour and more illustrated manuals are being prepared.

AIT has built a trial tank with *bamboo reinforcement* using bamboo bought in a market and is monitoring it. It has no programme of building in villages. However, the AIT Alumni Association is building an undetermined number of tanks in the Northeastern Region.

9.4 SMALL SCALE WATER RESOURCES PROJECT

This project, supported by the New Zealand government from 1978-83 and by the Canadian government in 1983-85, was run first by Brian Warboys, then by Evan Mayson and then by Jean-Rene Rinfret. Operating out of an office at Khon Kaen University, it assisted construction of rainwater tanks in the Khon Kaen area. From 1981-83, it helped construct 18 steel reinforced concrete tanks (3 m diameter and 3-4 m height, volume 21-28 m^3) and 10 *ferrocement* tanks (3 m diameter and 2 m height, volume 14 m^3) and 3 bamboo-reinforced tanks [43]. Further details of the tanks constructed were not available [46] but it is expected that the ferrocement tanks are very similar to or identical to the KKU design.

Chapter 10

THE THAI WATER JAR

10.1 THE TRADITIONAL JAR

The storage of water in Thailand is a traditional activity. The most common container for water is the traditional Thai jar. Made in Raj Buri and other centres, this open-topped concrete or clay jar with a glazed finish is seen throughout Thailand. Its dimensions are in Table 16. Construction of tanks of this size can be done by individuals by using a concrete mortar (1:2, cement, sand) on a burlap bag form filled with sand. The technique was developed by the Siam Cement Co. and is described in [66] and a publication (in Thai) from the ATA.

TABLE 16

Typical Dimensions of the Traditional and Jumbo Jars

	Traditional	Jumbo
Outside Diameter (m)	0.50 (top & base) 0.60 (middle)	0.60(top) 1.40 (80cm up) 1.14 (base)
Height (m)	0.67	1.2
Inside Volume (m^3)	0.16	1.22
Wall thickness (cm)	2(estimated)	2
Description	Open top, apparently of concrete mix, glazed outside, yellow lion motif.	High hipped, concrete with minimal wire reinforcement.

In many areas of the Northeast, a larger version has become very popular since 1980 and has been called the Jumbo Jar. The usual size of the Jumbo Jar is 1.5 to 2 m^3 with a wall 1.5 to 2.0 cm thick. However, sizes up to 5 to 7 m^3 are possible. The tanks are about 1.2 m tall with a 60 cm diameter opening on the top. At a height of 80 cm, they have a diameter of 1.4 m and at the base are 1.4 m in diameter. Shapes vary slightly from this depending on the builder.

Siam Cement, ATA, the Iodine, Iron and Clean Water Project and the Department of Community Development and the Office of Non-Formal Education of the Thai government run courses for local artisans who then build the tanks on site. Jar factories are located in a number of areas. Moreover, the Jar can be built by local artisans without a great number of special tools. For low-cost water storage, there is little that can beat the Thai Jumbo Jar. At a cost of 300 ฿ or 200 ฿/m^3 ($14 to $9 US) for materials for the 1.5 to 2 m^3 size, compared to 5000 ฿ or 500 ฿/m^3 ($23 US) for the bamboocement tank, it is a bargain.

Everyone interviewed on the author's study visit, including Drs. Chanchai and Prempridi of Chulalongkorn University and Dr. Sacha Sethaputra, head of Engineering at KKU, believed that the Jumbo Jar is the most economical means of water storage. PDA builds the tanks in Maha Sarakham province because the cost is lower than their poured concrete tank and roofs there are lower than the 3 m height of the PDA tank. However, PDA points to the large amount of ground area per m^3 of storage that the Jumbo Jar takes as one of its drawbacks.

Since the jar volume is small compared to other tanks, it is common practice for homeowners to have up to five jars which they have bought one at a time when their finances allowed and their needs required. Purchase of these tanks has usually been on an unsubsidized basis without external aid. Some government job-creation plans have been directed to training construction artisans in some areas.

10.2 CONSTRUCTION OF THE JUMBO JAR

The most remarkable feature of rainwater collection in Thailand is the degree to which local private industry is able to support the public demand for the necessary jars. This is shown particularly in manufacture of the Jumbo Jar in small, local jar factories. In one of these factories located south of Khon Kaen which was visited by the author, 20 men were employed in a facility that produced and delivered 20 jars per day. The method they used hinged on the type of form they used.

Although the burlap bag form is adequate for small jars, it is very poorly suited to a large jar because it is difficult to remove the 1.5 to 2 m³ of material that give the bag its shape and strength. Instead, a set of special bricks was used. The method using these bricks is being promoted by the Siam Cement Company, ATA and the Iodine and Iron Project.

About 90 curved bricks are needed for each form. Each brick is bevelled at the edges and curved on the outside face. The concrete mix used for the tank is 1:2 (cement, sand) unless otherwise noted. There are two systems: Dr. Chanchai of ATA advises the use of 11 different layers of 8 bricks each about 10 cm thick, each layer with a different curvature; the other uses a standard brick for all layers and fills in spaces with part bricks. However, for both systems, the procedure is similar and the construction sequence is as follows [39]:

1. A base 1 m in diameter and 5-6 cm thick is poured. This may be flat but is often raised in the middle by 3-5 cm. Number 8 wire was used in a star pattern for reinforcement.

2. After this had hardened for 24 hours, the bricks are assembled to give the desired shape. Part bricks are needed if a single brick is used for each layer.

3. A mud of non-organic soil is mixed up and used as a temporary mortar between the bricks which are not butted together directly. Bands of wire can be used to hold the bricks in place.

4. The top of the form is made of small pieces of available lumber (30-45 cm by 6 cm) stacked to taper to the central opening whose 65 cm diameter is shaped by a galvanized metal ring.

5. The form is covered with mud and smoothed to shape.

6. Concrete is applied to the mud form in two layers of 2 cm each. The factory used 2 layers 1 cm thick. Wire reinforcement is applied between layers. ATA advises using a vertical/ horizontal grid at 15 cm spacing. The factory used much less reinforcement, using a spiral of wire from top to bottom and 15 cm apart. In 24 hours, when the concrete has hardened, the form is easily removed from the inside because the mud will give way. Bricks and mud are removed for reuse.

7. The interior and exterior are finished with a cement slurry, the opening is finished with a thick lip and

a decorative moulding is applied to the top edge. The slurry is usually coloured red or black, again for decoration.

8. The jar is allowed to cure in the shade for a week before use.

PART III

SPECIAL TOPICS

Chapter 11

ESTIMATION OF TANK SIZE

11.1 INTRODUCTION

The size of the tank is determined by the rainfall pattern for the location, the size of the roof collecting the water, and the amount of water drawn from the tank.

A number of techniques have been developed to calculate the size, but for the most part they use actual recorded monthly data for a number of years. While strictly speaking, the estimates are valid only for that particular set of data which may not have any relationship with future rainfall, it is assumed that they adequately reflect future conditions.

The amount of water in cubic metres collected from a roof in some time period during which r mm of rainfall falls is

$$K \times A \times r / 1000$$

where A is the ground area covered by the roof in m^2 and
K is a coefficient from 0 to 1 that expresses how much water is actually collected.

K takes care of losses on the roof but can also be assumed to cover losses from the tank such as minor leaks and evaporation. The tank losses are generally assumed to be small so they can be included in K with little effect, although they strictly have no relation with the roof.

The amount withdrawn is expressed as:

$$N \times C \times T / 1000$$

where N is the number of people using the tank and
C is the amount of water in litres used by a person in a day (litres/cap/day)
T is the number of days in the time period being considered (usually 30 for 1 month)

The storage size is determined by a particularly severe part of the data, called the critical period, during which the amount collected does not meet the amount withdrawn and the shortfall is made up from the amount in storage. All models must estimate some critical period and use it and the demand in some combination to determine the storage required.

11.2 RULE-OF-THUMB METHODS

Most tank size estimates are calculated by multiplying the daily demand by the number of days of drought. The length of the drought can be calculated from rainfall data (worst drought in 5 years, 10 years, etc.), from a particularly dry year, or by asking the users how long they think the dry period is.

The assumptions made with this method are that sufficient rain is collected on the roof (size unspecified) to fill the tank every year and that the tank is 100% full when the drought begins. In areas with two rainy periods of different intensity and duration these assumptions may not be valid, but in the parts of Indonesia and Thailand seen by the author, they should be valid. In areas where raindata are not available, this method will be the best available.

11.3 CALCULATION METHODS USING RAINFALL DATA

A review of some of the methods available is in [76]. Any method is only as good as the data it uses. Poor and unreliable data decrease the significance of the tank size estimate obtained from the method.

11.3.1 Mass Curve

The simplest and most common method for a reservoir calculation using meteorological data is the mass curve which is described in any engineering text on hydrology. The method compares demand and supply graphically to calculate the volume but the method is easily computerized.

11.3.2 Computer Models

Computerized models can provide greater flexibility in the choice of storage calculation techniques, measures of reliability of the system and so on. However, they are difficult to develop and apply in the field. The major difference between the types that simulate the operation of the tank is when the computer calculates how much is spilled and how much water is withdrawn. The difference is small on a daily basis but can be considerable if monthly data are used as is common [75].

11.3.3 Latham's Model

The model used here for verification of the methods used by other groups is described in [75] and is intermediate between the usual theoretical reservoir . calculation algorithms. This is particularly suitable for use with monthly data.

The model can provide estimates of tank size with different levels and types of reliablity. Usually the reliability is the amount supplied as a percentage of the amount demanded but in some cases, it is the percentage of time that the full demand was met. Tank sizes based on time reliabilities are higher than those based on volume. It is the author's opinion that the volume reliability is a more practical measure.

The model produces a general, normalized design curve with demand and storage fractions from 0 to 1. Both the yearly demand and tank size are expressed as fractions of average annual amount collected (called KAR - where R is the average annual rainfall). Annual demand (assumed constant by the model) cannot be greater than the average annual amount collected so the demand fraction (D/KAR) must be less than 1. Storage can be greater than the average annual amount collected but it is assumed that it is a practical upper limit of storage. Thus the storage fraction (S/KAR) is practically less than 1.

The demand/storage curves are good only for the area where the data were collected but they express a full range of combinations of demand, roof size and tank size. They are used in the following way:

1. Estimate the total demand, D, for a full year in litres.

2. Estimate the area of the roof that will be used to collect the rain in m^2.

3. Estimate K. Galvanized roofs with good gutters and a good tank have a K of 0.9. For most good roofs, K is 0.8. Poor roofs with poor gutters may have K of 0.7 or less.

4. Determine R, the average annual rainfall in mm. It is printed on the graphs.

5. Multiply K, A, R together to get the average annual amount collected in litres.

6. Calculate the demand fraction by dividing D by KAR.

7. On the graph, choose the curve for the desired reliability percentage (usually 95% is adequate as in severe droughts, people will ration the water to make it last).

8. Read up from the demand fraction to the curve and across to the storage fraction.

9. Multiply the storage fraction by KAR to get the volume in litres.

A reverse procedure can be used to find the sustainable demand if the storage is known.

11.4 THE METHODS USED BY GROUPS IN INDONESIA

Overall, in most projects, there is little or no analysis of rainfall data for the purpose of relating it to collection area and demand. More likely, tanks are built as big as can be afforded and usually come in standard set sizes, the most common being about 10 m^3. Since the areas where most of the tanks are located have fairly heavy rainfalls and large roofs, the tank is certain to be filled by the rain unless an excessively large demand is made on it in the wet season. So, with a tank of given size, the demand will have to be tailored to match. This is done by restricting water usage to particular uses or by using larger amounts and having the tank run dry. For health reasons, the first option is preferable.

11.4.1 YDD's Method

It is felt by some [5] that a salient problem with YDD's tanks is that they have not been hydrologically designed. This criticism is probably correct as the tanks often do go dry. The major factor appears to be underestimation of demand.

In a survey of approximately 30 families [21], YDD found the following amount of water was being carried:

% of families	Water carried (1)
47	40
17	60
20	80
13	>80

However, Sir M. Macdonald and Partners found demand levels on the telagas in Gunung Kidul to be 80 l per day per

household which would indicate the minimum household need for all uses [11]. Family size is generally 6 (5.7 in [11]) but 4 was used in one YDD estimate [23] of tank storage). Thus the minimum demand for all uses is about 13 lcd.

11.4.1.1 Tank Estimates in Gunung Kidul

A review of rainfall in the Gunung Kidul area is given in [13]. There are four stations: Kali Kunung, Bantul, Wonosari and Playen. The mean monthly values of the first three stations and Yogyakarta are in Figure 20. In general, the data are not reliable or accurate [14], [32], especially in recording heavy rainfall amounts as the small collection tubes used overflow in days of heavy rain. Sir McDonald and Partners established the Playen station in 1977 to obtain accurate data [32].

YDD has done a small study of the relationship between rainfall, demand and storage size [73] but with the very little data available, its unreliability and the importance of economic factors in determining size, this is of little use in present conditions. Apparently a drought is estimated from average monthly rainfall values.

The method used is to look at the rainfall data is to find the period when rainfall is very low or zero. The length of this dry period is estimated and storage is then set equal to the total demand for that period. In Gunung Kidul, this should work well for two reasons:

1. there is a single, definite, annually-recurring dry period whose length can be estimated easily because it begins and ends abruptly;

2. there is more than sufficient water being collected. Roofs are large (some over 100m^2) and of good, impervious material so an average of 180m^3 will be collected per year. Even at 100m^3 (allowing for poor collection and a dry year) this will easily fill a 10m^3 tank and provide for any water used from the tank during the rainy season. Tanks of 8-9m^3 in Ngestirejo filled in 2 days [3] and those in Bandogede filled with about 14 hours of rain.

YDD estimates its 4.5m^3 bamboocement tanks could supply drinking water to a family of 4 for six months, which is equivalent to 6 lcd, but they usually go dry [23]. In Ngestirejo, 8-9m^3 tanks were to provide two families (12 people) for 2 1/2-3 months. This is 7.4-10 lcd with the expectation that the tank goes dry every year.

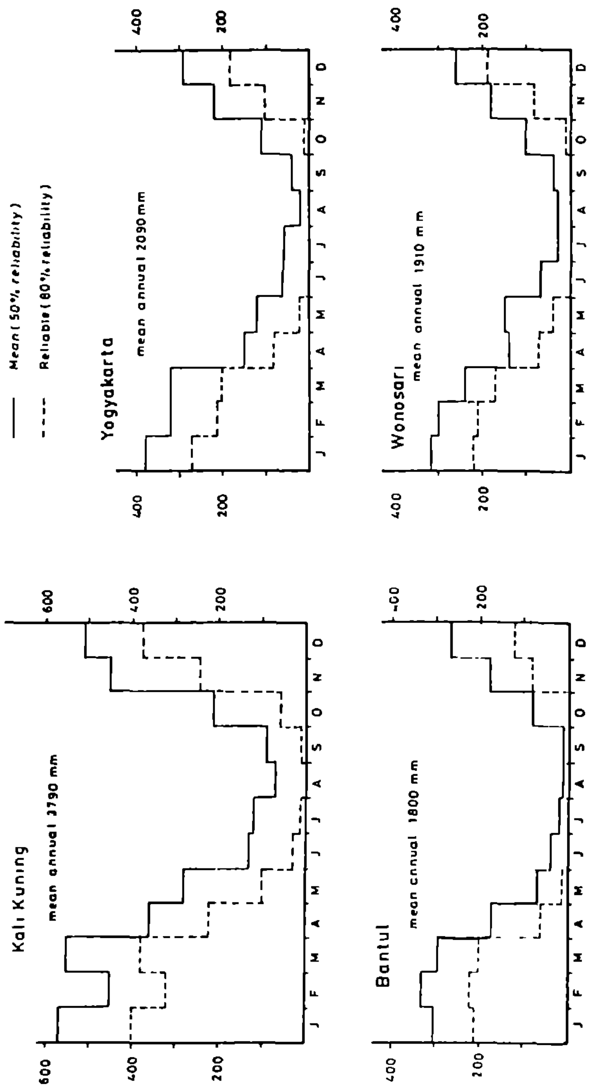


Figure 20: Mean Monthly Rainfall Values.

From this experience, it can be concluded that a good minimum storage volume per family which will supply <u>only drinking water</u> (5 lcd) is about $5 m^3$ for the Gunung Kidul area. If any other use is to be satisfied by rainwater, each family should have $10 m^3$ of storage.

11.4.2 <u>PLAN's Method</u>

PLAN has done no studies on sizing the tanks in Gunung Kidul but has relied on the experience of YDD. PLAN is presently building $9 m^3$ tanks for 3 families (15 people) [25] but the eventual plan is to have one for each family [34].

In Bali, a $9 m^3$ tank is used for families of about 5 people but use by two families (10 people) is common. Usually the roof area is $24 m^2$ for each family and both roofs are used in a shared situation. An estimate of maintainable demand was made and is discussed later.

11.4.3 <u>The Sizing Method of IWACO</u>

As outlined by Satijn [20], the computerized method used by IWACO is apparently the most detailed calculation used by any group in Indonesia. It is based on principles in [7]. A somewhat simplified hand-calculator version was developed from this by C. Pompe [16], also of IWACO but this has several empirical parameters specific to Indonesia and is not easily transferrable to other areas.

Satijn's method is basically what is called a 'yield before spillage' model which means that, in any given month, collected rain is added to the amount in store, the amount demanded is subtracted, and then it is determined if any volume is above the reservoir capacity and should be spilled. This method is expected to give low values for the storage when monthly data are used [75]. It incorporates an estimate of losses due to leakage and evaporation. It uses a runoff coefficient, K, of 0.8. Also, it restricts demand when storage is low (a rationing procedure). This rationing is a minor effect as it comes into play only when the storage is down to 10% of capacity. The model calculated the percentage of time that supply was less than 100% of demand.

The losses (leakage, evaporation, K = 0.8) are high and will tend to increase the estimate of tank size although the inclusion of rationing would tend to balance that somewhat. This combination of factors will likely give a fairly good estimate of storage, compared to other computer models.

Demand Level. IWACO used data for Juntinyuat as representative of the Krangkeng area. Costs of roof area and tank volume were estimated for a 10 m³ tank and the optimum combination was based on the lowest overall cost. The results of the analysis are in Table 17. In the final design in [8], page 4, 10m³ storage and a surface area of 40m² would provide 5 lcd to 20 people (four families). It would appear that this design was based on the percentage of time water was short between 5% and 10%.

TABLE 17

Results of Computer Analysis of Juntinyuat Rainfall

(A) % time Shortage	(B) Optimum Area m²/cap	(C) Tank Size m³/cap	(D) No days of storage at 5 lcd	(E) Users of 10 m³ tank	(F) Roof Size m²
5	3.0	0.9	180	11	33
10	3.0	0.6	120	16	48

NOTE: (D) = (C) x 1000 / 5
(E) = 10 / (C)
(F) = (B) x (E)

11.4.4 Verification of Sizing Methods in Gunung Kidul

Data obtained from [73] and [13] for 8 stations in Gunung Kidul were used in Latham's model to produce the demand/storage curves in Figures 21 to 28.

Due to the unreliability of much of the data, only the Playen station will be used to estimate the size of the tank. Thus R, mean annual rainfall, is 2243 mm and K is assumed to be 0.8. An average family has 5 members and a volume-based reliability of 95% is used. Roof sizes measured in visits [33], [34] varied from 12 to 31 m². The results are summarized in Table 18.

From a comparison of the other curves with Playen's, tank sizes should be about the same for Nglipar, Semin and Wonosari. They should be a little higher for Patuk, Ponjong

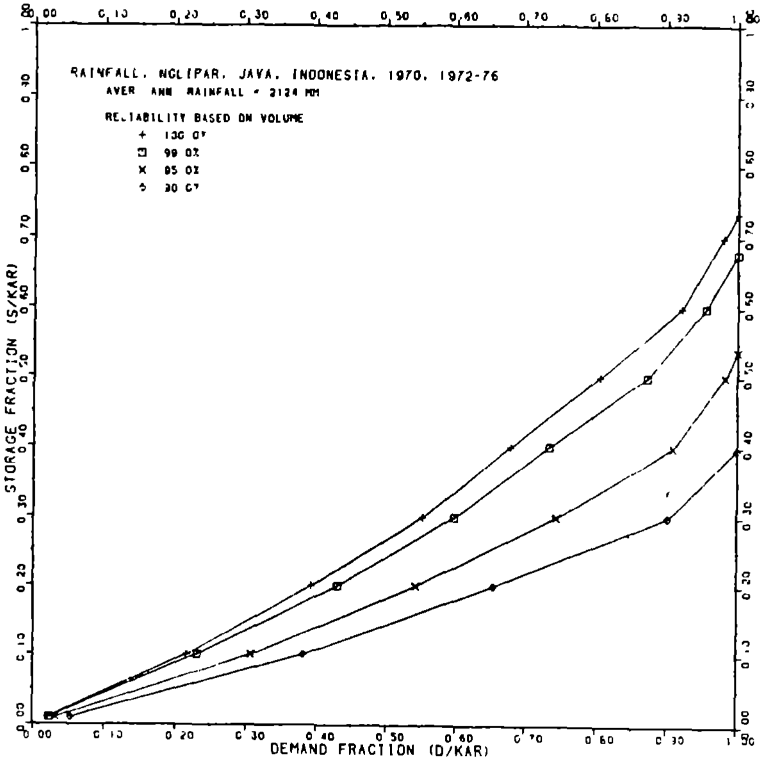


Figure 21: Rainwater Demand/Storage Curves for Nglipar, Indonesia

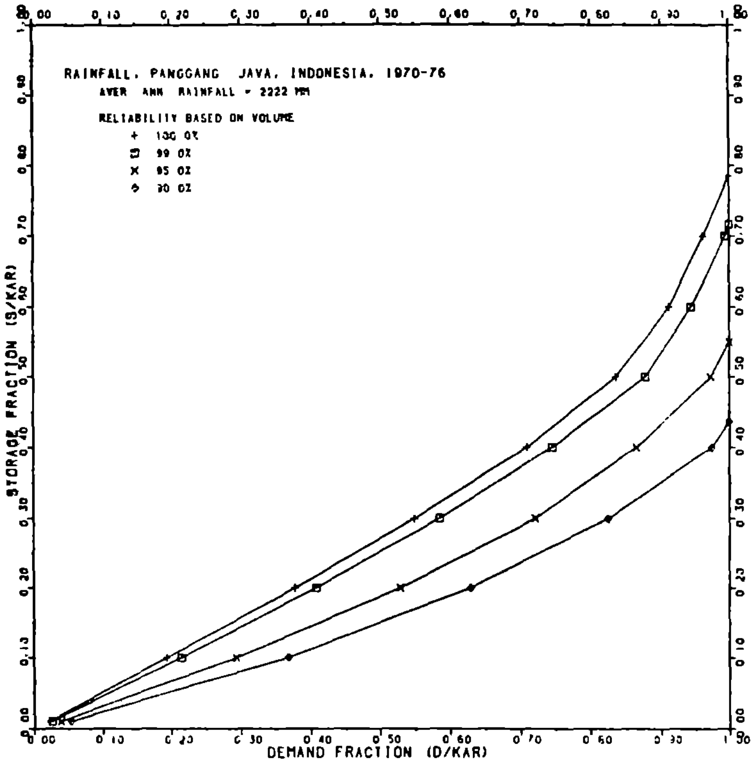


Figure 22: Rainwater Demand/Storage Curves for Panggang, Indonesia

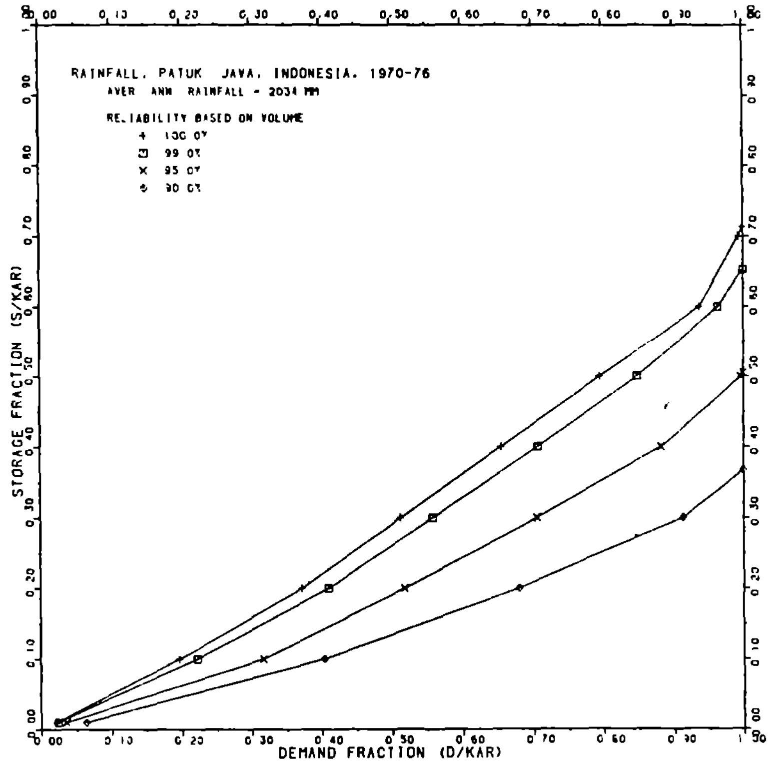


Figure 23: Rainwater Demand/Storage Curves for Patuk, Indonesia

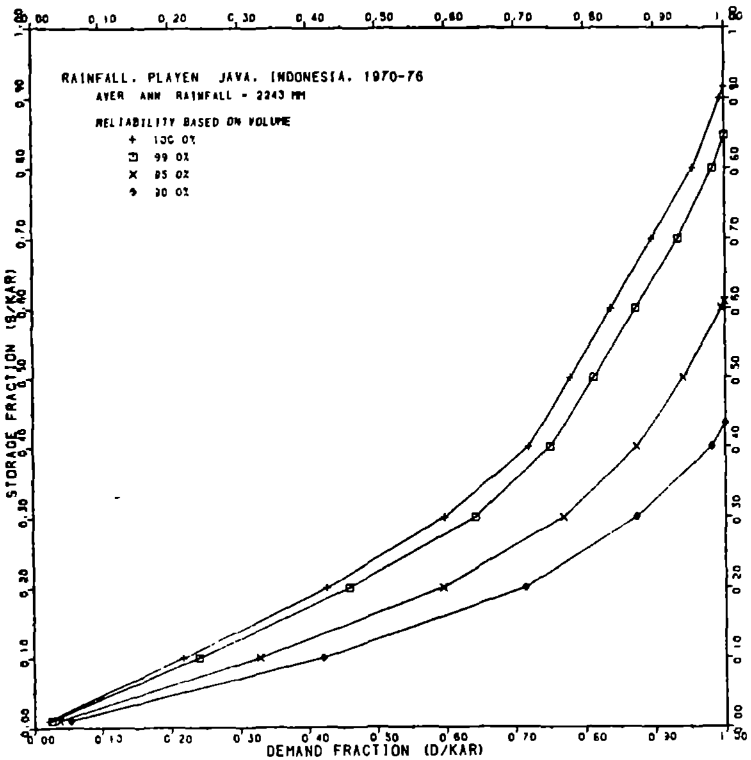


Figure 24: Rainwater Demand/Storage Curves for Playen, Indonesia

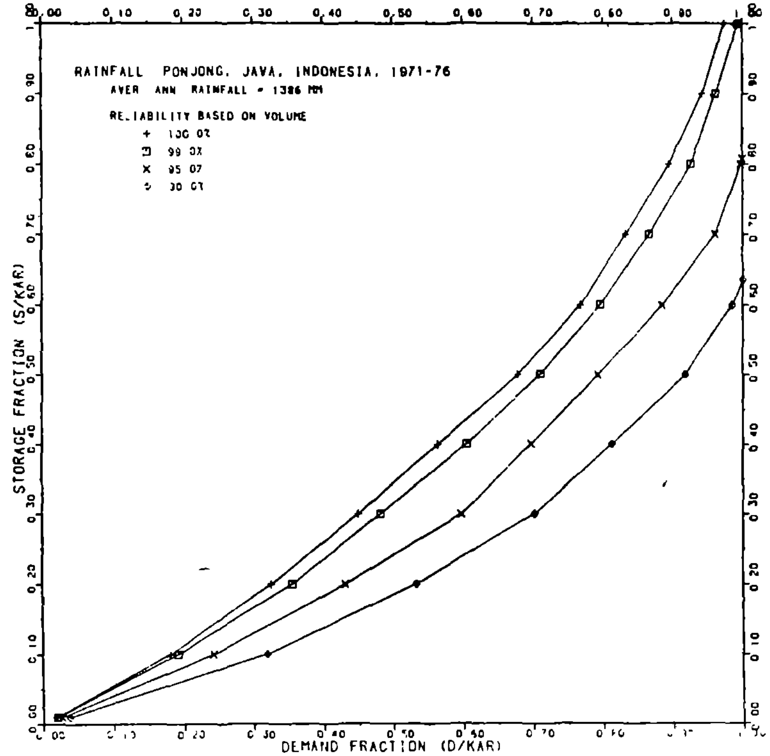


Figure 25: Rainwater Demand/Storage Curves for Ponjong, Indonesia

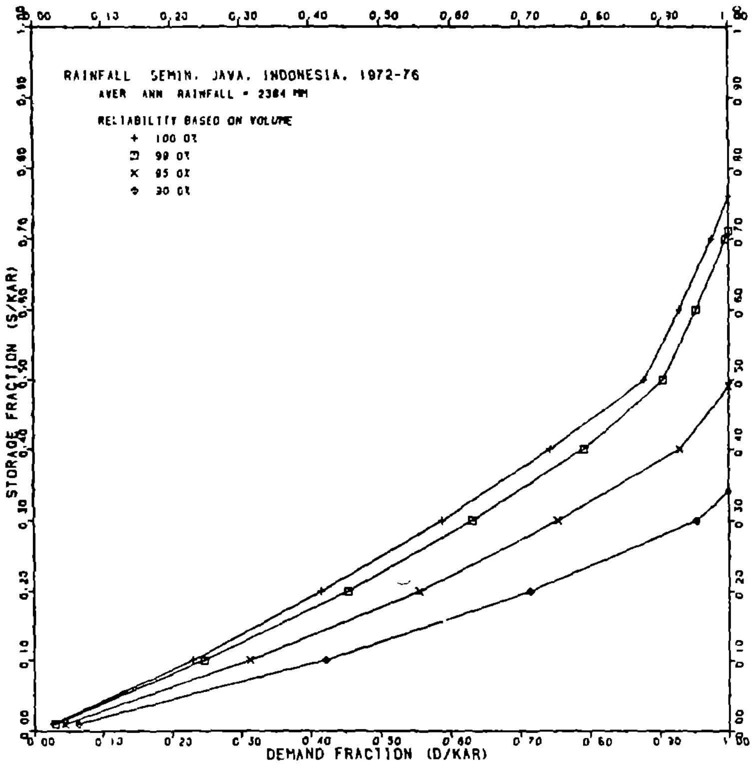


Figure 26: Rainwater Demand/Storage Curves for Semin, Indonesia

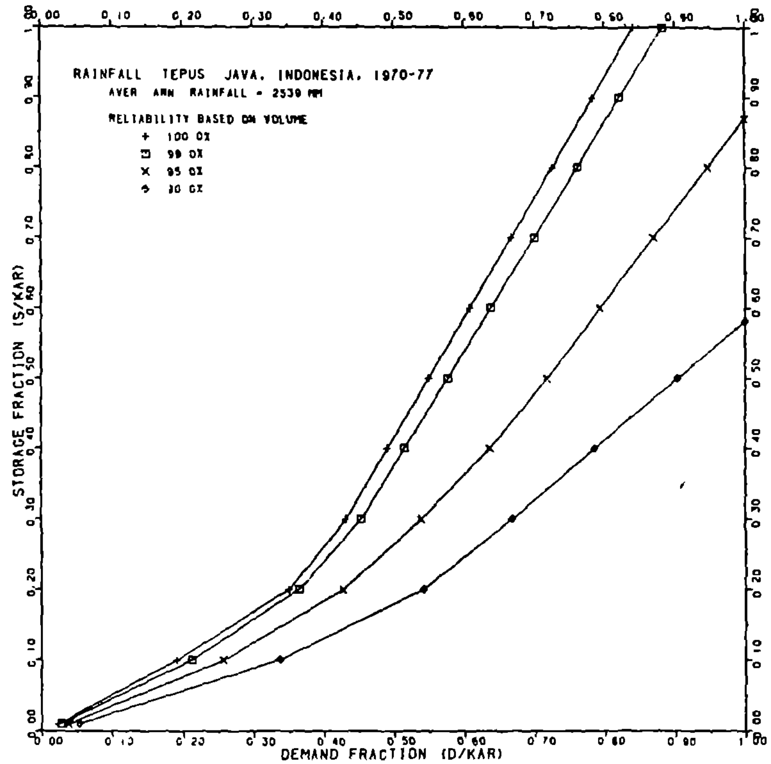


Figure 27: Rainwater Demand/Storage Curves for Tepus, Indonesia

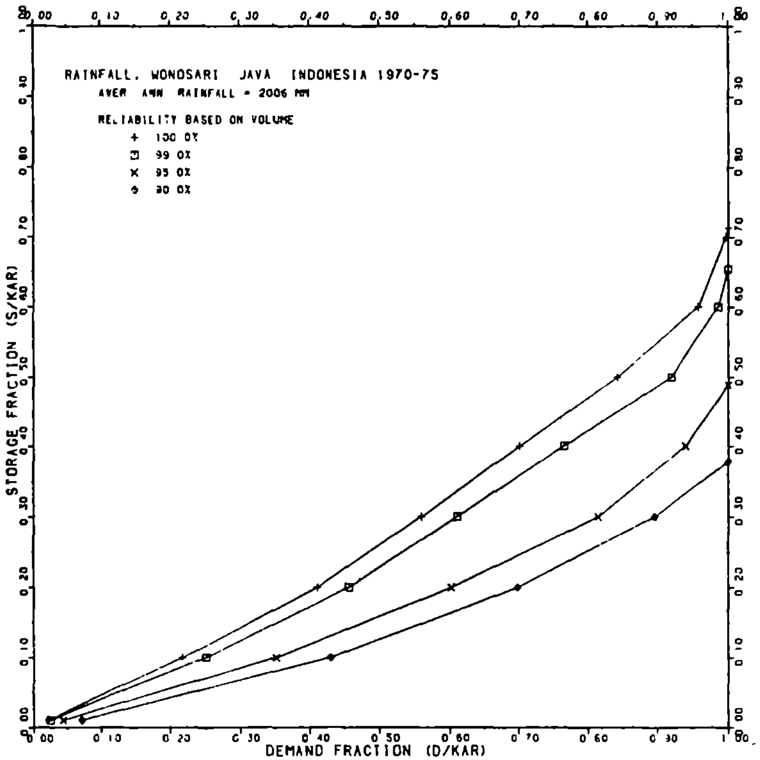


Figure 28: Rainwater Demand/Storage Curves for Wonosari, Indonesia

TABLE 18

Rainwater Tank Sizes (m³) for Playen, Indonesia Calculated from Figure 24

Daily Demand (lcd)	Area m² 10	15	20	25	30	35	40
5	2.97	2.85	2.70	2.64	2.59	2.66	2.70
10	11.61	6.62	5.95	5.75	5.29	5.47	5.20
15		17.42	10.43	9.26	8.93	8.87	8.43
20			23.22	15.04	13.24	12.19	11.91
25				29.03	20.17	17.37	16.13
30					34.83	24.68	20.90
35						40.64	30.06
40							46.45

NOTE: K=0.8, 5 people per group, 95% reliability.

and nearly twice as large for Patuk and Ponjong. However, separate charts should be made for the other stations if work is done near them and a certain amount of storage added to the values to make up for the unreliability of the data.

From Table 18, YDD's estimate that a family can obtain drinking water (5 lcd) from a tank of 4.5m³ is confirmed. Also a 9m³ tank should provide drinking water for 12 people if the collection area is over 15m² and 10m³ of storage should supply a maximum of 15 lcd for a single family if the collecting roof is 25m² or greater.

PLAN's use of one tank for three families can work only if 5 lcd is supplied and the collecting area is over 25m².

In conclusion then, a tank of 3m³ or more is needed to supply a family of 5 with a minimum of 5 lcd throughout the year with a 5% shortage. For 100% reliability, approximately twice as much volume is required.

11.4.5 Verification of Sizing Methods in North Java

Data were obtained from Satijn [20] for Juntinyuat and Pengakaran stations. The model was run with both time and volume reliabilities and the results are in Figures 29 to 32 Only the Juntinyuat time reliability case is analysed further and although Satijn worked with the cases of 95%, 90%, 85% and 80%, the author considers only the 95 and 90% cases to be practical.

The results of an analysis of the curves is presented in Table 19 and are plotted on a copy of Satijn's graph in Figure 33.A demand of 5 lcd is used, K is 0.8, and R is 1873 mm. They show conflicting results. For 5% shortage (95% reliability), the two estimates vary by at least 0.2 m³ per person with Satijn's estimates higher than Latham's. For 10% shortage (90% reliability), Latham's model gives values lower than Satijn's for low areas (i.e. for higher demand fractions) but Satijn's is lower than Latham's for higher roof areas (i.e. for lower demand fractions).

The higher volumes for the 95% case could be caused by the evaporation and loss factors in Satijn's model. In the 90% case, the divergence may be a result of a lack of points between 0.1 and 0.35 demand fractions in Latham's graph.

IWACO estimated that 10m³ would supply 5 lcd for 4 families (assumed 5 per family). Using areas of 12.5m² and 40m², as observed by the author [35] it is found that demand is greater than annual supply for the 12.5 m² area and no storage estimate is possible while for 40m², 18.1m³ storage is needed. This shows that 10m³ is not enough for this case. However, sustainable demand with 40m² area is 63.8 litres per day which, at 5 lcd, will supply only 12 people i.e. 2 families, not 4. Thus the estimate of the number supplied in [8] is twice the actual number.

11.4.6 Verification of Sizing Methods in Bali

In Bali, Whiticar's report [29] estimated approximate daily consumption assuming a volume of 9.04m³ and 10.1 people per tank. However, these calculations should have used the active volume (8.2m³) so they are a bit high.

The results of Latham's model for 7 Karangasem stations are in Figures 34 to 40. A comparison of these results with Whiticar's is in Table 20. Roof area is assumed to be 24m² for each 5-person family. The author observed that multifamily tanks were fed water from both roofs [36]. Since roofs and collection gutters were galvanized and well-maintained, K is set conservatively at 0.85.

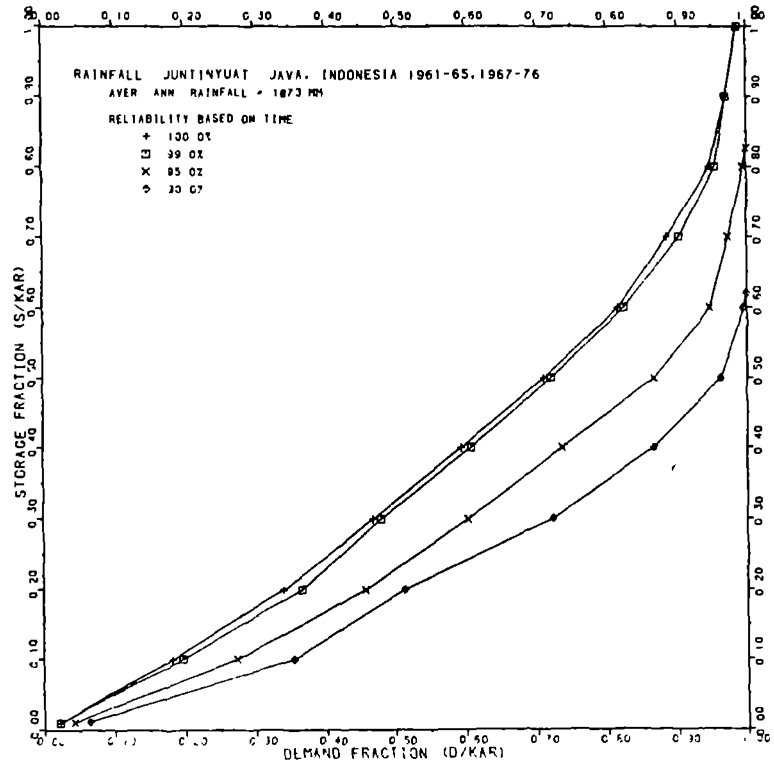


Figure 29: Rainwater Demand/Storage Curves, Time Reliability, Juntinyuat, Indonesia

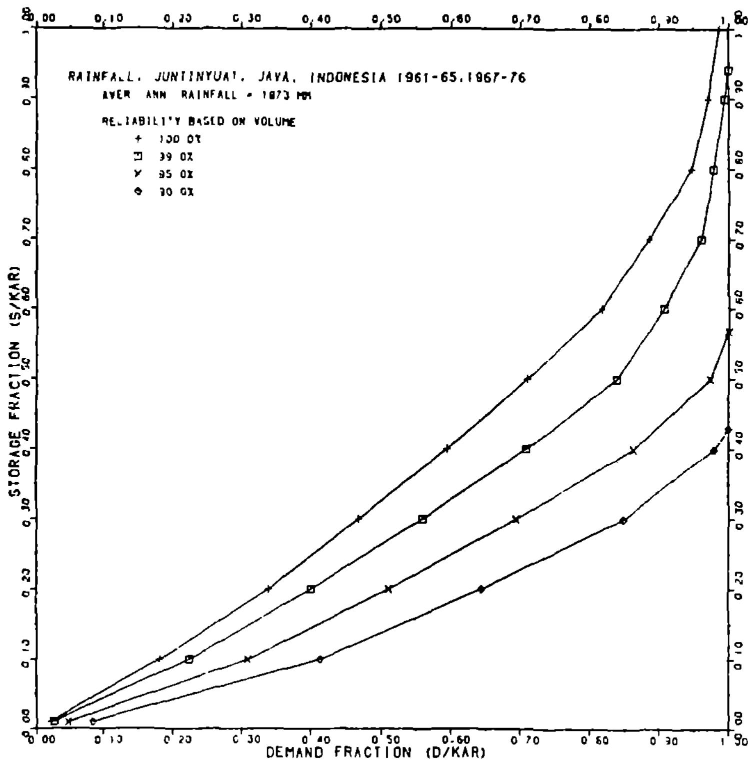


Figure 30: Rainwater Demand/Storage Curves, Volume Reliability, Juntinyuat, Indonesia

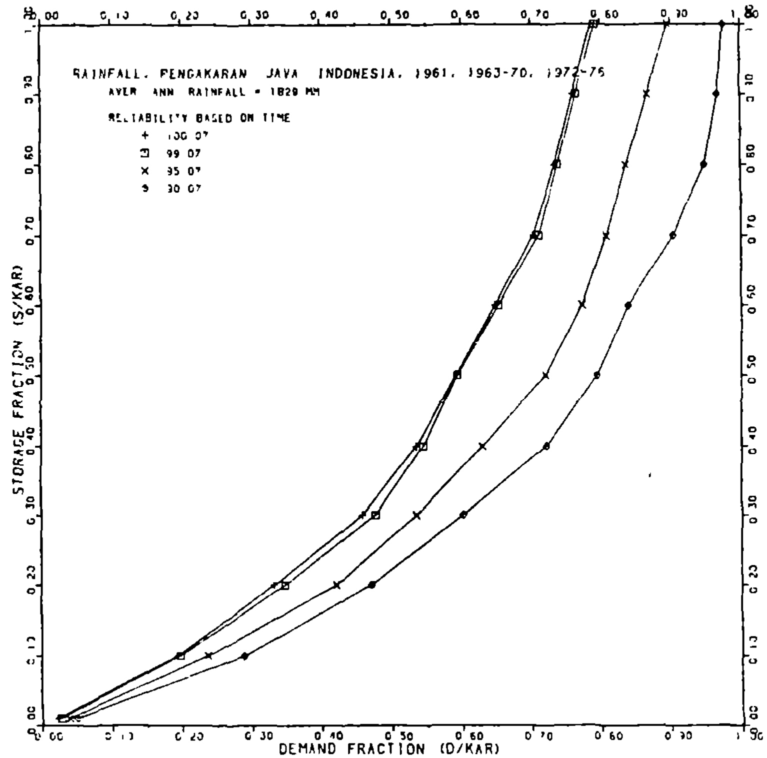


Figure 31: Rainwater Demand/Storage Curves, Time Reliability, Pengakaran, Indonesia

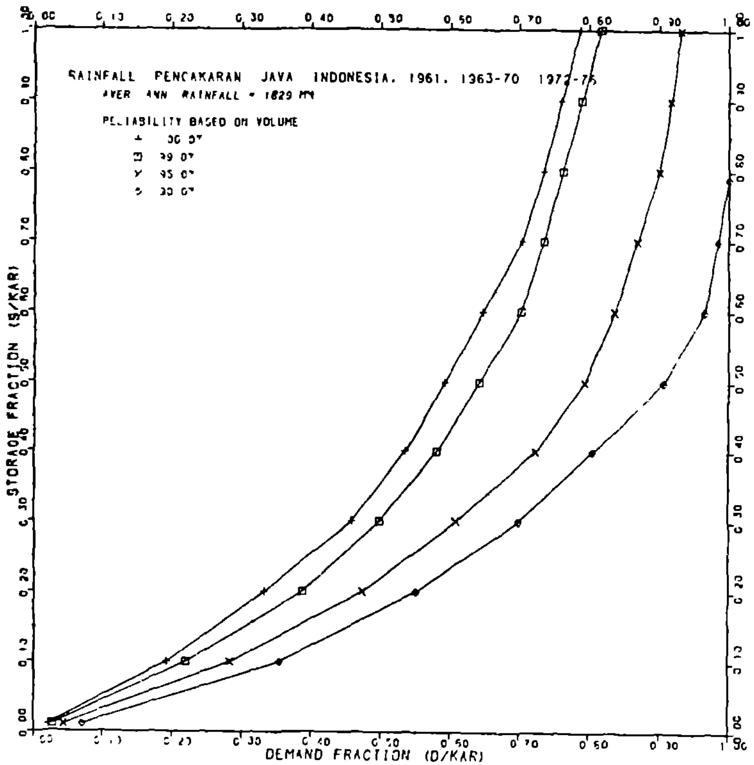


Figure 32: Rainwater Demand/Storage Curves, Volume Reliability, Pengakaran, Indonesia

TABLE 19

Storage Volumes (m^3) Per Capita, Juntinyuat, Indonesia According to Latham's Model

From Figure 29.

Area m^2/pers	Reliability 90%	Reliability 95%
1.5	.80	1.02
2.0	.73	.90
3.0	.59	.76
4.0	.50	.70
5.0	.49	.65
6.0	.48	.63

TABLE 20

Verification of Whiticar's Demand Estimates

STATION	MEAN ANN. RAIN (mm)	SUSTAINABLE DEMAND (lcd) Latham's Estimate	Whiticar's Estimate
Abang	2128	19.9	18.6
Amlapura	1703	16.1	16.5
Bebandem	1898	16.5	21.3
Besakih	2966	21.0	74.5
Seraya	1480	12.8	11.4
Singarata	3048	25.7	37.2
Tianyar	1189	8.9	5.5

Whiticar's estimates are surprisingly accurate for a simple calculation (the average number of months per year with rainfall less than 10 mm). Only one value is seriously wrong although most of Whiticar's estimates were too high. This means that the estimated drought period was too short, a normal and worrisome error experienced when average monthly values are used in this type of critical period calculation.

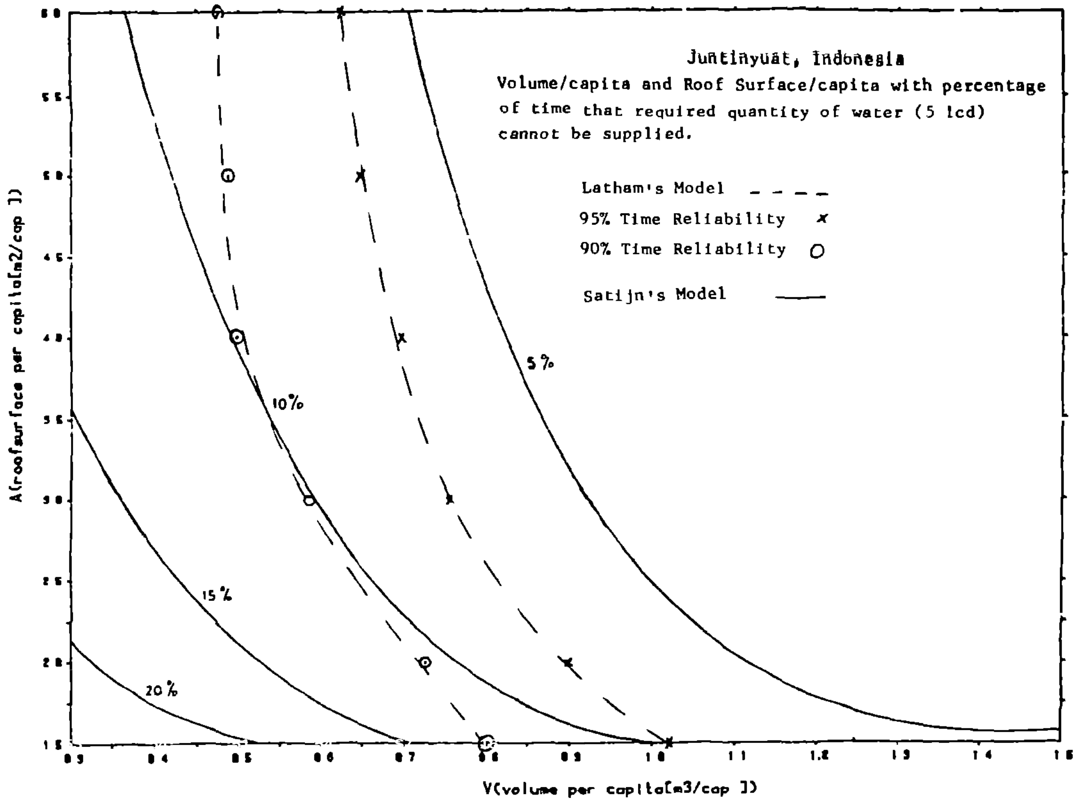


Figure 33: Comparison of Results of Latham's and Satijn's Models

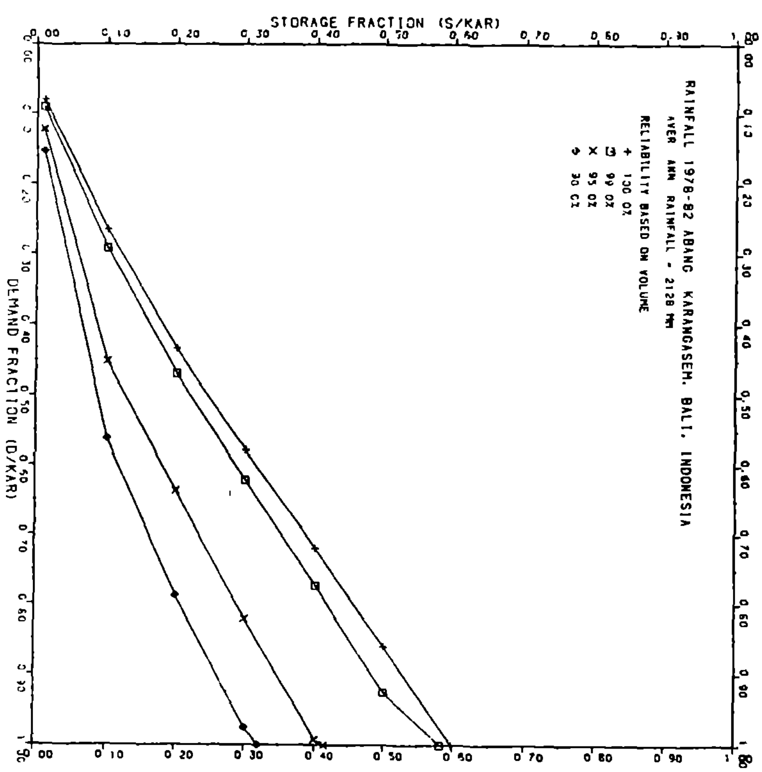


Figure 34: Rainwater Demand/Storage Curves for Abang, Bali, Indonesia

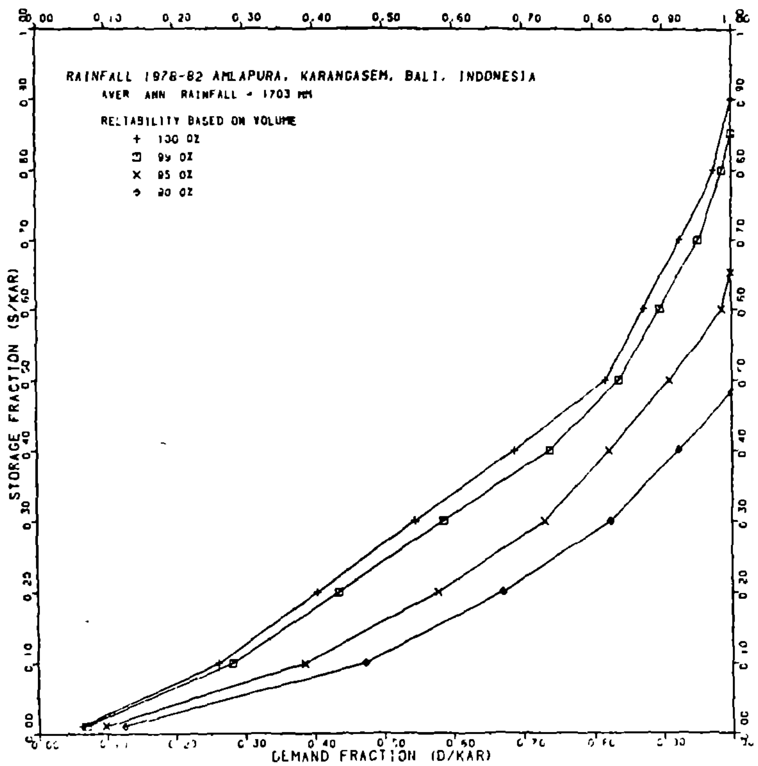


Figure 35: Rainwater Demand/Storage Curves for Amlapura, Bali, Indonesia

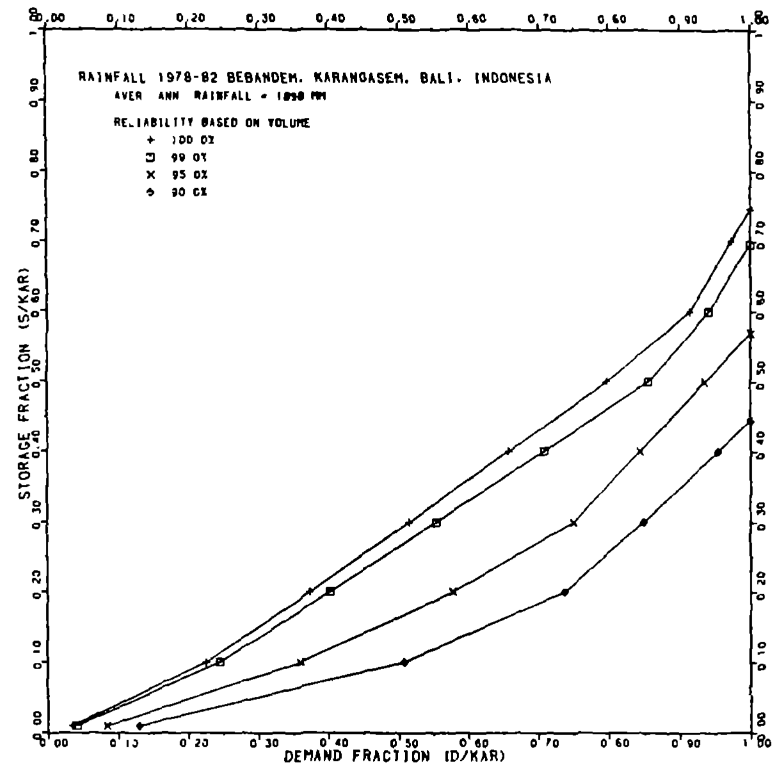


Figure 36: Rainwater Demand/Storage Curves for Bebandem, Bali, Indonesia

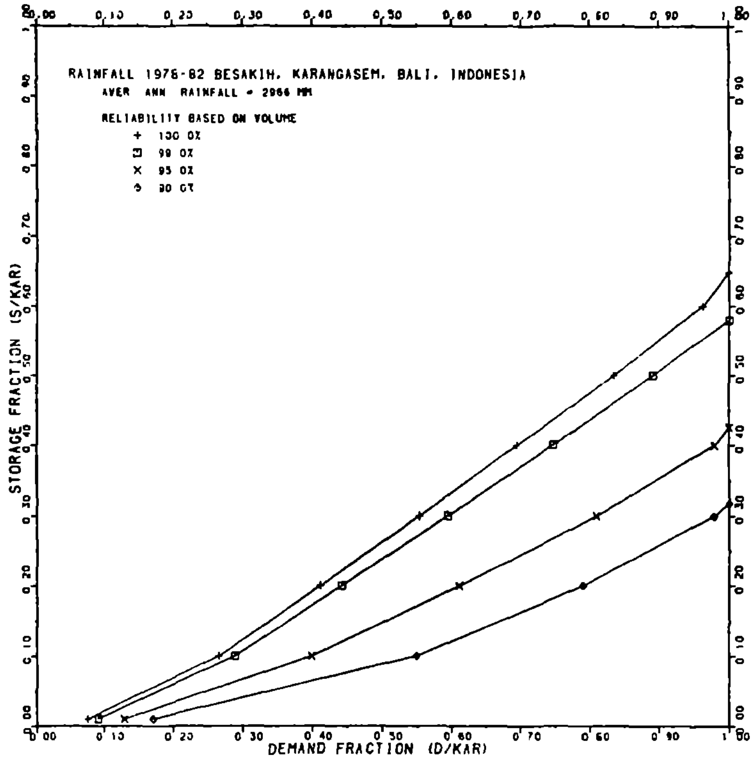


Figure 37: Rainwater Demand/Storage Curves for Besakih, Bali, Indonesia

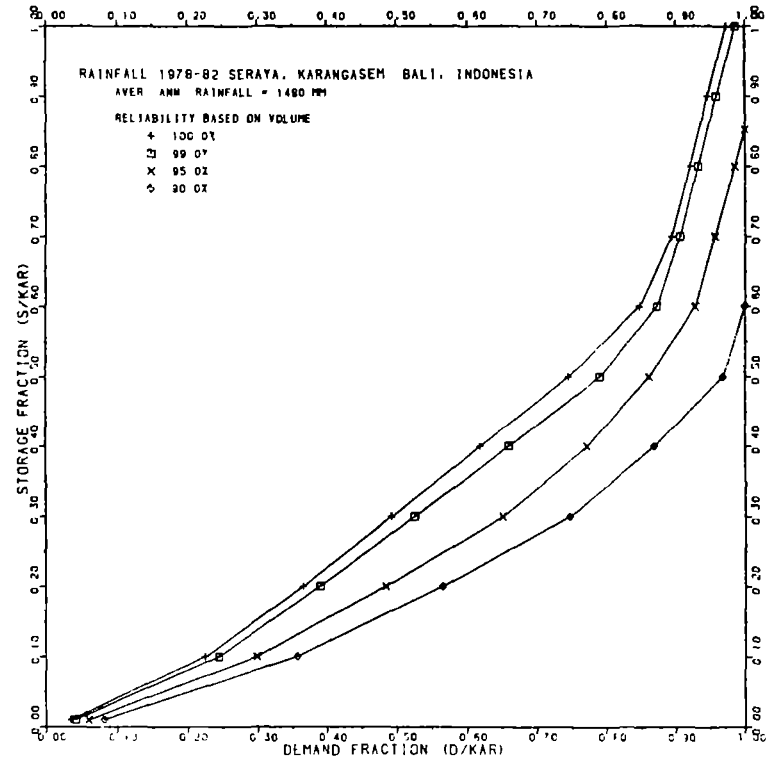


Figure 38: Rainwater Demand/Storage Curves for Seraya, Bali, Indonesia

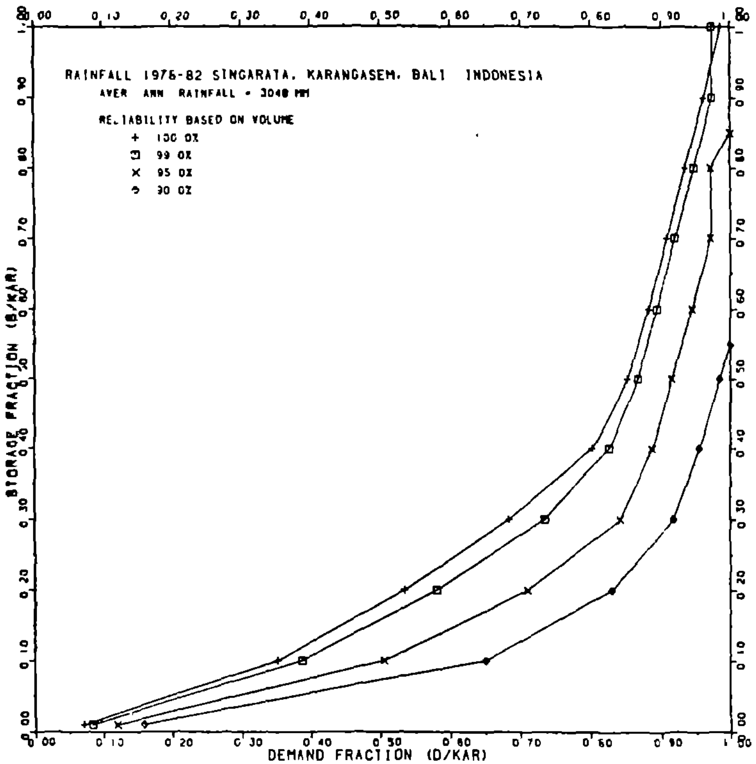


Figure 39: Rainwater Demand/Storage Curves for Singarata, Bali, Indonesia

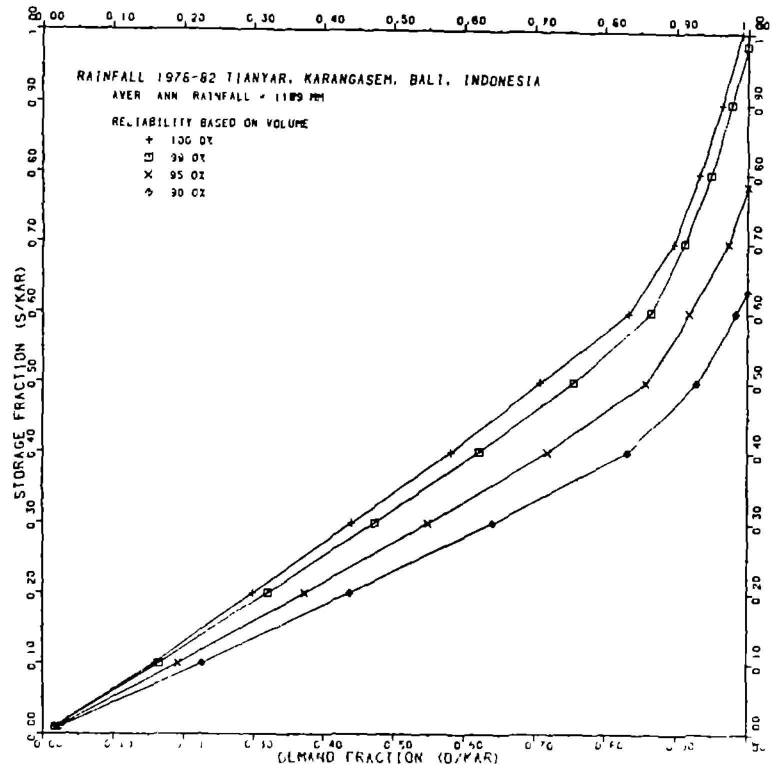


Figure 40: Rainwater Demand/Storage Curves for Tianyar, Bali, Indonesia

11.5 THAILAND

Very little work has been done to develop a method to estimate the size of the tank needed in a given location.

PDA apparently has not published any material to suggest that they have done any detailed studies into this although Paul Grover [42] estimated the amount of storage needed in the Khon Kaen area to be 0.85 m³ per capita by assuming a demand of 4 lcd and a drought period of 212 days from October 1 to April 30.

Dr. Nipon Thiensiripipat [60] estimated the tank size in a similar way but assumed a drought period of 180 days for Khon Kaen. For drinking purposes only, use of 4 lcd yielded a storage estimate of 0.72 m³ per capita while a total water demand (for drinking, cooking, bathing and clothes washing) of 55 lcd gave an estimate of 9.90 m³ per capita. For families of four (a small family in the present author's opinion), tanks of 2.9 and 39.6 m³ would be required.

Dr. Pradit Nopmongcol of the Khon Kaen University Civil Engineering Department has prepared a computerized model but the details of it and the results from it were not available and had not been published to date.

ATA [38] estimated that the demand was 5 lcd for a family of 5 and that the dry season was from January to April (120 days) so that a minimum of 3 m³ of storage was needed for each family.

11.5.1 Rainfall Studies at AIT

Because AIT has the facilities such as computers, sources of data and research time for examining rainfall data, several studies have been done [37], [58], [41]. However, after a search of the library at AIT, no analysis was seen that related directly to the determination of appropriate sizes of rainwater tanks. The work in [41] could possibly be used in an analysis because they provide isohyets of rainfall data other than mean monthly values. Mean values are simply an average and are easy to calculate. The average values have a probability of occurrence of 50%. Probabilities of occurrence of other values can be calculated but are more difficult. If higher percentages of occurrence are used, lower monthly values are obtained and a reasonable storage value could be obtained.

Some of the figures from these publications are reproduced below in Figures 41 and 42.

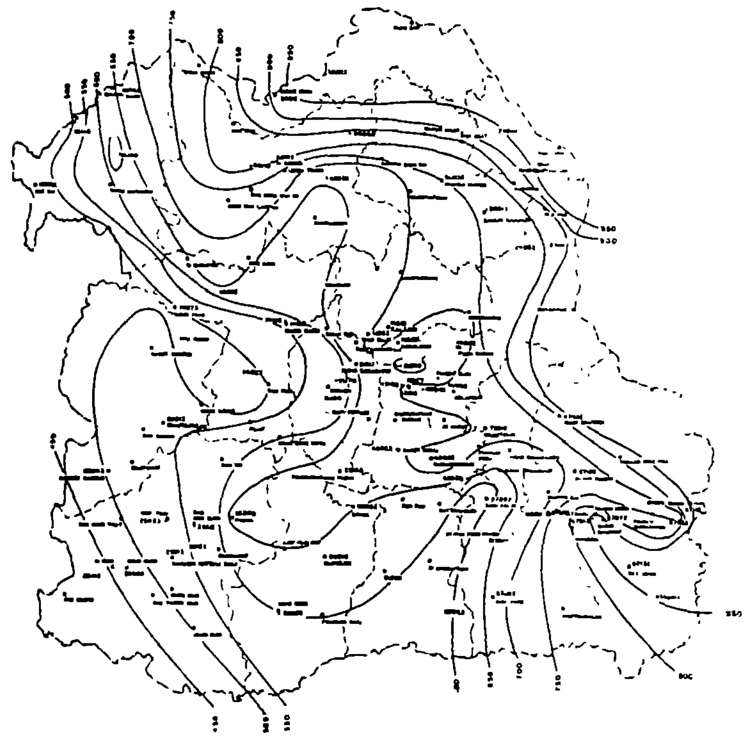


Figure 41: Cumulative Wet Season (May-Oct) Rainfall with 80% Chance of Exceedance, NE Thailand.

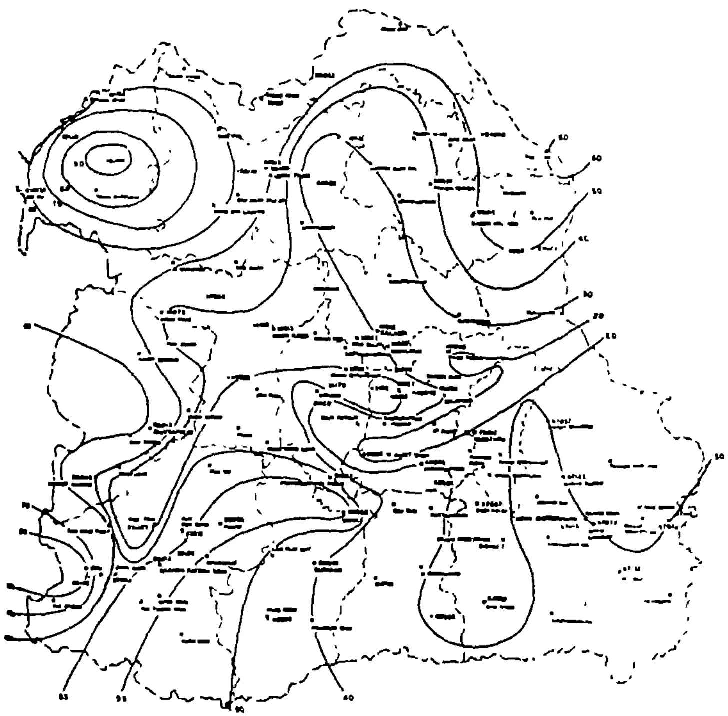


Figure 42: Cumulative Dry Season (Nov-Apr) Rainfall with 80% Chance of Exceedance, NE Thailand.

11.5.2 <u>Verification of Sizing Methods in Northeast Thailand</u>

A sizeable quantity of data was obtained from [77] for capital cities of each province in the Northeast. Demand/storage curves were calculated and plotted for Khon Kaen, Maha Sarakham, Si Sa Ket, Surin and Buri Ram in Figures 43 to 47.

For the Khon Kaen data, the estimates are done for an individual and compared with other workers' estimates in Table 21. A family size of 5 is assumed and a roof of $40m^2$ (estimated by the author) will give a per capita roof area of $8m^2$. K is 0.8 and the reliability is 95%. Average annual rainfall is 1200 mm.

From this, it can be seen that ATA's estimate is in accord with Latham's *computer* model while *Nipon's and* Grover's estimates were high. This means that their tanks can supply more water than they estimate, so they are in a *safe situation*. *Nipon's estimate of* volume needed for a complete supply of 55 lcd illustrates the point that any estimate should take into consideration whether or not a roof could collect enough the demand. *In this* case, it could not and 3 times as much roof area would be needed to supply enough. It should also be noted from the table that the $1.8m^3$ Jumbo Jar can supply 4 lcd for a family of 4.

For the other centres, the sustainable demand for the tanks seen by the author is summarized in Table 22. Area is $40m^2$, K is 0.8, families have 5 members and there is a 95% reliability.

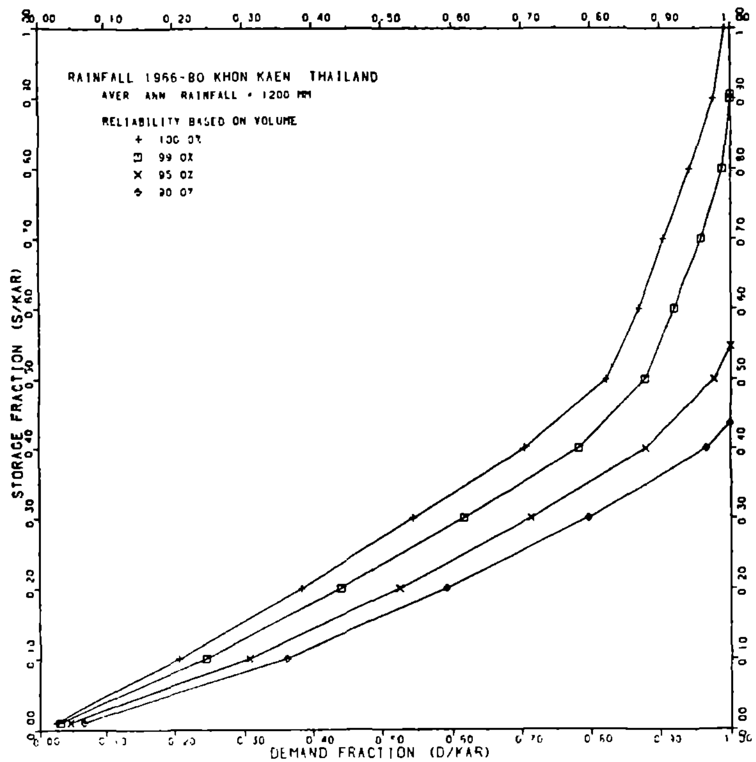


Figure 43: Rainwater Demand/Storage Curves for Khon Kaen, Thailand

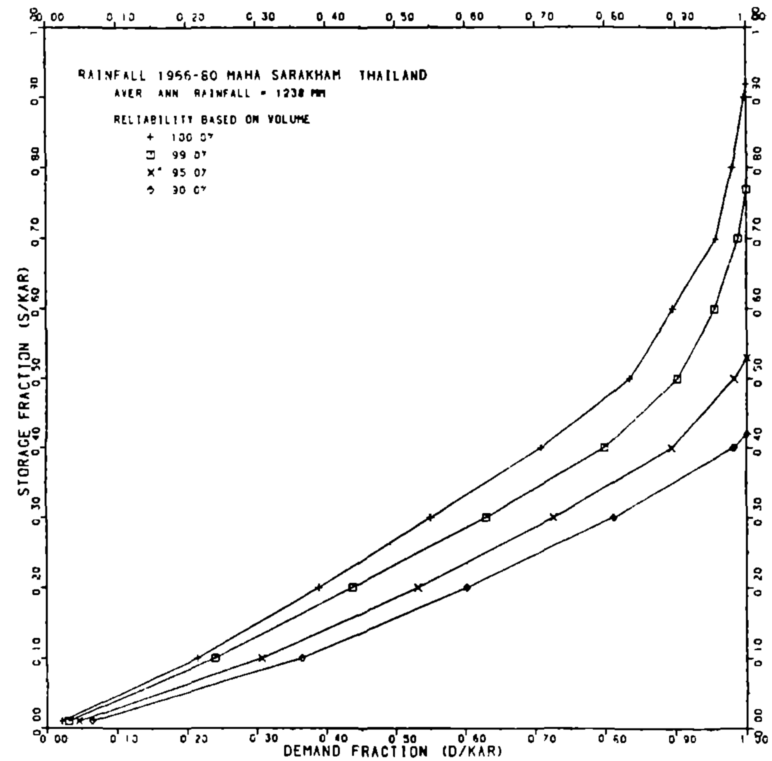


Figure 44: Rainwater Demand/Storage Curves for Maha Sarakham, Thailand

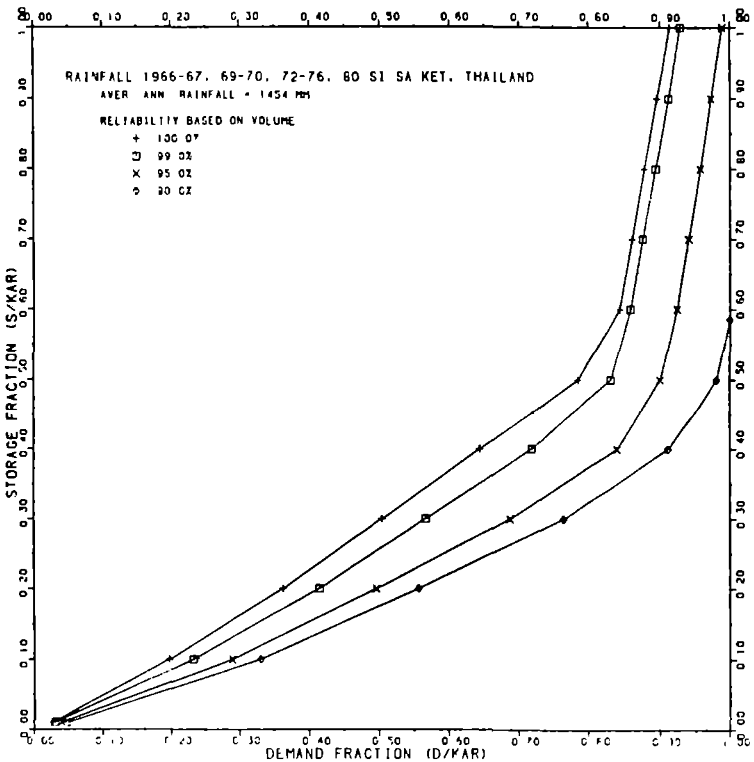


Figure 45: Rainwater Demand/Storage Curves for Si Sa Ket, Thailand

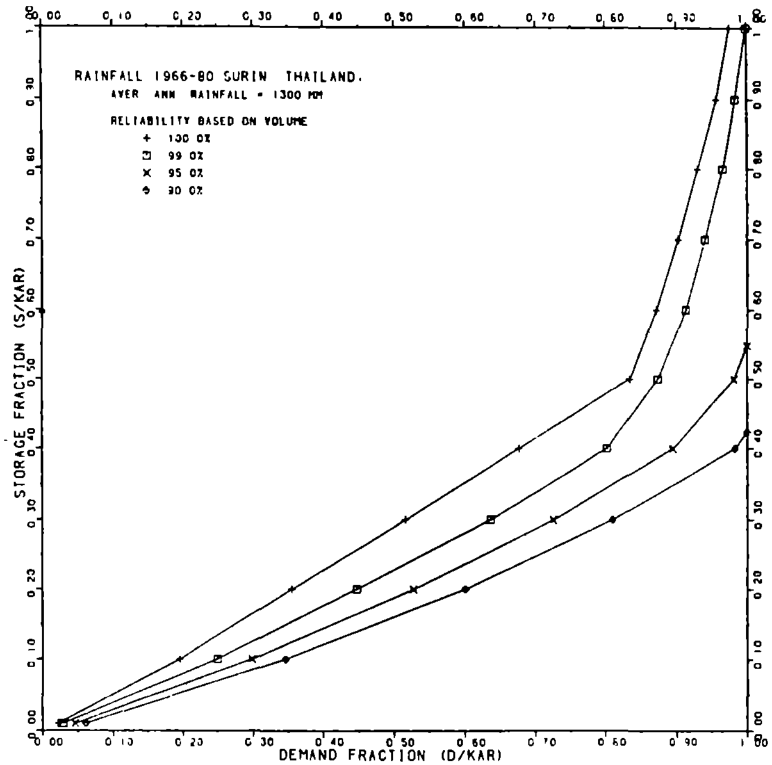


Figure 46: Rainwater Demand/Storage Curves for Surin, Thailand

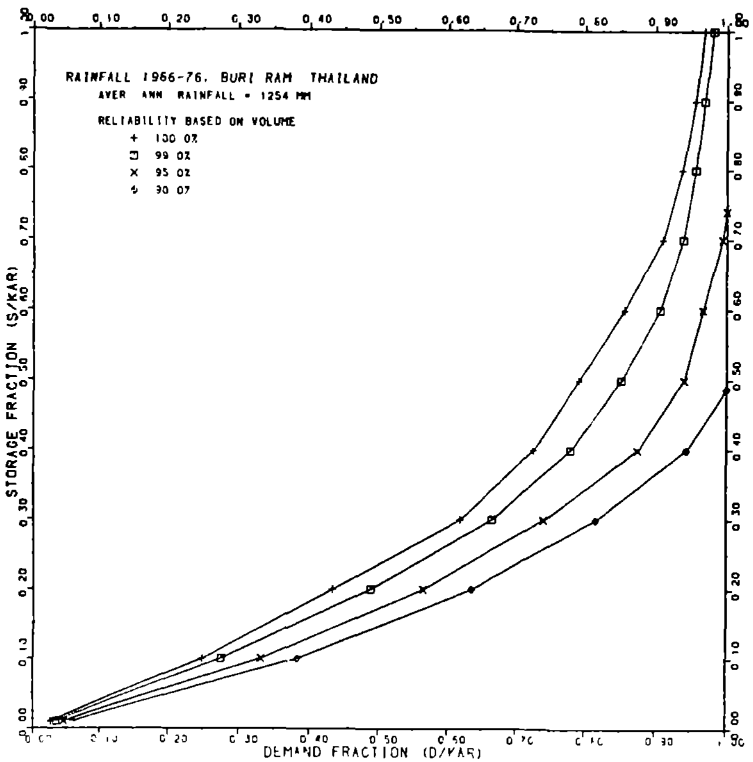


Figure 47: Rainwater Demand/Storage Curves for Buri Ram, Thailand

TABLE 21

Comparison of Storage Estimates, Khon Kaen, Thailand

	------Demand (lcd)--------		
	4	5	55
Annual Supply(l)	680	7680	7680
Annual Demand (l)	460	1825	20075
Storage estimates:			
Latham (m³/pers)	.45	.57	Not Possible
Grover (m³/pers)	.85		
Nipon (m³/pers)	.72		9.9
ATA (m³/pers)		.6	

TABLE 22

Sustainable Demand (lcd) for Common Thai Rainwater Tanks

Tank Type	Active Vol (m³)	Location: Khon Kaen	M.Sarakham	SiSaKet	Surin	B.Ram
PDA	9.6	12.9	13.1	12.8	13.3	13.7
KKU	11.5	14.9	15.2	14.8	15.4	15.6
ATA	6	8.9	9.0	8.7	9.1	9.6
JJ	1.8	3.1	3.1	2.8	3.0	3.1
I&I	5	7.7	7.9	7.5	7.8	8.3
SSWRP	12	15.3	15.7	15.2	16.0	16.2

Note:
PDA = Population and Community Development Assn.
KKU = Khon Kaen University, Civil Engineering
ATA = Appropriate Technology Association
JJ = Jumbo Jar
I&I = Iodine, Iron and Clean Water Project.
SSWRP = Small Scale Water Resources Project

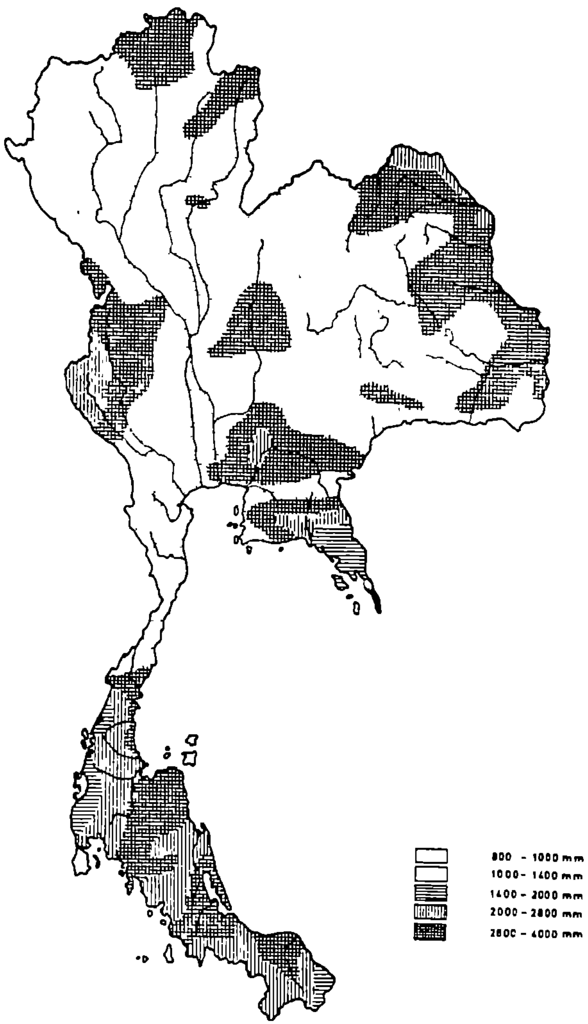


Figure 48: Annual Rainfall, Thailand

Chapter 12

DURABILITY OF BAMBOO REINFORCED TANKS

12.1 INTRODUCTION

A specific objective of this study was to observe and collect information on the use of bamboo as a reinforcing medium for rainwater tanks.

While properties vary with the variety, bamboo has the tensile strength of mild steel but the bond strength is low. In other words, if the concrete cracks and a stress is put on the bamboo, it will pull away from the concrete before it will break, although this is not as likely to happen in a circular tank where the hoops are in one piece. However, in the construction of small tanks with the low stresses involved, it could be used because for most cases, the concrete should be able to withstand the stresses.

The advantages of bamboo are that it costs little or nothing and is widely available in the areas seen. Since water-short areas are economically poor areas, costs for any water supply system must be kept as low as possible and substituting bamboo for steel reinforcement can lower the cost considerably. Also, using bamboo in a structure in a village makes the new structure less foreign because workers and users are familiar with bamboo, know how to use it and thus trust it.

The disadvantages of bamboo boil down to the fact that it is an organic material. Its shape changes with humidity so it can shrink away from the concrete. Its smooth skin also reduces its bonding strength with concrete. It is subject to degradation by fungus and bacteria and it can be eaten by termites (white ants) if any point is left exposed.

12.2 DURABILITY OF BAMBOOCEMENT TANKS IN INDONESIA

UNICEF has done a survey of 25% of the tanks built in Indonesia and is now processing the data [9]. Overall, 90% of the tanks are still in operation and this breaks down to 70% of bamboo- and 93% of steel-reinforced.

From the experience of YDD, there is about a 10% failure rate in bamboo-reinforced tanks built in 1979/81 [31], although tanks built in late 1978 are still standing [22]. Failures are not due to heat stress but water pressure which *is not being resisted by the bamboo reinforcement.* Post mortem examinations showed the cause of failure to be improper preparation of bamboo. Specific causes identified were:

1. termites got in at an exposed site and ate away the bamboo [22]. This was reported to be the major cause.

2. bamboo used was too young so it shrank and pulled away from the concrete [31].

Although the tanks have not been in use long enough for an accurate assessment, YDD estimates their economic life to be 5 to 10 years [31], [10] compared to a probable life of 30 years for ferrocement.

However, an independent observer [72] reported that all bamboocement tanks in Flores were cracked and unusable and that these failures were detrimental to the reputation of rainwater collection programmes in that area.

In the future, YDD expects to build bamboo-reinforced tanks in areas where cadres have been trained in construction and adequate supervision is possible but bamboo's general use appears to be restricted because the high level of supervision and the detailed work required by the bamboo are not always available. As a result, most of YDD's tanks are ferrocement and will continue to be so for the future. At least one agency, PLAN, has based its entire programme on ferrocement simply because they believe its greater durability is worth the added cost [25].

A survey of bamboocement, bamboo/ferrocement and ferrocement tanks built in Lombok was carried out by N. Truscott of CARE in 1981 [26]. Fifteen bamboocement tanks 3 years old, 15 bamboocement tanks reinforced with chicken wire 2 years old, and 11 ferrocement tanks 2 years old were reviewed. All of the fully bamboocement tanks were cracked with the best of the lot holding only half of its capacity. The other tanks were sound.

The techniques observed in Indonesia for improving bamboo reinforcement are:

1. use of thin strips of the outer skin of the bamboo. This makes use of the strongest and most dense part of the culm.

2. alternating strips in the framework, smooth side up, smooth side down, to improve the bonding strength.

3. drying the bamboo for only 2 days so that it contains some moisture but it is not green.

4. removal of stray slivers on the strips by burning them away. This prevents slivers from penetrating to the surface of the concrete and allowing water to enter. The charring may also improve bonding with the concrete.

5. taking care to cover <u>all</u> of the bamboo to prevent entry of white ants.

6. using bamboo and chicken wire in combination. The bamboo replaces only the steel rods which are the most expensive part and the hardest to transport and erect.

No projects were seen that coated or soaked the bamboo with any compounds.

12.3 EXPERIENCE WITH BAMBOOCEMENT TANKS IN THAILAND

A survey of bamboo-reinforced tanks has not been carried out but the major builder, PDA, freely admits that it relies on the concrete rather than the bamboo to resist the hydraulic stress. Hence their tank has a very thick wall (10 cm) and bamboo that is not carefully prepared (whole strips, no specific type of bamboo, not coated or soaked) and there is less than is theoretically required (see chapter on PDA). This strategy works for PDA as it reports few problems and feels confident in offering a 15-year guarantee against major cracks. If problems do develop with cracks, PDA would probably add chicken wire to the bottom metre of the tanks [74].

Dr. Nipon Thiensiripipat [61] felt that bamboo was an adequate reinforcing material but it needed proper design. He has produced a series of design calculations [60]. He said that dried bamboo should be coated with "dammar" (tree resin and gasoline). This apparently increases bonding strength by reducing shrinkage. It was felt by some PDA

people [44] that Nipon's design would have more problems from attacks by white ants because the design relies on the bamboo for strength whereas the PDA tank relies on the concrete. This criticism could probably be made of the ATA tank as well as it has even more bamboo that Dr. Nipon's.

Dr. Sethaputra of Khon Kaen University [56] said that bamboo has been used in walls for years in Thailand but the pulpy central part rots easily and must be completely removed before use. This can be done by washing it in a running stream or soaking it for several days in a 3% lime solution. Other preparation methods are coating it with tar or charring the bamboo.

A local artisan interviewed by the author near Khon Kaen [48] has built a number of large 25 m^3 poured concrete tanks similar to the PDA style. He did not dry or coat the bamboo but instead charred the inside face of the bamboo strips in order to dry them and increase the bonding strength.

12.4 CONCLUSION

Using bamboo as reinforcing excites the imagination of many people in tropical countries because it is a traditional indigenous material. However, it is apparent that its use in water tanks presents special problems because it is repeatedly subjected to dry and wet conditions. Thus, much of the work done on investigating the behaviour of bamboo in walls and slabs is not entirely applicable. Further study is needed of this effect and of the techniques to overcome the problems associated with it.

Study is also needed into methods of preparing the bamboo, including what part of the bamboo should be used, how it should be dried, whether it should be coated or not and how it should be assembled. The results of this study should be improved bonding strength and a lessening of biological degradation of the bamboo.

Bamboo has a future in small rainwater tanks but at present, the techniques for using it are not sufficiently well developed to recommend its use as a reinforcing material in general or as a direct replacement for steel. The experience of agencies involved in longterm programmes in Indonesia and Thailand bears this out as bamboo is increasingly downplayed as their experience with it increases.

Chapter 13

COSTS

It is the author's opinion that a discussion of costs of rainwater tanks in the areas studied will be of little use to a reader who is probably in a different country and is definitely in a different time. With a different set of costs in every area, inflation, exchange rate fluctuations and myriad other constantly-changing factors, costs are of very marginal utility, are not easily compared and are quickly out of date. Moreover, there is a further question of what should or should not be included in costs as, for example, administrative and infrastructure costs can often double the cost of materials that an agency usually charges to an owner.

However, a listing of costs obtained in the study follows for completeness. They are collected in this chapter for easy reference or omission as the reader wishes.

TABLE 23

Comparison of Costs of Indonesian Rainwater Tanks

All costs in 1000's of Rupiahs.
(980Rp = $1 US - 1983 rate)

GROUP	TANK TYPE	SIZE m^3	DATE	COSTS MATERIALS	LABOUR	TOTAL
YDD	Bamboo	4.5	81	35.8	4	80
	Ferro	9	83	100(est)		200
PLAN						
Java	Ferro	9	83			150
Bali	Ferro	9	83			300
IWACO	Ferro	10	83			300

TABLE 24

Comparison of Costs of Thai Rainwater Tanks

All costs in Baht.
(22฿ = $1 US - 1983 rate)

GROUP	TANK TYPE	SIZE m^3	DATE	COSTS MATERIALS	LABOUR	TOTAL
PDA	Bamboo	10	83	3500		4200
KKU	Ferro	12	83	4000		
	Bamboo	12	83			3900
	Block	12	83	3240		
ATA	Bamboo	6	83	3000		
I&I	Jar	5	83			800
AIT	Bamboo	10	83	6000		10000
JJ	Jar	1.2-1.8	83	300		500
SSWRP	Concrete	21	83			10000
	Ferro	14	83			4500
Priv.	Bamboo	25	82	6000	2000	8000

Note:
PDA = Population and Community Development Assn.
KKU = Khon Kaen University, Civil Engineering
ATA = Appropriate Technology Association
JJ = Jumbo Jar
I&I = Iodine, Iron and Clean Water Project.
SSWRP = Small Scale Water Resources Project

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