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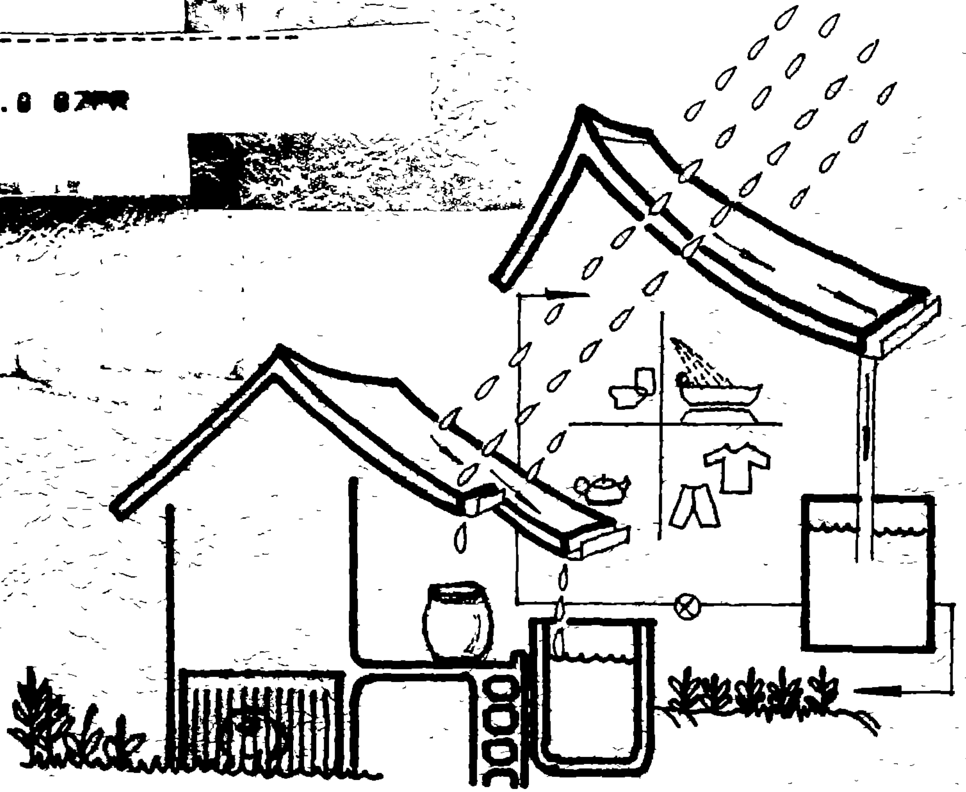
THIRD INTERNATIONAL CONFERENCE
ON
Rain Water Cistern Systems



Faculty of Engineering
Khon Kaen University, Thailand

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14-16 January 1987

PROCEEDINGS OF THE

THIRD INTERNATIONAL CONFERENCE ON

RAIN WATER CISTERN SYSTEMS

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Prinya Chindaprasirt
Sacha Sethaputra
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FOREWORD

The use of rain water cistern systems is increasing in both developed and developing countries. In developed countries, rain water use may supplement public water supplies which are inadequate to sustain urban growth. In rural areas where groundwater is unfit for consumption rain water collection may be the only alternative.

In developing countries, rain water use is particulary suitable for the rural areas where the cost of piped water supplies would be economically prohibitive. In these areas, villagers rely on rain water in ther rainy season and revert to groundwater from deep or shallow wells in the dry season. The use of well water, however, may not be possible or advisable in areas where the high mineral content or bacteriological quality render it unfit for human consumption. Promotion of rain water cistern systems which provide adequate storage for year round use may alleviate some of these problems.

In view of this, the first international conference on Rain Water Cistern Systems was held in Honolulu, Hawaii in 1982 under the very capable chairmanship of Dr. Yu-Si Fok and the second conference was held in the Virgin Islands in 1984 . The conferences dealt very comprehensively on varied aspects of rainwater catehment. However, it was felt that the conferences were lacking in representation from developing countries and the issues concerning community involvement, organization, operation and maintenance of the systems were not adequately considered. Hence, the third conference was decided to be held in a developing country and Thailand was chosen.

I wish to thank all the authors who, by responding to the call for conference papers, have contributed to the success of the conference. I am also thankful to the previous conference organizers for their useful advice, and the International Development Research Centre (IDRC) for its financial support.

Chayatit Vadhanavikkit
Co-Chairman

HISTORY

RAINWATER COLLECTION SYSTEMS: A LITERATURE REVIEW

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ABSTRACT

This is a corrected version of the original literature review first published by the authors in April 1984. That review is available from the International Institute for Co-operation and Development, University of Ottawa, Ottawa, Canada.

INTRODUCTION

Rainwater collection is the process of collecting, storing and using rainwater as a primary or supplementary water source. In this review, rainwater collection refers to the small-scale collection of rainwater on roofs, primarily for use as a domestic potable water supply. However, there are other larger systems that may involve many hectares of collection area in the form of roads, sealed pavements and ground-runoff catchments for the provision of water primarily for livestock and irrigation. Rigid distinctions between size and use of water are not possible as large areas in Bermuda [212], [221], Yugoslavia [97] and Hawaii [68, p.2], [69] are paved for the provision of water for human consumption but the scale of operation is the main criterion used to distinguish the two types here. Large scale collection is a separate area of study [12], [14], [40], [48], [94], [99], [100], and is reviewed elsewhere [164].

Rainwater has always been collected as a low-volume but high-quality source of water but since the nineteenth century its use in industrialized countries has received less attention than more technically-oriented centralized water sources. However, in recent times, the increasing cost of supplying treated water to remote and rural areas from a centralized source and of pumping from deep wells has meant that serious consideration is once again being given to rainwater collection in certain areas.

As a water source, the major advantages of rainwater collection systems are:

1. in most areas, rainfall water quality is excellent.
2. the concept is simple and thus they are easily built and maintained;
3. the ability to operate independently of outside systems is useful in remote areas and difficult terrain;

The conditions that make them a viable water source can vary from low groundwater tables to poor wellwater quality and even heavy seasonal rain [13]. Although consideration is usually given to systems supplying water year-round, significant benefits are obtained from smaller, partial supply systems as well. In fact, a study of benefit and cost showed that the highest returns were realized for very small systems that supplied water during the wet season and a small part of the dry season [175].

The main difficulty faced by researchers is that the literature on rainwater collection has not been properly referenced. An extensive computer search in Compendex (Engineering Index), NTIS and SWRA files revealed only five titles on this topic [121], [177], [178], [191], [218]. Even Ree's companion paper [190] was not included This is probably because work on rainwater collection is localized Hence, the results of work done appear in many small papers and practical pamphlets that are only available locally Considerable amounts of work are duplicated

Also, it is commonly believed that rainwater collectors are "home-made" and not as sophisticated as centrally controlled facilities This may, in fact, be the reason why it is assumed by many that rainwater collectors are primarily for use in developing countries Developed countries are presumed to have more sophisticated sources [49] Considering the proven advances in public health that followed the introduction of and strict adherence to central water supply and quality control in Europe and North America [35, p 1 5] and other areas, engineers and health workers in these areas are reluctant to endorse a water supply method that pre-dates the "modern" technique However, complexity breeds complexity and the development of sophisticated methods of water purification was necessitated by the large number of pollutants in the surface water that is normally the source of supply for centralized systems. Rainwater collectors are simpler in part because the rainwater itself is less polluted. In addition, the technology of water quality management developed for central systems is available (for a price!) to the rainwater user [259], [260].

Finally rainwater collection has been a neglected area of study and improvement Current work will update it and will assist the distribution of suitable systems to the public at an affordable cost By reviewing work that has been done directly on and in the general field of rainwater collection, the authors hope to assist and stimulate the work of researchers in a number of fields.

GENERAL REFERENCES

Keller [125] prepared a review for WASH and USAID of 87 titles that centred on the need for rainwater collection, some of the existing methods for calculation of the storage size required, design and construction of roofs, gutters and storage tanks and a comparison of estimated costs Other literature lists have been prepared by the International Reference Centre for Community Water Supply and Sanitation (IRC) [113], [114]. They have also produced a general review [97]. The United Nations through UNEP has published a general review of rainwater collection [21] which incorporates the work of a review paper [226] and a series of commissioned geographical reviews [122], [123], [134], [171], [186], [34], [206], not all of which discuss small collectors. Intermediate Technology Development Group has a review of roof catchment and micro-irrigation technology in preparation [115]. The topic is covered in [249] as a rural water supply source.

Rainwater collection has been discussed in several conferences and symposia including Water for Peace, 1967 [266], Water Harvesting Symposium, Phoenix, Arizona, 1974 [229], Rainwater Cistern Symposium, Monterey California, 1979 [31], American Water Works Association meeting, 1979 [177], American Geophysical Union, 1979 [67], International Water Resources Association, 1979 [68], Rainwater Cistern Systems Conference, Honolulu Hawaii, 1982 [71]

AREAS OF USE

EUROPE In the Mediterranean area, rainwater collected on roofs and stored in cisterns was the principal source of water during Phoenician, Carthaginian and early Roman times [42], [134] from the sixth century onwards. Cisterns were later used by the Romans for storing transported surface water when cities became larger [35], [134]. Rooftop collection and storage of rainwater was practiced in Venice as the principal water source for 1300 years [11], [88] until the 16th Century [69] One hundred and seventy-seven public and 1900 private cisterns in Venice held 665,000 m of water to supply about 16 l cap/day [265]. In 1703, a plan was presented to the French Academy of Sciences to provide a rainwater cistern with a sand filter in every house [135] Use up to present times in Germany is mentioned [160], [205]

AFRICA In Sudan, the traditional use of baobab or tebeldi trees (Adansonia digitata) for storage is reported [56], [60]. When hollowed out, these 5 m. or greater diameter trunks are fed by water collected from the tree branches or by buckets from ground collectors. In Kenya, use of small tanks is reported [165] and Grover [84] described a proposed community rain harvesting system for Manda Island on the Kenyan coast Ongweny [21], [171], quoted extensively from Grover's paper and reviewed traditional and modern roof catchment techniques: thatched to corrugated roofs, open jars to cement tanks. Upwards of 10,000 people use rainwater collectors in each of Kenya (Gussi Highlands), Tanzania, Uganda, Zambia, Lesotho, Ethiopia, Nigeria, Ghana and Botswana [171]. General reviews of collectors are available [78] and are in preparation [81], [82] for Botswana where use of threshing floors as collectors is suggested [78], [250]. Rock outcrops and roofs are used as collectors in Zimbabwe [63], [192]. Parker [175] did a benefit/cost analysis of partial supply systems in Kpomko, Ghana. Rainwater systems were observed in Mali [245], Kenya [77] and Zimbabwe [80]. Modern pilot projects are being run in Botswana [145], Ethiopia [153, p. 33], Sudan [60], Ivory Coast [1], [57], Rwanda [83], Upper Volta [8], [117], Sierra Leone [112] and Zimbabwe and Malawi [63] by regional departments of agriculture and foreign aid agencies. Ray [189] reviews projects in Yemen, Libya, Kenya, Botswana, Ghana and Lesotho. Wider use in Nigeria is proposed [49].

CARIBBEAN. Rainwater collectors are used in much of the Caribbean. Their use is reported in the Virgin Islands [139], [140] and Trinidad [133]. The Jamaica Rainwater Catchment Project [47], [119], [144] is almost entirely a large area harvesting project although there is a small collection component.

ATLANTIC. Bermuda is known for using rooftop and larger catchments for practically all its potable water. In all, approximately 2.7 million m are caught annually. Use began in 1628. Short histories are given by Raine [188] and McCallan [154]. Histories and a general description of the systems are given in [221] and [212]. The size of tanks and system construction are prescribed by law [17], [18], [19]. Waller [241] reviewed all pertinent acts and histories and discussed quantity and quality of water, maintenance and future demand.

Gibraltar is similar to Bermuda. Rooftop collection began in the early 1800's and since 1869 has been required by the Public Health Ordinance where central service is not available [74]. In 1903, this source was supplemented by a 25-hectare sealed harvesting catchment on the east side [73], [210].

WEST AND CENTRAL ASIA. Use is reported in the Anatolia region of Turkey from ancient times [172]. Ancient buildings in the Negev Desert were served by roof collectors and tanks as are many modern Israeli areas [186], [189], but other references to their use in this area are peculiarly absent. Prasad [186] mentions rooftop collection in Rajasthan. There is some limited use elsewhere in India [211] and its use in the Himalaya region is proposed [86]. Collection of rain on a large scale in Sri Lanka is reviewed and mention is made of use in the Maldive Islands [189].

EAST ASIA. In Thailand, numerous types of tanks are used [137], [246]. Work by Khon Kaen University [39], [85] shows that up to 5,000 tanks per year are being installed and rainwater collectors are proposed for general rural use [187]. The Population Development Association tank programme run by its CBATDS division is well known [39], [189]. A major study of all aspects of rainwater collection is being undertaken in Northeast Thailand [128], [166], [232], [233], [234], [235].

In Malaysia, rainwater has always been collected but continues to be a minor supplementary source of potable water [146], [147]. Wider use is reported in Sabah and Sarawak states [7].

Rainwater collectors are being used in a number of areas of Indonesia and are well-studied, especially in Java [58], [116], [117], [137], [184], [185], [189], [199], [214], [224], [236], [255], but also in Lombok [223], [262] and Bali [251].

Use in Singapore [5] and Japan [104] is proposed for non-potable purposes.

PACIFIC. Water supply is difficult on small coral islands and rainwater collection is a major source of drinking water [151]. Usage of rainwater collectors is examined in Belau, W. Caroline Islands [170], [198], Majuro, Marshall Islands [217], Rota [218] and is reported in Fiji, Samoa, Vanuatu [102] and Tuvalu [143]. Costs of construction and plans for tanks are given for the Solomon Islands [22], [89], [90], [91]. Longtime use of rain collectors in the Kona area of Hawaii is reported [46], [69], [129], even when alternate sources are available. Other use in Hawaii is reported [68], [69], [247]. Traditional use of rain water in Papua-New Guinea was examined in [64], where the use of trees as collectors was reported.

NORTH AND SOUTH AMERICA. Use is widespread in rural areas of the United States and is reported in rural Pennsylvania [208], [209]. Instructions for construction of systems are given for Ohio [10], [131], [169], Virginia [238] and California [30]. Construction is regulated in Ohio [168] and Pennsylvania [264]. Use is proposed in California [31], [105], [121], [177]. Chanlett [33] mentions use in the Florida Keys. Material is also available for national distribution [4], [61], [261].

In Canada, use is mentioned in Saskatchewan [162]. Waller and Inman [242] studied usage and water quality in Nova Scotia, a report was prepared [167] and legislation is pending. Wider use in Canada is proposed and present usage is extensive but unstudied [201].

In Mexico, cisterns were in use in the Yucatan Peninsula from 300 AD onwards. An ancient ground storage system is described [216, p. 148-9]. Roof catchment was used only by the Spaniards in large haciendas to supplement hard and contaminated well water sources [73]. A study was done in northern Mexico [237] and future use is proposed [75]. A hydrologic study was done in Brazil [117] and a project was described [189]. Use in Brazil as part of an aid project is known [256].

AUSTRALIA. In Australia, rainwater collectors are widespread and have been examined in New South Wales [178], [179], [180], [181], South Australia [9], [95], [96], and nationally [23], [24], [38].

SOCIAL AND ECONOMIC ASPECTS

While some socio-economic factors are covered in some publications [21], [29], [64], [99], [173], [175], the only reference specifically directed towards this area is Ray's [189]. Although a review of reports rather than the result of independent research, it does provide lists of benefits, problems and experiences.

RAINWATER QUALITY AND HEALTH ASPECTS

Water quality is a major objection to use of rainwater collectors for potable water. This was recognized by the International Development Research Centre [153, p. 34] and others [31], [173], who also showed more contamination in urban areas than in rural. Contamination is due to air particles, roof materials such as asbestos [161], dust on roofs and biological material, mostly bird droppings [133], [221], [241]. A study of cistern water itself [208] revealed that a major source of contamination was the lead joining compound in the pipes. Contamination of water by airborne pesticides has been reported [140]. Waller and Inman [242] found that most roof rain runoff studied in Nova Scotia could meet Canadian drinking water standards. In developing countries, the quality may be much better than surface sources [65], [173] but WHO standards [258] are not met. The type of roof has been found to have little effect on water quality. Even thatch added only colour and turbidity [232].

Rainwater composition studies and/or coliform counts were done in San Francisco [121], (30 metals were measured with emphasis on iron and lead), California [126], Pennsylvania [208], rural and urban areas of Tennessee [20], Hawaii [62], parts of the continental U.S. [37], [101] [138], [242], Nova Scotia [225], various settings in Europe [163], rural England [152], [182], Germany [160], Trinidad [44], the US Virgin Islands [139], Bermuda [221], Upper Volta [15], Nigeria [26], Kenya [27], South Africa [2] and Indonesia [51] (27 constituents), [224]. A study of rain and cistern water quality and the effects of roof materials is underway in Northeast Thailand [28]. Further references are given in [126].

Reduction of the quantity of contaminants is accomplished by proper roof materials and maintenance [240], [241], wasting of initial rain water [28], [121], [125], proper construction of tank [4], [19], [73], [240], [264], settling and drawing of water from the surface [208], storage [153, p. 82], [156], [173], [240], [245], chlorination [121], [139], [240], [264], filtration before and/or after the tank [4], [263].

There are some suggestions that because of its lack of minerals, rainwater is detrimental to human health if drunk exclusively [200] and, from other studies, effects such as increased incidence of heart disease may develop due to mineral deficiencies such as magnesium [150] and other hardness [194], [248]. It was noted that soft-water areas in Britain had high rainfall as well as high levels of death from heart disease [43]. It is felt by the public in rural Malaysia that rainwater causes rheumatism [147] but no scientific studies have been conducted. The only specific study of health effects from rainwater found is being conducted in Australia [66].

DESIGN AND CONSTRUCTION

Design and construction of all components are discussed in [45], [97], [98], [106], [125], [115] with some additional features given in [131] and [222]. A manual for training village workers [59] and a set of audio-visual training materials for technicians [257] are available.

The hydrology (the inter-relationship between collection area, rainfall, demand, and storage volume) has been well studied. A number of techniques have been used [69], [121], [136], [141], [142], [177], [180], [183], [185], [190], [199], [201], [202], [252], but for the most part the methods are discussed in [157] and are mainly versions of the mass curve method [193]. Some methods are oversimplified by the use of too little data [107], [125], [239]. Some of the above were compared [201], [202]. In general, the relationship between storage size and raindata statistics is not simple [136], [204]. Design curves are given for specific areas [9], [96], [136] with some based on cost optimization [92], [93], [117] or optimization of net returns [142]. In areas with distinct wet and dry periods, the storage volume required is usually calculated by daily demand multiplied by the maximum number of days in the dry season [165]. Raindata for use in these methods can be procured locally but selected monthly data are published [36], [230], [231].

Roofs are discussed in [127] and [132]. Most roofs used in warm climates are corrugated iron or clay tile but even thatch can be used [78], [87]. In cold climates, asphalt shingle and clay tile are common. Construction of cement roof panels is possible using asbestos (not recommended) [176], palm fibre [53], [54] or bamboo [215]. Gutters and pipes have been studied [16], [25] and are discussed in [108], [110], [125].

Filters are reviewed briefly [97], [205] and a commercial inlet model is available [253]. Kincaid [131] is skeptical of settling basins in the literature and advocates one particular design and the use of a floating outlet filter.

The complete design of tanks in general is covered in [149]. General principles for rainwater collection tanks are given [109], [224] (includes many types) and drawings and instructions for various reinforced poured concrete tanks are available [30], [61], [83], [103], [111], [162], [165], [264]. Use of steel fibre reinforcement (small lengths of wire) is reported [102], [158], [159]. Ferrocement is popular in many areas. Its design is covered in [174], [224], [244], [245] and a review of areas of use is in [195]. Reports on specific sizes have been prepared [51], [52], [63], [118], [196], [207], [234], [254], [255], [267]. Some are buried [32], [250]. Square tanks from precast concrete panels are reported [90], [91], [130]. Reviews of ferrocement tanks in use in Bali, Indonesia [251] and East Java [70] were done. Use is also made of bricks [232], [233], [235], [250] and corrugated iron [78], [144].

Bamboo has been used as a general reinforcing material in tropical areas [41], [72], [148], [228] and lately has been applied to rainwater tanks in poured concrete [70], and ferrocement-type tanks [6], [50], [55], [83], [124], [128], [137], [166], [197], [219], [220], [224], [254], [255]. Force and moment analyses for bamboo-reinforced tanks have been done [220]. There are indications that it is not sufficiently stable to warrant widespread use [137], [223], [232]. Although not specifically applied to tanks, other works discuss bamboo reinforcement construction in general [120], [155], [213], [228].

Unreinforced concrete jars up to 7 m are in use in Thailand [137]. Construction is described in [245] and [243] and from these, in various places [83], [111], [125], [227].

A framework of a cost analysis was presented for a centralized storage system [3]. Actual costs of rainwater collectors are given for a number of countries [125], [189], Thailand [220], Indonesia [196], [197], [224], Solomon Islands [91], Botswana [82], Zimbabwe and Malawi [63], and Rwanda [83]. A comparison with other water sources has been done [29], [173].

CONCLUSION

The collection of rainwater as a water source has an increasingly bright future. Previous study of its application has suffered because most work has been done in isolation from other, often similar endeavours. However, very recently, renewed emphasis is being put on the topic by researchers and it is now clear that rainwater collection is a unique area of applied science that incorporates a wide range of fields, among which are reservoir theory, hydrology, design, construction, water treatment, environmental pollution, history, archaeology and economics.

Much remains to be done and it is hoped that this review will save researchers and technologists valuable time in their work. Copies of articles and other materials not listed here would be appreciated by the authors.

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RAIN WATER CISTERNS IN ISRAEL'S NEGEV DESERT

PAST AND PRESENT DEVELOPMENT

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ABSTRACT

The paper deals with water harvesting and management over the ages in a country (Israel) of which sixty percent of its area has less than 250 mm of rainfall a year.

Archeological research and the Bible give ample evidence that during the Stone Age 5000 BC and the Bronze Age (2000 BC), this desert was relatively well populated.

During and after the rains (which may fall on less than 10 days a year) there is occaisionally runoff. The inhabitants learned to control, increase and store these floods and become "run-off" farmers or water harvesters.

Storage was in underground cisterns excavated in soft impermeable chalk formations with volumes of up to 300 cubic meters - enough for 10 families and their flock for a whole year.

Groundwater aquifers form the "modern cistern" in the desert areas. These are being refilled by construction of retention dams and the release and controlled infiltration of the stored flood water into the underground aquifer.

1. INTRODUCTION

Israel with a total land area of 20,000 square kilometers, has desert conditions extending over 60 percent of its land area. This area is known as the Negev has an annual average rainfall less than 250 mm and average daily temperatures of almost 30°C (in the shade) for most of the year.

A desert or arid zone, can be defined as a function of rainfall plus temperature, (originally deserts were defined only by rainfall, the most measured climatological parameter).

Many empirical formulae exist (none of which are entirely satisfactory) to define arid conditions, E. De-Martonne supported a formula:

$$K = \frac{n \times p}{t + 10}$$

n = number of rainy days;
p = rainfall in cms;
t = average daily temperature at time of rainfall in centigrade.

For K = 20-30 semi-arid conditions prevail
K = <20 arid conditions prevail

In the Negev representative figures may well be taken as $n = 10$ days, $p = 18$ cms, $t = 15°C$. Hence $K = 7.2$.

The word desert gives us "deserted" or abandoned, but this connotation is not always true. The desert has always been a place that fascinated and attracted man, the "riddle of the desert" has been the cause of many an exploration, and many civilizations have existed and flourished therein. Worldwide interest in the desert is growing.

The growing world population requires additional land and very little unused and useable land remains available in so called temperate or "wet lands", hence deserts must be considered for future intensive devlopment.

FIG. 1

THE MAJOR DESERTS OF THE WORLD

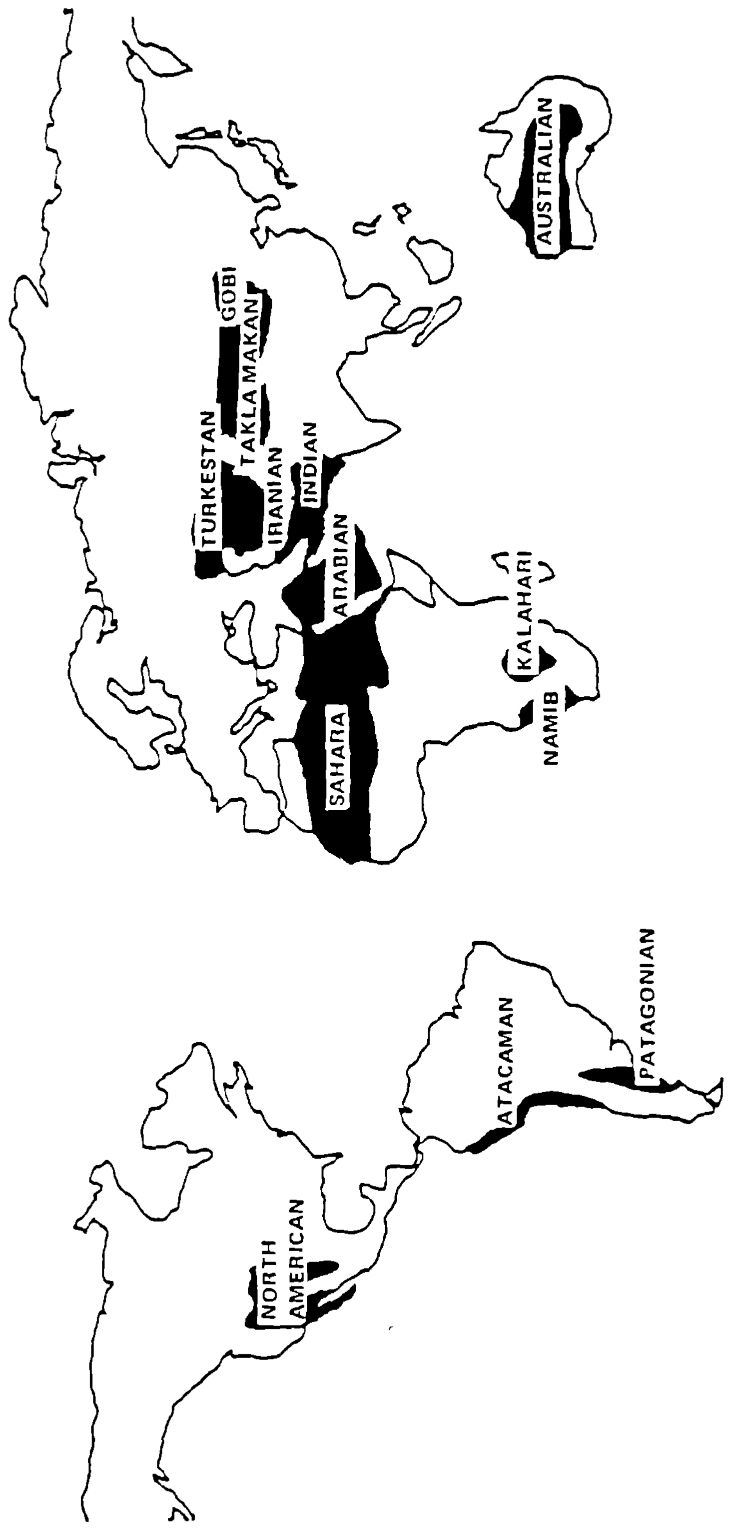
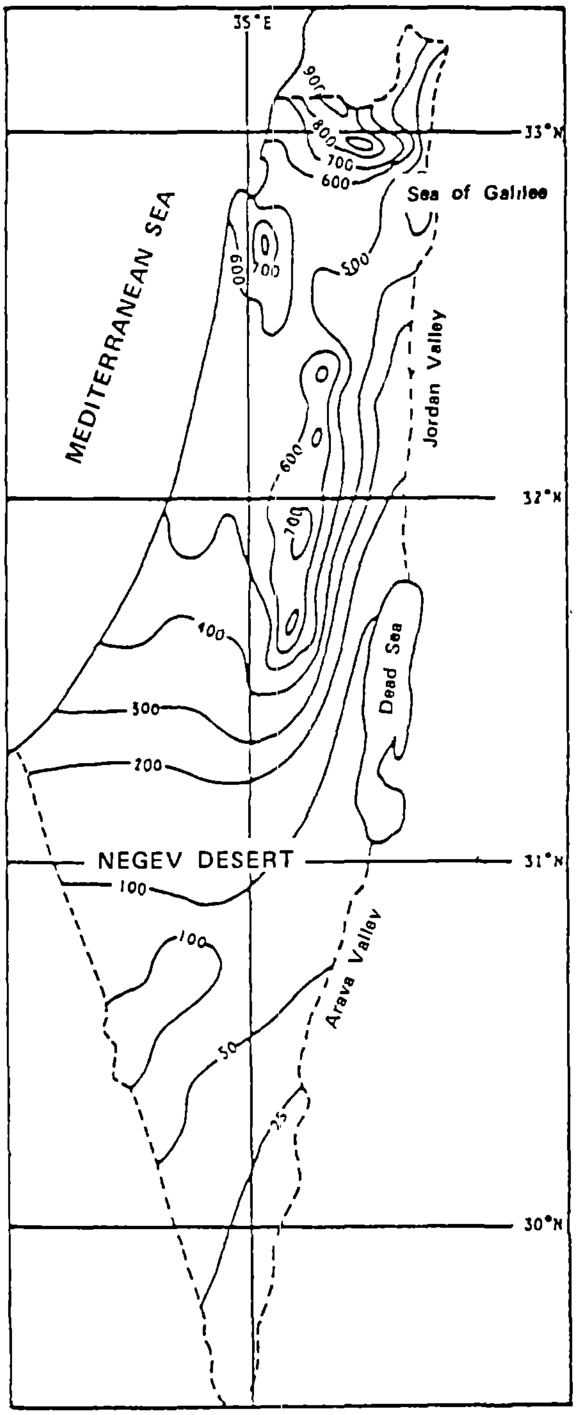


FIG. 2
RAINFALL MAP WITH ISOHYETS IN MM



Total land area on earth is 143 million square kilometers of which some 14 percent (20 million sq.km) is presently classed as arid desert (see figure 1). However, almost one quarter of the world's population live on the periphery and has contact with the desert.

One of the great paradoxes regarding the desert is in its typical landscape, starkly etched by flowing water!

Water is anything but equally distributed throughout the world, 97% is in the oceans and as such unuseable for most of man's needs, 2% in glaciers and again not yet economically accessible, only the remaining 1% is reasonably available to meet man's requirements and this small percentage is anything but evenly distributed.

Americans use about 300 litres/day of water on the average whilst if agricultural and industrial use is included (i.e. indirect usage) the Americans consume nearly 8,000 litres/person/day. People who live in the desert learn to live on from 5 to 10 litres/day.

The paper describes how people who lived in the Negev desert over 2000 years ago, ingeniously increased surface runoff in order to collect and store the meager and occasional rainfall in order to meet their personal needs and that of their goats and donkeys, throughout the year.

These systems are contrasted with the present day methods of building dams in the desert (which cannot store water due to high percolation and evaporation rates) in order to artificially recharge underground aquifers, and thereby increase their ability to meet the evergrowing demands, which without this artificial recharge would quickly become depleted.

2. WATER STORAGE AND NEED FOR RELIABLE DATA

In the 15th century, King Akbar the Great built a grand, beautiful and ornate model town in the arid area of Northern India (Fatehpur Sikri). The town was walled on three sides and a large artificial lake was dug on the fourth side, to provide both water and defence. A series of droughts followed the construction of the town, the lake dried out. The town has been abandoned for the last 400 years, serving only as a tourist attraction. Insufficient attention had been paid to hydrology.

Even relating to modern times we can find further examples of water storage systems wherein the rate of use is greater than the anticipated rate of refill.

In the Great Plains area of the USA there is a ground water aquifer (Ogallala aquifer) from which water is being pumped at a greater rate than the natural rainfed replenishment, the general water table is dropping and unless state wide action is taken the watertable will drop below all existing wells, making a mockery of all existing investment in boreholes and equipment.

The first requirement of any storage system is reliability and an understanding of both of demand and the hydrology of the system.

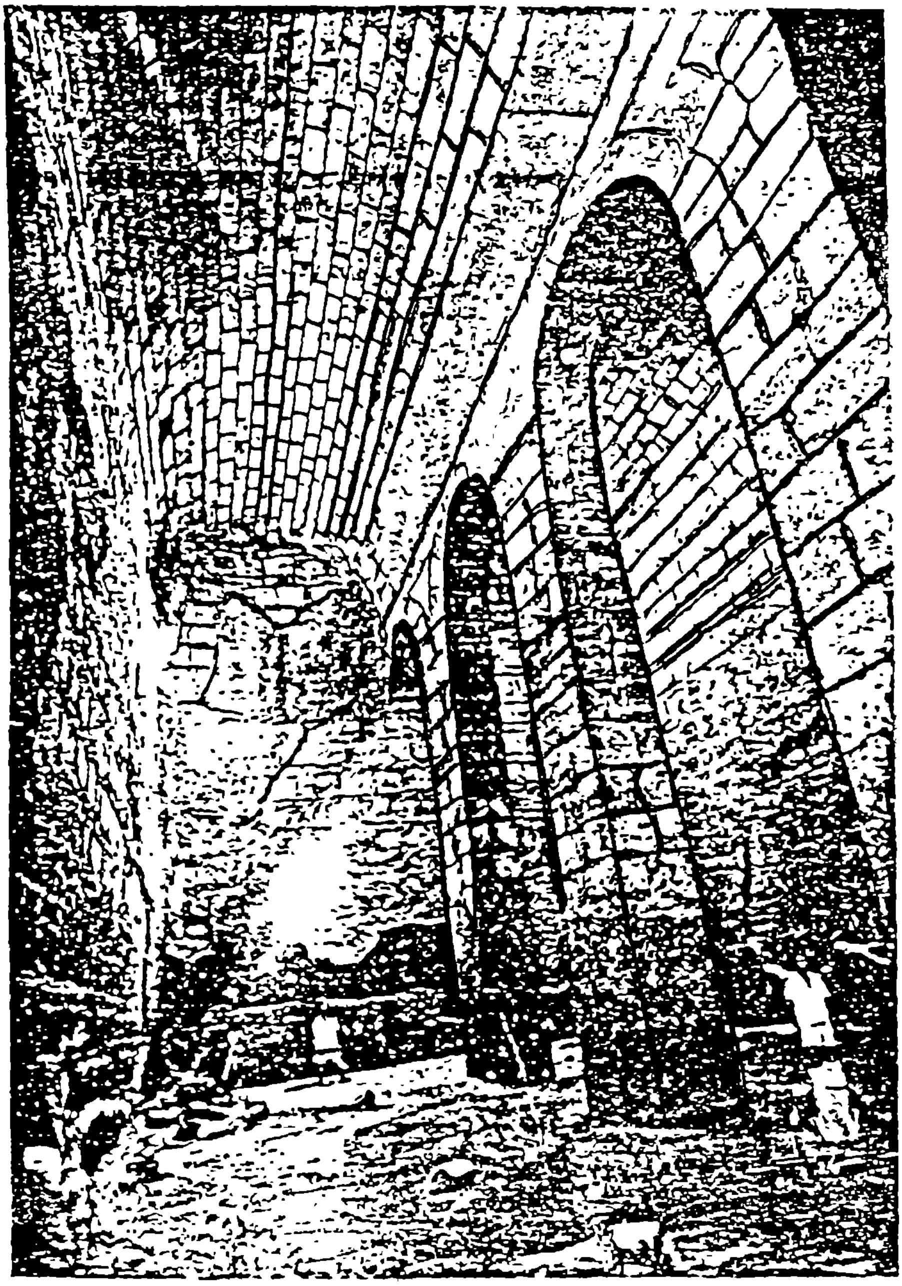
3. ANCIENT WATER HARVESTING AND CISTERN STORAGE IN ISRAEL

Cisterns were a common and time honoured method of storing water throughout the Middle East. The city of Jerusalem, for instance, was supplied with water for many centuries by underground cisterns hewn into the bed rock and fed by specially sloped and channeled roofs, streets and courtyards. These cisterns were fully utilized as late as 1948 in order to supply drinking water to the beseiged city during Israels' war of independence. Even in the 1950's modern apartment houses in Jerusalem were often constructed on large concrete underground cisterns which can be filled from the piped water supply and form a reserve in case of system failure, drought or firefighting.

The story of how the biblical people of the Negev contended with their arid climate, is a story of diligence, experience and trial with no place for error. There were many ways to gather, conserve and utilize water in the desert.

FIG. 3

UNDERGROUND CISTERN--HIRBE EL-AHMAR
(JUDEAN DESERT)



Though cisterns are not unique to the Negev, there they were essential. Without the establishment of cisterns the settlements and trade routes throughout the Middle East would have been impossible. Every group of houses had its own cistern, and whilst many are today (after more than 2000 years) often choked with debris, many are still serviceable after years of continuous use.

The major source of water has always been the surface runoff from sloped desert ground occurring perhaps only two or three times a year and then only for a few hours, during the occasional "heavier" winter rains. Runoff was gathered into cisterns in either of two ways:

- intercepting by gutter, and concentrating the water trickling off small and specially prepared the desert slopes (and before the water reaches the river beds). These are known as hillside cisterns.

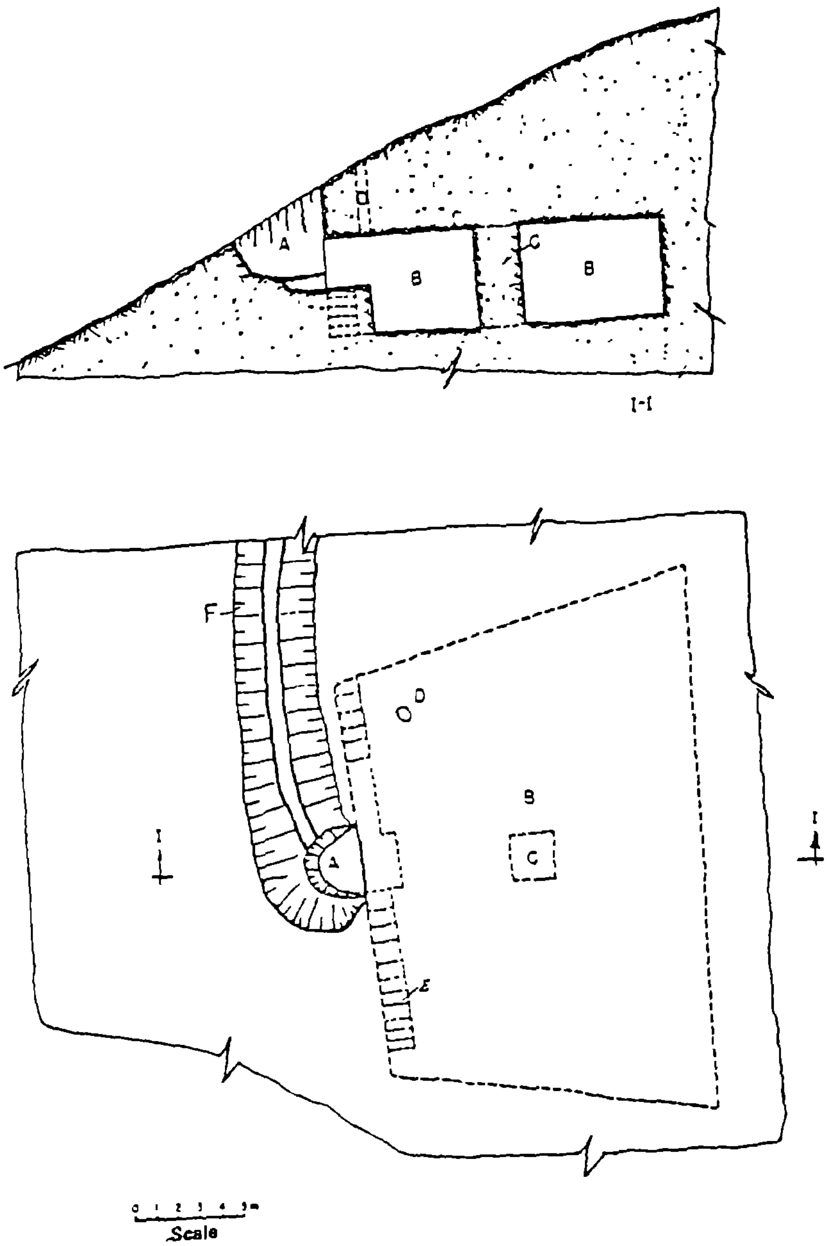
- by trapping or diverting the natural flood occurring in river beds.

The earliest storage was probably provided by natural waterholes or hollows in the beds or banks of wadis where small pools or puddles of water remain after each flood. The desert dwellers must have discovered quite early that they could obtain more water, at least for a short time, by simply digging or chiseling to enlarge small pits or depressions in places where runoff accumulated naturally. Such "pools" were obviously inefficient, subject to seepage and evaporation losses. The inhabitants of the Negev learned how to line the walls and bottoms of their artificial water holes with close-fitting stones, plastered watertight with lime and to cover them with wood and cloth against evaopration. We do not know exactly when such watertight cisterns were developed, though it is known that the technique of "burning" lime to make cement and plaster was discovered as early as the fourth millennium B.C.

The siting of cisterns in the river bed obviously suffered numerous disadvantages, not the least being silting. The next advance in cistern construction involved cutting and quarrying into bedrock outside and away from the river bed. Water being collected and directed off specially smoothed areas of hillside via a system of channels or gutters conveying

FIG. 4

SCHEMATIC CROSS–SECTION AND TOP VIEW OF A HILL SIDE CISTERN



PLAN

A- Entrance
B- Cistern
C- Rock Pillar
D- Hole for Drawing Water
E- Steps
F - Collection channel

the water into a (stilling) basin where some of the silt would settle out before allowing the partly cleared water to enter the cistern. Boulders were arranged around the entrance to the cistern to form a protective circle and to prevent the entry of large animals.

Nearly all of the ancient cisterns in the Negev that are still serviceable were hillside cisterns excavated sideways and into the exposed rock formations of the hillsides, their roofs, walls and floors formed of the bedrock itself (see Fig. 4). Wherever possible, the cistern makers of antiquity shunned the fissured, hard limestone formations in which quarrying was difficult, and chose soft chalk and marble easy to cut into and naturally impervious. In the process of learning how to build cisterns, they had to study the geology as well as the hydrology of their region.

Some of the ancient cisterns, cut in bedrock, are very well preserved and amazing to behold. They vary in capacity from several cubic meters to several thousand. The larger ones are huge underground halls, perfectly dimensioned, with smooth walls and with pillars to support the overburden of the rock ceiling above (see Fig. 4). Crawling into a rock-hewn cistern through one of its narrow openings, the visitor is immediately made aware of the extreme difference between the sun-seared, dry, hot exterior and the dim, dank, cool interior. The floor is often covered with a thick mantle of silt that the Negev dwellers of old must have had to clean out periodically.

To minimize evaporation, each cistern was generally given a minimum of openings: one for water to enter and one for water to be withdrawn. Runoff was directed to the cistern via collection channels, which often led to a stilling basin, the overflow of which entered the cistern proper. The opening for the withdrawal of water was often marked by grooves, cut into the stone facing of the hole by the repeated friction of the sliding ropes that served to raise water.

Where cisterns were situated along the course of a natural riverbed, they were filled directly with the floodwater, often raised by the construction of a stone weir in the natural watercourse, which allowed most of the silt to be left in the river bed.

3.1 Harvesting Runoff

During the rare heavy downpours the natural runoff from the bare hills or loess soils is usually vey small, measurements give values of from 5 to 20 percent of the total rainfall depending on size of catchment, slope of ground, rock outcrops and soil type and depth.

The hillsides of the Negev are naturally covered with loose stones and gravels partially embedded into the soil. This gravel increases the infiltration into the soil and slows any overland flow down the slope.

The Nabatean and Byzantines who inhabited the Negev many centuries ago did more than merely gather the runoff in contour aligned channels cut along the lines of the slopes to intercept and funnel the water into the cisterns. They actually cleared the stones off the slopes and then smoothed the surface exposing finer loess soil with its selfsealing crust. Thereby inducing rainfall to be transformed into useable runoff.

If clearing and smoothing carried out many centuries ago could increase the total runoff, then today using modern cleaning, levelling and compacting machinery (including use of plastic films and water proofing chemicals) we could undoubtably double or even quadruple the 5 to 20% of the winter rainfall harvested by our forefathers. No economic evaluation of these options have been made.

For scale, one hectare of land receiving 100 millimeters of annual rainfall could (at 20% runoff factor) yield a harvest of 200 cubic meters of water enough to suffice for quite a large family.

3.2 Some Recent Small-Scale Experiments on Run-off in the Negev Desert

In the 1960s a number of run-off measuring plots were constructed on a natural desert hillside covered with stones and adjacent to an ancient water cistern collection system.

The experimental plots were each divided by walls into 20 meters long (downslope) by 4 meters wide. At the lower end of each slope a gutter collected run-off, from each plot, and fed it into buried barrels.

A number of surface conditions were compared. The following extreme examples (only) are herein reported.

Plot (a)	- natural conditions, desert covered with strewn stones, (natural slopes of 10% and 20% chosen)
Plot (b)	- bare and rolled, i.e., all stones removed, surface smoothed and wet rolled, (slopes 10% and 20% prepared).

The following annual measurements were made:

TABLE 1

Runoff Figures from Small Experimental Plots

Year	Annual rainfall mm	Run-off collected in mm depth slope 10% (a)	(b)	slope 20% (a)	(b)
1962-63	25.6	1.7	2.2	0.9	0.7
1963-64	152.7	44.7	44.6	36.2	29.8
1964-65	159.8	43.6	52.9	22.9	29.8
1965-66	90.7	23.6	31.5	13.6	17.2
1966-67	69.3	9.5	15.3	4.7	9.2
Average	(99.6)	(24.6)	(29.4)	(15.7)	(17.3)

From the above table a number of inferences can be drawn.

- removing the stones increases the run off from small areas irrespective of slope.
- slope is important factor. The results given in Table 1 show (in general) that the greater the slope, the less the run-off which contradicts the expected results. However this was found to be a local phenonema, due to soil type and depth. It was later found that on the steeper slopes the soil cover was very shallow and that

fissured rock was to be found on the surface or at small depths causing percolation loss. On the more gentle slopes the soil cover was nearly always considerably greater.

The run-off figures measured from small catchment areas (averaging from 15 percent up to 30 percent of the rainfall) are not however representative of larger catchment areas covering many square kilometers of desert, wherein the average figures for runoff (as shown later) are much lower.

4. MODERN WATER HARVESTING IN THE NEGEV

The construction of classical type storage dams with their large open surface reservoirs has in the Negev, not been a feasible proposition, due to three factors:

(a) unpredictable rainfall with an even less predictable runoff

(b) unusually heavy seepage losses in the sandy gravelly soils usually encountered at the reservoir sites

(c) high rates of evaporation from open water surfaces.

However, in many areas of the Negev, groundwater (of varying quality) is often found at reasonably shallow depths. This groundwater has accumulated and stabilised over may thousands of years. Any appreciable abstraction of water from this source would in most instances lead to a rapid depletion in level and quantity of the groundwater as the natural recharge rate is in most cases very small.

In order to increase the slow natural rate of recharge of groundwater, dams have been constructed at a number of experimental sites in order to store the occasional winter floods that occur in major water courses. The sites chosen are adjacent to existing groundwater source, used for irrigation and water supply, exploited at a rate above that of its natural rate of replenishment.

The function of the dam is solely to trap and store flood waters for a short period to enable settlement of suspended solids.

The dams are usually equipped with both service and emergency spillways and outlet structures.

A series of infiltration areas (or pans) are constructed on permeable sites downstream from the dam and fed thereto by gravity. From the pans the water permeates naturally into the underground aquifer.

Monitoring of the infiltration system is carried out, including:

- Rainfall, evaporation, and other meteorological measurements;
- Water level measurements in the dam;
- Measurement of silt settlement behind the dam (carried out in the dry season);
- Measurements to record releases from the dam into the infiltration areas;
- Water level measurement in the infiltration areas.
- Water level measurements in the aquifer.

4.1 Runoff and Rainfall Measurements from Larger Natural Desert Catchment Areas

The author was personally involved in the building of three Negev storage projects built in the early 1950s, these dams, small in size, were constructed more as experiments to study runoff and percolation figures, than as workable projects. From these three dams the following runoff-rainfall statistics measured over a 15 to 20 year period are available:

Shuval Dam - Catchment Area 15 sq.km

Average annual rainfall	268 mm	
Maximum annual rainfall	438 mm	
Minimum annual rainfall	91 mm	
Average annual runoff	270,000 m^3	(7%)
Maximum annual runoff	1,670,000 m^3	(42%)
Minimum annual runoff	nil	(0%)

Grar Dam - Catchment Area 54 sq.km

Average annual rainfall	255 mm	
Maximum annual rainfall	490 mm	
Minimum annual rainfall	76 mm	
Average annual runoff	605,000 m^3	(4%)
Maximum annual runoff	3,798,000 m^3	(27%)
Minimum annual runoff	nil	(0%)

Yerucham Dam - Catchment Area 120 sq.km

Average annual rainfall	99 mm	
Average annual runoff	284,000 m^3	(2.4%)

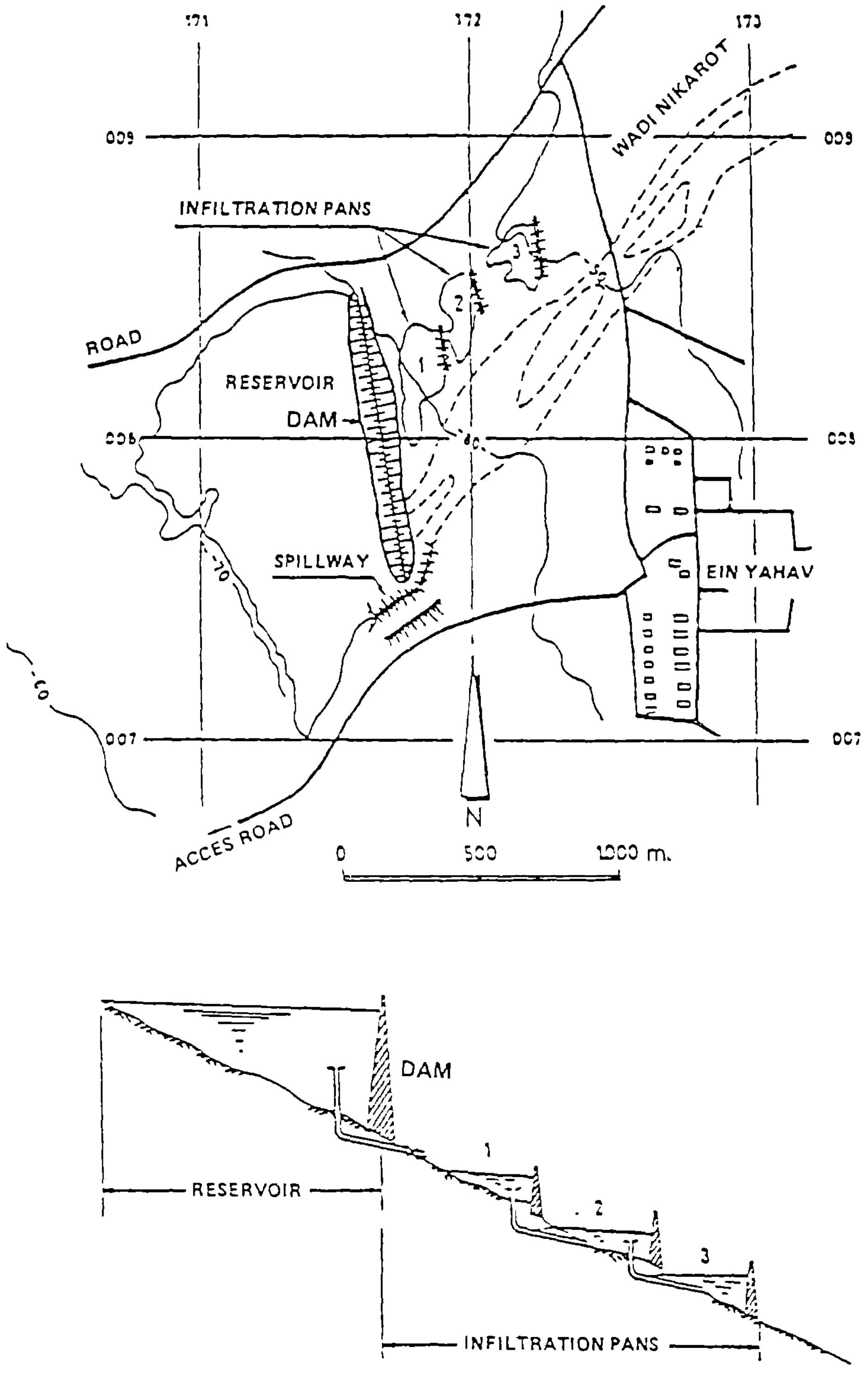
A typical schematic layout of an aquifer recharge scheme is shown in Fig. 5. This scheme (Nikarot Project) is located some kilometres south of the Dead Sea and has an annual average rainfall of 100 mm.

The project was built in 1975. The dam 13 meters high, was constructed from local available gravel material found in the river bed, and has a storage volume of 4 million cubic meters. The service spillway is designed to accommodate the 1 in 100 year flood (700 m^3/sec reduced to 350 m^3/sec by routing) whilst an emergency spillway (two meters below dam crest) could pass an additional 200 m^3/sec, without overtopping the dam.

FIG. 5

THE NIKAROT PROJECT

SCHEMATIC PLAN AND SECTION



An exceptionally good year of operation was 1980/1981, when the following measurements were made:

TABLE 2

The Nikarot Project

- Total runoff (stored) behind the dam	4,170,000 m^3	
- Total volume lost by evaporation		
- behind dam	670,000 m^3	
- infiltration pans	100,000 m^3	
Net available water		3,400,000 m^3
Percolation into river bed and aquifer from behind dam	1,770,000 m^3	
Infiltration into aquifer from pans	1,630,000 m^3	
TOTAL volume of infiltration water		3,400,000 m^3

The average volume of net infiltration water over the years has however been less than 1 million meter cube. The local tube wells sunk in the vicinity were designed to supply 1 million meter cube a year. During the 1960's these wells had led to an ever decreasing level of the existing aquifer. Since 1975 the level of the aquifer has stabilised considerably.

Acknowledgements and References

Much of the original research into the runoff and ancient water cisterns in the Negev was carried out by Messrs Evanari Shanan and Tadmor and recorded in their book "The Negev - The challenge of a Desert".

PLANNING

LABORATORY EXPERIMENTS ON
EFFICIENCY OF FOUL FLUSH DIVERSION SYSTEMS

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ABSTRACT

Laboratory experiments on the efficiency of foul flush diversion systems to be used in roof catchment rainwater supplies were carried out at Dundee University in 1985. Devices that collect the initial rainwater flush, and once are full act on the principle of overflow were tested: their efficiency in not allowing the suspended matter of the initial flush to enter reservoir storage was examined. The diverters used were full-scale models of three box-shaped and three pipe diverters. Assuming that (a) the first flush in a rainfall event is foul and is equal to the capacity of a diverter, and that (b) the subsequent flow is clean water, then it was proved that one of the pipe diverters is the most efficient design.

INTRODUCTION

Roofs accumulate pollutants during dry periods. The first run-off from a roof at the start of a storm carries with it the maximum concentration of dirt from the roof and gutter. This highly polluted element of the flow is known as the foul flush. It is essential that this foul flush is consistently prevented from entering storage and contaminating the water body. Diversion or separation of the foul flush is an important component of rainwater harvesting.

Full scale field studies of the variation of water quality off catchment roofs throughout the period of rainfall events can determine how much of the initial flush is to be diverted from storage.

No work has been done by any researcher to investigate the operation of foul flush systems and to optimise their design. This is the subject of the investigation that is described below.

SCOPE OF EXPERIMENTS

Foul flush mechanisms may be distinguished as:

(a) Devices that (if properly operated) fully separate the initial and subsequent rainfall; the movable downpipe, the diversion valve, the floating ball, the twin funnel, and trough pivoting are included in this category **(MICHAELIDES and YOUNG, 1984)**.

(b) Devices that collect the initial flush, but once are full, they act on the principle of overflow; these are the foul flush containers, simple or baffled.

What the devices of the first category can achieve is predictable: they fully separate the initial (which is "foul") and subsequent rainfall. Thus, there is no need to investigate how they operate. In this paper, the efficiency of the devices of the second category in not allowing the suspended matter of the initial flush to enter storage is examined. In other words, the objective of most experiments that were carried out, was optimising the efficiency of systems of the second category so as to approach as much as possible the efficiency of systems of the first category.

The experiments were carried out in the laboratory under similar conditions. In most experiments, an amount of "foul flush" equal in volume to that of the "diverter" filled the "diverter", and then only "clean" water flowed. Several designs of foul flush diverters were tested. The basic criterion of effectiveness was to carry as little of the foul flush (collected in the foul flush mechanism) into the storage tank.

VARIABLES

Each experiment carried out resembled a single rainfall event. The variables in a rainfall event are: (a) the total rainfall amount (volume), (b) the intensity (flow rate), and (c) the particulate matter. These were the variables employed in each experiment.

Volume

The experiments were designed to model a roof catchment area of $40m^2$ and roof runoff coefficient of 0.8. These values were selected because they are the design dimensions of the idealised rainwater harvesting system that was built by the author (for experimentation on water quality aspects) in Reduit, Mauritius. This system is a model of that which might be used to supply water for domestic use in a rural area of a developing country, not specifically Mauritius. Noting that Volume = roof area X runoff coefficient X rainfall, the volume varied as V1=64 litres, V2=160 litres, and V3=224 litres representing rainstorm events of 2,5 and 7 mm respectively. These rainstorm events were chosen because in Reduit, 0.3-8 mm are very common in most months of the year: 100% of rainfall events in October 1984 were of this range; 92% in November, 67% in December, 56% in January 1985, 31% in February, 70% in March, 82% in April, 100% in May, 86% in June, 91% in July, 96% in August and 86% in September 1985. It should be noted that these values are based on daily rainfall statistics rather than single rainfall events. Thus percentage values listed above would be higher if single rainfall events were considered.

Flow

Two different types of water flow were used in the experiments: a flow of "foul" water and a flow of "clean" water . The foul water flow represented the initial flush of foul water and the clean water flow the subsequent rainfall in a rainstorm event. The flow of clean water varied as $Q1=41.07 \times 10^{-3}$ litres / second (4.6 mm/hr), $Q2=68.21 \times 10^{-3}$ l/s (7.7 mm/hr) and $Q3=96.43 \times 10^{-3}$ l/s (10.8 mm/hr) or readings of the flow meter (size 18) used of 5, 10 and 15cm respectively. The highest flow (Q3) is based on a single rainfall event, quoted from a foul flush investigation in England **(WHEELER and LLOYD, 1983)**. Unfortunately, no rainfall intensity records in Mauritius could be identified. The flow of the foul water of each storm varied as 56.5×10^{-3} l/s (6.4 mm/hr) and 30.6×10^{-3} l/s (3.4 mm/hr) or readings of the flow meter (size 14) used of 28cm and 15cm respectively. The flow rate of foul flush does not really matter much because the main purpose of the experiments is to consider how the subsequent flow (once the diverter is full) affects the contents of the diverter. The flow of each type (foul or clean) of water was kept constant throughout each experiment for the sake of simplicity.

Particulate Matter

The input of the particulate matter depends on the length of the dry period, local factors and maintenance practices for catchment systems. Only one relevant record was identified. In the Kuala Lumpur-Petaling Jaya area of Malaysia (**IRISH, 1980**) it was found that the particulate fallout was generally less than 10 grams per m^2 roof area per month, and was assumed that for most sites the quantity will be less than half this amount, especially in rural areas. This figure was used in the experiments. Because it is the only quantitative value available it should not be considered as absolute. The results of the experiments would not be affected because the measurements obtained would be comparative. The experiments were performed for 1,3 or 5 dry days by putting 6.6,19.8 and 33.0 grams (or 586, 1757 and 2928 mg per litre of water) of suspended matter respectively in the amount of the water (11.3 litres, which is the capacity of a diverter) which was then termed "foul".

In Reduit, Mauritius there were only 3 out of 44 dry periods (dry period = at least one day without any rainfall) that the dry period lasted more than 5 days in the period November 1984 to October 1985.

In most experiments, the foul flush volume is defined by the volume of diverter because the basic aim of the experiments is to assess to what extent various diverter designs can separate the initial (foul flush) from the subsequent rainfall. In some experiments, however, the foul flush volume was varied.

The capacity of a diverter is 11.3 litres because that is roughly the same capacity as that of the diverter installed by the author in Mauritius. Since there has been no extensive research on how much foul flush to discard, the capacity of the diverter was based on what was built in N.E. Thailand (**POWER, 1983**), a place of similar annual rainfall to Mauritius, and similar pipe diverter as the one that was built by the author in Mauritius. Due to the generally small dry periods in Mauritius, the diverter capacity was kept rather small. Even if there were a long dry period, cleaning the catchment surface before the first rainstorm of the rainy season, would have been enough to avoid the need for a larger diverter capacity.

SYSTEM ARRANGEMENT

Water Tanks And Flow Meters

Two tanks were employed, one to contain the "clean" water and other the "foul" water.

Two Rotameter flow meters were used. The Rotameter Tube size 18 with float type S was used to measure the flow of "clean" water and the Rotameter Tube size 14 with float type S was used to measure the flow of "foul" water. The flow meter was read in cm of tube reading which was converted to flow units by using a calibration chart.

The water tanks, the flow meters and the foul flush apparatus were joined by plastic hoses. The water tanks were placed at a higher level than the flow meters and the foul flush apparatus so that the water can flow through gravity.

Foul Water Preparation

The particulate matter in a real rainfall event is a complex variable from place to place. The substance used to make water "foul" was PVC polymer to give a model suspension. This powder and water were mixed using a stirrer that was incorporated within the "foul" water tank. The stirrer was "on" throughout the flow of foul water. The characteristics of suspension proved satisfactory in that it did settle with time; settlement was neither too quick nor too slow.

FOUL FLUSH MECHANISMS

Three pipes and three box systems were manufactured in full scale. These are shown on figures 1, 2 and 3 and the following:

Type A: Pipe diverter of capacity 11.3 litres

Type B: Pipe diverter of capacity of vertical component 11.3 litres and of horizontal component 2 litres.

Type C: Box diverter with horizontal baffle and capacity 11.3 litres.

Type D: Box diverter with vertical baffle and screen and capacity 11.3 litres.

Type E: Box diverter with horizontal baffle and capacity 11.3 litres below baffle and 2 litres above baffle.

Type A is comparable to Types Aa, C and D, and Type B to Type E in terms of capacity.

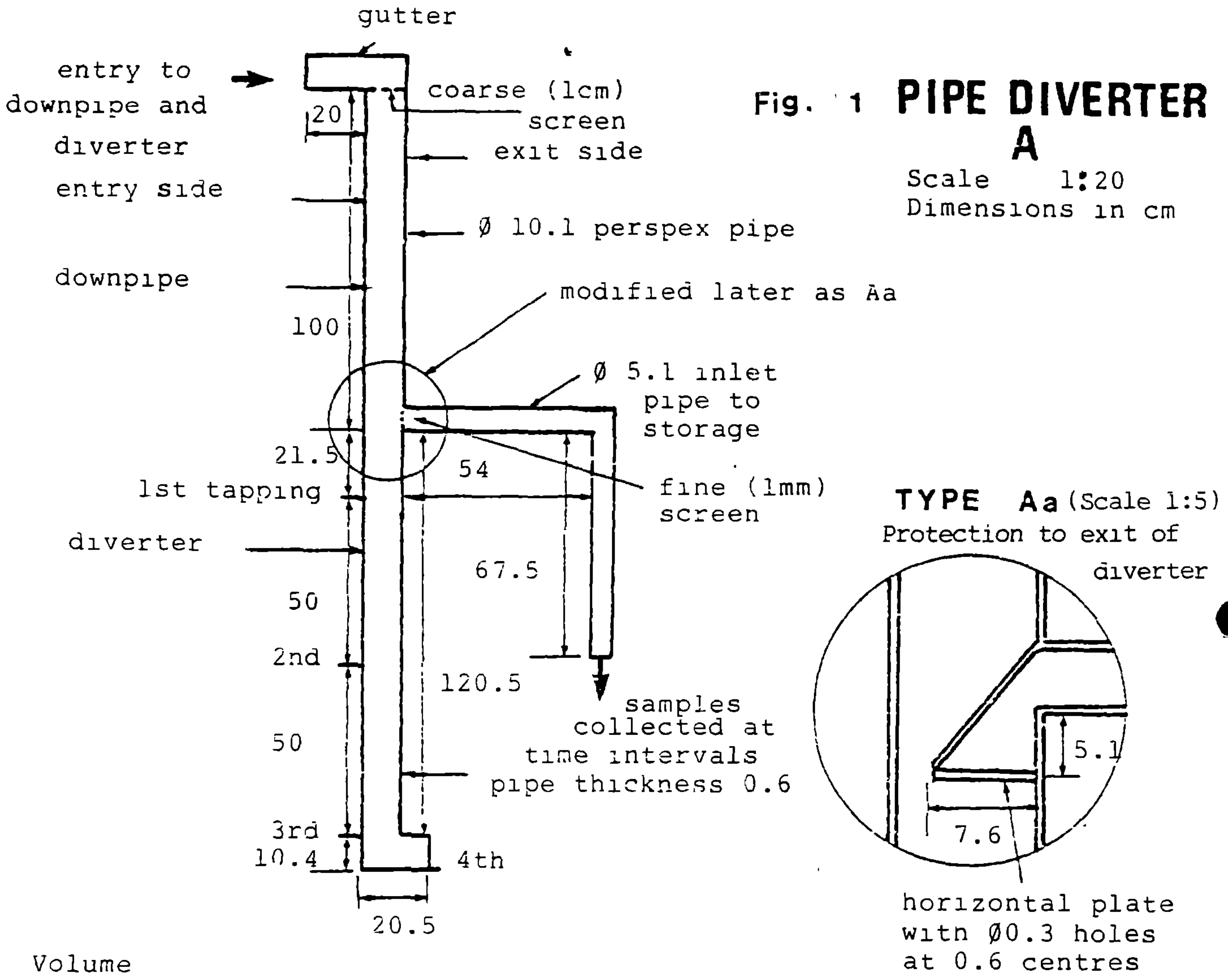
SAMPLING AND TESTING

Samples of water pouring out of the foul flush mechanism's exit were collected at 0, 2, 5, 10, 20 and 30 minutes depending on the duration of each experiment. For every experiment time 0 was taken as the water began to overflow from the diverter. Samples were also collected from the bottom of the diverter (fourth tapping) and three other tappings (Figures 1, 2 and 3) along its depth at the end of each experiment. Sampling from the diverter assisted in evolution of the design of diverters.

Each sample collected was 400 millimetres and was examined for turbidity. The Laboratory Turbidimeter Model 2100A of the Hach Company was used to determine

Fig. 1 PIPE DIVERTER A

Scale 1:20
Dimensions in cm



Volume of diverter = 11.3 litres
= 11.5 litres when functioning

Fig. 2 PIPE DIVERTER B

Scale 1 : 20
Dimensions in cm

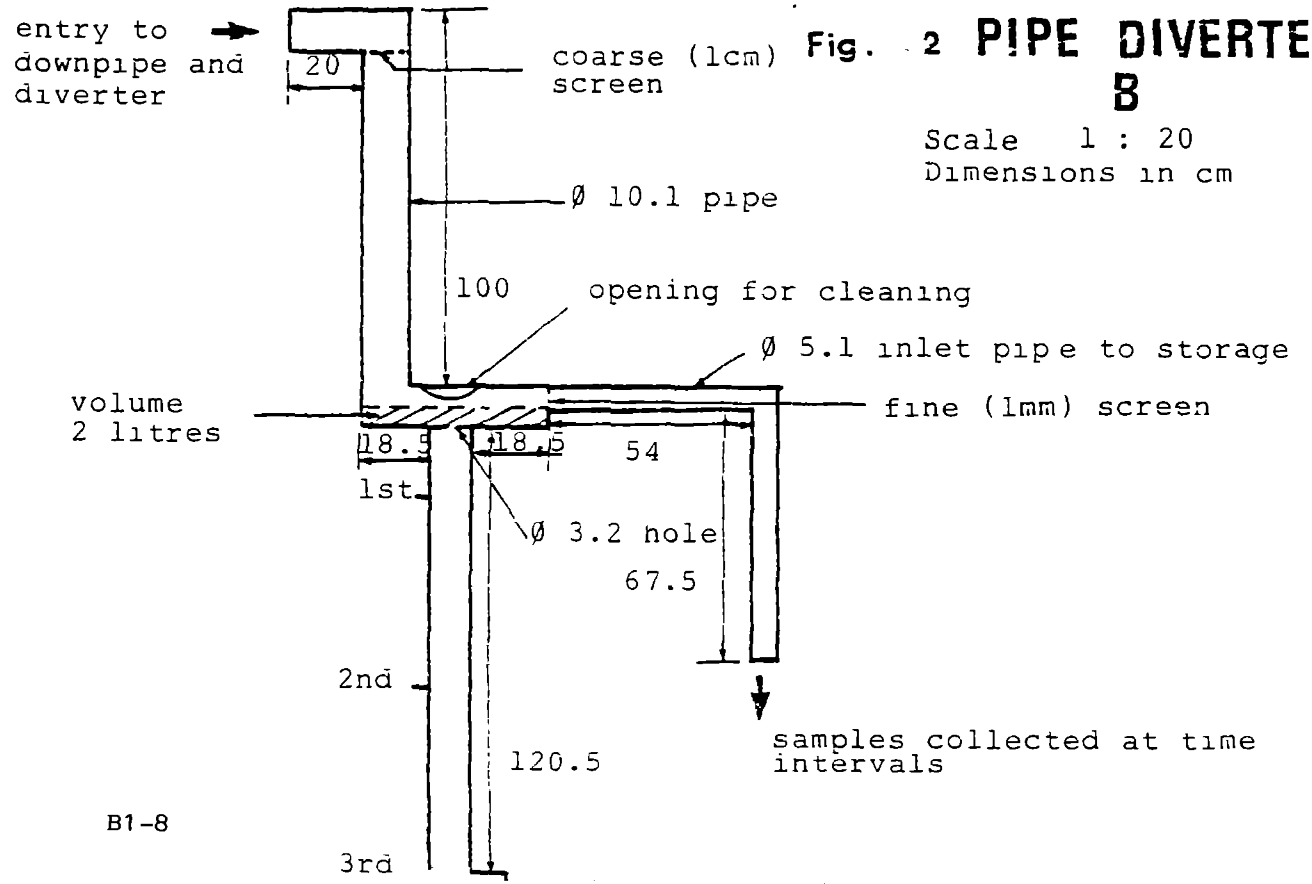
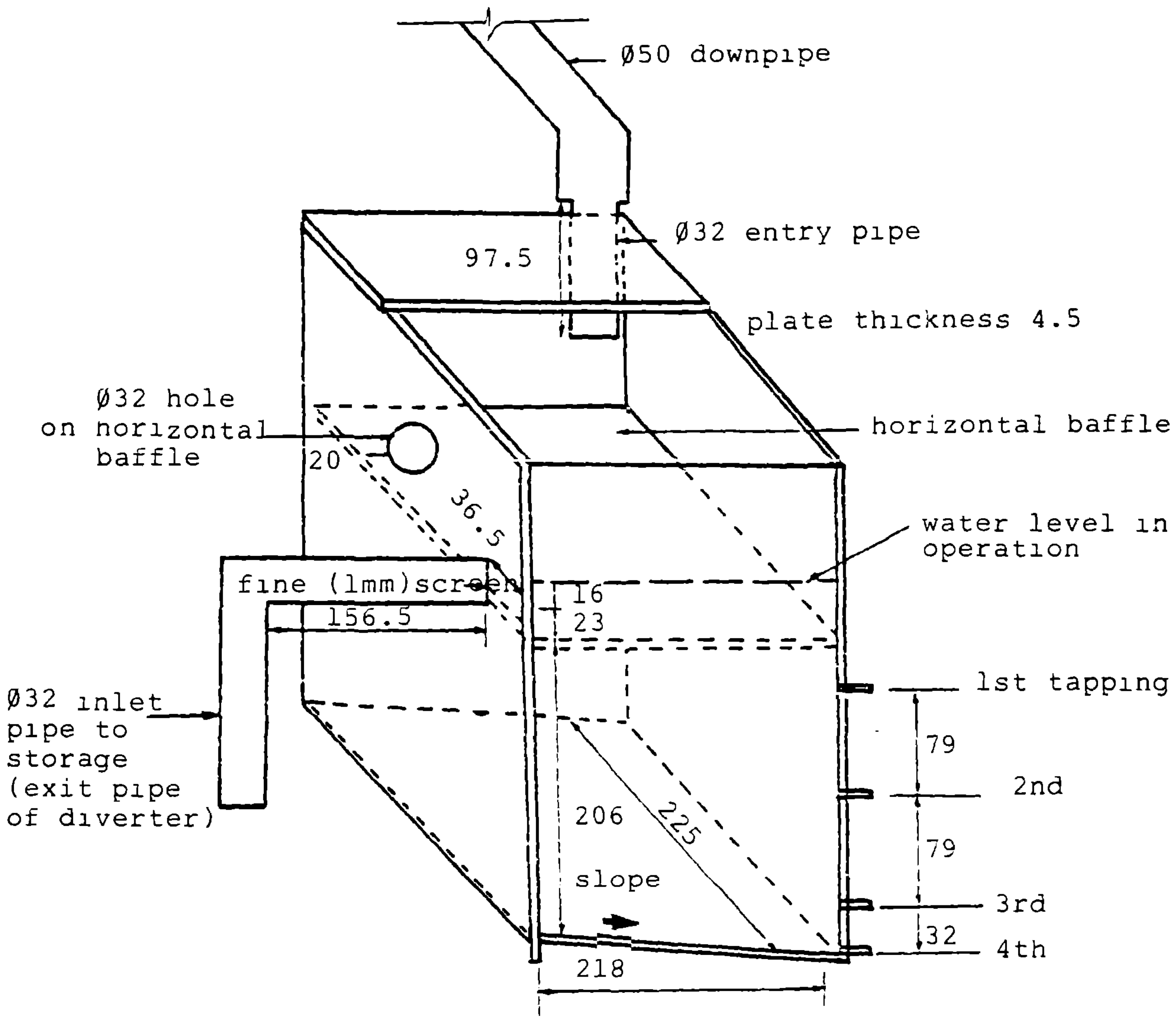


Fig. 3 BOX-SHAPED DIVERTERS

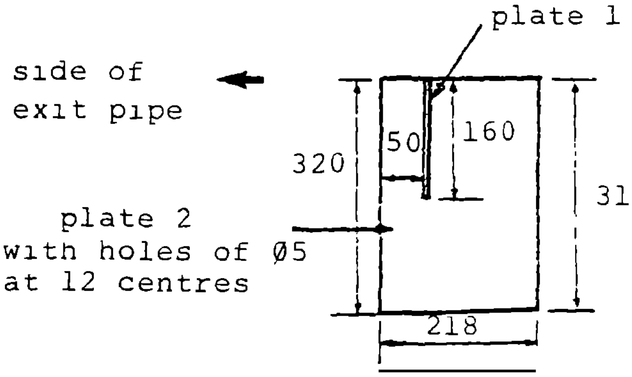
Scale 1:5 Dimensions in mm



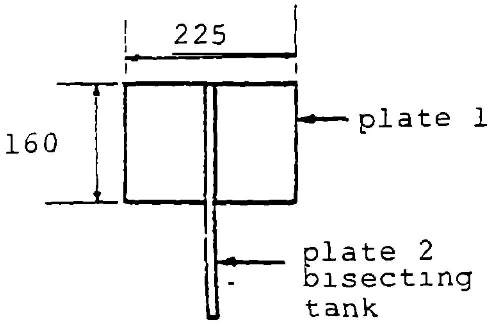
Type C diverter: as shown above

Type E diverter: as shown above but with horizontal baffle raised by 21mm and exit pipe (inlet to storage) by 40 mm.

Type D diverter: as shown above but with two vertical baffles instead of a horizontal one, as shown below:



FRONT VIEW
Scale 1:10



SIDE VIEW
Scale 1:10

turbidity in FTU units.

PROGRAMME AND CHARACTERISTICS OF EXPERIMENTS

The experimental procedure was as follows. Initially, the diverter was filled fully with foul water, with the exception of some experiments where the foul flush volume varied and only a proportion of the total diverter volume was filled with foul water. Then, only clean water procedure were: (a) an experiment for each type of diverter with foul (11.7 litres) and clean water both running from the beginning; they ran simultaneously for as long as the foul water lasted and then only clean water was running: (b) an experiment for each type of diverter in which no clean water was run in order to test how quickly the powder used settles by collecting samples from the diverter tappings at 0 and at 20 minutes. The results showed that the powder settles gradually to the bottom of the diverter.

During and at the end of each experiment, several other measurements and observations were made. The level of water above the horizontal baffle (Diverter E) and the level of the water above the junction between the vertical pipe diverter and the horizontal pipe component (Diverter B) were measured during and at the end of each experiment. The levels were converted into capacities.

The visual level of the foul water in the diverter as examined at the end of each experiment was measured and expressed as a proportion of the total diverter capacity, though, in many cases there was no distinct level. Observations were made on the scum, the turbulence of water, how water was falling in the downpipe (Diverters A, B) which was dependent on the flow, and when water above the horizontal baffle was clearing (Diverter C).

How well the diverter was cleaned before each experiment could have some effect on the results. The box diverters (C and E) were cleaned thoroughly unlike the pipe diverter A. Pipe diverter B was easier to clean than A, because of a cutting made at the top of its horizontal component, especially to achieve access at the upper parts of the diverter for cleaning purposes.

RESULTS AND DISCUSSION

Evolution Of Design

The experiments for each type of diverter were performed in the following chronological sequence: A, Aa, D, C, E and B. This sequence was not accidental. The detailed design of each type of diverter was developed on the way depending on the results and observations obtained from the previous types of diverters tested.

The first design tested was pipe diverter A which is the same as the one incorporated in the project in Mauritius. Based on the laboratory results, this diverter may be considered as reasonably successful. What was not anticipated, however, when the Mauritian project was being designed (built before laboratory tests) was how the water falls in the downpipe. There may be water escaping to the storage tank before the diverter was filled. It was observed during the experiments that the way water falls in the downpipe depends on the flow of water: for higher flows, the water finds its way out into the exit pipe easier. When foul water flows, any passage of foul water through the exit pipe is undesirable. When its flow is 30.6×10^{-3} l/S (indication of 15 cm by flowmeter), the water falls in downpipe towards the entry side, but when its flow is 56.5×10^{-3} l/s (indication of 28 cm by flowmeter), then some water passes through the exit pipe (roughly 1.5 litres of foul water) before the diverter is filled. To overcome this problem, diverter A was redesigned as diverter Aa (Fig. 1). This modified design was tested and no foul water was lost before diverter overflow.

The next design test was box diverter D. Various positions of the vertical screen and baffle in the box were investigated. This design proved to be markedly inefficient.

A horizontal baffle is required in a box diverter to avoid the failure of diverter D. Thus, diverter C was designed. It was observed that the water above the horizontal baffle clears relative to the variables in each experiment: quicker at higher flows of clean water and slower at higher concentrations of particulate input. The 3cm diameter opening in the horizontal baffle proved to be unnecessary during the initial filling of the diverter with foul water because the sides of the horizontal baffle were not glued on to the walls of the diverter (so that it can slide in and out). During each experiment, some foul water was being resuspended from below the baffle through this opening.

At that stage, diverter D was eliminated as inappropriate. On the whole, diverter C proved to be more effective than A when comparing turbidities of water at exit and from the first tapping of the diverter; diverter A proved to be more effective (meaning in the case of diverter readings: higher turbidities) than C for water from the 2nd, 3rd and 4th tappings of the diverter. These results (turbidities at exit) are explained by the fact that a horizontal baffle was incorporated in diverter C. A pipe diverter, however, would be better in keeping foul water within it and especially at its lower parts and not allowing foul water to overflow. Turbidity readings of diverter samples were taken especially to contribute in the development of designs. Thus an improved pipe diverter was conceived with a barrier at its top (similar to the horizontal baffle of diverter C) plus a horizontal component on top of the vertical pipe, so as to avoid turbulence at the overflow point and to avoid the effect of the way water falls in the downpipe. The improved design is Type B. To compare the pipe diverter with the box diverter, diverters B, and E were designed and tested.

During experiments with diverter B, the turbulence and the way water was falling in the downpipe depended on the flow. It must be emphasized that there is no turbulence at all in the vertical component of the pipe diverter in any experiment, as desired.

Comparison Of Diverters

Evaluation of results means primarily comparison of designs. Summarised results are shown on Tables I and II. A diverter is considered more "efficient" than another diverter if the turbidity (sum of turbidity results from various experiments as shown in tables) of the water that comes out of its exit is less as compared to that from another diverter. In contrast, it would be desirable for a diverter to retain along its depth as much turbid water as possible (in this case higher turbidities are desirable) rather than to allow it to overflow into the storage tank. Ratios of sum of turbidities of diverters at time intervals from exit of diverter are less than 1.0 if the diverter shown in the numerator position is more "efficient" than the diverter shown in the demoninator position. The opposite is true for turbidities along depth of diverter. What is really important in the comparison exercise, is turbidities from the exit of diverter.

Accoring to Table I, diverter B is more efficient than diverters A, C and E; E is better than A (with the exception of turbidities at the 3rd and 4th tappings) and C; and C is better than A with the exception of turbidities at the 2nd, 3rd and 4th tappings. The lowest ratios are: B/A, B/C, E/A, E/C at 0 minutes; B/A, E/A,

TABLE I. SUMMARISED RESULTS AND COMPARISON OF DIVERTERS

	Sum of Turbidity results of experiments (except: no clean water flow; clean and foul simultaneously)									
	Type of Diverter				Ratios					
	A(a)	B	C	E	B/A	C/A	E/A	B/C	B/E	E/C
At0'	3035	396	2274.5	617	0.13	0.75	0.20	0.17	0.64	0.27
2'	581	59	196	154.5	0.10	0.34	0.27	0.30	0.38	0.79
5'	297.5	47	125.5	98	0.16	0.42	0.33	0.37	0.48	0.78
10'	160	39.5	102	79.5	0.25	0.64	0.50	0.39	0.50	0.78
20' (b)	92	30	73	53	0.33	0.79	0.58	0.41	0.57	0.73
30' (c)	67	21.5	44	39.5	0.32	0.66	0.59	0.49	0.54	0.90
1st tap	121	1695.5	477.5	660.5	14.01	3.95	5.46	3.55	2.57	1.38
2nd tap	1077	2292	809	1082	2.13	0.75	1.00	2.83	2.12	1.34
3rd tap	1555	2512	1210	1288.5	1.62	0.78	0.83	2.08	1.95	1.06
4th tap	2543	3687	1607.5	1617	1.45	0.63	0.64	2.29	2.28	1.01

(a) = For experiment V_2Q_2 with foul flash flow 28, the result from diverter was used since water was lost in diverter A.

(b) = 7 and 10 experiments; (c) 5 and 8 experiments

Table II Summarised results and comparison of diverters for each experiment

eriment			Sum of Turbidities of each experiment at time intervals from exit of diverter										Sum of Turbidities of each experiment along depth of diverter									
			Type of diverter				Ratios						Type of diverter				Ratios					
flow	Particulate matter	Volume and flow of clean water	A	B	C	E	B/A	C/A	E/A	B/C	B/E	E/C	A	B	C	E	B/A	C/A	E/A	B/C	B/E	E/C
	1757	V_1Q_1	337.3	47.3	163.8	94.8	0.14	0.49	0.28	0.29	0.50	0.58	639.5	954	472	518.5	1.49	0.74	0.81	2.02	1.84	1.10
		V_1Q_2	274	27.3	154	61.5	0.10	0.56	0.22	0.18	0.44	0.40	583.5	995	658.5	551	1.71	1.13	0.94	1.51	1.81	0.84
		V_1Q_3	189	27	173	73.1	0.14	0.92	0.39	0.16	0.37	0.42	784.5	1060	690	660	1.35	0.88	0.84	1.54	1.61	0.96
		V_2Q_1	443.6	58.1	270.3	138	0.13	0.61	0.31	0.22	0.42	0.51	244	748	148	258	3.07	0.61	1.06	5.05	2.90	1.74
		V_2Q_2	255.9	60.8	200.1	146.5	0.24	0.78	0.57	0.30	0.42	0.73	585.5	768	254.5	343	1.31	0.43	0.59	3.02	2.24	1.35
		V_2Q_3	224.6	62.5	189.8	88.2	0.28	0.85	0.39	0.33	0.71	0.46	604.5	583	279.5	381.5	1.41	0.46	0.63	3.05	2.24	1.36
		V_3Q_1	449.4	70.2	179.3	123.6	0.16	0.40	0.28	0.39	0.57	0.69	107.5	693.5	187.5	214	6.45	1.74	1.99	3.70	3.24	1.14
		V_3Q_2	449.1	65	191.5	129.7	0.14	0.43	0.29	0.34	0.50	0.68	169	826	274	253	4.89	1.62	1.50	3.01	3.26	0.92
		V_3Q_3	279.6	70.6	242	120.4	0.25	0.87	0.43	0.29	0.59	0.50	304	823	204.5	383.5	2.71	0.67	1.26	4.02	2.15	1.88
		clear and foul V_2Q_2	328.1	408.6	382.5	324.7	1.25	1.17	0.99	1.07	1.26	0.85	197.5	357.5	94.5	86.5	1.81	0.48	0.44	3.78	4.13	0.92
		V_2Q_2	Aa 397.5	60.5	214.6	85.5	0.16	0.57	0.23	0.28	0.71	0.40	Aa 366.5	897	292	504	2.45	0.80	1.38	3.07	1.78	1.73
	586	V_2Q_2	164.9	77	152.7	117.9	0.47	0.93	0.71	0.50	0.65	0.77	121.5	274	53.5	50	2.26	0.44	0.41	5.12	5.48	0.93
	2928	V_2Q_2	475	56	266	128.4	0.12	0.56	0.27	0.21	0.44	0.48	782	1295	590	531.5	1.66	0.75	0.68	2.19	2.44	0.90

Note : Sum of turbidities at time intervals obtained by adding turbidities at 1,3,5,7.... up to 29 minutes.

B/C, C/A, B/E at 5 minutes; B/A, B/C at 10 minutes; B/A, B/C at 20 minutes; B/A, B/C at 30 minutes. On average, the greater the time interval, the higher the ratio (the efficiency of the one diverter over another is less distinct).

On Table II results are summarised for each experiment. The greater the particulate matter, the smaller the ratio comparing diverter turbidities (the efficiency of one diverter over another is more distinct) at time intervals. On average, the ratios of diverter turbidities at time intervals increase in this order: B/A, B/C, E/A, B/E, E/C and C/A, that is, the greatest improvement in efficiency is that of diverter B over A and the least that of C over A. These is no trend that depends on the flow and total time an experiment lasts for. On average, however, the greater the flow, the greater the ratio is (averaged over all experiments and all diverter ratios). It is also observed that ratios are higher for medium lasting (25 to 40 minutes) experiments. As concerns turbidites along depth of deverter, on average A is more efficient than E and C, and C is more efficient than E in keeping foul water in the diverter.

It should be noted that although all diverters are initially filled with the same amount of foul water in the main experiments, the total capacity (including space above barrier) of diverters E and B is greater of water above the baffle in diverter E is greater by a factor of 1.17 on average than the amount of water in the horizontal component of diverter B during experiments. This difference, however, is partly an inherent feature and an advantage of one system over another.

According to table I, the diverters are classified in order of merit as follows if the criterion is low turbidity of water from exit of diverter:

(1) Diverter B (least turbid)
(2) Diverter E
(3) Diverter C
(4) Diverter A

RECOMMENDATIONS

The aim is to design an efficient system which will also be of minimum complexity.

For each individual rainstorm, a different diverter volume is required. If the volume of the initial flush of rainwater to be diverted were constant (as is the case for the type of diverters studied in this article) clean water would be lost in some rainstorms or foul water would flow to the storage tank in other rainstorms.

Assuming that after overflow of the diverter, all the subsequent flow is clean water, then it has been proved that pipe diverter B and box diverter E are the most efficient designs.

Diverter B can be cleaned via: (a) an opening in the horizontal component of the pipe which is on top of the junction between vertical and horizontal pipes; this opening was incorporated in experimental design; to facilitate further in cleaning the whole diverter, the plate dividing the vertical and horizontal components of the diverter could be made removable if connected to the cover of the opening which is situated above it; (b) a plug at the bottom end of the diverter.

The box diverter should incorporate (as in experimental design) a sliding baffle so as the baffle could be removed and the diverter and the baffle itself be cleaned. The entry pipe should enter the diverter through a diverter wall so as to be able to remove baffle when required.

In the box diverter there are gaps around the sliding horizontal baffle. The diverter is filled with foul water through these gaps. Additionally, there is a 3cm diameter hole in the baffle. Field studies would determine whether this hole is needed.

To avoid blockage there should be no screen between any diverter and the exit pipe.

Whichever type of pipe diverter (A, Aa, or B) is used, and especially if B is used, it would be less expensive to give a bulk order of diverters at a factory to manufacture complete pipe diverters rather than put together expensive pipe connectors like tees, reducers and elbows.

FIELD APPLICATION

Pipe diverter "A" was the method of diversion in the rainwater harvesting system built by the author in Mauritius in September 1984. The rainwater as collected in various water quality parameters (**MICHAELIDES et al, 1986**). Based on the results of the laboratory experiments (described in this article) that were performed in February-June 1985, the system in Mauritius was changed by installing a Pipe diverter "B" in October 1985. It is believed that bagasse (a problem in Mauritius) and light suspensions in a real situation would behave in a similar manner to the powder employed in the laboratory experiments.

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FRESHWATER STORING BY THE KARL DUNKERS'S METHOD

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ABSTRACT

In arid and semi-arid regions as well as in some parts of the Swedish archipelago, there are periodical shortages of drinking water. In order to ensure a constant supply of freshwater in these regions there is a need to store water. The Swedish inventor Karl Dunkers has developed three operational systems for the collection, storage and conservation of rainwater. Each of these systems contains storage elements, simple treatment units and circulation facilities. Collected rainwater is constantly kept in circulation through the treatment unit, thus remaining fresh for infinite periods of time.

The Department of Water Resources Engineering is involved in the development and testing of Karl Dunkers's storage systems. Since the technique of storage water according to Karl Dunkers's method is new, several questions about its hydraulic and hydrologic functions must be answered. The method must be adapted to local conditions before fresh water can be produced in a cost-effective manner.

A full-size installation for storing and treatment of rainwater from roofs has been built during the spring of 1985 on the island of Värmdö just outside the city of Stockholm. The storing unit consists of two tanks, 21 m^3 each, equipped with an external circulation system. The circulation system consists of circulation pumps, sand-anthracite filters and sodium hypochlorite dosing pumps.

This paper gives a general description of Karl Dunkers's method and presents the details of the research program aiming at testing the hydraulic and hydrologic function of the installation on the island of Värmdö.

INTRODUCTION

In many countries in the world there are unprecedented sufferings due to lack of drinking- and irrigation-water. Many diseases are caused by infected water. An adequate amount of water of sufficiently good quality, available the year round, is a necessity for a reasonable standard of living. All over the world there is a need of storing water on a seasonal as well as on a yearly basis in order to guarantee water availability for different types of use.

Water problems are often related to climate conditions and land use. Periods without precipitation can be extremely long and can be followed by periods with a very high amount of precipitation. Another problem is that the prevailing urban water management does not include sufficient water treatment, which means that there are big risks of degradation of the water quality.

Even in Sweden lack of water can periodically be a problem. The problem arises mainly in the Swedish archipelago, along the coast, and on the large islands of Gotland and Öland. Periodically water is supplied by tankers or trucks in these regions. The lack of water is usually caused by long periods of drought together with excessive pumping of ground water. Excessive ground water exploitation in costal zones leads to salt water penetration into the aquifers.

The method of collection, storage and conservation of rainwater, put forward by the Swedish inventor Karl Dunkers, is now being tested at the Department of Water Resources Engineering, University of Lund. The method eliminates some of the shortcomings associated with the traditional way of collecting and storing rainwater, thus promising a solution of acute water shortage problems in drought regions. According to Dunkers, reservoirs for the storage of rainwater can be situated on land or at sea. The land-based storage consists of underground plastic tanks or concrete basins. Storage at sea consists of floating tanks with flexible sides which float on the water. Due to the difference in density between fresh- and saltwater the containers do not have to have a fixed bottom.

Dunkers's idea has great potential for further development and it can be modified for numerous areas of use.

A land-based test plant has been constructed at Värmdö just outside Stockholm. Water has been collected from roofs, to be purified and used as drinking water. A model of the sea-based storage system has been tested in the laboratory. A full-scale sea-based plant has been funded and will be installed in Sweden during the later part of 1986.

Both types consist of three parts:

- A collection system
- A storage system
- A treatment unit

THE WATER COLLECTION SYSTEM

For the collection of surface water or rainwater there are four main types of construction:

1) Rainwater from roofs can be collected
2) Cracks can be stopped up and smoothed out on a rock-side so that the water can be caught by edgings and chutes
3) Hillsides can be covered by plastic sheets facilitating the collecting of rainwater
4) Water from rivers is collected and stored

One of the problems with rainwater collection from open surfaces is how to avoid or minimize water pollution.

Obviously the materials used are of importance for the water quality. The run-off pollutants from the relevant areas must be controlled. Painted sheeting on the roofs, copper sheets and rainwater pipes can release heavy metals and thus contaminate the water. If the collecting area is located near trees, leaves, seeds and needles it will affect the water quality. Insects, worms and other animals can also cause a degradation of the intake water quality. Therefore a coarse screen must be mounted where the water enters the collection pipe system. When the collection area is a roof, coarse boxes can be located on the wall. The coarse screen boxes must be easy to clean, as this must be done at least after every heavy rain. In areas with a lot of birds it may be necessary to use some kind of scarecrow so that the bird droppings will not pollute the water. Roofs can be in series and the rainwater led to a central tank, see Figure 1.

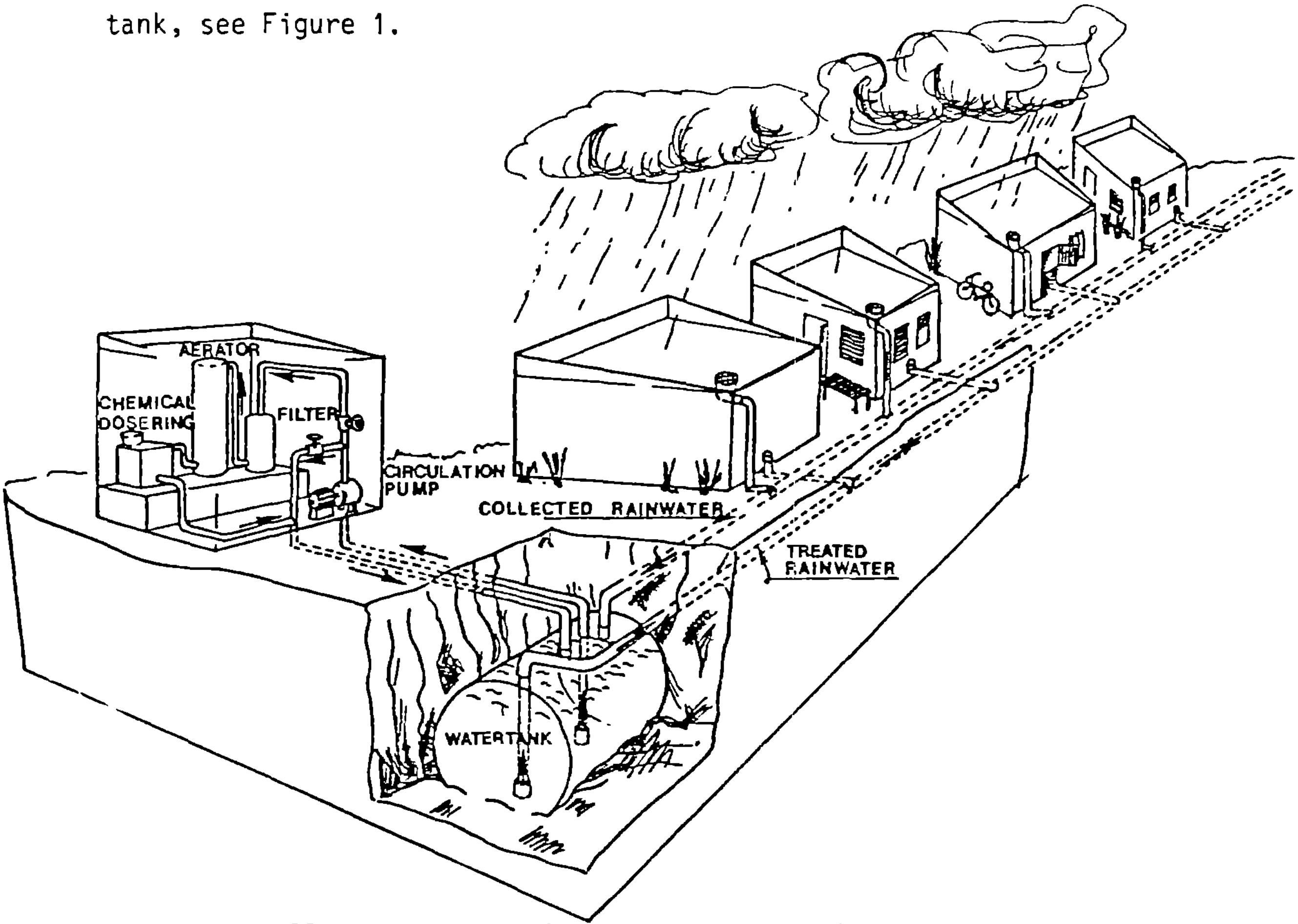


Figure 1 Collection system for processing drinking water from series of roofs.

Another problem in connection with collection of surface water is how to avoid water losses. Losses from the systems can occur as evaporation, leakage into cracks in the bedrock, leakage from edging constructions and pipe joints. The edging constructions and rainwater pipes may be overloaded during heavy rianfull. The losses can be reduced by careful maintenance of the construction and by regular cleaning.

If the collection area is a mountain side, the moss and grass must be removed first of all, and the cracks and depressions must be filled with concrete. A collector of metal or a trench must be constructed down hill for the water collection. The collector has to be cleaned regularly. A hillside can also be covered with plastic sheets to be used for rainwater collection. In these two methods the clearing of the mountain side, and the use of edging, trenches and plastic sheets must not unduly violate the environment. Water from creeks and rivers can also be led into storages. This method is especially convenient when a large amount of water is needed for instance for irrigation purposes. If the intake water is rich in sediments, it will be necessary to construct a sedimentation basin before the water enters the storage. It is also often important to let the first water flush pass by. In many areas wastes and litter are emptied into the riverbed during dry periods and are then flushed away by heavy rainfalls. To get enough water when using these three methods, it may be necessary to supplement with ground water. On islands, for instance, there usually is a ground water table during the rainy season. This water can be pumped up and stored. Otherwise, in many cases it leaks out into the sea to no avail. The ground water admitted into the storage must of course also be tested to ensure that it is of high quality. The storage circulation system will also maintain the ground water in a desinfected status.

THE STORING OF THE WATER

The water can be stored in two different ways:

a) Landbased storage in tanks, covered ditches in concrete basins
b) Storage in the sea

Storage in tanks or in concrete basins

One possibility of storage of water is to use plastic tanks, which can be coupled together in series. Prefabricated tanks can cover a total volume of several hundred m^3 up to a thousand m^3.

Another possibility is to use concrete basins. A styrofoam sheet cover is convenient in order to reduce evaporation and contamination from pollutants such as algae, bacteria, parasites and insects etc. If the intake water contains silt, sedimentation problems may arise. This type of storage can consist of one or several basins storing thousands of m^3.

Storage in the sea

Floating tanks of weighted plastic curtains hanging down from pontoons can be used for off-shore storing of water for irrigation and drinking purposes (see Figure 2).

Due to the difference in density, fresh water floats on top of salt water. Water can be taken from a hillside or a river. The advantages of the method are obvious, not least because of the simple way of removing sediment and silt. They are carried away by the currents. Large-scale versions of this kind of storage can consist of hundreds of tanks containing up to 150 000 m^3 each. There are also possibilities of moving the tanks from one area to another with a tugboat. A test and demonstration plant is to be constructed on the Swedish west coast during the autumn of 1986.

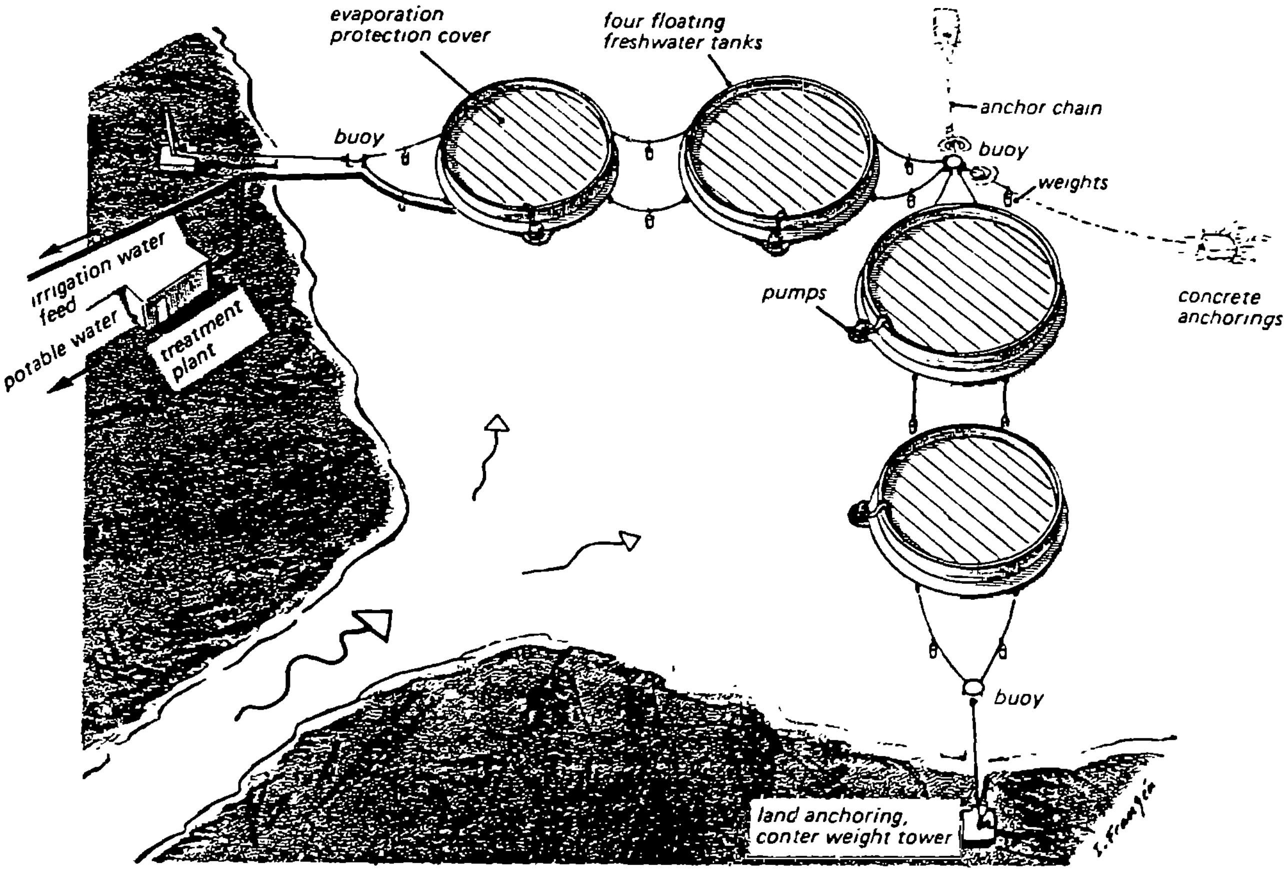


Figure 2 Off-shore storing of water (according to Dunkers).

THE TREATMENT UNIT

A system for treatments of water is presented in the following chapter about the Värmdö full-scale plant.

THE VÄRMDÖ FULL-SCALE PLANT

Location

Värmdö is an island south-east of Stockholm. During dry summer periods there is a shortage of water of good quality. This situation is for instance unsatisfactory for the Salvation Army establishment at Värmdö. Normally the hotel is supplied with water from a ground water well, but during the summer this does not give enough water of adequate quality.

The yearly average precipitation is about 550 mm, of which about 230 mm falls during the period from May to August. During the same period the potential evapotranspiration is 465 mm.

The new method for processing high-quality drinking water from roof-collected rainwater is being tested as a full-scale demonstration plant. Rainwater is collected from 1 360 m^2 roofs and a 70 m^2 cleared hillock side. The covering material is mainly roofing-tiles and plastic coated metal sheets. The water is collected from the roofs in rainwater pipes as described.

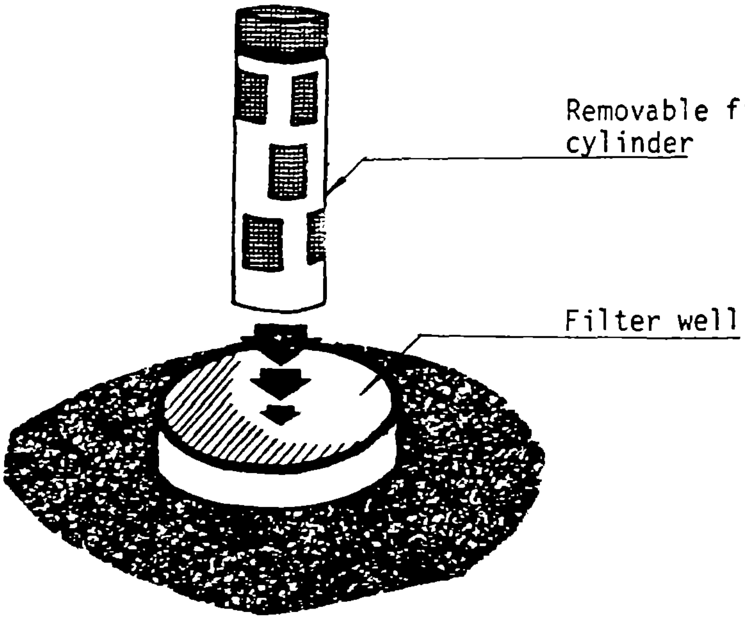


Figure 3 Fine screen.

Figure 4 shows that the collected and stored rainwater is processed in a number of ways. There are coarse and fine screens (see Figure 3). The coarse screens are installed in downspouts one meter above the ground. The fine screens are installed in wells in the ground. Sodium hypochlorite is added to the raw water as well as to the circulating water. In the first place the dosage is controlled by the pump in the pump chamber. In the second place the dosage is controlled by a timer. The water is circulated through a pressure filter with sand and anthracite for a number of hours every day. There is a system for aeration in the tanks.

The water is also treated in a small filter with granular activated carbon. Normally this treatment is supposed to be adequate. At this site there is an existing water system with a drilled well, a pressure tank and a pressure filter for softening and iron removal. The groundwater and the treated rainwater are mixed before entering the pressure tank. The removal of suspended solids and algae takes place in the sand filters included in the circulation. The aerator is used to avoid septic effects, to maintain an acceptable oxygen concentration and to prevent odours. Sodium hypochlorite is used for disinfection and for pH adjustments.

During the summer of 1985 samples were taken to get an idea of how to conduct a study on how to optimize the treatment system. The storage unit consists of two plastic tanks located underground, each measuring 21 m^3. The plant has been planned to be a complement to the existing drilled well. In Figure 4 a scheme over the water supply unit for Värmdö is shown.

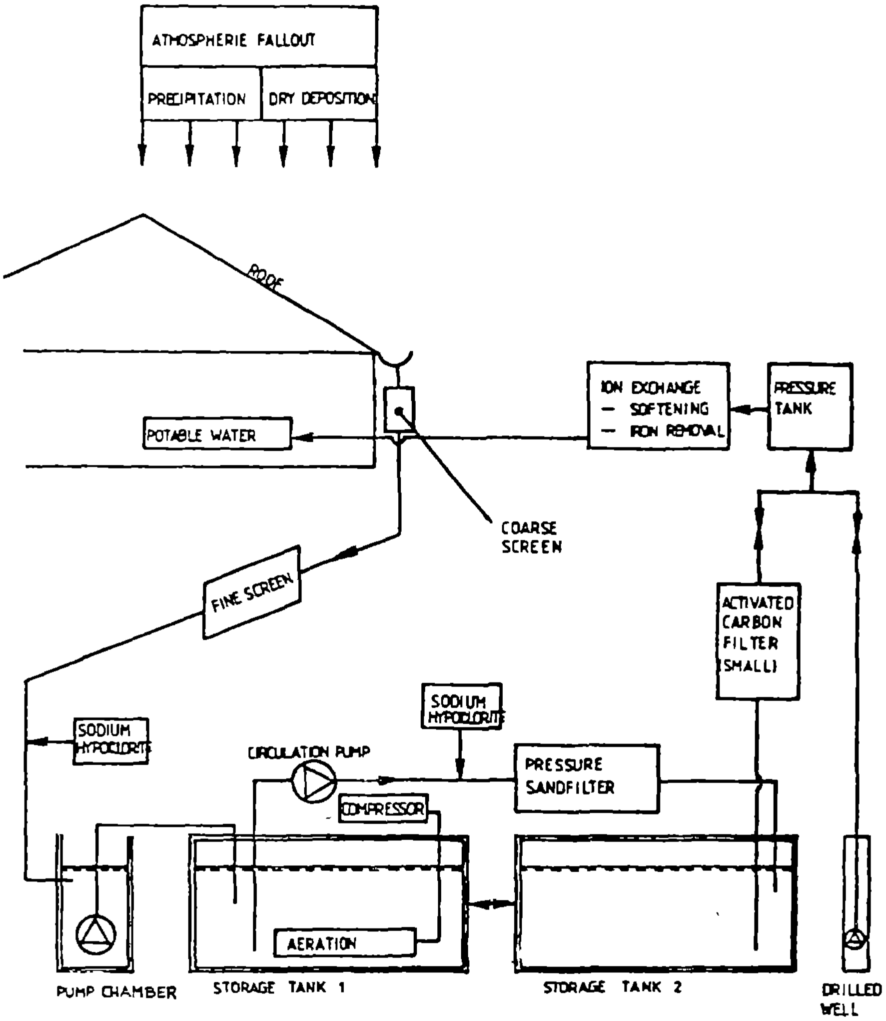


Figure 4 Scheme for the pilot plant at Värmdö.

WATER BALANCE FOR THE PILOT PLANT

Precipitation

The precipitation was measured by a Hellman raingauge during the period from May to November. The total rainfall during that period was 241 mm. This can be compared with the 30 year average in Stockholm, which is 339 mm. During the measuring period the average precipitation was 1.3 mm/day which gives about 1.8 m^3 rainwater per day in the plant. The total amount of rainwater available for collection from the roofs was about 328 m^3. In Figure 5 the distribution of rainfall over the period is shown.

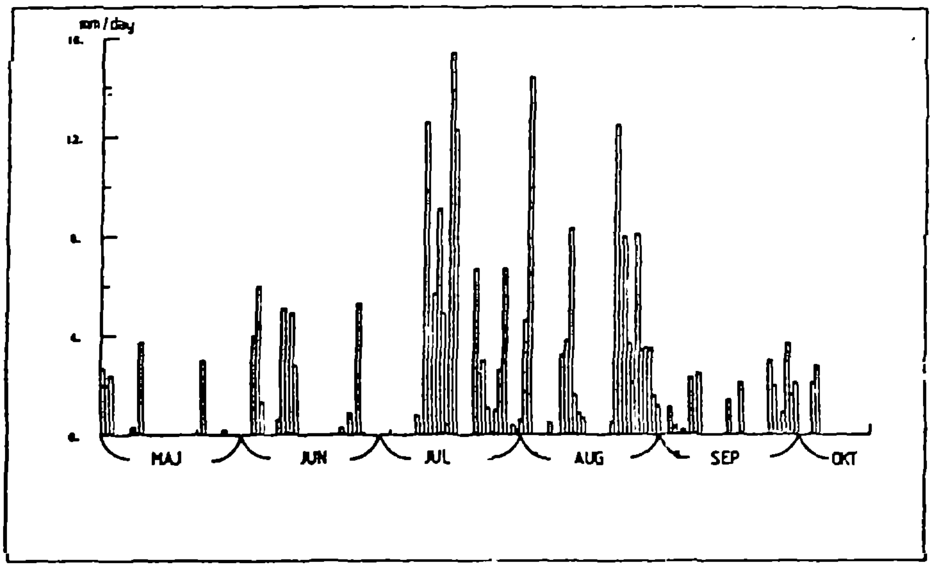
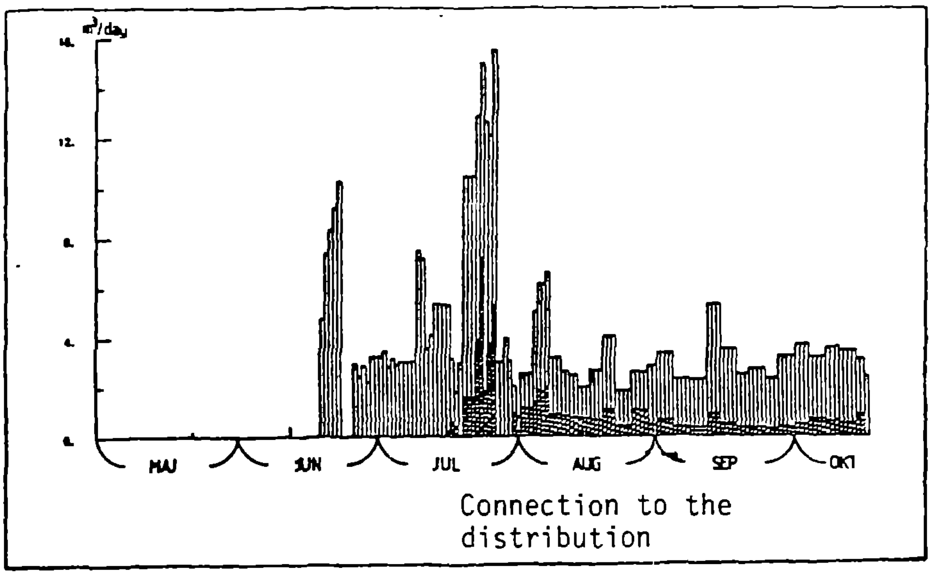


Figure 5 The distribution of the precipitation. The maximum daily precipitation was 15 mm.



Connection to the distribution

Figure 6 The total water consumption and utilized rainwater part as a function of time.

The number of consecutive dry days is also of importance for the daily amount of rainwater for consumption. There were in all ten dry periods longer than a week when the precipitation was less than 2 mm. Three periods lasted 14 days and one 15 days. However, during very dry summers much longer periods without rain can be expected. During the years between 1970 and 1980 in Stockholm there was one period of 24 days and three periods of 22 days with a rainfall amount less than 1 mm. We can roughly assume that 25-day-long dry spells have a return of about 10 years.

Water consumption

The maximum number of guests at the hotel was 129 per day and the minimum was 6 per day (including the staff). The average number of guests was 37 per day. The water consumption varied between 35 l per person and day to about 600 l per person and day. Both ground water and rainwater were used for consumption. The mean consumption was 110 l per person and day, of which 85 l per person and day were teken from the ground water well and 25 l per person and day from converted rainwater. Figure 6 illustrates the rainwater and the total water consumption. The water consumption varies a lot, like the number of guests. Since the storage capacities is 42 m^2, theoretically, a rain of 30 mm will fill up the whole storage. The effective precipitation in the area of Stockholm is about 550 mm per year. This means that in this special case the storage is smaller than 1/10 of the yearly rainfall.

Calculating a maximum of 130 water users and a water consumption of 50 l per person and day, we can see that the storage would be emptied in less than a week if there is no rain and if no additional water is delivered.

The total water budget

In Figure 7 the flow scheme for the Värmdö plant is shown.

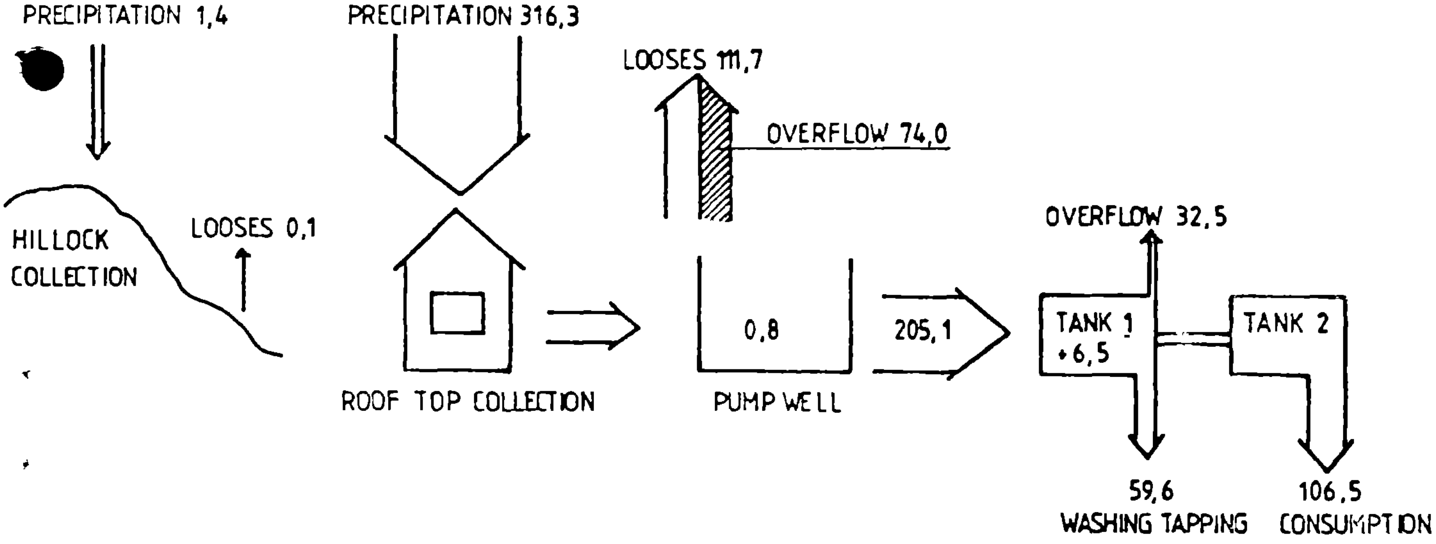


Figure 7 The flow scheme for the pilot plant at Värmdö during the period from June to November 1985. Unit: m^3.

The low contribution from the hillock is due to the fact that it was only connected to the system for a few weeks in October and the area is only 70 m^2. The water loss from the hillock was only 5% of the precipitation. The losses on the roof and in the intake pipes were found to be about 12%. The overflow from the pump well was 23% of the precipitation. Due to overpumping the tanks, overflow discharge was possible from Tank no 1. About 10% af the precipitation flows over. If larger tanks had been used, this overflow water could also have been captured. In the Värmdö plant it is necessary to use all the rainwater; accordingly only 42 m^2 storage has been constructed. About 19% av the precipitation was used for cleaning the tanks or needed to be discharged before cleaning. The amount of water for cleaning the tanks can be reduced a lot in the future. The collecting system must be washed very carefully after the construction period and before the intake pipes are connected to the tank. Finally we can see that about 33% of the precipitation was used for consumption. If tanks of larger volumes are connected to the system this percentage can be increased to about 80-90%.

THE WATER QUALITY

The atmospheric fallout was measured as dry and wet deposition with a NILU SF1 dust sampler. The results of the measurements during May-August 1985 are presented in Table 1. During the whole period when the plant was studied there was about 318 m^3 precipitation. The approximative amount of pollutants added to the intake water as atmospheric fallout is presented in Table 2.

Table 1 Atmospheric fallout during the period May-August 1985 at Värmdö.

PH	Cl^-	SO_4^{2-}	Cu	Zn	Pb	Cr	Cd	Al	
3.7	43	168	1.5	2.1	<0.6	<0.11	<0.18	5.0	mg/m^2, month
	0.7	2.8	0.03	0.05	<0.01	<0.002	<0.003	0.08	mg/l, precipitation

Table 2 Amont of pullutants in the collected rainwater prior to the course screen during the measuring period.

Cl (kg)	SO_4^{2-} (kg)	Cu (g)	Zn (g)	Pb (g)	Cr (g)	Cd (g)	Al (g)
0.2	0.9	9.5	16	<3	<0.6	<1	25

The values in Table 1 and Table 2 are low compared to those in studies carried out in urban areas in Sweden, see for instance Malmquist, 1983, and Hogland, 1986. This is to be expected since the hotel is located in the countryside. In Table 3 criteria for drinking water are shown.

Table 3 Criteria for drinking water (WHO, 1984).

Cl	SO_4^{2-}	Cu	Zn	Pb	Cr	Cd	Al
<250	<400	<1.0	<5.0	<0.05	<0.05	<0.005	<0.2 (mg/l)

The above-mentioned literature on atmospheric fallout in urban areas shows that the concentration of the fallout can be as high as or sometimes higher than the drinking water criteria in the case of some of the constituents, especially copper and lead.

CONCLUSIONS AND DISCUSSION

The idea of collecting, storing and conserving rainwater according to Karl Dunkers's method has a great development potential and can bring about a significant improvement in water supply in areas with scarce water resources.

By this method rainwater can be collected from different impermeable man-made surfaces like roofs and paved hill-sides. The water can also be collected from natural sources like rivers.

Collected water can be stored in land-based reservoirs or in a low-cost flexible construction off-shore.

In order to keep the approved quality of the stored water constant, a simple circulation and treatment system has been designed and attached to the storages.

Water storage according to the Dunkers's method can be arranged on different scales: from small tanks collecting rainwater from one roof and meeting the needs of one family, to huge sea-based systems, which collect run-off from entire rivers and meet the irrigation needs of whole agricultural regions.

There are, however, several questions which have to be answered before this technique can be regarded as fully developed. Research and development of this technique is in progress at the Department of Water Resources Engineering, University of Lund.

Tests of land-based storage systems are performed at a full-scale test facility on Värmdö island in central Sweden. The Varmdö studies have shown that rainwater can be successfully collected and long term stored according to the Dunkers's method. The water quality meets all the requirements in accordance with the high Swedish standards for drinking water.

Tests of sea-based storages were performed on a small scale at the laboratory. A full-scale test facility will probably be constructed in west Sweden within one year.

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AN EXPERIMENTAL ROOFTOP RAINWATER HARVESTING SYSTEM AT A SEMIARID TROPICAL SITE

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ABSTRACT

Two systems for collecting rain water from tiled roofs were built in Ungra, a village situated in South India. On the basis of the measured domestic water consumption and normal rainfall, a mass curve analysis showed that a roof area of 65 m^2 and a storage capacity of 12.6 m^3, with collection efficiency of 90%, would supply the needs of a six-member family for the entire year. Two types of storage pits were built. One was a kind traditionally built in the area for storage of grain, and the other a pit of rectangular section. Two materials for the gutter (G.I channel and tree trunk) were tried. The pits were lined with clay and lime for water proofing. The performance of the two systems were monitored for one monsoon period. The collection efficiency was 62% with the G I gutter but because of losses, it went down to 50% with the tree trunk gutter. The capital costs of the two systems, are not very different, but were found to be much higher than that of handpump-based systems. Both the systems encountered the problem of lizards, rats, frogs etc. getting into the tank.

INTRODUCTION

Rooftop water harvesting for drinking water is not practised in India, since ground water supplies, the major source of drinking water in rural areas, have generally been adequate, at any rate till recently. There are arid and semi arid regions in the country where the technique might prove useful. The eastern half of Karnataka State (Fig. 1) can be classed as semi arid, with normal annual rainfall varying from 400 to 750 mm. About 65% of this rainfall occurs, e.g., in April, August, September and October at the village Ungra (Table 1) in Karnataka (Prasad et al 1981), where the normal annual rainfall is 677.5 mm. Typically, this is the situation in almost the entire country, through the actual months contributing the major part of the rainfall may vary from region to region. Overland runoff stored in small reservoirs called tanks, primarily meant for irrigation, also serves nearby households for domestic water for a couple of months after the end of monsoon (i.e. upto the end of December or January). For the rest of the dry period, people have to depend on ground water. As ground water in shallow wells became scarce during summer, alternatives were thought of, and a substantial program of drilling deep borewells and installing handpumps in them was launched about a decade ago. This has achieved a measure of success in ensuring perennial water supply, although there are maintenance problems with handpumps. In the present paper, work carried out on the feasibility of rooftop water harvesting as another alternative is reported.

TABLE 1: Normal Monthly Rainfall (mm) at Ungra

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
3.5	5.0	6.0	31.4	90.9	59.0	67.0	92.9	124.4	132.9	60.0	8.0

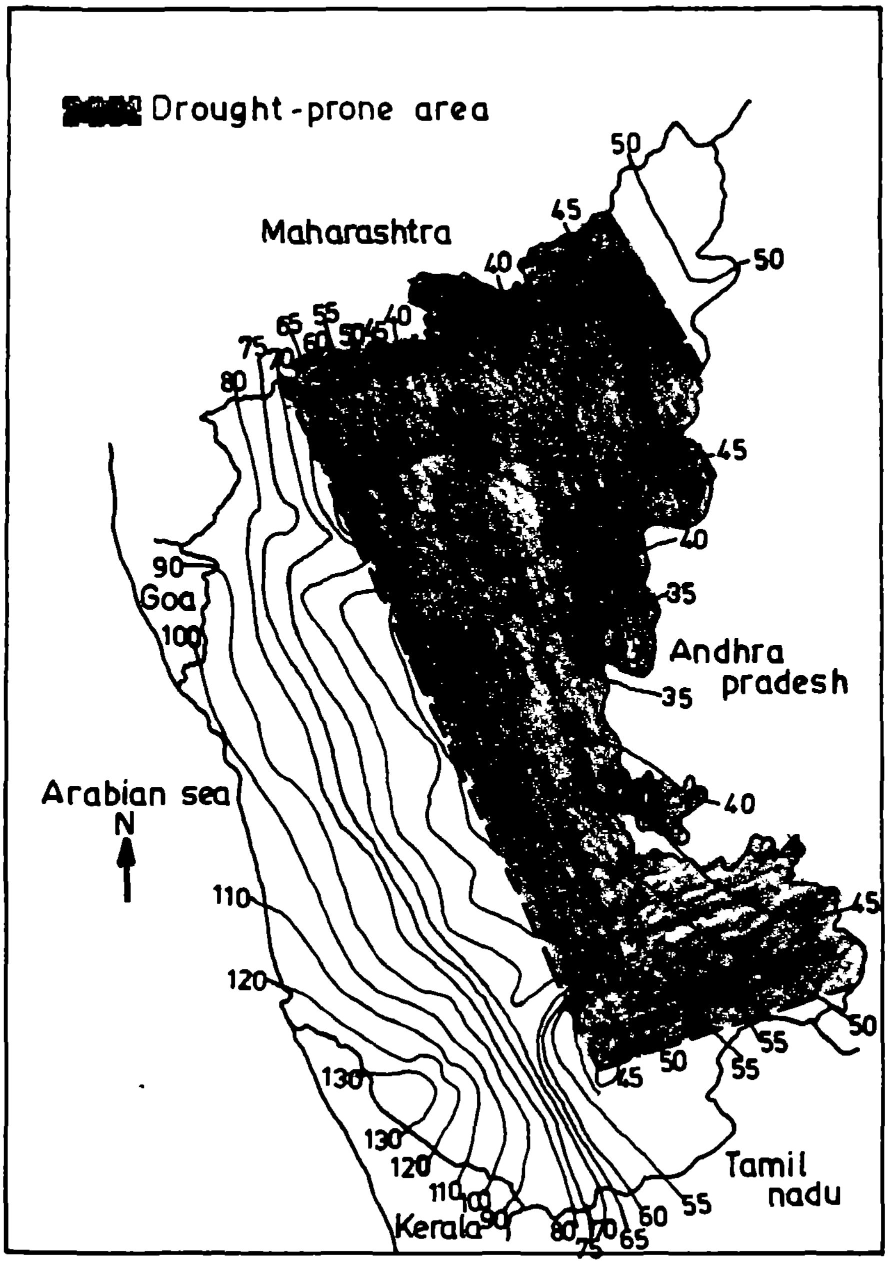


Fig. 1 - Number of rainy days in Karnataka

PRELIMINARY CONSIDERATIONS

The first question that arises is whether the quantities of water harvested can match the needs. The harvested quantity can be estimated with reasonable precision since measured rainfall values are available. The consumption, however, is not a definite figure, since it depends on how easily the water is available. When one gets water at the turn of a tap, consumption is much higher than when one has to walk a kilometre and fetch it in a pot. The design of the systems in this work ignored this factor, and it was assumed that the water demand after installing the system would remain the same as before.

The existing average consumption of domestic water as measured at Ungra (Reddy 1980) is 17 litres per capita per day. An average family of six thus needs about 37.2 m^3 of water per year. Ground water is the main source, and an irrigation canal running through the village is a secondary seasonal source. Rooftop-harvested water can be either the main or a supplementary source depending on the roof area available and the storage capacity created. To collect 37.2 m^3 per year, therefore, the average house in Ungra has to have a (horizontally projected) roof area of about 63 m^2, assuming a collection efficiency of 90%. The storage required, if this is to be the only source of the water, can be determined by constructing the supply and demand mass curves. The demand mass curve is a straight line (Fig. 2), and the supply mass curve can be drawn using accumulated values of 90% (efficiency) of the normal monthly rainfall from Table 1. The maximum difference in ordinate between the supply curve and a tangent at its crest drawn parallel to the demand line gives the storage capacity needed. From Fig. 2, this capacity for the average Ungra household is about 12.6 m^3. Thus a

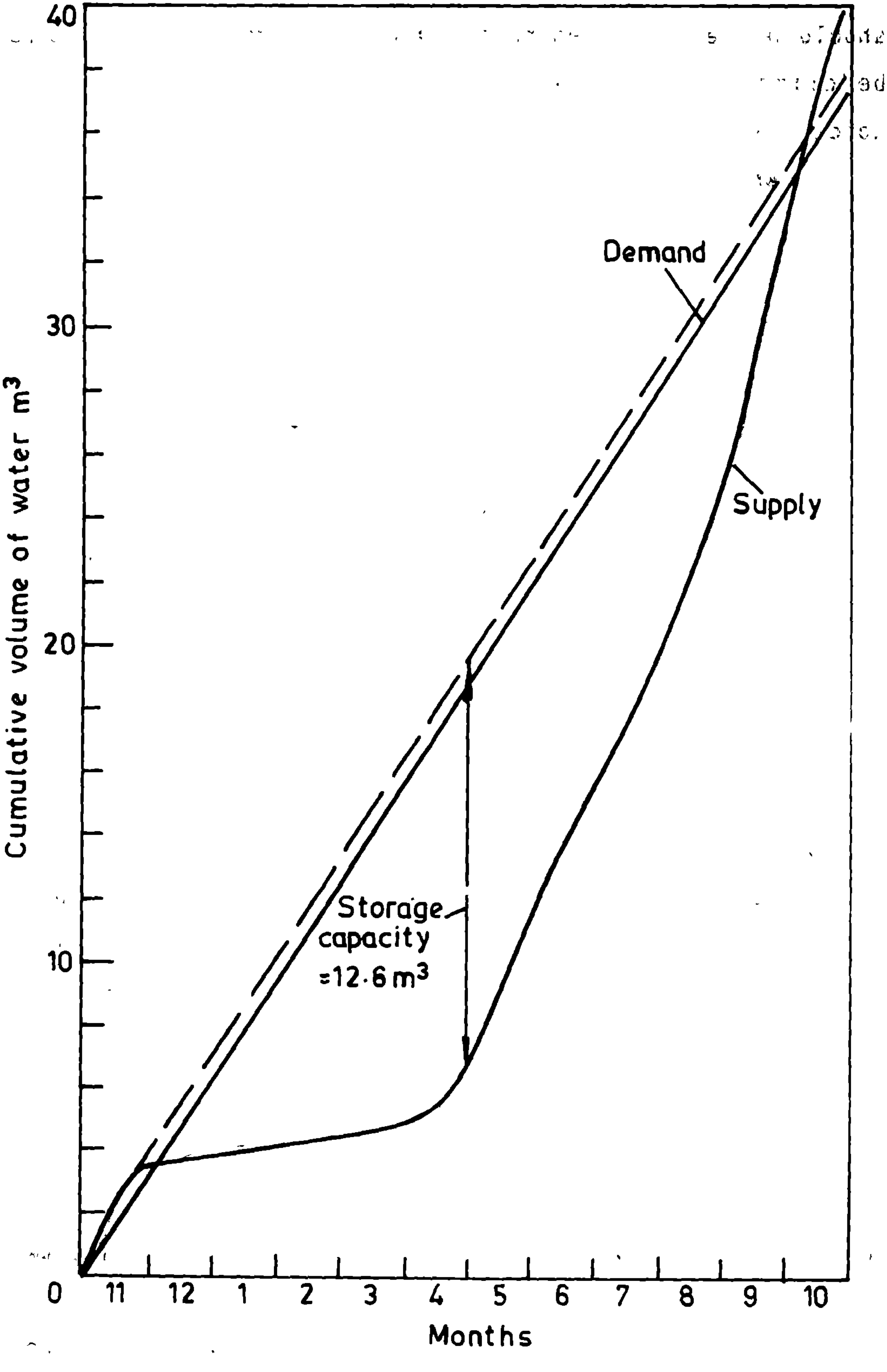


Fig.2 - Demand and supply mass curves for drinking water from rainwater harvesting in Ungra

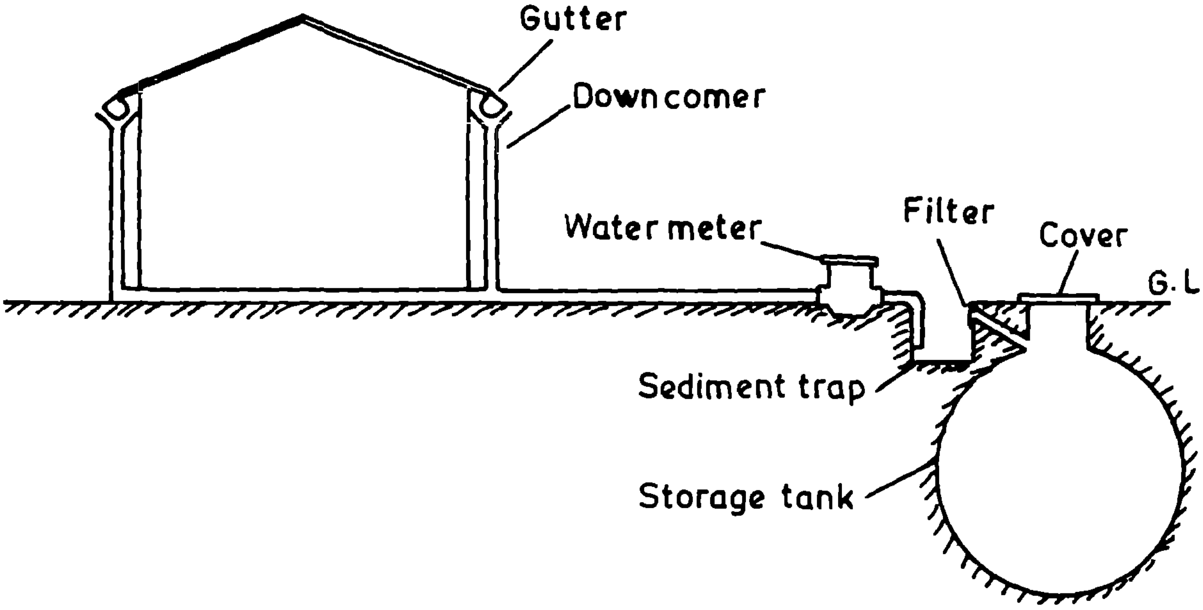
storage capacity of about a third of the annual water requirement should be created if dependence on other sources of water is to be eliminated. In areas where rainfall distribution is concentrated over fewer months, higher storage capacity is needed, while a more even distribution requires less capacity.

DESCRIPTION OF THE SYSTEMS

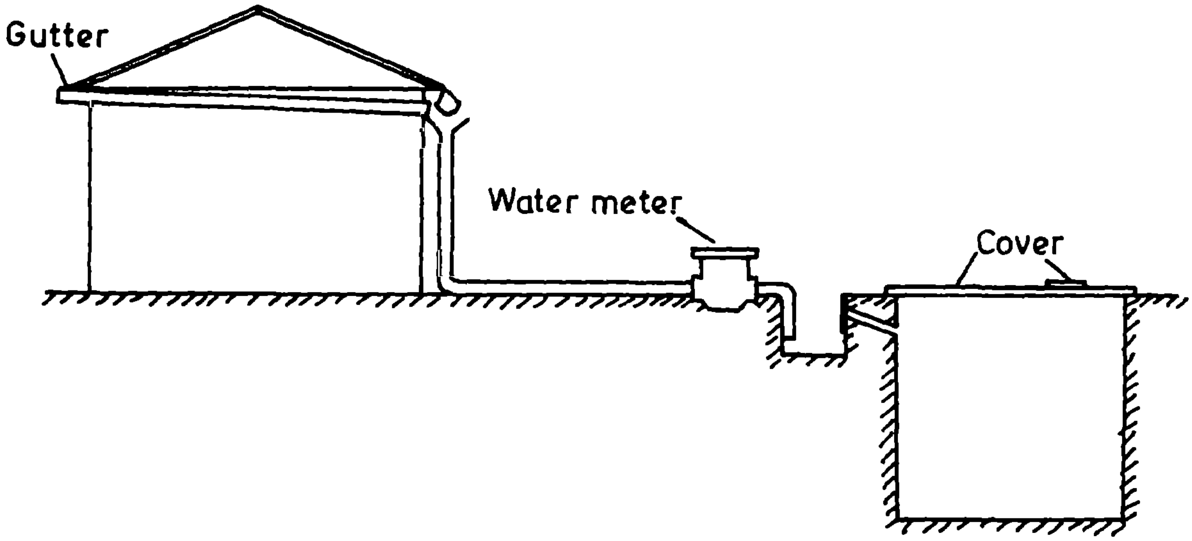
A rooftop harvesting system consists of a collecting channel, first-flush diverter, storage and plumbing. Storage accounts for the major part of the system cost. At the outset, it was decided to construct the storage underground, considering the simplicity of technology involved, cost, possibility of using family labour and local materials, and a certain familiarity already existing. The area has a tradition of storing harvested grain in underground pits locally called "hagevu". A system involving this type of pit was built first, but due to difficulties faced in excavating it, another system with a pit of rectangular cross section was also designed. Since there were two systems, it was decided to use two different materials as well for the collecting channels, one being the split trunk of a palm tree, the other made of galvanised iron sheet, and compare their performance. The two systems were installed at two small buildings with tiled roofs in the extension centre at Ungra of ASTRA, Indian Institute of Science, Bangalore.

System A

The catchment for this system is a gabled roof with a projected area of 56 m^2. Fig.3 shows the system details. The two parallel collecting channels (gutters) installed at the opposite eaves were fashioned out of an arecanut (a palm species) tree trunk. A trunk with an average diameter of 150 mm was split



SYSTEM A



SYSTEM B

FIG. 3 - SCHEMATIC DIAGRAMS OF THE TWO SYSTEMS

longitudinally in the middle. The pith was removed from the halves to obtain two channels roughly semicircular in cross section. These channels were suspended by G.I. wires from the roof below the eaves to catch the runoff. A longitudinal slope was provided to the channels. The upstream ends were closed. The downstream ends opened into two large funnels, which entered the downcomers. The two downcomers were coupled at ground level into a single pipe. No first-flush diverter was provided for either of the two systems, since the primary objective of the experiment was to examine its feasibility and the system was to be quickly installed. Instead, a sediment trap followed by a filter just upstream of the entrance into the storage cavity served to remove floating and suspended material.

The storage cavity for this system was fashioned after the hagevu. As shown in Fig. 3, it is nearly spherical in shape, the top communicating to the ground through a 45 cm diameter opening, through which water can be withdrawn. The volume of the cavity is 12.3 m^3.

The pipe bringing the water enters the cavity below ground level, and the opening is normally kept covered. In order to prevent loss of stored water by seepage, the wall of the cavity was lined with a 3:1 mixture of clay and lime, used for a similar purpose in China (Anon 1979). Water was added to the mixture to the consistency of a paste, which was then left to stabilise for seven days. The mixture was then plastered on (to a thickness of about 5 cm) to the compacted cavity wall. The coating was then compacted with a hammer and the surface smoothened. At the bottom, a thin layer of sand was spread to provide foothold for people who might have to get into the cavity for future maintenance.

A water meter was fitted in the pipe a little distance from the storage cavity for measuring the harvested quantities. The opening of the cavity was normally kept covered throughout the season.

System B

Two of the four slopes of a hipped roof (Fig. 3) serve as the catchment for this system. The projected area of the catchment is 45.5 m^2, which is a little smaller than that of System A. The two gutters, made of 20 guage galvanised iron sheet, are perpendicular to each other and empty into the same funnel and downcomer (Fig. 3). The gutters were semi circular in section, with a diameter of 150 mm. In this system also, a water meter, sediment trap and filter were incorporated in the line leading to the storage tank.

The storage tank built for this system was of rectangular cross section. The tank has the measurements 3m x 2m x 2m (depth) and so has a storage capacity of 12 m^3. The top of the tank was covered with 100 mm thick granite slabs (each about 500 mm wide) spanning the 2m width of the tank. One of the slabs contained a covered manhole, which gave access to the stored water. The sides and bottom of the tank were treated in the same way as in System A.

Construction Costs

The major part of the cost of either system was in constructing the storage tank. In system A, the shape of the tank limited the number of persons who would excavate the soil as well as the rate of progress. Because of the narrow opening, ventilation inside the cavity was poor and heat considerable.

This necessitated frequent pauses. Furthermore, only small tools like chisels could be used as there was no room to swing pickaxes. These slowed the work down and increased the cost of excavation. However, cost of materials was relatively much lower in this case, mainly because the opening to be covered was small. The rectangular tank of the second system, in contrast, was easier and cheaper to excavate, but the cost of covering the top was higher. Table 2 shows details of the cost break-up. The cost of either system per unit of water stored is also shown therein. System B is 10% cheaper than System A, and would have been still cheaper were it not for the heavy expenditure on the lining and cover. Lining costs are more because the rectangular cross section leads to a higher surface area than the spherical tank of System A. The cost of covering is higher because of the larger opening. The increased cost on these two accounts offsets virtually the entire saving on excavation.

TABLE 2: Construction costs of the two systems

Work	System A		System B	
	Cost (Rs.)	Per cent of total	Cost (Rs.)	Per cent of total
Gutters and Plumbing	246	28.5	201	26.4
Excavation of storage tank	468	54.2	112	14.7
Lining of the tank	140	16.2	243	32.0
Cover for the tank	10	1.1	205	26.9
Total	864	100.0	761	100.0
Capital cost of system per unit storage	Rs.70/m^3		Rs.63/m^3	

RESULTS AND DISCUSSION

Water Harvesting Efficiency

The performance of the two systems, installation of which was completed in August 1982, was monitored during the four months from September to December of the same year. The normal rainfall during these months amounts to 48% of the normal annual rainfall. Table 3 shows the rainfall events and harvested water quantities for System A during this period. The overall harvesting efficiency of the system is 49.6%, as seen from the Table. However, the low efficiency is due to the insufficient

TABLE 3: Rain water harvested by System A

Date	Rainfall depth mm	Rainfall volume litres	Inflow into tank litres	Percent of rain water harvested
15.9.82	59.0	3304	1260	38
19.9.82	12.5	700	320	46
18.9.82	3.5	196	115	59
19.9.82	11.0	616	403	65
20.9.82	11.5	644	187	29
21.9.82	11.8	660	307	46
7.10.82	42.0	2352	238	10
18.10.82	2.5	140	104	74
19.10.82	6.0	336	185	55
23.10.82	27.0	1512	1198	79
24.10.82	22.5	1260	948	75
5.11.82	91.0	5096	3125	61
8.11.82	7.0	392	145	37
Total	307.3	17208	8535	49.6

capacity of the gutter. On individual rainy days, the efficiency varies from a low of 10% to a high of 79%. Low efficiencies were recorded for storms of high intensity, when the rate of run off from the roof was too high for the gutter to discharge, and considerable quantities of water overflowed and were lost. On the contrary, efficiency was high when rainfall was of low intensity. The capacity of the gutter can be increased by either increasing the slope or diameter or both. Increasing the slope beyond a certain limit would reduce the efficiency, since the downstream part of the gutter would be too far below the eaves and the falling water would be easily deflected away by slight winds. The diameter of the gutter in System A is constrained by the natural limit to the size of tree trunk. System B, which had a gutter of the same size and slope, but made of GI sheet, had a harvesting efficiency of 62%. Since the roughness of the gutter was much less in this case, its discharge capacity was higher and less water spilled. The major contribution to the total annual rainfall in the area in question comes from events of high intensity. It is therefore necessary to use a gutter of large enough discharge capacity. This is possible if a fabricated gutter is used, but not a tree trunk. If a sufficiently large gutter is used, there is no reason why the assumed harvesting efficiency of 90% should not be reached.

Seepage loss

The loss of water from both the tanks was measured by monitoring the levels through the period. Since the openings were fully covered, preventing evaporation, seepage through the tank walls was the only source of loss. This amounted to 46.2 litres out of the 8.7m^3 collected in System B, or about 0.5%, which is negligible. The clay-lime mixture lining should therefore be considered to have performed very well.

Comparative Cost Analysis

This analysis is made assuming a 90% collection efficiency, which appears to be attainable. Since the larger size of the gutter needed to achieve it affects the total system cost only marginally, the costs given in Table 2 are assumed to be valid. Since System B is cheaper, and is the only one of the two to permit the use of a larger gutter, this system alone is considered here. The roof area of 45.5 m^2 used for this system is also representative of the average rural house in this region. Since this is less than the 63 m^2 required for the system to function as the only source of water supply, it can be treated as the main source, needing to be supplemented by a well, tank or other source of domestic water.

The system would be able in a normal rainfall year, to harvest 27.7 m^3 of water, so that the capital cost works out to Rs.27.4/m^3 of annual water supply, or Rs.127 per capita assuming six consumers. This can be compared with the costs of urban and rural water supply programmes currently in vogue in the State (excluding traditional sources like dug wells).

The City of Bangalore, with a population of 2.9 million, is being supplied with 2.10^8 m^3 of water per year at a cost (at 1982 prices) of Rs.2,400 million. This includes industrial consumption estimated to be about 7%, but ignored here. The capital cost of this project therefore amounts to Rs.12/m^3 of annual water supply, or Rs.828 per capita. The roof water harvesting system is therefore more than twice as expensive as the urban programme on unit water basis, but costs only 15% as much on a per capita basis. This apparent contradiction is due to the differing per capita consumption in the two cases (189 litres per day per capita in Bangalore against 17 in the village). Economy of scale is responsible for the low unit cost of urban water supply.

A rural water supply programme based on handpumps installed in borewells is in operation in the State for a decade now. Each borewell with a handpump costs (at 1982 prices) about Rs.12,000, and is assumed to supply domestic water to 300 people. At a per capita consumption of 17 l/day, the handpumps will therefore supply about 1860 m^3 of water per year. The capital cost would therefore be Rs.6.45/m^3 of water supplied annually, or Rs.40 per capita. Both these figures are considerably lower than for rain water systems as well as urban projects. Even if the annual recurring costs (estimated at Rs.1000 per pump) of handpump maintenance is taken into account and capitalised, the handpump programme remains cheaper.

Problem Encountered

The water in the two tanks attracted a number of pests like frogs, lizards and even rats. A rat hole was found running from the wall of the tank into the house. There was no solution to this problem, which persisted, no matter how much care was taken in sealing crevices, joints etc.

CONCLUSION

The experiment reported here has demonstrated that roof water harvesting is technically feasible in areas with rainfall conditions similar to those at the test site, and can supply the major part of the rural domestic water need (or even the entire need if sufficient roof area is available) at current levels of consumption. However, it is much more expensive than the handpump based programme, at least in regions where enough ground water is available within 60 m from the surface as at the test site. Besides, pests are a major problem with rain water systems with storage tanks below ground level. In other areas where e.g., groundwater is inadequate or available at great depths, rain water harvesting systems may be attractive.

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DRINKING WATER AND SANITATION

A VILLAGE IN ACTION

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Abstract

This study on methodology for village based sanitation development program is research to test for an appropriate model for sanitation development work in the future.

An experimental design was used as one approach for the study. Two villages that are similar in terms of geographical location, socio-economic status and culture located in Banphai district, Khon Kaen province were selected for the study. Ban Can Nua served as the experimental village and Ban Nong He was the control village.

In Ban Can Nua, 3 craftsman training programs and village cooperative funds were set up. Regular supervision and follow up of the program were carried out. Ban Nong He was left alone as a control village. Before project implementation, a survey for baseline data, knowledge, attitude, and practice of the people was conducted as a pretest. The same survey was repeated again

eight months after the project implementation as a posttest. The results of data analysis show that there is a significant improvement in knowledge, attitude and practice among the people of Ban Can Nua as compared to the Ban Nong He people. In addition, it was found that water and sanitation systems work when the number of cement water tanks, jars, latrines and garbage cans have reached the set goal.

The second approach used in this study was the anthropological approach. The anthropologist went to live in the village for two months to learn about the development process from the three main factors that have an effect on sanitation development in the village. These factors include:

1. A strong village organization especially a leader who understands community development concepts

2. An establishment of a village health development fund (sanitation cooperative fund)

3. An effective training of village sanitation craftsman

It can be concluded from the analysis of data from the survey and from the anthropological study that the success of community sanitation development work depends on the above three factors as well as other supporting factors such as an effective monitoring and follow up method, potentials of the village, economic condition of the people, power structure in the village, social relationship among villagers, characteristic of community leaders, and an effective community preparation.

Introduction

In Thailand most water and sanitation programmes for villages have up to now been carried out by government health workers, with little community participation. Various shortcomings have hindered implementation. New approaches are therefore being tried out in which emphasis is placed not merely on the active participation of the communities in the implementation of the programmes but also on their full responsibility for planning, financing and maintenance.

Main Text

A pilot project was conducted in 1981-82 in a number of villages. This project conducted community preparation, the trainning of village sanitary craftmen, the setting up of village health development cooperative funds, and project implementation through the community development principle.

The results were satisfactory and the strategy was incorporated into the National Public Health Development Plan for 1982-86.

However, since no formal research had been done to confirm the results, it was decided to undertake a comparative study in the village of Ban Can Nua and Ban Nong He, to be used for experimental and control purposes respectively. These villages were selected because

1. They were within 30 minutes of the District Hospital.

2. They each contained 100-150 households.

3. No training programme for sanitary craftsmen and no revolving fund existed in the villages before the study.

4. The number of latrines, the number of rain water containers, and the state of cleanliness were similar in the two

villages.

5. Each village had a strong village committee.

The aims of the study were:

- establish a viable village sanitation cooperative fund;
- develop management skills among the villagers so they could handle the fund;
- train village sanitary craftsmen to construct water supply and sanitation facilities, such as cement rain water tanks and latrines;
- prepare the villagers to become trainers of sanitary craftsment;
- evaluate the effectiveness of the sanitary development model and;
- judge the results of the project against the basic minimum-need criteria.

The essential features of the operational model were the preparation of the community, the training of craftsmen, the organization of a village committee, and the establishment of a revolving fund.

Social Preparation

In the past, community organization was a matter for village development committees under the Ministry of the Interior. There was a lack of understanding about the responsibilities of the committees, and the basis of local development policy was outdated. The committees were not familiar with the concept of using cooperative funds for the development of primary health care.

After links were established between government officials working in the study village and the community, field staff were sent to ensure that the village leaders first understood and supported the proposed programme. This also allowed for some dissemination of information to the villagers before a village meeting was held and established relationships in accordance with normal Thai protocol and standards of courtesy and respect. By the time the sanitation cooperative was set up, the working relationship between the villagers and the field staff was soundly based. It should be pointed out that the social structure of Ban Can Nua greatly helped the scheme. Many of the villagers were related, and in general the people respected and helped each other. The unity of the village was reflected in the existence of a women's group and other social organizations.

Training of village craftsmen

The training of village craftsmen involved an experimental teaching/learning process. The aim was that the participants should understand the methodology of implementing water and sanitation programmes and acquire the skills needed for making water storage tanks, jars, latrines, and enamel watersealed slabs. The participants were also trained in organization and management, including financial management, so that they could organize themselves and train other villagers.

The training of craftsmen was geared to the development of practical skills, rather than to the mastery of theoretical concepts. The teaching/learning process was adapted to each participant's motivation and interest. The best trainees from the first group were selected to train the second group, and so on.

Cooperative Revolving Fund

A viable cooperative revolving fund was essential in order to finance work on drinking water supplies and sanitation. To become a member of the cooperative, a villager had to buy at least one share, costing 100 bath (US$ 4). The administrative committee of the cooperative was empowered to consider applications for membership and to grant loans not exceeding 4300 bath (US$ 150) to villagers wanting to build private rain-water tanks or sanitary facilities; the loans were usually repayable in instalments. The village committee and craftsmen met monthly to discuss cooperation and implementation.

Two problems were encountered with the fund:

1. At the beginning of the project, some groups competed for the purchase of shares. This resulted in misunderstandings among some villagers about the nature of shareholdings in the project.
2. Each month between four and eight borrowers did not pay on time, and in two cases no payment was made for three consecutive months. This meant that the lending of money to other borrowers had to be delayed.

Assessment

Surveys were carried out in the two villages before and 9 months after the project was established. The villages were similar in geographical location, socioeconomic status, and culture. After 9 months there was improvement in the knowledge, attitudes and practices of the people in the experimental village relative to the control village. The most significant differences were in the numbers of new jars and water-seal latrines (see table); personal hygiene was less affected.

Interviews

An anthropologist was engaged to interview: the cooperative fund committee, in order to obtain information on its organization, its effectiveness, the management of the fund, community participation in the fund, the way the fund was revolved for sanitation purposes, the nature of shareholding and membership, and the interest payments made to shareholders. A sample of villagers were also interviewed in order to discover their opinions and attitudes regarding the fund.

A questionnaire was used to assess the knowledge of the village craftsmen before and after training.

Data on the training of craftsmen, the revolving fund, and related matters were collected from the minutes of fund committee meetings, progress reports, financial statements, records of shareholders and borrowing, and other sources.

Improvements in sanitation facilities 9 months after start of project

Village	Number of households	New water-seal latrines	New jars (1600-2000 litres)
Ban Can Nua (intervention)	145	29	61
Ban Nong He (control)	137	3	18

The village headman, acting as coordinator, played a major role in the project. Members of the fund committee stated that because they had been elected, they were determined to fulfill their duties to the best of their ability. Some committee members did not know about the payment of dividends until they had received them. Those who had been aware that dividends would be paid stated that this had not influenced their decision to join, and that their interest was in helping to achieve development in the community so that everybody could live well. The committee perceived the cooperative fund as belonging to and being managed by the community, with some support from the government.

The villagers considered that the committee was doing a good job. Some said that the members of the committee were prepared to serve because their economic situation was satisfactory and their children were grown-up. The committee was accepted by the villagers because it was elected, not appointed.

The headmen, committee and craftsmen were very well accepted and trusted by the villagers, who usually responded positively to their proposals. The leaders also acted as monitors, advisers, coordinators, and motivators. The headman regularly inspected the work done, gave advice when necessary, and helped the craftsmen to plan their activities. He also tried to set a good example for the villagers and urged the committee and craftsmen to do likewise by constructing latrines and rain water tanks for themselves in the first instance, if they did not already possess them.

Follow-up supervision and evaluation of the craftsmen's work are very important. The villagers were very favourably disposed towards government supervisors, whose visits therefore had a beneficial effect. The villagers themselves also acted a monitors of progress; both the fund committee and the shareholders followed the work very closely, and the people in general were very interested in what was going on.

The cooperative fund at Ban Can Nua has met with considerable success. Participation is of a high order, and implementation is continuous and effective. The power structure and social relations in the village have helped the process of problem-solving and community development through the efforts of the villagers themselves. The village has a high potential for development. The government officals are aware of this and give the appropriate assistance. This village is the district representative in a model village contest at provincial level, and this has attracted many development projects, with supervision and follow-up by government officials at least every two weeks who give encouragement for even greater participation by the villagers.

Conclusion

The success of the project depends on income levels, the relationships between villagers and government health workers, and associated factors. The teaching/learning process used in the training of village craftsmen is highly effective in imparting the skills needed, since it has been possible for the villagers themselves to become either effective trainers or highly motivated trainees. Furthermore, by stimulating the thinking of village leaders it has been possible to improve planning implementation, and the monitoring of progress in the water supply and sanitation project.

The essential features of the operational model were the preparation of the community, the training of craftsmen, the organization of a village committee, and the establishment of a revolving fund.

The village headman, acting as coordinator, played a major role in the project.

Acknowledgment

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Appendices

Craftsmen Training Program, Group 1

Ban Can Nua

Background and justification

Primary health care is the strategy to achieve health for all by the year 2000. This is the goal of the Ministry of Public Health.

Banphai District Hospital and Banphai District Health Center have been implementing the primary health care work since 1980 by training village health volunteers, village health communicators as well as community leaders such as priests, teachers and women to expand the health services to all in order that they can be self-reliant, help their community and solve village health problems by themselves. The first group of sanitary craftsmen was trained in 1981 at Ban Hua Nong, Banphai district, Khon Kaen province. The second, third and fourth groups were trained the following year. The first group acted as trainers for others and was very successful. The water and sanitation work expands very quickly. However, the cost to implement water and sanitation work is very high so it is necessary to set up a revolving fund to help poor people. In doing so, the craftsmen and the committee need to have a good knowledge of the role and management of the fund. For the Jacque Parisot project, village craftsmen as well as village organizations will be trained and monitored.

Overall objective

To give the participants knowledge on environmental sanitation, provision of clean water, and primary health care so that they can teach, motivate, advise as well as be effective leaders in water and sanitation in the village

Training objective

After the training course, the participants are expected to be able to:

1. explain precisely how to implement water and sanitation work

2. Teach and advise others on water and sanitation work. (Craftsmen with good knowledge and character will be selected to be trainers)

3. Be able to construct the following facilities:

    a. cement rain water tank

    b. enamel seal water slap

    c. cement block

    d. latrine casing

    e. cement water jar

4. Understand and manage the village cooperative fund

Participants

Each village selects 2-3 people as representatives to attend the training.

Number of participants 29 people per training

Ban Can Nua	9 people
Ban Nong Ranya	5 people
Ban Nonza	5 people
Ban Kudpeng	5 people
Ban Nong Na Voa	5 people

Qualification of participants

- literate
- basic masony knowledge
- between 25-50 years of age
- willing to sacrifice for the community
- accepted by the community
- middle income, not too rich and not too poor.

Place

Craftsman training center, Ban Hua Nong Mu 1. Tambon Banphai, Banphai District, Khon Kaen Province.

Duration

May 25-29, 1984

Resource persons

Resource persons are from the following organizations:

- Craftsman Training Center Ban Hua Nong, Tambon Banphai, Banphai district, Khon Kaen province.
- Sanitation and Health Promotion Division, Banphai District Hospital
- Banphai District Health Center.
- Sanitation Division. Khon Kaen provincial Health Office
- Region 4 Sanitation Center, Khon Kaen

Curriculum

Theory 8 hours

Trainer craftsmen 2 persons x 50 Bahts x 5 days = 500 Baht
Level 3,4 staff 2 persons x 50 Bahts x 5 days = 500 "

2. Allowance for participants (Ban Can Nua only)
craftsmen 9 persons x 40 Bahts x 5 Days = 1,800 Baht
3. Demonstration material = 1,000 "

4. Other equipments

1 set of jar mould size 1600-2000 liter = 1,200 "

1 set of cement block mould = 1,000 "

Total 6,000 Baht

Evaluation

- Pretest
- Observation and discussion during training
- Post test

Follow up

Field visit after training every 7 days for 1 month

Craftsman Training Center, Ban Hua Nong, Tambon Banphai, Banphai District, Khon Kaen Province

time te	9.00-10.00	10.00-11.00	11.00-12.00	12.00-13.00	13.00-14.00	14.00-15.00	15.00-16.00	16.00-17.00	19.00-21.00
ay 25, 984	opening ceremony Banphai District Head Officer orientation	Pretest	together as a Group (Chom Marasri and others)	Lunch break	Cement block and cement tank construction Theory and practice (Gong Paodang, and others)				Review recreation
ay 26, 984	enamel water seal slab construction Theory and practice (Saithong Sovong)			Lunch break	enamel water seal slab (continued) (Resource persons from Ban Hua Nong)				Review recreation
ay 27, 984	enamel water seal slab and stool construction (Saithong Sovong, Kam Poohin, and others)			Lunch break	enamel water seal slab cement jar and cement tank construction (Saithong Sovong, Sudjai Sriclabutr)				Review cooperation fund setup and management (Chom Marasri)
ay 28, 984	enamel water seal slab and stool construction (Resource persons)			Lunch break	enamel water seal slab and stool construction (Resource persons)				Review village broadcasting system management (resource persons)
ay 29, 984	How to apply odor to enamel water seal slab and stools (Resource persons)			Lunch break	Maintenance of materials and equipments (Resource persons)	Posttest	closing ceremony and presentation of certificates (Banphai District Hospital Director)		

STRATEGIES TO PROVIDE DRINKING WATER IN THE RURAL AREAS OF THAILAND

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ABSTRACT

The best method of providing drinking water in rural areas of Thailand is by storage of rainwater. This method is economical, provides water of high quality and can be carried out virtually anywhere because the volume of rainwater available is adequate throughout the country. A cement jar of 2 cubic meter capacity is the most suitable container for most households because it is cheap and can be built by villagers themselves or bought individually depending on each household's financial capability. Three jars of this size can store sufficient water for drinking and cooking to last a household of six persons throughout almost seven of the dry season. A rainwater storage tank of 6 to 12 cubic meters capacity is suitable for use by a larger, relatively more affluent family and for public places such as schools. The design and methods for construction of such tanks have been greatly improved so that costs have greatly decreased.

The program for constructing rainwater storage jars to provide drinking water in rural areas has been a joint effort between government and private or non-profit agencies and is directed towards supporting construction of jars and tanks by villagers themselves. Government officials are responsible for training village technicians, for providing money to be used in establishing a revolving fund and for providing forms and tools for use in the construction of jars at each village. If implementation of this jar construction program proceeds according to the targets set out, Thai and will have resolved the problems of inadequate safe drinking water in rural areas before the year 1990. This should include providing economical 6 to 12 cubic meter capacity rainwater tanks at rural schools as well.

1. SOURCES OF DRINKING WATER IN RURAL AREAS

Small scale sources for drinking and domestic water in most villages may generally be grouped into 5 categories:

1. Storage of roof rainwater runoff in jars or tanks
2. Shallow wells
3. Deep wells
4. Naturally occurring ponds or lakes
5. Dug ponds

The needs of each household for drinking and for domestic water are different with respect to both the volume and quality of each. In terms of drinking water, a person needs approximately 5 liters of water per day. This must be safe water of good quality (1, 2). As for water for domestic use, each person requires about 45 liters per day of moderately high quality water which does not cause irritation (3). The separation of water for drinking from water to be used for domestic purposes was an important starting point in enabling Thailand to establish a plan for providing drinking and domestic water in rural areas that could be effectively and economically implemented (3).

Storage of rainwater is an easy, economical method for providing clean drinking water and has already been in use for a long time in Thailand (1). Analysis of water quality and the costs of various drinking water facilities shows that storage of rainwater runoff from roofs in tanks and jars is the most suitable and most economical. In addition, it is a method which can be implemented anywhere.

The next most suitable methods or sources for providing drinking water in rural areas are sanitary shallow wells and deep wells.

2. AMOUNT AND QUALITY OF RAINWATER

The average annual rainfall in the various regions of Thailand is rather high when compared with other parts of the world due to the country's position in the humid tropics. The rainy season begins in May and lasts until October in the northern, central, eastern and northeastern regions. The average annual rainfall is approximately 1000 to 2000 millimeters per year, 85 percent of which falls during the six months of the rainy season. The remaining six months are considered to be the dry season.

The average annual rainfall in the southern region is higher than that of other regions being more than 2000 millimeters per year. There the dry season last only three months from January to March and even during these months there is rainfall of approximately 50 millimeters per month.

The total area of Thailand has been divided into 23 zones, each with a representative station from which recorded rainfall data are used. Rainfall information has been collected at these stations since 1952. This information has been analyzed using the Thomas Plotting method to determine the draught rainfall of each month which may be expected to occur one year in 10 (the probability of rainfall being higher than this level in any one year is 90 percent). The average level of low rainfall during the rainy season for each month and for each region is shown in Table 1.

Table 1 Draught Rainfall Expected for all Regions
(Probability of 90 % of exceedance)

Region	Rainfall (mm)							
	April	May	June	July	August	Sept	Oct	Total
Northern (6 Zones)	28	79	113	134	256	161	132	903
Central (4 Zones)	35	100	102	125	130	257	93	842
Northeastern (5 Zones)	73	115	111	182	197	211	78	967
Eastern (2 Zones)	43	92	282	261	248	245	115	1286
Southern (6 Zones)	56	143	183	143	165	197	256	1573*

* Includes rainfall during November (290 mm) and December (140mm)

Determining the volume of rainwater needed to be stored depends on the rate of water use and the period of time during which the stored water will be used. In the case where stored water will be used for drinking and cooking, approximately 5 liters per person is required each day. For a household of 6 persons, this translates into storage of about 6 cubic meters of water for use during the 200 days of the dry season. As for the southern region where the duration of the dry season is shorter (approximately 2 months), storage needs are only around 2 cubic meters per household.

From surveys it was found that the size of roofs in rural areas varies between 50 to 150 square meters, with an average size of about 80 square meters (4). For a roof of 80 square meters, only 75 mm of rainfall is necessary in order to store 6 cubic meters of water. When this amount is compared to the levels in Table 1, it can be seen that even in relatively dry years the amount of rainfall during any one month of the rainy season is sufficient to supply drinking water throughout the dry season. When the entire amount of rainfall during the rainy season is considered, it requires an efficiency in collecting rainwater from roofs of only 9 percent in order to store sufficient drinking water for the entire year. From these arguments, it is possible to conclude that the amount of rainfall is not a constraint to storage of rainwater from roof run-off for consumptive use in Thailand. A study was conducted utilizing a rainwater storage system model based on an input-storage-output system. Rainfall information from various points in the northeastern region was fed into this model in order to conduct a reservoir routing to find appropriate sizes of storage containers for various rates of water use. The results of this study are similar to the conclusions already presented with respect to storage of rainwater as a source of drinking water (4).

In general, the quality of rainwater in Thailand is high with respect to World Health Organization drinking water standards (1,5). Most contamination occurs when the rainwater runs over roofs, from dirty storage systems (especially at the beginning of the rainy season) and from unsanitary use of the water (5,6). Testing of 2042 water samples obtained from rainwater jars and tanks in the northeastern region showed that 69 percent of the samples passed safety standards with respect to bacterial content. This is considered very good in comparison with the quality of drinking water obtainable from other sources (2). It is hoped that if a campaign is waged to educate rural people about sanitary methods of using water and the importance of cleaning the water storage system each year at the beginning of the rainy season the quality of drinking water will improve to a higher level than is currently found.

3. RAINWATER STORAGE CONTAINERS

There are many types of rainwater storage containers. Those generally used in Thailand may be grouped into three types:

1. Cement tanks and jars
2. Metal tanks
3. Plastic and fiberglass tanks

The cost of metal, plastic and fiberglass tanks is about 1300-1600, 2400-2700 and 4800-5200 baht per cubic meter, respectively (7). These are rather expensive and thus not suitable for use in rural areas.

Cement tanks and jars, being much cheaper per volume of storage, are preferred for use in rural areas. The most popular type, especially among the rural poor, is the 2-cubic-meter jar. It is the cheapest type, costing about 250 baht per cubic meter of storage, and villagers are capable of building the jars themselves. In terms of rainwater tanks, many designs have been developed and tested. Most are of a size between 6 to 12 cubic meters. The types of tanks may be grouped according to the material and techniques used in construction as follows:

1. Steel reinforced concrete tanks
2. Ferrocement tanks
3. Bamboo-ferrocement tanks
4. Wire reinforced mortar tanks
5. Mortar block tanks
6. Brick tanks
7. Tanks made of concrete pipes.

Table 2 shows a comparison of costs for each type of tank design (3). It can be seen that wire reinforced mortar tanks are the least expensive per volume of storage and are similar in cost to 2-cubic-meter jars. This is because the same construction technique is used for both types of containers. The second most inexpensive tank designs are the mortar block tank and tanks made of concrete pipes. Concrete pipes referred to here are not those purchased locally because such pipes are more costly and would result in a more costly tank than is noted.

Table 2 Costs of materials for construction of a 6 cubic meter volume tank of various types (8)

Type of Tank	Cost of materials (baht)			
	Walls	Base, Cover and others*	Total Cost	Cost/cu.m
1. Steel reinforced concrete	970	850	1820	304
2. Ferrocement	1380	850	2230	372
3. Bamboo-ferrocement	830	850	1680	280
4. Wire reinforced mortar	660	850	1510	252
5. Mortar block	770	850	1620	270
6. Brick	1280	850	2130	355
7. Concrete Pipe	770	850	1620	270

* Steel reinforced concrete base : 500 baht
steel reinforced concrete cover : 250 baht
"Other" refers to faucets outlets: 100 baht

It can be concluded that the wire reinforced mortar tank is the most suitable type of tank specially for cases where a large number of tanks are to be constructed because the cost of forms is relatively inexpensive (1500 baht per form) and this is offset by the saving of material cost. The construction process of mortar block tanks is more difficult. Steel reinforced concrete tanks and tanks made with concrete pipe are suitable only where forms for construction are already available. No more funds should be invested in producing forms for these two types of tanks. Brick, ferrocement and bamboo-ferrocement tanks are appropriate for situations where only a few tanks are to be constructed since these types do not require forms.

4. THAILAND'S JAR CONSTRUCTION PROGRAM

The jar is a rainwater storage container which has been in use for quite some time in Thailand. A large cement jar with a 2 cubic meter capacity has recently become very popular due to the simplicity of construction and inexpensive cost which enable villagers themselves to build jars one at a time according to the funds available. Results of a study of water quality and an analysis of the costs of various water supply facilities (2) provided the initiative for a collaborative effort between the Thai-Australia Village Water Supply Project and the Water Resource and Environment Institute, under the Faculty of Engineering at Khon Kaen University. Together they proposed a "Jar-Construction Program to Provide Drinking Water to Rural Areas" to the Thai government (9). The program received such a wide base of support and interest that it has become a national program. A committee to administer the project to provide rainwater storage containers to rural people throughout the country was established in November, 1985. The Deputy Minister of Interior serves as the chairman. The essence of the program may be summarized as follows :

Goals

1. To provide one 2-cubic-meter jar to each of 3 million households still lacking suitable drinking water, allowing 2 liters per person per day, by 1987.

2. To provide an additional two 2-cubic-meter jars (total of 3) to each of the households still lacking an adequate supply of drinking water, allowing 5 liters per person per day, by 1990.

Implementation Strategies

Strategies used to implement this project are critically important to its successful attainment of goals. Important facets of the strategies proposed to the government may be stated simply as follows :

1. Villagers should be involved in the project from its establishment, management of finances, and implementation including construction.

2. The project should be implemented in the form of a revolving fund and should begin with a group of individuals who have money to invest and are eager to participate so that the

revolving fund can be quickly established and its initiators serve as models for others to follow.

3. The government is responsible for supplying tools and materials for jar construction and for supporting the revolving fund. Villagers are to provide free labor and the cost of materials used in constructing the jars.

4. The government is responsible for arranging and supporting training of villagers in jar construction and for establishing the revolving fund in each village.

Preparation of the Community

The first step in preparing the community is to wage a campaign to make villagers more aware of the importance of clean drinking water and the usefulness of building rainwater storage jars. This preparation may complement and be conducted together with other types of development campaigns. The preparation should include informing villagers of the details of implementation, especially the need for cooperation between villagers in construction of jars and the workings of a revolving fund. Community preparation should be part of provincial policy and be a cooperative effort between local administration officials at the district level, the subdistrict working committee and the village working committee.

Training

Each province is responsible for implementing and coordinating the work of various technical agencies such as the Department of Accelerated Rural Development and the Provincial Office of Department of Health. These agencies train village technicians in jar construction and then the village technicians are expected in turn to train other villagers. A simple manual which includes many illustrations was written by the Thai Australia Village Water Supply Project and Khon Kaen University for use in this training.

The Revolving Fund

The government is responsible for providing a fund for purchasing materials and for assisting in combining this fund with other funds already existing within a village (if desired) to create a revolving fund. Supervision and management of the fund should be a cooperative undertaking between villagers, village committee members and subdistrict council members.

From experiments in implementing the jar construction project in villages targeted as the very poor, it was found that rural villagers are able to repay funds at a rate of 100 baht per month. It thus seems that designating the rate of repayment at 100 baht per month should be feasible for most rural areas.

In order to estimate the amount of time required for the project to achieve its goals at a particular village, it may be useful to present an example. Suppose that a village consists of 100 households. An initial fund of 10,000 baht is established and two forms for jar construction are provided. One to two jars may be built each day. Each household that participates in the project must pay 400 baht to the fund to cover the cost of materials. This 400 baht is divided into a down payment of 100 baht paid upon joining the project and then a series of 3 payments at the rate of 100 baht per month. If implementation proceeds without obstacles, the financial status and number of jars constructed during each month can be calculated. This example is shown in Table 3.

Table 3 Example of a revolving fund and the theoretial number of jars which can be constructed

Schedule	Number of households able to participate	Amount of money paid into fund (baht)	Amount of money in fund (baht)	Number of jars built	Cost of materials
1st month	33	3,300	13,300	33	13,200
2nd month	11	4,400	4,500	11	4,400
3rd month	15	5,900	6,000	15	6,000
4th month	19	7,800	7,800	19	7,600
5th month	15	6,000	6,200	15	6,000
6th month	17	6,600	6,800	17	6,800
Number of Jars Built within the First Six Months = 110					
7th month	17	6,800	6,800	17	6,800
8th month	16	6,500	6,500	16	6,400
9th month	16	6,600	6,700	16	6,400
10th month	17	6,600	6,900	17	6,800
11th month	16	6,500	6,600	16	6,400
12th month	16	6,500	6,700	16	6,400

Number of Jars Built within the First Year = 208

Project Duration and Budget

If the government was able to provide 10,000 baht to each village facing a shortage of drinking water to initiate a revolving fund as well as training of village technicians and two forms for jar construction, the total budget required would be about 470 million baht (9) and it would take only a year and a half for the project to reach its goals. These calculations are in accordance with the figures presented in Table 3. These figures, however, do not take into consideration various problems often encountered in project implementation. For example, villagers are able to build jars only during the dry season and many households may not yet be ready or willing to participate in the project. These factors slow the project schedule of implementation and so the more reasonable interval set for the project to reach its goals is between 3 to 4 years.

The Results of Project Implementation up to the Present

During 1986, project campaigning resulted in the construction of approximately 1.7 million jars (10). It is expected that by the end of 1987, the goal of constructing 3.0 million jars will be reached. As for as the methods used in implementation, many approaches and many agencies have worked together. Government and private agencies as well as villagers themselves have contributed to the effort. In several cases, credit for purchasing materials was obtained from merchants, with officials serving as the guarantors.

5. RAINWATER TANKS FOR SCHOOLS

The 6 to 12 cubic meter rainwater tank is suitable for storing drinking water at public areas such as schools, providing water for students when schools are in session. If a project to provide rainwater tanks at rural schools is initiated, it will greatly complement the current efforts to provide clean drinking water to all villages and enable more complete coverage. An elementary school at the subdistrict level has, on average, 600 students and staff. Five 12-cubic-meter tanks can store sufficient drinking water for 200 days at a rate of 0.5 liters per person per day for such a school. The cost of materials for this size of wire reinforced mortar tank (which uses a construction technique similiar to that for jar construction) is about 2,800 baht. Each school would thus require around 14,000 baht to cover the cost of materials and the recruitment of teachers and villagers to help in construction. Aside from this, there should also be a project at schools to repair or improve existing rainwater tanks which have fallen into disrepair. This requires initial work to make school administrators more aware of the importance of providing clean drinking water at schools.

6. SUMMARY

If Thailand's Jar Construction Project is successful in meeting its goals within the expected time, Thailand may be the only developing country to provide clean drinking water for every rural household by the year 1990. The repair of rainwater tanks at schools and construction of a greater number of inexpensive rainwater tanks will enable youth in rural areas access to clean drinking water both at home and at school.

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APPLICABILITY OF
ROOF RAINWATER CISTERN SYSTEMS
IN JORDAN

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ABSTRACT

The potential for use of roof rainwater cistern systems (RRWCS) in Jordan was investigated by analyzing the rainfall data for five stations, selected to represent all rainfall variations in the country.

Daily and monthly rainfall data for 20 years were subjected to computerized mass curve analyses For each year, maximum rainwater that can be stored and the corresponding allowable consumption (demand) rate were calculated and correlated with the annual rainfall. There were no observable spreads neither for individual stations nor among the stations. Each correlation was expressed by a linear relationship.

Storage capacities obtained from monthly data were less than those from daily data by as much as 30%. From cost comparisons with bottled-water, optimal cistern volumes were found to be equal to the maximum storage capacities determined by the maximum annual rainfalls.

80% of the rainstorms in Jordan occur during the 4-month period from November to March. On the basis of this observation, it is proven that adjustment of the consumption rates at the end of rainy seasons would improve usage efficiency of RRWCS systems.

INTRODUCTION

Scarcity of suitable surface or groundwater sources, in terms of quantity and/or quality, has accelerated the adoption of roof rainwater catchment (or cistern) systems (RRWCS) as primary or supplementary water sources over many regions of the world.

Due to limited water resources and a significant rural population, RRWC systems appear to have a high usage potential in Jordan. Another factor that enhances such a potential is the high mineral content of even the piped water supplies in many parts of the country. Thus bottled water is preferred for drinking and cooking purposes.

Even though there is some sporadic use of cistern systems, especially in rural areas, a systematic study on the subject could not be found. Hence the present study is initiated to investigate the feasibility (or potential) of the use of RRWC systems in Jordan. The objective of the study was to determine the optimal storage capacities needed and the maximum daily consumption rates that could be supplied in various parts of the country.

To answer the above questions rainfall characteristics in the country were studied and the rainfall records from representative meteorological stations were analyzed. Optimality of the storage capacities were investigated, and guidelines were established for application of the findings to practical situations. Ways were sought for more effective use of both new and existing cistern systems.

RAINFALL CHARACTERISTICS

The amount and the distribution of the rainfall are both important in determination of the required storage capacities and the consumption rates that can be established.

According to the annual average rainfall, Jordan can be classified into the five zones listed in Table 1 (Arar, 1978):

TABLE 1. Annual Average Rainfall and Areal Coverage in Jordan

Zone	Rainfall (mm)	Area (km 2)	% of Total Area	Total Rainfall (MCM)
Desert	less than 100	73178	79.1	2522
Arid	100-200	11392	12.4	1630
Marginal For Rainfed Agriculture.	200-300	3948	4.3	987
Semi-Arid	300-500	3041	3.2	1190
Semi-Humid	more than 500	989	1.0	566
Total	—	92548	100.0	6896

As seen in Table 1, even though the annual rainfall ranges from 50 mm or less to about 600 mm, most of Jordan receives rather limited precipitation. For representation of these variations, the zonal classification in Table 1 appears convenient. Therefore, each zone was searched for meteorological stations with suitable rainfall records. The stations selected and some of their characteristics are presented in Table 2. The locations of the stations are marked in Fig. 1, which shows the distribution of annual rainfall in Jordan. In view of the available record lengths and the required computational efforts a twenty year period is considered sufficient for analysis purposes.

The rainfall patterns in Jordan are such that the rainy season usually begins in October and ends in April. The rest of the year is dry with clear skies. Historically, 55% of the rainfall occurs during a three month period including November, December and January. The percentage increases up to 80 when the month of February is also included (Abandah, 1978).

TABLE 2. Meteorological Stations Selected For Study

Zone	Desert	Arid	Marginal For Rainfed Agriculture	Semi-Arid	Semi-Humid
Station	Azraq	Mafraq	Shaubak	Um Qeis	Ajlun
Average Ann. Rain fall	68	151.8	288.4	455	615.8
Altitude (m)	533	695	1300	360	760
Period of Analysis	64/65 to 83/84	64/65 to 83/84	60/61 to 79/80	64/65 to 83/84	64/65 to 83/84

ANALYSIS OF RAINFALL DATA

The relationships among rainfall, the required catchment areas and storage capacities, and the consumption rates that can be satisfied were extensively studied by means of the mass curve method (Institude For Rural Water, 1982; Edwards et. al., 1984). Typically, the cumulative rainfall volumes that can be collected from a given catchment area are compared with the cumulative consumptions corresponding to the same period to determine the maximum difference as a measure of the required storage capacity. An average daily or monthly consumption rate may be defined from the yearly rainfall total. The analysis is started at the beginning of the rainy season and some allowance is made for losses in calculation of collactable rainwater volumes. In this study, 20% of the rainfall was assumed for the losses as recommended in Institute For Rural Water (1982b), and by Hofkes (1983) and Edwards et. al. (1984). November was considered as the beginning of the period of analysis.

A computerized version of the above procedure was prepared for use with both daily and monthly data.

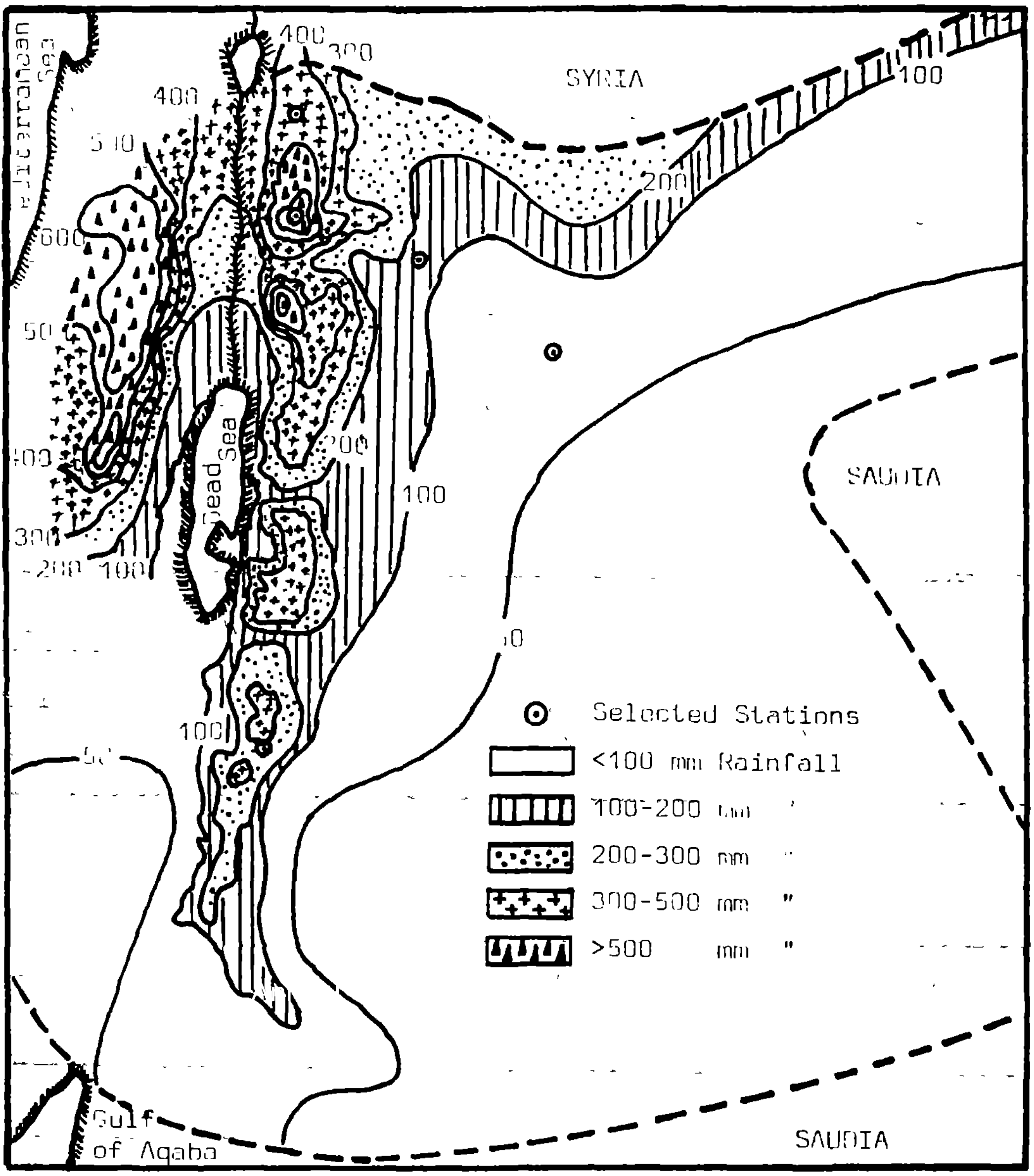

Fig. 1. Average Annual Rainfall in Jordan and the Stations Selected for Study (Abandah, 1978).

RESULTS OF RAINFALL ANALYSIS

Daily Analysis

The daily rainfall data for the selected stations were obtained from The Water Authority of Jordan, the agency responsible for collection of the basic data as well as the planning and management of the country's water resources. The data was subjected to a daily analysis, considering a catchment area of 100 square meters. The storage volumes and the possible daily consumption (demand) rates were determined for each year of analysis. The results are summarized in Table 3.

TABLE 3. Summary of Results for Daily Analysis

		Azraq	Mafraq	Shaubak	Um Qeis	Ajlun
Daily	Average	14.9	33.4	63.4	100.0	135.5
Demand	Minimum	2.2	14.5	16.5	43.6	64.2
(lit/day)	Maximum	27.9	66.2	122.3	169.6	225.2
Storage	Average	3.1	7.6	14.8	21.	28.3
Volume	Minimum	0.5	3.2	4.3	11.2	15.8
(cu m)	Maximum	6.1	13.3	29.6	35.3	48.1
Annual	Average	68	152	288	455	616
Rainfall	Minimum	10	66	75	199	3383
(mm)	Maximum	127	301	558	771	1024

The results indicate that variations of ±50% are typical in the average demand and storage values, as for Mafraq, Um Qeis and Ajlun stations, but variations of the order of ±100% are also possible, as for Azraq. Due to these extreme variations, establishment of a suitable tank capacity becomes rather difficult. This question will be addressed further in a later section.

When the annual variations in storage volumes and demands were studied graphically, the variations for all stations were found to be similar implying that all the country was under the influence of the same precipitation patterns.

The annual storage volumes required and the corresponding demand rates are plotted against the annual rainfalls for all the stations. As seen in Fig. 2, all the results exhibit essentially the same trend, indicating that the zonal differences can be represented in terms of the annual rainfalls. Straight lines, visually fitted, approximate the trends rather well. The fitted lines can be represented by the following equations:

$$S = 0.0047\ AP \tag{1a}$$

$$D = 0.0022\ AP \tag{1b}$$

in which S = storage volume (m^3), A = area (m^2), P = annual precipitation (mm), and D = daily demand (lt/day). Since these relationships, whether in graphical or equation form, show no zonal dependence, they can be generalized to all of Jordan for practical usage.

Monthly Analysis

Since the daily rainfall data may not be as readily available as the monthly data, the analysis was repeated with the monthly versions of the available rainfall data. When the results were compared, the daily demands were found to be the same, as would be expected, since they depend only on the annual rainfall totals. However, the storage volumes obtained from monthly rainfall data were found to be less than those obtained from daily data. The comparisons for Um Qeis station are shown in Table 4 for illustration. The range of the observed differences are summarized in Table 5. As seen, the storage volumes determined from daily data may be higher by as much as 30%. The differences are acceptable since the daily extremes are damped, and thus disappear in monthly records.

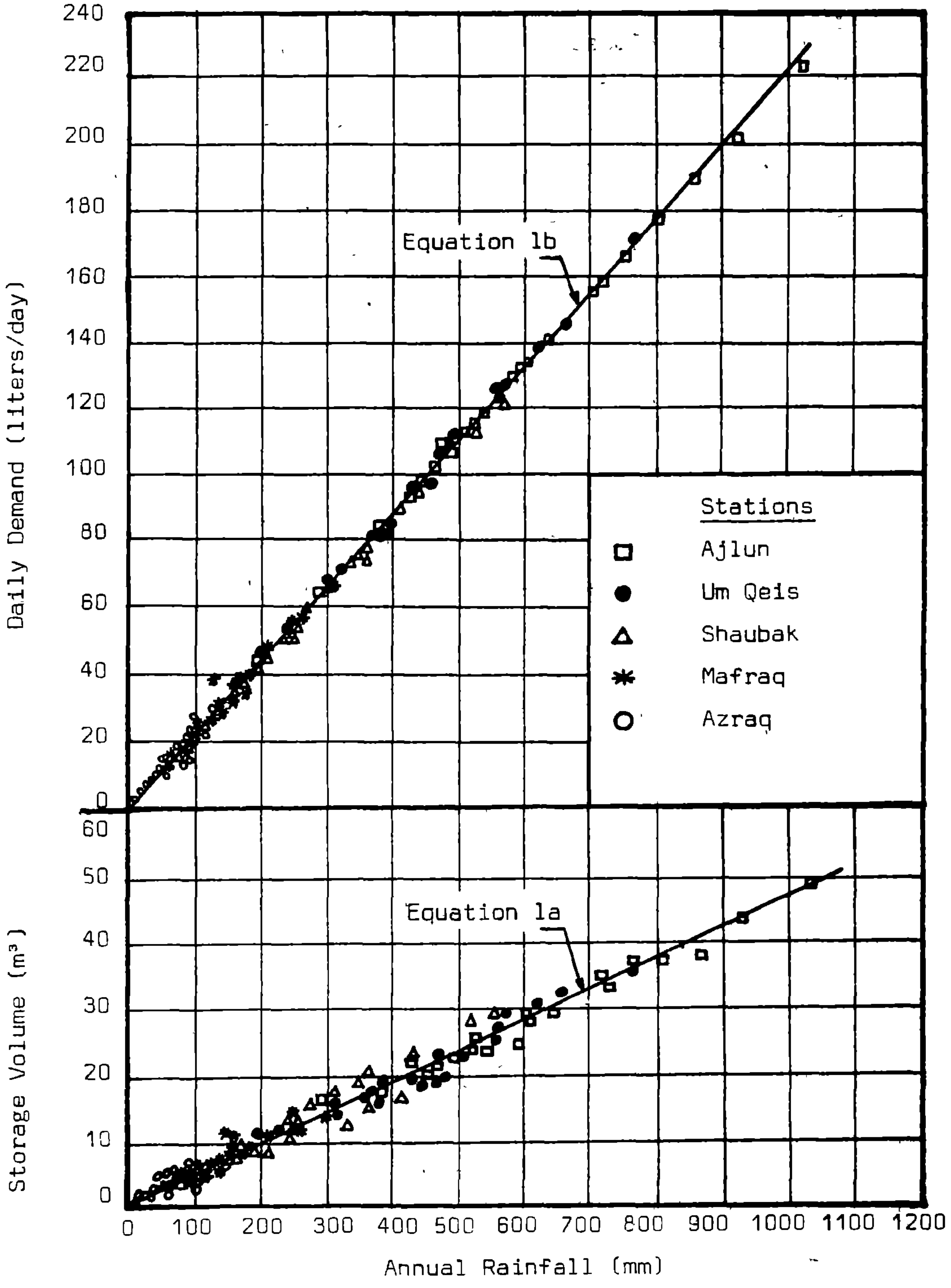

Fig. 2. Variations of Daily Demand and Storage Volume with Annual Rainfall (Catchment Area = 100 sq. m).

TABLE 4. The Annual Maximum Storage Volumes and Average Daily Demands for Um Qeis Station

Year	Annual Rainfall (mm)	Storage Volumes (cu m)		$((S_D-S_M)/S_D)\times 100\%$
		Daily A.	Monthly A.	
64/65	476	22.8	20.2	11.4
65/66	377	15.9	15.1	5.0
66/67	621	30.1	29.0	3.7
67/68	446	18.1	16.4	9.4
68/69	658	32.1	28.3	11.8
69/70	472	19.2	16.2	15.6
70/71	573	28.8	26.7	7.3
71/72	435	19.4	17.9	7.7
72/73	299	15.5	12.7	18.6
73/74	557	25.4	22.4	11.8
74/75	365	17.3	16.0	7.5
75/76	370	17.0	15.6	8.2
76/77	481	19.6	17.3	11.7
77/78	383	17.4	16.9	2.9
78/79	199	11.2	10.7	4.5
79/80	771	35.3	27.7	21.5
80/81	498	23.3	21.9	6.0
81/82	239	11.9	10.2	14.3
82/83	560	26.8	25.7	4.1
83/84	321	13.7	12.8	6.6
Avg.	455	21.0	19.0	
Min.	199	11.2	10.2	2.9
Max.	771	35.3	29.0	21.5

Note: S = Storage volume, D = daily, M = Monthly.

TABLE 5. Observed Percentage Decrease in Storage Volumes Determined from Comparison of Daily and Monthly Analyses

	Azraq	Mafraq	Shaubak	Um Qeis	Ajlun
Minimum	0.0	1.1	0.9	2.9	0.0
Maximum	25.0	20.2	23.9	21.5	29.9

In view of the above results, the desirability of using daily rainfall data is apparent.

OPTIMAL STORAGE CAPACITY

Due to significant variations of the annual rainfalls, determination of an optimal storage capacity for a cistern requires additional considerations. As optimal storage capacity may be defined as the volume maximizing the net benefits to be derived from the RRWCS. The results of such an analysis will be summarized here (Mahmood, 1986).

Considering that the major contribution to the cost of a RRWCS would be from the storage tank, tank costs were calculated for reinforced concrete tanks upto capacities of 80 m³. Local material and labour costs were used and the costs of the accessories commonly needed were also included. The annual equivalents of these costs were compared with the cost of an equivalent supply of bottled-water. Bottled-water was considered to be a suitable alternative supply, since it is available at places without a public water supply system. Besides, even in places with a supply system, bottled-water is preferred for drinking and cooking due to the low quality of piped water.

The cost difference between bottled-water and water from an RRWCS were found to increase with increasing demand rates or storage volumes, as related by Eq. 1 or Fig. 2. Since the cost difference essentially represents the net benefits expected from RRWCS, the optimal storage volume emerges as the maximum storage volume determined from analysis of historical rainfall data. Further confirmation for adoption of the historical maximum storage volume may be found in the fact that, in areas with important water shortages, as much water as possible should be stored. Thus the maximum storage volumes presented in Table 3 are recommended for the various rainfall zones of Jordan.

EFFECTIVE USE OF RRWCS

Using a constant demand rate, such as the historical average, throughout the year will lead to a storage deficiency by running dry in a dry year or by spilling in a wet year. At the beginning of a water year prediction of the expected annual precipitation would be impossible. Therefore, establishment of an effective usage rate, which will assure no spillage or shortage for the year, becomes extremely difficult. However, a more efficient usage may be assured by modifying the demand rate at the end of the rainy season in accordance with the current rainfall total (or with the water available in storage). The relative improvement in utilization of the water in storage can be quantified by defining an efficiency parameter as:

$$E = 100 \times (V - V_s)/V \tag{2}$$

in which E = efficiency in %, V = volume of water that can be stored; V_s = volume of water spilled or left in storage unused. As apparent from this definition, efficiency would be 100% when the spillage and excess are both zero. The efficiency parameter may be used with annual data as well as historical records.

The comparison between management for constant and variable demands for Um Qeis station, as shown in Table 6, will be used to illustrate an application of the above efficiency parameter. For the comparison, the roof area is assumed to be 100 square meters, and the maximum storage capacity and the average demand are taken from Table 3 as 35.3 cubic meters and 100 liters/day, respectively. The rainy season is assumed to be six months long. In the last column of Table 6, the

TABLE 6. Comparison Between Management for Constant and Variable Demands for Um Qeis Station

Year	Annual		Consumed Volume	Remaining Volume	Adjusted Demand	Volume Needed or Unused with Constant Demand
	Rainfall (mm)	Volume (cu m)	(cu m)	(cu m)	(lit/d)	(cu m)
64/65	476	38.1	18.0	20.1	110.0	2.1
65/66	377	30.2	18.0	12.1	66.7	-5.8
66/67	621	49.7	18.0	31.7	173.5	13.7
67/68	446	35.6	18.0	17.7	97.0	-0.3
68/69	658	52.6	18.0	34.6	189.3	16.6
69/70	472	37.8	18.0	19.8	108.5	1.8
70/71	573	45.8	18.0	27.8	152.2	9.8
71/72	435	34.8	18.0	16.8	92.1	-0.2
72/73	299	23.9	18.0	5.9	32.5	-12.1
73/74	557	44.6	18.0	26.6	145.7	8.1
74/75	365	29.2	18.0	11.2	61.5	-6.8
75/76	370	29.6	18.0	11.6	63.7	-6.4
76/77	481	38.5	18.0	20.0	112.3	2.5
77/78	383	30.6	18.0	12.6	69.1	-5.4
78/79	199	15.9	18.0	-2.0	-11.2	-20.1
79/80	771	61.7	18.0	43.7	239.1	25.7,(17.3)
80/81	498	39.8	18.0	21.8	119.4	3.8
81/82	239	19.1	18.0	1.1	6.3	-16.9
82/83	560	44.8	18.0	26.8	146.7	8.8
83/84	321	25.6	18.0	7.6	41.8	-10.4
Total		728				+ 93,-84.4

negative quantities indicate the volume needed while the positive quantities designate the spilled volumes; therefore, +93.0 and -84.4 indicate the total spill and shortage volumes, respectively. The maximum yearly shortage occurred in 78/79 and required an additional 20.1 cubic meters of water. The maximum amount of water that could not be used was 25.7 cubic meters (in 79/80). 8.4 cubic meters (=43.7-35.3) of 25.7 had to be spilt because of limited storage capacity, while the 17.3 cubic meters of water remained unused in storage. Efficiency with constant demand would be

$$E = 100 \times (728-(93.+84.4))/728 = 75.6\%$$

With the spilt 8.4 cubic meters in 79/80 and the shortage of 2.1 (=18.0 - 15.9) cubic meters in the first half of 78/79, the efficiency for variable demand becomes:

$$E = 100 \times (728-(8.4 + 2.1))/728 = 98.6\%$$

Thus, demand should be adjusted at the end of the rainy season to assure better utilization of the RRWCS.

GUIDELINES FOR APPLICATION

A RRWCS for a specific site in Jordan may be designed and operated rather easily using the findings of this study. The procedure below may be followed:

1. For the nearest meteorological station, the historical maximum and average annual rainfalls should be obtained. For this purpose, Table 7 is compiled from the records of The Water Authority (1980). Then the storage volume corresponding to the maximum annual rainfall should be determined from Fig. 2b or Eq. 1a. For operation of the RRWCS, the average daily demand should be found from either Fig. 2a or Eq. 1b using the average annual rainfall. Both the volume and the demand obtained from Fig. 2 should be corrected in proportion to the

area if the roof area under consideration is not equal to 100 square meters.

2. If the site under consideration is not close to any of the cities listed in Table 7, the zone to which this site belongs may be determined from Fig. 1 and Table 2 may be used to find the representative station for this zone. Then the results recommended for this station may be obtained from Table 3.

3. Once the storage volume and average demand are determined, either from Step 1 or Step 2, the consumption rate should be varied for effective usage of the RRWCS. For this purpose, the average demand should be used through the rainy season and a new rate should be established at the end of that rainy season depending on the amount of water available in storage.

TABLE 7. Maximum and Average Annual Rainfalls For Major Cities in Jordan

City	Annual Rainfall (mm)	
	Maximum	Average
Amman	843	291
Irbid	815	417
Ramtha	502	283
Mafraq	301	152
Ajlun	1024	616
Zarqa	280	135
Azraq	128	68
Salt	1038	625
Tafila	751	275
Shaubak	558	288
Aqaba	114	35

CONCLUSIONS

The study of the feasibility of using RRWCS in Jordan led to the following conclusions:

1. The relationships among annual rainfalls, the amount of rainwater that can be collected and the consumption rates (or demands) that can be satisfied indicated that the regional differences in rainfall characteristics, and hence, storage and demand variations, can be expressed in terms of annual rainfalls (Fig. 2).
2. The storage volumes obtained from monthly rainfall data are less than those obtained from daily rainfall data by percentages ranging from 0 to about 30. However, the daily demand is the same in both monthly and daily analyses.
3. Cost-benefit considerations indicated the optimal storage capacities to be the maximum volumes defined by historical rainfall analysis (Eq. 1a).
4. Use of a variable, rather than a constant, demand throughout the year can improve the usage efficiency for RRWC systems significantly.

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SELF-RELIANCE IN SCIENCE AND TECHNOLOGY AT THE THAI VILLAGE LEVEL : CASE STUDY OF RAINWATER CISTERN SYSTEMS

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ABSTRACT

To solve the problem of storing good clean rainwater for use during the long dry season in Thailand, a rainwater cistern system is required. But as usually found in most rural villages in Thailand, the villagers' socio-techno-economic background and their capability to understand certain technologies involved are not up to the point where they can make wise decisions in selecting appropriate technology. This paper discusses the principle of self-reliance of rural Thai people illustrated with case study at Ban Pa-La-U-Bon, Province of Prachuabkirikand, 250 km Southwest of Bangkok.

1. INTRODUCTION

In most rural villages in Thailand, rainwater often is the only source of good clean water for human consumption. As found in many areas, the dry season can extend as long as seven months in any one year. It is necessary to store rainwater harvested during the rainy season for use during the dry season and the storage capacity must be adequately provided for so that shortages can be avoided. Large capacity storage often requires large initial investment, hence a low cost cistern system constructed with appropriate technology is called for. Not only must the technology be appropriate but the villagers' capability must also be upgraded to understand the technology so that they are able to implement and maintain the system with a high degree of self-reliance from the user's point of view.

2. OBJECTIVE

(a) To study the principle and quantitative measurement of self-reliance in Science and Technology at the community level in the rural area.

(b) To apply the principle of self-reliance in upgrading the capability of community members to the point of being able to make decisions on the appropriateness of the technologies involved in the construction to rainwater cistern system and others.

3. THEORY

3.1 Technology

Technology is defined as any knowledge, process, method or equipment that will make man work better, faster or produce better quality products at lower cost or raise the quality of life of man. The technolgy when used must serve the society or be well accepted by members of the society. It should give economic benefit to the techno-users while the environment is not disturbed too much nor the available resources depleted too quickly. Figure 1 summarizes the interrelation of these five components.

Levels of difficulty of technology

The level of technology can be divided into 5 levels as follows

Level 1. Traditional or Village Technology

These are technologies that are with the villager for a long time. Often they are simple technologies. Demomstration is often sufficient for them to follow a newly introduced traditional technology. Examples are water jar, watertight bamboo and rattan jar,etc.

Level 2. Intermediate Technology

Often involves a simple machine or simple techniques but usually requires a trainer or teacher to teach new technology. Examples are cement jars, hand or foot pumps, etc.

Level 3. High Technology

Often involves a complicated machine or is difficult to understand, such as techniques which involve multidisciplinary knowledge. Users are required to attend school to learn these technologies properly. Examples are reinforced concrete tanks, steel or stainless steel tanks, centrifugal pumps, etc.

Level 4. Advanced technology

Often derived from innovative ideas and involves or requires the results of recent research or development. Users must have good basic knowledge and must also seek advice from techno-experts. Examples are plastic lined ponds, bamboo concrete tanks, computer control storage etc.

Level 5. Future Technology

These are newly create technologies that still require extensive testing. Examples are artificial rain making, etc.

Level of Application of technology

The level of ability of the techno-user to apply any technology can also be divided into 7 catogories

Level I Observe from a distance or benefit without involvement

Level II Copy / Operate / Maintenance

Level III Wisely select technology

Level IV Replicate or be able to produce a better product of the same design as the original

Level V Adapt / Modify to suit local needs
Level VI Innovate new idea based on the same principles
Level VII Create new technology

Appropriate technology

These are technologies that fit well with the socio-techno-economic background of the users. They must utilize local resources and local skills. They must not be too difficult for the user to manage. It must be noted however that any technologies, no matter how they qualify for appropriateness, if no one utilize it, then it is still inappropriate.

3.2 Concept of Self-Reliance

Self-Reliance in science and technology is addressed to human capability to decide to accept / reject any technology. If they decide to accept the technology they must possess the ability to absorb and manage it with a high degree of self-reliances.

Quantitative Measurement of the Degree of Self-Reliance

To attempt to quantitatively measure the degree of self-reliance, the techno-system model as appears in Figure 2is suggested.

There are three main components of the model : input, techno-system and output. The following techno-system and output characteristics are viewed as important to the measurement of self-reliance. Each characteristic can further be subdivided into variables. A simple 1, 2, 3 indicator is thought to suffice to describe the degree of self-reliance : 1 for low or not at all, 2 for acceptable and 3 for completely self-reliant.

Output characteristics are :

1. Direct Output
2. Indirect Output

Techno-system characteristics are :

3. Goal Setting
4. Control
5. System Dynamics

6. System Memory
7. System Feedback
8. System Maintenance
9. Vertical and Horizontal Integration

The average value of output and system indicators should exceed 2.0 to qualify for an acceptable degree of self-reliance.

Target of Self-Reliance

To set a reasonable target for an acceptable degree of self-reliance in technology at the rural community level, the conditions of that community must be critically reviewed. In general, the following conditions can be looked upon as average for the rural Thai areas.

(1) Poor economic conditions or high level of debt (National debt is close to 20,000 million US dollars).

(2) People belong to a "soft" culture. They view social development as far more important than the use of technologies to increase production or raise quality of life. Many beliefs are against the advancement of science and technology.

(3) Manpower is readily available but of low quality or capability to utilize new technology.

(4) Good infrastructure such as a school in every community, a health center and agricultural extension offices in every subdistrict, electricity in more than 70 % of the rural community.

(5) Resources vary from one locality to another.

With this background it is possible to set a self-reliance target for the rural Thai at the level to wisely select technology to increase production or raise the quality of life. The level of difficulty should be at an intermediate or high level at the most.

4. GUIDE TO SELECTION OF TECHNOLOGY

In order that people can make a wise decision in selecting technology appropriate to use, the following guidelines are suggested

4.1 Main characteristics

For technology to serve the community well it must be socially acceptable, not change the environment too much and not use up local resources too rapidly. The output must also be quantitatively adequate and the enterprise should be economically feasible. Above all else the people must be able to absorb the newly introduced technology. The following characteristics, technology (T), Social Factors (S), Economic Factors (E), Environment (En) and the Output (O) are thought to be essential elements for the selection of technology. To be applicable all these characteristics should be quantified. For simplicity the quantification of all these characteristics is subdivided into 5 levels with a weighted factor ranging from 1.0 for very good, 0.8 for good, 0.6 for fair, 0.4 for bad and 0.2 for very bad (See Table 4.3 also).

4.2 Copying New Technology

To copy a new technology, the technological background of members of the community must be taken into account. The following matrix is suggested to assess the possibility of copying new technology.

Table 4.1 Technology Compatability Matrix

Existing Technology	Level of Introduced Technology Village	Intermediate	High	Advanced	Future
Village	1	0.8	0.6	0.4	0.2
Intermediate	0.8	1	0.8	0.6	0.4
High	0.6	0.8	1	0.8	0.6
Advanced	0.4	0.6	0.8	1	0.8
Future	0.2	0.4	0.6	0.8	1

4.3 Selection of New Technology

For the people to be able to absorb a newly introduced technology, the matrix as appeared in Table 4.1 is recommended. For the people to make a wise decision concerning the use of a new technology, other characteristics must be included in the decision making process. Weighted factors for the variable degree of disturbance of social and other factors are as shown in Table 4.2.

For complete satisfaction with the selection of technology, a full mark of 100 is suggested and the importance of each characteristic is thought to be of equal weight with the weight of the technology slightly higher.

Table 4.2 Selection Guide by Weighted Mark

Characteristic		Full mark	Weighted Factor	Reduction Factor	Weighted Mark
Social	S	100	0.16	S	16 S
Technology	T	100	0.20	T	20 T
Economic	E	100	0.16	E	16 E
Resource	R	100	0.16	R	16 R
Environment	En	100	0.16	En	16 En
Output	O	100	0.16	O	16 O
		Total	1.0		Final Mark

5. CASE STUDIES AT BAN PA-LA-U-BON

5.1 General

The community of Ban Pa-La-U-Bon is a newly formed community under the supervision of the border patrol police. It is situated at the Thai-Burmese border in the District of Hua-Hin, Province of Prajuabkirikan 250 km southwest of Bangkok. There are 55 households spread across an area of about 5x5 km. When it was first formed in 1980, the economy of the community was based on agricultural production at a subsistence level and the technology could at best be described as primitive. There is a school in the community where children can get up to 2nd grade primary education. The level of application of technology was at copy/operate condition and the difficulty level was low or traditional. Water for drinking and other domestic uses was drawn from a near-by running stream.

5.2 Development Target

The border patrol police try to develop the community by using technology. Assistance was sought and obtained from the Petchburi Teacher Training College for upgrading the education of the people and from the Faculty of Engineering, Chulalongkorn University, for upgrading of the technology to a level of wise selection of appropriate technology. Other government agencies also joined in the development. Technologies to be introduced were those that can raise the level of agricultural production and for constructing basic infrastructure e.g. water conveyor, road and school. The method of technology transfer agreed upon was to be a people participation technique.

5.3 Results of Development

(a) Basic Infrastructure

These included construction by the Accelerated Rural Development Administration Unit of a medium size dam, with a reservior capacity of 2 million cu.m.; a small diversion dam that can divert up to 0.2 cu.m/sec. of water through a partly lined canal to the center of the community ; and an unpaved road system connecting the community with the general provincial highway network.

(b) School and Medical Service

The border patrol police together with the community members built a school house with two classrooms run by border patrol officers and a hut to serve as a medical service center, manned by a medic attached to the border patrol police unit.

Trainees from Petchburi Teacher Training College went up to help teach the children general education and on-farm practices such as chicken raising, raising fish in ponds and vegetable growing.

Table 4.3 Reduction Factor

Characteristic	Qualification	Reduction Factor
Social (S)	Well accepted	1.0
Economic (E)	Very good (B/C>2)	
Resource (R)	Gaining resources	
Environment (En)	Improvement of Environment	
Output (O)	Large output enough for consumption and export	
S	Accepted	0.8
E	Good (B/C 1.5, 2)	
R	Slightly gaining	
En	Slightly better	
O	Enough for local consumption and some left for export	
S	Nondifference	0.6
E	Fair B/C = 1.1-1.5	
R	Renewable	
En	Remain the same	
O	Enough for local Consumption only	
S	Dislike	0.4
E	Poor 1-1.10	
R	Use up slowly or require Some import	
En	Slightly worsening	
O	Not enough for local consumption	
S	Rejected	0.2
E	Very Poor B/C < 1.0	
R	Used up rapidly or large requirement Import	
En	Intolerable supply	
O	Less than 50% of local consumption	

(c) Water Technology

Engineering students of the Appropriate technolgy Group of the Faculty of Engineering, Chulalongkorn University, designed and constructed two hydraulic rams to lift water from the running stream to the school house through a galvanized steel pipe system. The water is stored in a steel reinforced concrete tank and a bamboo reinforced concrete tank. Water is used for domestic use and for crop irrigation purposes. A vegetable plot of 20 X 40 m was provided with a PVC pipe system and taps. Water is lifted from a nearby pond by a bicycle-pump. A slow sand filtering system designed by Dutch students from Delft University of Technology was constructed by the students and the villagers. This system provided clear and fairly clean water fit for human consumption.

All technologies mentioned above were already installed.

(d) Energy Technology

The students also conducted a survey of the energy needed and resources available within the community. A small microhydroturbine with a design output of 2 KW was constructed and tested in the laboratory, ready for installation. A solar cell panel with a simple tracking device was also designed, ready for installation.

(e) Assessment of technology selection

The assessment of technology selection was carried out as suggested in section 4. Details appear in the Appendix. A Summary of selection ranking and people preferences obtained from the independent survey are as follows.

Technology	Selection Ranking	People Preference	Remark
1. Vegetable growing	1	Did not ask	
2. Chicken raising	2	Did not ask	
3. Dam Construction	6	7	
4. Cement jar	3	3	
5. Slow sand Filter	6	3	
6. Sprinkler system with bicycle-pump	4	3	
7. Hydraulic Ram	5	6	
8. Microhydro power	8	1	
9. Solar cell	9	1	

(f) Assessment of Self-Reliance

The assessment of the degree of self-reliance was done as shown in Appendix B. The final score of 1.77 to 1.86 indicated that the people's degree of self-reliance on technology for community development is still poor or below a passable level. Improvement could be done by human resource development, especially technical training and upgrading of human managerial capability.

6. CONCLUSION

Appropriate Technology for rural development is difficult to select because human capability to absorb and manage the technology is equally important and should be included in the selection process. Success will result only if the technology is truely appropriate and the capability of the user is raised to the point where they can wisely select and manage the technology. It should be selected and implemented with a high degree of self-reliance, set at a reasonable target based on the capability of the people. Rainwater cistern system is a system based on successful implementation using technology as means for development. For people to wisely select technology required, the same principle of selection should be applied. With the suggested quantitative approach, a better selection can be made and the successful use of technology with a high degree of self-reliance is ensured.

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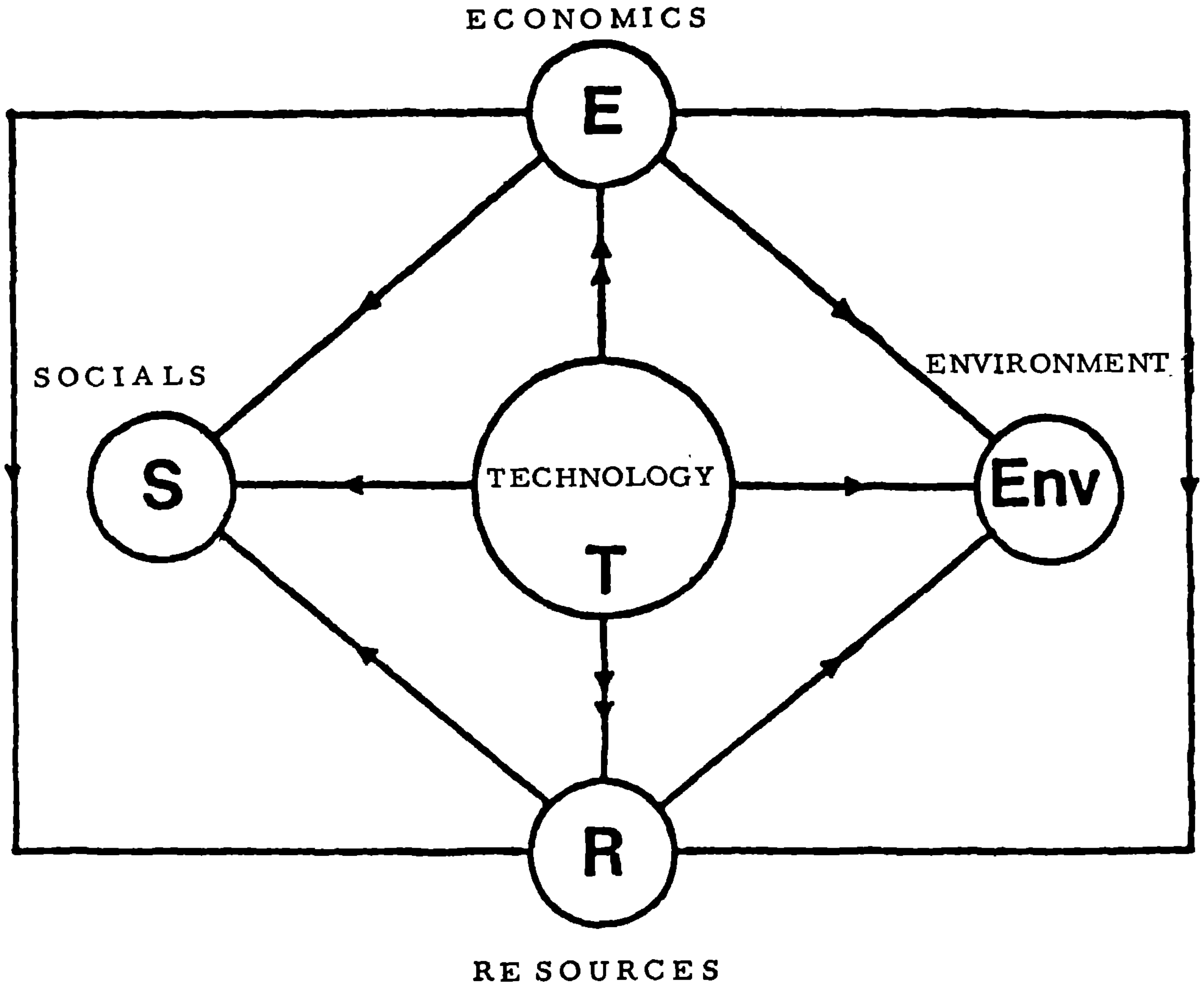

Figure 1 Impact of the Use of Technology upon the Social, Economic, Environment and Resources of the Community

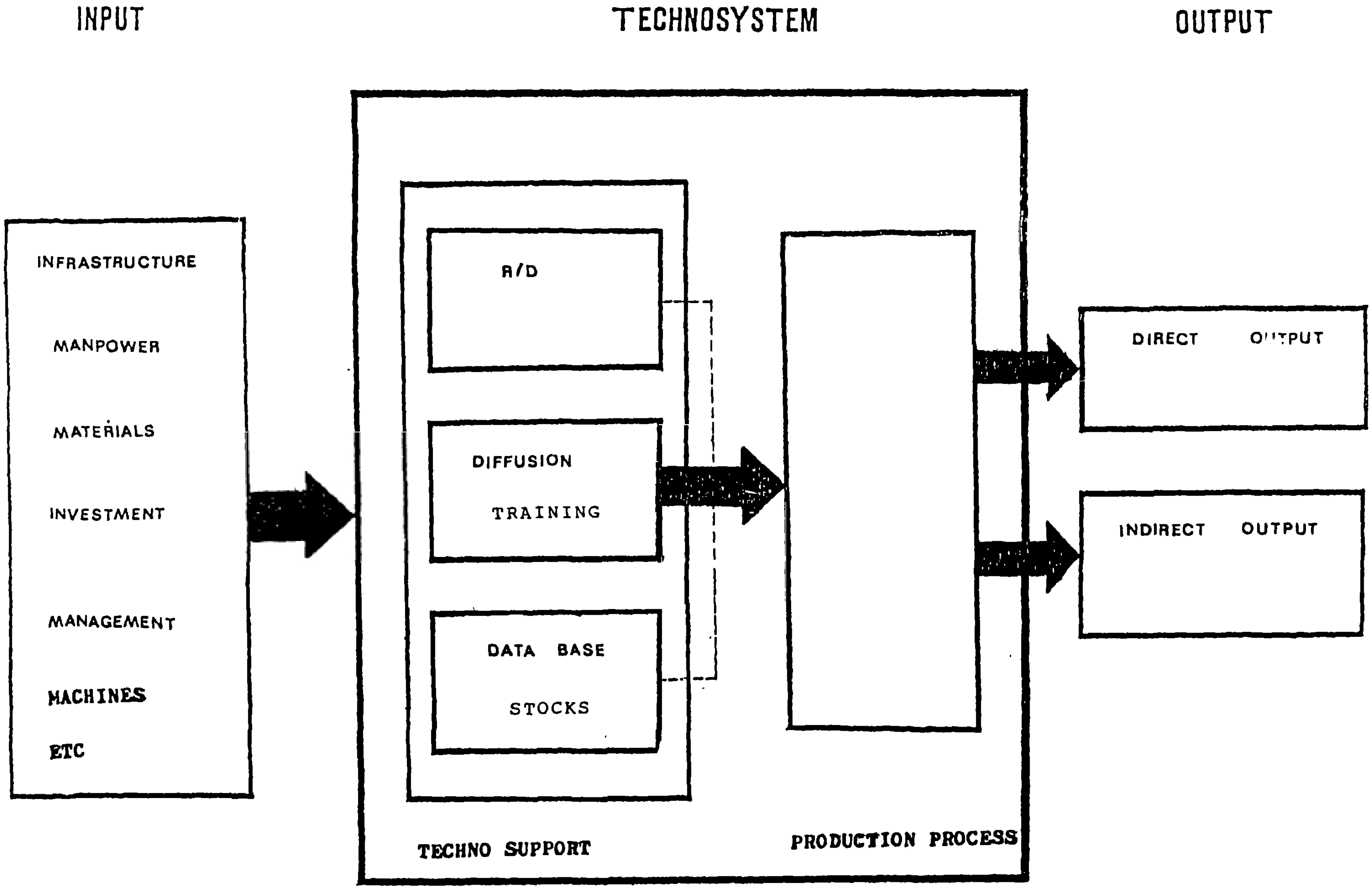

Figure 2 TECHNOSYSTEM MODEL

TABLE B-1 SYSTEM INDICATOR OF SELF-RELIANCE IN S/T : WATER STORAGE TECHNOLOGY BAN-PA-LA-U

SYSTEMS CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.O TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
1.1 GOAL SETTING	1.11 EMPHASIS ON LEARNING IN THE FORMULATION OF GOALS	1.111 EXISTENCE OF TECHNICAL TRAINING/MEETING PROGRAMS IN CORPORATE PLANS	SUBDISTRICT PLAN	2	SAME	2	SAME	2
		1.112 EXISTENCE OF R.D PROGRAM IN CORPERATE PLAN	NONE	1	NONE	1	NONE	1
	1.12 EMPHASIS ON LOCAL AUTONOMY	1.121 EXISTENCE OF PLAN FOR LOCAL AUTONOMY	YES. SUBDISTRICT DEVELOPMENT PLAN, COMPLETE LOCAL AUTONOMY. WEAK IN IMPLEMENTATION	2	SAME	2	SAME	2
		1.122 PLANS FOR VERTICAL INTEGRATION	NONE	1	NONE	1	NONE	1
	1.13 ARTICULATION OF TECHNOSYSTEM POLICIES	1.131 ROLE OF NATIONALS IN POLICY FORMULATION	LOCALS HAVE COMPLETE CONTROL OF POLICY.	3	SAME	3	SAME	3

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
1.2 CONTROL	1.21 ROLE OF NATIONALS IN CORPORATE DECISION MAKING	1.211 NATIONALITY OF MANAGEMENT	ALL THAI LOCALS	3	ALL THAI LOCALS	3	SAME	3
		1.212 EQUITY OF PARTICIPATION	FULL PARTICIPATION	3	PART PATICIPATION	2	SAME	2
	1.22 ROLE OF NATIONALS IN THE FLOW OF INPUTS	1.221 CONTROL OF MANAGERIAL INPUTS	THAI LOCALS CONTROL ALL	3	SAME	3	SAME	3
		1.222 CONTROL OF TECHNOLOGICAL INPUTS	THAI LOCALS CONTROL ALL INPUTS	3	SAME	3	SAME	3
		1.223 CONTROL OF PRODUCTION INPUTS	COMPLETE CONTROL OF INPUT	3	ALMOST COMPLETE CONTROL OF INPUT EXCEPT STEEL RAIN FOR CEMENT	2	COMPLETE CONTROL	3

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
		1.224 CONTROL OF FINANCES	LOCALS COMPLETELY CONTROL OF FINANCE	3	SAME	3	SAME	3
1.3 SYSTEMS DYNAMICS	1.31 INNOVATIONS BY TRAIS IN THE RELEVANT TECHNOLOGIES	1.311 NUMBER OF RESEARCH PROJECTS DONE ANNUALLY	WELL ESTABLISHED BUT RESEARCH ON FERROCEMENT ARE STILL CARRIED OUT	2	SAME	2	SAME	2
		1.312 NUMBER OF INNOVATION	NOT MUCH NOW	1	SAME	1	SAME	1
		1.313 USE OF LOCAL MATERIAL INPUTS TO THE VARIOUS PROCESS	50 % FROM COMMUNITY	2	LESS THAN 50 % FROM COMMUNITY	1	50 % AND ABOVE	2
		1.314 ADAPTATIONS OF SOME OF THE PROCESSES TO LOCAL CONDITIONS	NO NEEDS WELL ESTABLISH ALREADY	2	SOME	2	SOME	2

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
	1.32. CHANGE IN NUMBER OF THAIS WITH RELEVANT KNOW-HOW	1.321 CHANGE IN NUMBER OF THAIS WITH THE TECHNICAL NOW-HOW IN RELEVANT TECHNOLOGIES	VERY SMALL SLOWLY RISING	1	SAME	1	SAME	1
		1.322 CHANGE IN THE NUMBER OF THAIS WITH MANAGERIAL KNOW - HOW	VERY SMALL SLOWLY RISING	1	SAME	1	SAME	1
1.4 SYSTEMS MEMORY	1.41 DOCUMENTATION OF THE TECHNIQUE/DATA	1.411 EXISTENCE OF DOCUMENTS TECHNICAL LIBRARY LOCALLY	VERY SMALL	1	SAME	1	SAME	1
		1.412 EXISTENCE OF DOCUMENTS AT THE EXPERIMENT STATIONS	VERY SMALL. THAI DO NOT RECORD FINDING	1	SAME	1	SAME	1
		1.413 EXISTENCE OF DOCUMENTS AT THE EXTENSION SERVICE STATION	VERY SMALL	1	SAME	1	SAME	1

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
		1.414 QUALITY OF INFORMATION SUBSYSTEM	VERY POOR	1	SAME	1	SAME	1
1.5 SYSTEMS FEEDBACK	1.51 LINKAGE OF THE TECHNOLOGY WITH LOCAL R+D	1.511 SUPPORT OF LOCAL R+D BY LOCAL PRODUCERS	NOT MUCH	1	NOT MUCH MOST R+D ARE FOR CONSTRUCTION INDUSTRY	1	SAME	1
		1.512 UTILIZATION OF R+D RESULTS	NOT MUCH	1	NOT MUCH	1	SAME	1
	1.52 LINKAGE WITH RURAL DEVELOPMENT	1.521 UTILIZATION OF LOCALLY TRAINED TECHNICIANS	ALL ARE TRAINED WITH IN THE COUNTRY SOME ARE TRAINED WITH IN THE COMMUNITY	3	SAME	3	SAME	3

TABLE B-2 SYSTEM INDICATOR OF SELF-RELIANCE IN S/T FOR ENERGY CONVERSION TECHNOLOGY BAN-PA-LA-U

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
1.6 SYSTEMS MAINTENANCE	1.61 ADEQUACY OF LOCAL TECHNOLOGICAL EDUCATIONAL	1.611 RELEVANCE OF CURRICULA	GOOD-BOTH AT UNIVER UNIVERSITY AND VOCATIONAL LEVEL. NOT SO GOOD AT SCHOOL LEVEL	2	SAME	2	GOOD AT UNIVERSITY LEVEL ONLY	1
		1.612 ADEQUACY OF NUMBER OF GRADUATES	ADEQUATE RIGHT DOWN TO RURAL COMMUNITY LEVEL	2	NOT AT RURAL LEVEL	1	SAME	1
		1.613 QUALITY OF THE GRADUATES	GOOD	2	NOT GOOD AT RURAL LEVEL	1	SAME	1

SYSTEM CHARACTERISTIC	VARIABLE	INDICATOR	TYPE OF TECHNOLOGY					
			CEMENT JAR		R.C TANK.		AMBOO CEMENT TANK	
			REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
	1.62 ADEQUACY OF LOCAL SUPPLY OF HARDWARE AND MAINTENANCE	1.621 LOCAL SUPPLY OF HARDWAR	ADEQUATE AT SUBDISTRI SUBDISTRICT LEVEL	2	SAME	2	SAME	2
		1.622 LOCAL MAINTENANCE OF HARDWARE	GOOD POSSIBILITY	2	GOOD	2	NOT SO GOOD	1
1.7 INTERDEPENDENCE/ INTERGRATION	1.71 EXISTENCE OF THE VARIOUS COMPONENTS OF THE TECHNOSYSTEM FOR PRODUCT	1.711 COLLECTIVE FUNCTION OF THE SYSTEMS COMPONENTS	NO INTERGATION	1	INTERGRATE WITH OTHE RURAL CONSTRUCTION	2	SAME	2
			AVERAGE OUTPUTS INDICATOR	1.86	AVERAGE OUTPUTS INDICATOR	1.93		1.86
			AVERAGE SYSTEM INDICATOR	1.86	AVERAGE SYSTEM INDICATOR	1.76		1.78
			AVERAGE SELF-RELIANC INDICATOR	1.86	AVERAGE SELF-RELIANC INDICATOR	1.80		1.77

TABLE B-2 OUTPUT INDICATOR OF SELF-RELIANCE IN S/T FOR , WATER STORAGE TECHNOLOGY BAN-PA-LA-U

CHARACTER OF OUTPUT	VARIABLE	INDICATORS	EMPIRICAL / EXISTING REFERENCES	TYPE OF TECHNOLOGY					
				CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
				REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
2.1 DIRECT OUT-PUT CHARACTER	2.1.1 QUANTITY OF OUTPUT	2.1.1.1 SUFFICIENCY FOR LOCAL CONSUMPTION	2.1.1.1 FOR CONSUMPTION WITH IN THE COMMUNITY	INSUFFICIENT FOR LIGHTING NOW	1	SAME	1	SAME	1
			2.1.1.2 FOR LOCAL MARKET	NONE	1	NONE	1	NONE	1
			2.1.1.3 FOR OUTSIDE	NONE	1	NONE	1	NONE	1
	2.1.2 QUALITY OF OUTPUT	2.1.2.1 MEET WITH STANDARD SET BY THE DEMAND	2.1.2.1.1 MEET WITH LOCAL DEMAND STANDARD	YES STORE GOOD CLEAN WATER	3	YES	3	YES	3
			2.1.2.1.2 MEET WITH INDUSTRY DEMAND STANDARD	NO	1	NO	1	NO	1
			2.1.2.1.3 MEET WITH INTER INTERNATIONAL STANDARD	NO	1	NO	1	NO	1

CHARACTER OF OUTPUT	VARIABLE	INDICATORS	EMPIRICAL / EXISTING REFERENCES	TYPE OF TECHNOLOGY					
				CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
				REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
2.2 INDIRECT OUT-PUT CHARA CHARACTERS	2.2.1 ECONOMIC IMPACT	2.2.1.1 B/C	2.2.1.1.1 FARMER B/C AT FARM GATE-	SLIGHTLY OVER 1	2	SAME	2	SAME	2
	2.2.2 SOCIAL IMPACT	2.2.2.1 PERCENT OF UNEMPLOYMENT	2.2.2.1.1 LOCAL UNEMPLOYMENT	CREATE MORE EMPLOYMENT BUT NOT MUCH	2	SAME	2	SAME	2
		2.2.2.2 SOCIAL CAPABILITY OF ABSORBING TECHNOLOGY	2.2.2.2.1 LOCAL FARMER CAPABILITY	REQUIRE MORE DIFFUSION AND TRINING	1	SAME	1	SAME	1
	2.2.3 ENVIRONMENTAL IMPACT	2.2.3.1 WATER POLUTION'	2.2.3.1.1 LOCAL WATER POLLUTION	SLIGHTLY	2	SAME	2	SAME	2
			2.2.3.1.2 REGIONAL WATER POLLUTION	NONE	3	NONE	3	NONE	3
		2.2.3.2 NOISE, AIR POLLUTION	2.2.3.2.1 LOCAL POLLUTION	SOME	2	SOME	2	SAME	2

CHARACTER OF OUTPUT	VARIABLE	INDICATORS	EMPIRICAL / EXISTING REFERENCES	TYPE OF TECHNOLOGY					
				CEMENT JAR		R.C TANK		BAMBOO CEMENT TANK	
				REFERENCES	VALUE	REFERENCES	VALUE	REFERENCES	VALUE
			2.2.3.2.2 OTHERS SIDE OFFECT POLLUTION	NONE	3	NONE	3	NONE	3
	2.2.4 RESOURCE IMPACT	2.2.4.1 RATE OF RESOURCE DEPLETION	2.2.4.1.1 FINANCIAL RESOURCE	BUY METERIAL FROM OUTSIDE	1	SAME	1	SAME	1
			2.2.4.1.1 WATER RESOURCE	RENEWABLE	3	NO EFFECT	3	SAME	3

DESIGN

SUITABILITY OF RAIN WATER CISTERN SYSTEM IN MALAYSIA

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ABSTRACT

Malaysia is a country gifted with abundant rainfall that is unfortunately unevenly distributed chronologically and geographically. Consequently various parts of the country are occasionally afflicted with floods and water shortages.

Nearly half of the country's population living in rural areas is still without piped water supply. The fact that water supply to rural areas is a low budget priority in the previous Malaysia plans coupled with population densities which are too low for reticulated supplies to be economically justified puts the rural water supply problem into perspective.

In some areas, a solution to the above problem may be the catchment of rain water collected during the wet season to be used in the dry season.

Lastly this paper deals with the suitability and practicality of rain water cistern systems in Malaysia including the design of such a collector using locally available material.

INTRODUCTION

In line with the Water Decade (1981-1990) as proposed by the United Nations Water Conference, the Malaysian's government policy is to supply clean and sufficient water to all households thereby increasing the health and standard of living of the people.

Efforts towards this direction has been hampered by the increase in population and rapid urbanisation coupled with rapid industrialisation. Hoping to exploit the full potential of the country's water resources, the government carried out a National Water Resources Study which was completed in 1982. The main objective of this survey is to predict the water supply demand for drainage, water supply and other uses up to the year 2010. The study also identifies water resources that can be developed to supplement the water requirement in Malaysia.

The study provides a Master Action Plan which also includes recommendations for the required institutional framework and legal provisions. From the study, it has been shown that the estimated water demand for domestic and industrial purposes will approximately triple at the end of the century i.e. the demand will increase from 1.3×10^9 m^3 per year in 1980 to 4.2×10^9 m^3 per year by the year 2000.

CURRENT WATER RESOURCES SITUATION

Malaysia is a country endowed with abundant rainfall. Annual rainfall in Peninsular Malaysia, Sabah and Sarawak are 2420mm, 2630mm and 3830mm respectively. Compared to a world average of 973mm, Peninsular Malaysia has about 2½ times the world's annual average precipitation.

The abundance of rainfall in Malaysia has been disadvantaged by its uneven distribution both in time and space. Consequently, in the extreme form this can result in severe flood which has often brought about significant loss of human lives and considerable damage to property and crops. On the other extreme, several regions are occasionally subjected to drought.

Precipitation in Malaysia is seasonal. The North-East Monsoon brings heavy rain to east coast of Peninsular Malaysia, North Sabah and South Sarawak between November and March. The South-West Monsoon prevails between May and September in West Coast of Peninsular Malaysia, Sabah and Sarawak. Figure 1 shows the monsoons of Malaysia.

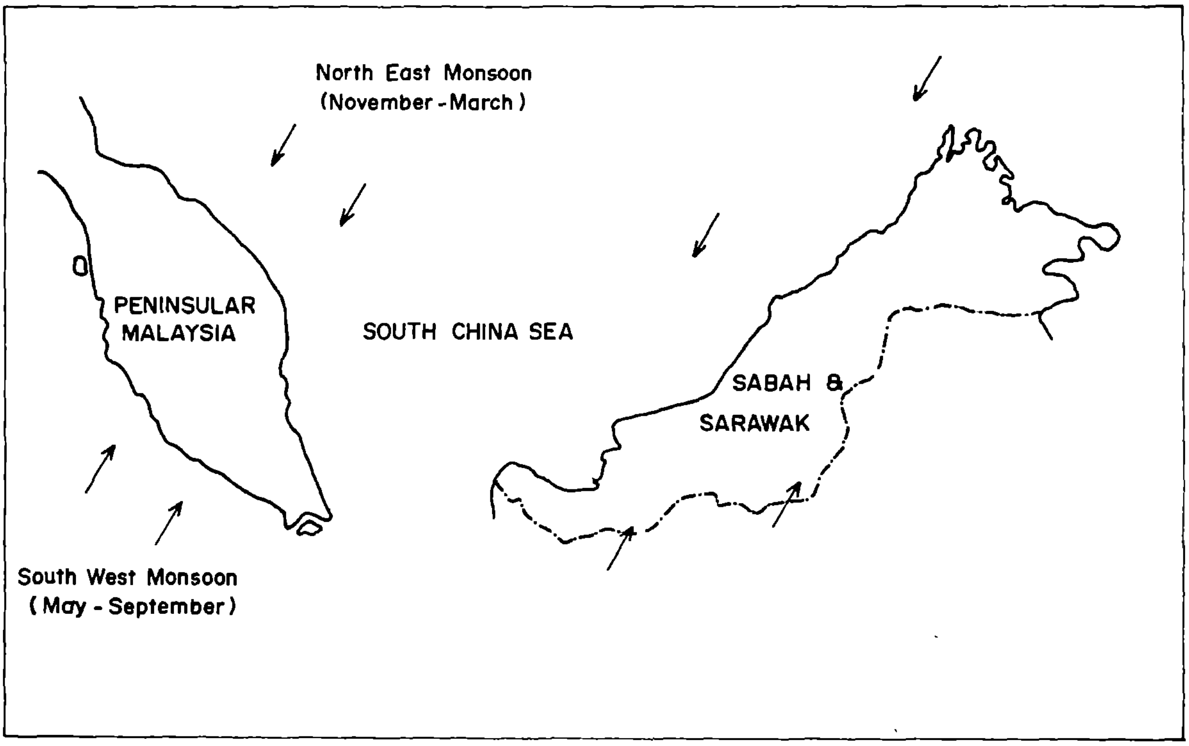

Figure 1: Monsoons of Malaysia

MALAYSIA PLANS : WATER SUPPLY

In 1985 it was estimated that 93.1% (5,502,899) of urban dwellers and 57.6% (5,687,584) of the rural population in Malaysia had access to piped water supply. Tables 1 and 2 show the water supply coverage for urban and rural sectors in every state in Malaysia from 1980-1990. For a country with 60% rural population, the real problem seems to be in the rural areas where nearly half of the population is still without this basic amenity.

In 1971 the Malaysian Government embarked on the New Economic Policy (NEP) in order to restructure society through economic developments and national unity. Increasing piped water supply coverage throughout the country is one of the objectives of the NEP.

Table 3 shows the water supply expenditure/allocation under the Second, Third and Fourth Malaysia Plans. Under the Second Malaysia Plan, expansion of the water supply scheme programme in rural areas was virtually neglected. Rural areas was only given 1.8% of the total water supply expenditure compared to 92.5% given to the urban sector.

TABLE : 1

Malaysia : Urban Population with Piped Water Supply

1980 - 90

States	1980		1985		1990	
	Population	%	Population	%	Population	%
Johor	508,520	87.0	669,779	91.6	865,152	96.0
Kedah	146,250	90.0	174,705	95,0	203,742	98.0
Kelantan	145,058	58.0	198,705	65.0	283,500	75.0
Melaka	107,310	98.0	114,400	100.0	120,400	100.0
Negeri Sembilan	163,618	86.8	207,890	89.3	263,083	92.7
Pahang	194,948	92.0	241,205	95.0	300,076	98.0
Perak	566,208	96.0	642,652	98.0	677,853	99.0
Perlis	11,880	90.0	15,252	93.0	20,090	98.0
Pulau Pinang	441,544	97.0	555,072	98.0	677,457	99.0
Sabah[1]	208,494	99.0	289,400	100.0	388,300	100.0
Sarawak	207,234	87.0	281,580	95.0	358,974	98.0
Selangor[2]	1,354,860	90.0	1,876,109	94.5	2,505,468	98.0
Terengganu	175,350	75.0	254,150	85.0	364,420	95.0
Malaysia	4,231,274	89.0	5,502,899	93.1	7,028,515	96.5

Note: 1 Includes Federal territory Labuan
2 Includes Federal territory Kuala Lumpur

TABLE : 2

Malaysia : Rural Population with Piped Water Supply

1980 - 90

States	1980		1985		1990	
	Population	%	Population	%	Population	%
Johor	296,912	28.0	688,276	61.3	847,325	72.9
Kedah	502,044	52.4	592,579	57.7	835,138	76.4
Kelantan	110,109	17.0	216,180	30.0	410,972	51.6
Melaka	249,970	70.0	308,907	81.7	383,420	95.6
Negeri Sembilan	255,684	66.0	294,450	75.0	353,512	90.7
Pahang	277,441	47.0	484,120	65.0	889,586	94.9
Perak	672,375	55.0	972,900	75.0	1,092,959	80.6
Perlis	61,020	45.0	74,350	50.0	112,015	68.7
Pulau Pinang	392,340	78.0	410,890	85.0	392,680	87.5
Sabah[1]	152,010	18.0	376,238	38.0	614,607	54.4
Sarawak	222,580	20.0	411,312	33.0	656,186	47.3
Selangor[2]	648,180	65.0	722,262	73.0	792,085	82.1
Terengganu	77,325	25.0	135,120	40.0	329,719	89.8
Malaysia	3,917,990	42.9	5,687,584	57.6	7,710,204	72.8

Note: 1 Includes Federal Territory Labuan
2 Includes Federal Territory Kuala Lumpur

TABLE : 3

Malaysia : Water Supply Expenditure/Allocation 1971-85
(Million Ringgits)

	2 MP Expenditure 1971-75	3 MP Expenditure 1976-80	4 MP Allocation 1981-85
Water Supply	172.85 (100)	509.09 (100)	1287.74 (100)
Urban	159.96 (92.5)	254.12 (49.9)	736.00 (57.1)
Rural	3.16 (1.8)	123.10 (24.2)	349.76 (27.2)
Others	9.73 (5.7)	131.87 (25.9)	201.98 (15.7)

Under the Third, Fourth and Fifth Malaysia plans, rural water supply was given more emphasis with increasing budget expenditure/allocation. Under the Fifth Malaysia Plan, the objective is to increase the number of people with access to piped water supply in both urban and rural areas up to 96.5% and 72.8% respectively.

To put the water supply programme in Malaysia into perspective, a population of 22 million is envisaged in the year 2000, assuming an annual geometrical growth of 2.2% . That population would need a total capacity of 13,150 million litres per day of water. Discounting inflation, the government would have to spend an estimated 14.8 billion ringgit.

RURAL WATER SUPPLY SCENE

Even if the latest Malaysia Plan is implemented to the fullest (highly improbable due to the current world recession) a large percentage of the rural population would still have to do without piped water supply for several more decades.

In the planning of a water supply scheme to serve the rural population, the estimation of the long term water demand and growth of demand is made very uncertain due to the difficulty in predicting the rate of growth.

The high per capita cost due to very low population densities and the low rates of return to justify the implementation of the rural water supply scheme to bid for Government's limited financial resources in competition to other development projects are major drawbacks.

The unfortunate rural population without piped water supply would have to make do with either surface or underground sources. Surface waters in Malaysia is much more a part of life of the people than in developed nations since they are dependent on them for potable and washing purposes and for some, their livelihood as well and a lot less for their aesthetic value.

For centuries mankind has spoilt and wasted water and Malaysians are no exception. Fortunately Malaysia has assessed its position with some sensitivity and foresight by passing the Environmental Quality Act in 1974 and subsequently the establishment of the Division of Environment to administer the Act. Despite of these efforts in 1984, 14% and 48% of Malaysian rivers are classified polluted in terms of BOD and suspended solids respectively.

Water pollution in Malaysia is due to two main factors - those arising as a result of development of land and natural resources and those arising through the indiscriminate discharge of undesirable wastewater in watercourses.

Currently it is estimated that about 5 million people in rural areas are without piped water supply. Out of this, 1.5 million people are provided with potable well water. The rest will have to rely on surface sources which apart from being polluted, occasionally dry up during the drought period.

SUITABILITY OF RAIN WATER CISTERN (RWC)

In some areas, a solution to the above problem may be the catchment of rain water collected during the wet season to be used in the dry season. RWC will provide an immediate, though limited, safe water supply for drinking and cooking purposes or if circumstances warrant, for any other purposes. For all other purposes which do not require good quality water, surface sources of any kind if available are sufficient.

The implementation of RWC could reduce the occurence of water related diseases such as typhoid, dysentery, cholera and hepatitis which are rampant in Malaysia due to drinking water from sources which have faecal continimation.

In Malaysia, the period of drought usually extend for not more than 3 months. The dry spell on the west and east coast of Peninsular Malaysia for example are from January to March and May to July respectively. These are the periods of urgency since the rivers, streams and wells virtually dry up, thus worsening the pollution level due to surface sources losing their self cleansing capacity.

Realising the fact that it costs far less to provide clean water and sanitation than the price paid for its shortages, the government implemented other alternatives to piped water supply by constructing wells and RWCs. Under the Fourth Malaysia Plan (1981-85) 5,600 wells equipped with hand pumps and 420 wells with direct supply to households were constructed. Apart from utilising underground water, about 14,300 RWCs were built mostly in remote areas in Sabah and sarawak.

In Malaysia RWCs can act as a long-term precautionary measure in overcoming the problem of safe drinking and cooking water during the drought period where surface or underground water either dry up or deteriorate in quality and in areas where piped water supply is intermittent, a feature almost exclusive to rural areas. In some places where water is polluted or quality water unavailable throughout the year, RWC can be the sole means of providing quality water.

The use of RWC is recommended in Malaysia due to several reasons:

- ° simplicity: not much expertise is needed
- ° cost effectiveness: depending on affordability, a RWC in its simplest form can just be an empty drum or on the other extreme a reinforced concrete tank
- ° versatibility: depending on geography, the capacity can vary to suit individual needs
- ° practicality: RWC is the easiest and cheapest means to have clean water
- ° reliability: If it rains when it should, RWC provides water that needs only to be boiled before consumption.

AREAS SUITABLE FOR RWC

From this juncture, this paper will deal only in Peninsular Malaysia since it receives less rainfall, the watercourses are more polluted, more people are without piped water supply and less widespread use of RWC than in Sabah and Sarawak.

Areas with longer dry spells in Peninsular Malaysia where RWC system can play a vital role correspond with those regions having relatively low annual rainfall or lower average number of rain days per year. Figure 2 shows the map of Peninsular Malaysia depicting the average number of rain days.

As a rough guide, areas with less than 180 rain days are considered more susceptible to longer dry spells and will require some form of precautionary measure to obtain drinking water during this period.

Other areas which RWC can be of service all year round are along rivers which are grossly polluted ; Kelang River, Selangor River, Linggi River, Langat River, Melaka River, Segamat River, Johore River, Muda River, Trengganu River, Kelantan River, Perak River and Juru River to name some. Figure 3 shows the river basins whose rivers are polluted.

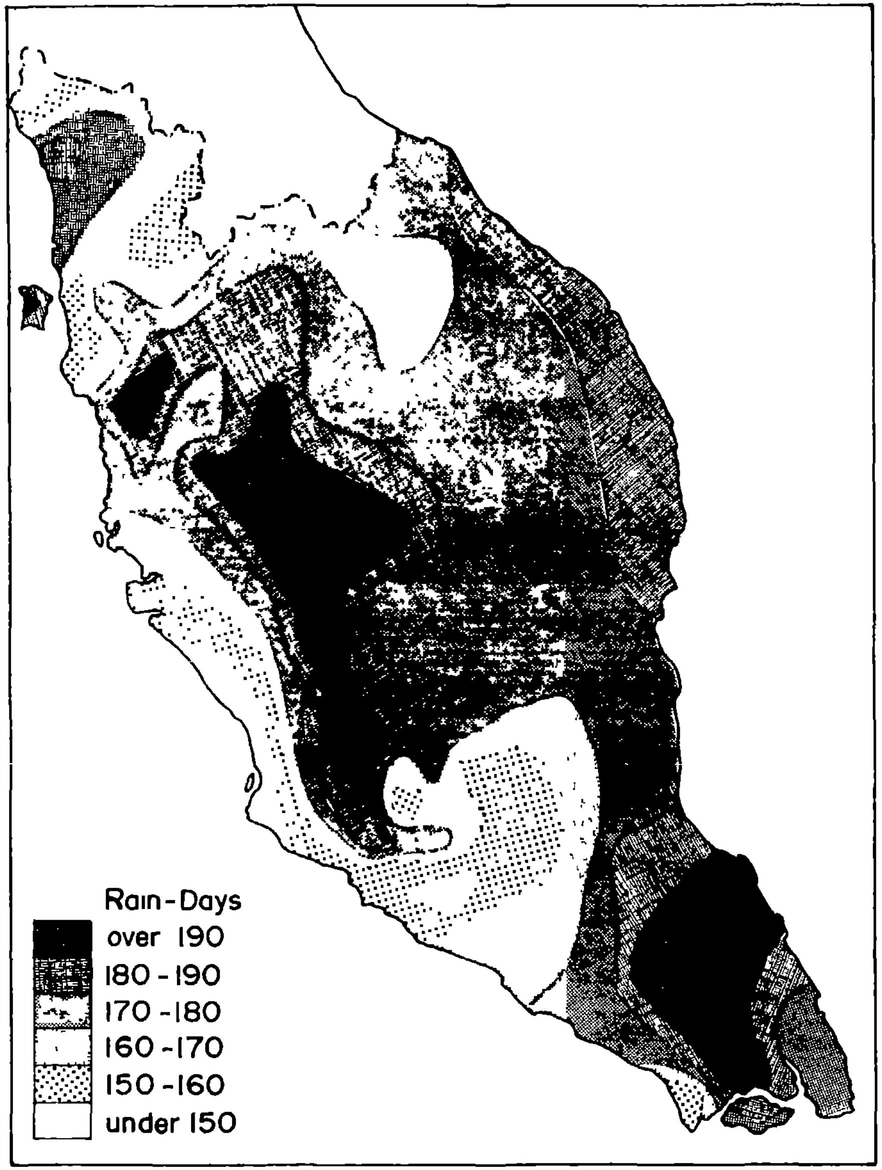

FIGURE 2: Average Number of Raindays in Peninsular Malaysia.

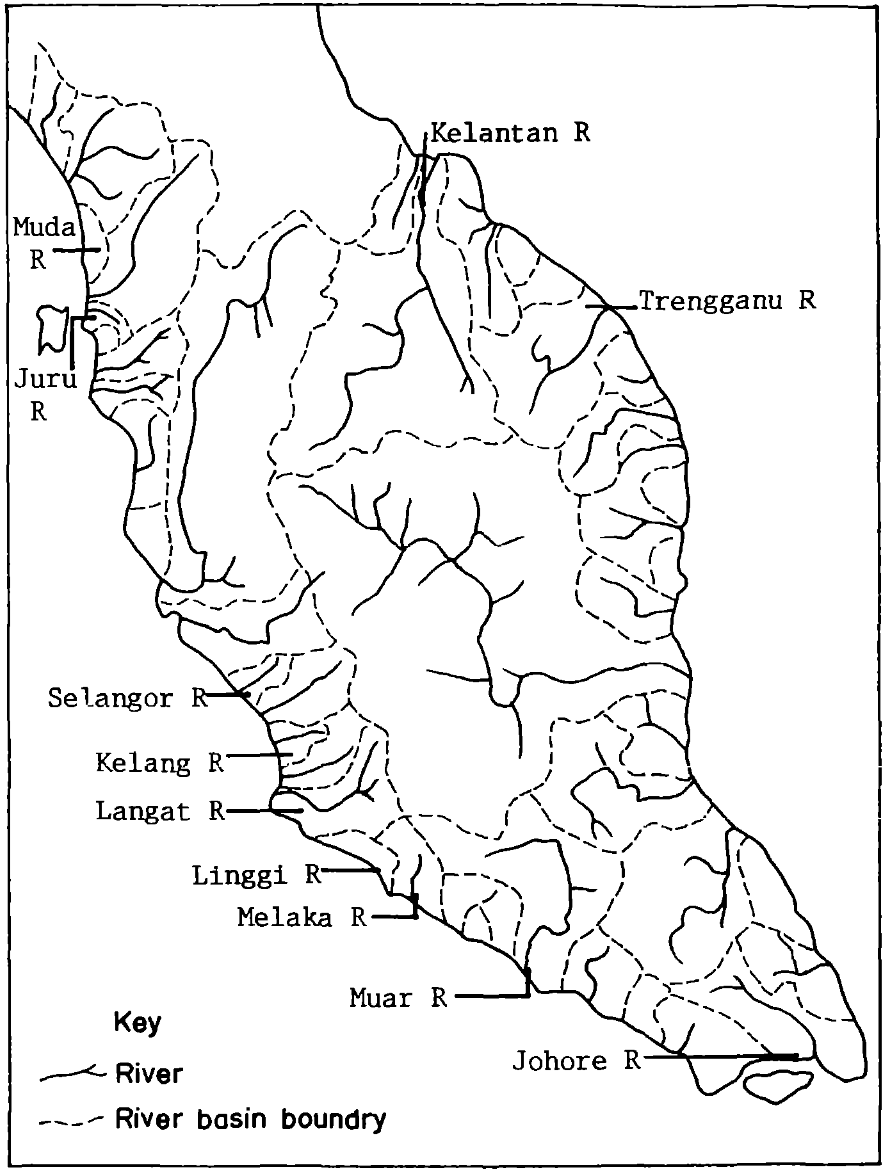

FIGURE 3: River Basins Whose Rivers are Polluted

CAPACITY OF RWC

The capacity of a RWC will depend on several factors:

- whether water required only for drinking or other purposes as well
- length of drought period
- area of roof catchment
- annual rainfall
- losses i.e. evaporation and leakages

On the assumption that the minimum drinking and cooking needs of 3 litres per person per day, a 25% losses, a dry season with an average length of 100 days, an average six-member family will require a storage capacity of ($6 \times 3 \times 100 \times \frac{125}{100} = 2250$ l) 2.25 m^3 or 0.75m^3 per month.

A typical rural Malaysian house with a 25m^2 roof area and an average monthly rainfall of 75mm during the drought period will collect ($0.075 \times 25 \times 3 = 5.625m^3$) 5.625$m^3$ of rain water during the three-month spell or 1.875m^3 per month. This simple calculation is valid if some rain falls during the dry spell, which is the situation in Malaysia. Even if no rain at all falls during the three month period, there would not be any problem at all accumulating 2.25m^3 of rainfall in Malaysia during the wet season.

From the above calculations, it can be deduced that demand exceeds supply by 2.5 times. This simply means that during the months where the average rainfall exceeds 150mm, a 25m^2 roof catchment will collect 3.75m^3 of water per month, thus allowing a six member family about 20 litres of water per person per day, a luxury by any standard.

Figure 4 shows the average monthly rainfall distribution in Peninsular Malaysia. This figure is an essential aid in determining the capacity of a RWC.

As a simple guide, a RWC with a capacity of at least 2m^3 is sufficient to provide drinking and cooking water needs during the dry spell and enabling the user to use the water for some other purposes as well outside the dry period.

DESIGN OF RWC

Most rural houses in Malaysia are either roofed by iron/aluminium sheets, clay tiles or thatched roofing. Basically any type of roofing is acceptable with thatched roofing being least effective.

A setback for RWC installations is the absence of gutters in most rural houses. This problem could be overcome by using matured bamboo stems cut along its length as gutters - a material abundantly available. With a bit of ingenuity, a system of gutters can be constructed by the householder.

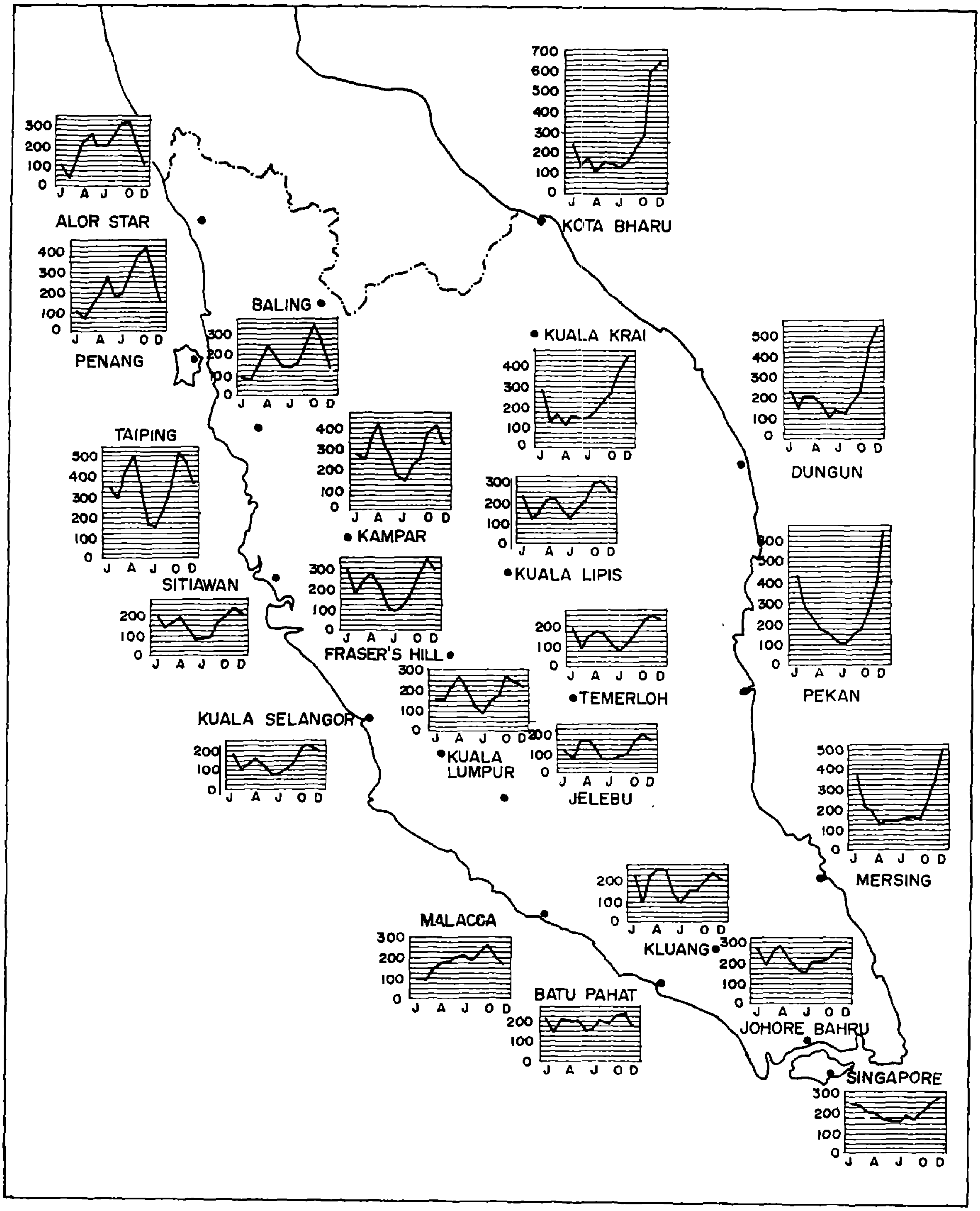

FIGURE 4: Average Monthly Rainfall Distribution in Peninsular Malaysia.

A small rainwater collector with a storage capacity between 2-3m^3 for single households can be constructed using either of the following materials:

- corrugated metal sheets (Drum/barrel of any sort sufficient)
- ferrocement (wire-mesh reinforcement)
- Clay/brick
- Bamboo reinforced concrete
- Fibreglass (usually factory made)

Larger capacity collectors could be constructed to serve several households. For this purpose, either a ferrocement with reinforcement tank or a reinforced concrete tank is needed. For those who can afford it, a large RWC can substitute altogether piped water supply to supply water for all needs and purposes.

CONCLUSION

For about five million people in Malaysia, mostly in rural areas without piped water supply, RWC seems to be the most viable alternative (cheap and simple) to supply safe drinking and cooking water especially during the drought period. RWC offset the disadvantage of the uneven though abundant rainfall by collecting water during the wet season to be used in the dry season.

Although every householder can construct a RWC system, the trend should be encouraged by an organised campaign led by an official body at the Federal level.

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SECOND, THIRD, FOURTH and FIFTH MALAYSIA PLANS.

AN ASSESSMENT OF ROOF AND GROUND CATCHMENT SYSTEMS IN RURAL BOTSWANA

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ABSTRACT

Botswana is a semi-arid country with mean annual rainfall varying from less than 250mm in the southwest to more than 650mm in the north. The most common domestic water sources consist of traditional hand-dug pits in sand rivers and modern piped borehole schemes based on deep groundwater supplies. The low rainfall and its highly seasonal nature make Botswana a marginal area with respect to rainwater catchment systems' development. Nevertheless, the low population density and multiple dwelling places resulting from Botswana's unique triangular migration system, make the provision of alternative improved water sources in rural areas difficult and expensive.

Using information gathered from an extensive questionnaire and technical field survey the current and future potential development of rainwater catchment systems was assessed. The analysis of mean monthly rainfall data from 10 stations using a computer modelling technique revealed that for all the stations the most effective storage tank capacity should have a volume equivalent to approximately 40%(0.4) of the collectable annual roof runoff. This tank size would maximize the supply while minimizing the costs and could supply about 70%(0.7) of the annual roof runoff with 95% reliability. Owing to the small size and scarcity of corrugated iron roofs in rural Botswana roof catchment systems are generally only feasible as a supplementary supply. Bacteriological examination of rainwater samples showed that while roof tanks, if properly maintained, provide high quality water, ground tanks were susceptible to considerable contamination.

INTRODUCTION

Botswana is located in the centre of Southern Africa between 18°S and 27°S (Fig.1). It has an area of 582,000 square kilometers supporting a population of only one million people, most of whom live in the east of the country. Botswana lies on a flat featureless plateau and 80% of the country is covered by a thick deposit of Kalahari sand. The climate consists of distinct wet and dry seasons with virtually no rain falling between May and October. In the wet season most of the rain falls in heavy convectional storms. The unpredictability of this form of rainfall makes drought a common feature of the climate. Mean annual rainfall increases uniformily from less than 250mm in the southwest to more than 650mm in the north of the country (Fig. 2a). The semi-arid nature of Botswana is not due to lack of rainfall alone but is more a result of the highly seasonal, erratic and unreliable nature of the rainfall and the very high evaporation rates prevailing throughout the country. These factors coupled with the sandy nature of surficial material make water an extremely scarce resource indeed. Apart from the Chobe, Okavango and Limpopo rivers which have most of their catchment basins outside of the country, all the rivers in Botswana are ephemeral and most of them flow for only a few weeks a year. These "sand rivers" along with hand dug wells are the most important traditional water sources. They are, however, generally only found in parts of eastern Botswana.

The scarcity of water has led to the development of a unique triangular migration pattern in Botswana. People move from their villages to "cattle post" and "arable lands" areas at different times of the year depending on the availability of water for humans, cattle and arable agriculture. This has resulted in diverse settlement patterns in rural areas with many families effectively having three different homes spread over an enormous area. The scattered nature of settlement makes the provision of improved piped groundwater supplies difficult and expensive. The average depth of groundwater in Botswana is about 100m and although it is generally of good quality, saline and polluted groundwater exist in some areas and a total lack of groundwater altogether in others. Traditional sources are still used by many people as a major or alternative form of supply. These sources are often far from dwelling places and in addition are frequently polluted. (Enge 1983). Despite claims that Botswana will soon achieve the goals of the IDWSS Decade, the field realities reveal that many people in rural Botswana still lack a clean, safe and convenient water supply. Johnson(1982) noted that even if all the villages in Botswana had a reticulated water supply only 55% of the popuation would be served.

It is the purpose of this paper to assess what rôle, if any, rainwater catchment systems might play in providing a safe and convenient water supply to the rural inhabitants of Botswana still lacking clean water.

Figure 1. The Republic of Botswana

ROOF CATCHMENT SYSTEMS

An initial reconnoitre of about 20 villages in rural Botswana in 1983 revealed that although, households were still predominantly grass roofed, especially in smaller villages, a rapid transition to corrugated iron roofs was taking place. Few of the households with corrugated iron roofs had permanent catchment tanks, however, since lack of capital and know-how restricted most privately installed tanks to makeshift temporary affairs fed from totally inadequate guttering. Old oildrums were the most common type of tank used by private households.

The vast majority of permanent rainwater catchment tanks used in Botswana are corrugated iron ones found at schools, clinics and other public biuldings. Only a small fraction of these institutions have tanks, however, and even among those that do catchment tank volumes are generally totally inadequate when compared with the volume of roof runoff available and the demand for water.

Field Survey Results

In order to determine quantitatively the water usage pattern in rural Botswana and the rôle which rainwater catchment plays, or might potentially play in that pattern, an extensive questionnaire and technical field survey was conducted. 200 households were visited in 4 villages (Nata, Thini, Selolwane and Borolong) in the northeast of Botswana (Fig.1), and a postal questionnaire survey resulted in 64 responses from primary schools throughout the country.

The four villages surveyed had populations between 970 and 1850 (Table 1)and an average houseshold size of 7.0. Few people owned cars (11%) or latrines (12%), and although cattle outnumbered people by almost 3 to 1 many households (35%) owned none. The mean distance to the nearest reliable water source varied from 421m in Selolwane to 1285m in Thini, and was 640m on average.The mean daily domestic water consumption varied from 57 litres to 84 litres per household averaging 67litres or less than 10 litres per capita for the 4 villages, (Table 1).

Although, three villages had boreholes, the highly saline nature of the groundwater in Nata and maintenance and running problems with the supply in Borolong, meant that only in Selolwane did the majority of households (77%) use standpipes as their main source of water. Most of the remaining 23% of Selolwane's residents collected water from a nearby sand river as it was closer than the nearest standpipe.

Overall 65% of households in the four villages used sand rivers or surface water as their main source, 29% used standpipe water, 3% used rainwater and 3% used other sources (transported water or water piped directly to the house). Although, only 3% of households used rainwater as their main source 46% of households did collect and use some rainwater (Table 1). Only 33% of the surveyed

Table 1. Summary of Village Field Survey Results

VILLAGE	SELOLWANE	NATA	THIHI	BOROLONG	MEAN
Population(1983)	970	1850	1150	1050	1255
Rainfall(mm/a)	520	550	520	480	518
Mean distance to nearest water source in metres	421	422	1285	433	640
Mean daily water collection in litres					
a) per household	57	84	68	59	67
b) per capita	8	13	9	9	10
Water sources*					
a) Sandriver	21%	85%	95%	60%	65%
b) Standpipe	78%	0%	0%	35%	29%
c) Rainwater	1%	5%	1%	5%	3%
d) Others	0%	10%	4%	0%	3%
% of households collecting rain	22%	64%	34%	64%	46%
% collecting rain from thatch roofs	4%	14%	4%	0%	5.5%
% of households with at least one:-					
a) Iron roof	30%	14%	18%	70%	33%
b) Catchment tank	10%	14%	4%	14%	11%
% of householders who felt rain was clean	74%	98%	90%	68%	83%

* as a % of households per village using each type as their primary source.

households, however, had a corrugated iron roof and of these only a third had any kind of temporary or permanent tank. Even in Borolong, where 70% of the households had at least one corrugated iron roof and where 64% of them collected some rainwater from their roofs, only 8% had permanent guttering,(Table 1). Most people simply collected rainwater by placing buckets and basins under the eaves of corrugated iron roofs.

For those households without access to a corrugated iron roof, some collected rainwater by simply placing small containers in the open, while a few (5.5%), collected runoff from thatched roofs especially in Nata which was desparately short of clean, fresh water and where the vast majority of households had only thatched roofs,(Table 1).

Survey questions directed at trying to determine the villagers attitudes and perceptions regarding rainwater collection revealed that while most considered rainwater clean (83%) and tasty, almost all referred to runoff from their thatched grass roofs as "dirty", "discoloured" and "unhealthy", and only one householder admitted using it for drinking. The most commonly cited reason for not installing proper permanent catchment tanks was given as lack of money. In 1983 the cost of installing commercially available corrugated iron tanks was P137 and P384 (US$103 and US$288) for 2.25m^3 and 9m^3 tanks, respectively.

Primary School Survey Results

A postal questionnaire was sent to approximately half of Botswana's more than 400 primary schools and 64 reponses were recieved. In addition, 6 schools were visited and a detailed site survey conducted at each. In Table 2 the main findings are summarized.

Table 2 School Postal Questionnaire Results

TOTAL NUMBER OF SCHOOLS SURVEYED		64	(100%)
NUMBER OF SCHOOLS USING:			
- Piped water(usually a standpipe)		42	(66%)
- Local borehole		11	(17%)
- River bed pits and pools		8	(13%)
- Transported water		3	(4%)
SCHOOLS WITH CORRUGATED IRON ROOFS		64	(100%)
SCHOOLS WITH CATCHMENT TANKS		28	(44%)
- Total number of tanks	121		
- Tanks reported leaking	52		
MEAN SCOOL ENROLLMENT	403 (S.D. 203)		
MEAN ROOF AREA (m^2)	901 (Range 126-2260)		
MEAN ANNUAL RAINFALL (mm)	469 (S.D. 79mm)		

Mean Annual Roof Runoff for a Typical School in Botswana

$$= \text{ROOF AREA} \times \text{RAINFALL} \times \text{RUNOFF COEFFICIENT}$$

$$= 901\text{m}^2 \times 0.469\text{m} \times 0.8 = 338\text{m}^3$$

Although, the results indicate that only 22 (34%) of the surveyed schools did not have water piped to their sites, a number of schools with piped water complained of frequent breakdowns or of water too saline to drink. In fact less than half of the schools had clean, reliable convenient improved supplies. This situation makes supplementary rainwater supplies very attractive. Despite the frequent praise given to the usefulness of existing tanks, among those schools with tanks the average total storage capacity was only 18m³. Considering the mean annual roof runoff from an average school is about 338m³ (Table 2), and taking into account the need for storage throughout the long dry season, current storage capacities are only a fraction of that required to make full use of this form of supply. Although the designs for new rural schools sometimes include 4.5m³ corrugated catchment tanks when funds permit, the life expectancy of these is usually only a few years as indicated by the number of tanks reported leaking,(Table 2).

At a number of primary schools in Botswana, including those visited at Borolong, Thini and Nata in 1983 (Fig.1), the lack of piped water or adequate rainwater catchment tanks resulted in children collecting water of dubious quality from river beds and open pools frequently at a considerable distance from their schools.

In general the large roof areas, 901m³ on average, (Table 2), and the desparate stortage of suitable clean convenient alternative supplies in many rural areas, indicate a great potential for increasing the number and size of rainwater catchment tanks at schools, clinics and other corrugated iron roofed institutions throughout rural Botswana.

GROUND CATCHMENT SYSTEMS

Natural and man-made drepressions which concentrate rainwater runoff from ground surfaces are known as haffirs and have been used in Botswana for centuries as sources of domestic water. Attempts to upgrade and develop these traditional sources began in the late 1960's with a much publicized project to build subsurface ground catchment tanks by ITDG (Intermediate Technology Development Group) and Oxfam,(ITDG 1969). The low cost, labour intensive tanks were originally developed in the Sudan(Ionides 1964) and required only polythene, wire, sand, cement and mud for their construction. A project to construct tanks at 12 primary schools in Botswana using local labour was the first attempt to field test these tanks. Partly as a result of the enormous labour requirements only 7 tanks were ever completed and after 3 years only two were still functioning,(ITDG 1971). Although, tanks were also built in Zimbabwe and Swaziland, and some replication did occur elsewhere in Botswana, only a handful of tanks were still functioning in 1983,(Gould 1984).

The ALDEP Ground Catchment Tank Project

Despite the failure of the ITDG tank project to take root, a successful and expanding ground catchment project is currently being administered through the ministry of agriculture's Arable Lands Development Program (ALDEP). This is probably the largest single ground catchment project in the world and has already accounted for the construction of more than 500 tanks mainly in eastern Botswana. The aim of the project is to provide a water supply for people and draught animals in remote "lands areas" where alternative water sources are few and far between, in order to encourage agriculture in these areas. Most of these remote dwelling places lack corrugated iron roofs.

The most common design for the ALDEP ground catchment tank is a simple ferrocement one described by Whiteside (1982). Chicken wire is pegged to the sides of a circular hole and mortar is plastered to it. Corrugated iron or ferrocement is used for the cover essential for reducing evaporation and contamination. The catchment apron for these tanks consists of a traditional mud and dung threshing floor in which a coarse sediment filter is constructed. A brick tank design is used in areas of sandy unconsolidated soils. A survey of 16 tanks revealed that despite design specifications for $10m^3$ tanks having been given to builders, the average tank capacity was $16m^3$ and the mean catchment area was $108m^2$. The distance to the nearest alternative water source averaged 6km.

Financing of the main project (following a pilot phase in which free tanks were provided) was initially done through a loan/subsidy scheme. The average cost of the tanks in 1983 was P500 (US$375). Farmers were expected to provide labour including the preparation of the "threshing floor" catchment apron and excavation for the tank, as well as paying back a loan taken for the tank over 5 years plus interest payments at 6½%.

Problems in administering the loan repayments led the ALDEP team to adopt a subsidy/downpayment scheme in 1984 through which an 85% subsidy was provided once a 15% downpayment had been received. Lack of trained builders has been a logistical restraint to the expansion of the project in some areas, lack of demand for tanks a restraint in others. Among physical problems affecting the project, cracking of 10%-15% of the tanks and undersized and poorly constructed threshing floor catchment aprons, have been among the most serious. Damage to the covers of unfenced tanks and contamination of water in some tanks are among other problems encountered.

Following a postal questionnaire survey distributed to agricultural extension staff throughout Botswana, Ainley(1984) made a series of recommendations regarding the ALDEP ground tanks, these included the following:

1. All tanks and threshing floor catchment aprons should be fenced with, at least, a thorn bush fence.

2. Farmers should have the option of cementing their threshing floor catchments at additional cost. to improve the quality and quantity of runoff.

3. Tanks should be located in order to make maximum use of local drainage.

4. Where farmers have corrugated iron roofs these should be utilized as a catchment surface.

5. A chain and bucket (permanently attached to the tank) and a simple sand filter should be provided to help improve the quality of water from the tanks.

The quality of water from the catchment tanks has been a constant concern of the project staff (Maikano and Nyberg 1981). Despite directives to agricultural extension staff that farmers be advised to boil water from the tanks before drinking it, there was little evidence in the field that this advice was being taken.

BACTERIOLOGICAL ANALYSIS

Owing to the concern regarding the water quality in existing ground catchment tanks in Botswana, and in order to determine the suitability of roof runoff for consumption, data related to the bacteriological quality of stored rainwater was gathered. This required both the compilation of existing data and the collection and analysis of new samples. Standard sampling and analysis proceedures were followed in accordance with Department of Water Affairs instructions, (Gould 1985). The results of these bacteriological analyses for both roof and ground catchment systems are shown in Table 3.

The results for roof tanks indicate that the total and faecal coliform counts lie within acceptable WHO limits for all but one sample, where the tank had no cover. High faecal coliform counts are usually indicative of contamination of human origin and presents the most serious health risk. The high faecal streptococci counts recorded for 8 of the 13 roof tanks sampled, are probably indicative of contamination from birds, lower animals and plant debris. This does not pose a serious threat to human health, and Stenstrom and De Jong (1983), concluded, that if "correctly constructed rainwater catchment tanks could be a realistic and hygenic drinking water alternative" in Botswana. In a study by Koplan et al(1978) however, it was postulated that water heavily contaminated by bird droppings may have been the cause for an outbreak of a rare form of salmonella in northern Trinidad. This nevertheless, seems to have been an exceptional case.

The results for ground catchment tank samples , on the other hand, clearly demonstrate that the water quality represents a serious health threat, particularly as untreated water from most of the tanks was used for drinking purposes. Although, all the tanks sampled were covered, in every case both total and faecal coliform counts exceeded WHO limits, and in 7 out of 8 cases they were at excessive levels. The low nitrate levels suggest that contamination from the mud/dung threshing floor is not a serious problem. The main sources of contamination are most likely due to animal and human contaminants entering the tank.

Table 3 Results of Bacteriological Analysis of Roof and Ground Tank Water conducted in Botswana

Location of Roof Tank	Total Coliform[1]	Faecal Coliform[1]	Faecal Streptococci[1]	Other Details
Tutume	0	0	0	Corrugated Iron Covered Tank
Nata	0	0	0	" "
Francistown	0	0	0	" "
Francistown	0	0	0	" "
Tlokweng	0	0	46	" "
Morwa	0	0	84	Partly Covered Brick Tank
Morwa	0	0	158	" "
Morwa	0	0	164	Covered Brick Cement Tank
Not Known[2]	0	0	44	" "
" " [2]	0	0	75	Covered
" " [2]	0	0	90	" "
" " [2]	1	0	1	" "
" " [2]	29	6	62	Not Covered
WHO Maximum Recommended Limit	10	1	1	

Location of Ground Tank	Total Coliform[1]	Faecal Coliform[1]	Nitrate (NO^3+)mg/l	Other Details
Mosetse	342	15	-	Covered
Tlokweng	2	6	-	" "
Sebele	CG	174	-	" "
Sebele	CG	150	-	" "
Mosime[3]	TNTC	600	13	" "
Jabe[3]	TNTC	1000	0	" "
Thatayaone	TNTC	400	2	" "
Kefetoge[3]	6	300	2	" "

CG=Confluent Growth   TNTC=Too Numerous to Count

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[1] Per 100ml (from analysis of 5ml and 50ml samples.
[2] Source: Stenstrom and De Jong(1983)
[3] Source: Dept. of Water Affairs, P/Bag 29, Gaborone, Botswana

DESIGN CONSIDERATIONS

The two most important techical considerations which have to be dealt with before rainwater catchment systems are implemented are the design and construction of the storage tanks. Rainwater catchment is a relatively costly water supply option particularly in more arid regions, and since the storage reservoir is the most expensive component of any catchment system the efficient use of available storage capacity is highly desirable. In Botswana the design of storage tanks generally involves an attempt to maximize rainwater supply while at the same time minimizing costs.

Using a computer the laborious calculations required in the analysis of rainfall data for accurate tank sizing, can be done extremely rapidly. In this study the Ottawa Model developed by Latham(1983) was used for the analysis of mean monthly data for 10 stations located throughout Botswana. Where possible consecutive 30 year rainfall periods (1954-1983) were used, but in the case of three stations Palapye, Sebina and Gweta (Fig.2b) only 23, 21 and 17 years of consecutive data were available, respectively.

The Ottawa Model is based on the same principle of critical period analysis that was originally developed by Rippl(1883), in his mass curve analysis technique for reservoir sizing. Through determining the most severe (critical) periods in a series of data, the Ottawa Model determines the storage requirement needed to overcome this for a given level of supply. The model also allows different levels of reliability to be attached to rainwater supplies. This is very useful since in drought prone environments such as Botswana, demanding a 100% reliable supply would require an unrealistically large storage requirement. A 95% reliability level was found to be the most appropriate for tank design in Botswana, since it allows for a virtual halving of the storage capacity at the expense of only a 5% reduction in the efficiency of the supply; since the tank is unable to meet supply requirements for 5% of the time. This 5% period (2½ weeks a year on average) could, however, be eliminated completely if rationing or stocking of the tank was conducted when the supply began to dwindle. A detailed explaination of why a 95% reliability level was deemed most appropriate is provided by Gould(1985) and McPherson and Gould(1985).

Using the Ottawa Model the storage-supply curves for a 95% reliability of supply were produced for 10 stations in Botswana (Fig.2b). The curves for four of these stations are shown in figure 3. The similarity of rainfall regimes throughout Botswana resulted in the shape of the curves being similar for all the 10 stations, and the four selected (Fig.3) represent the full range of variation. The curves revealed that on average, a storage capacity equivalent to about 0.4(40%) of the

Figure 2a.
Mean Annual Rainfall

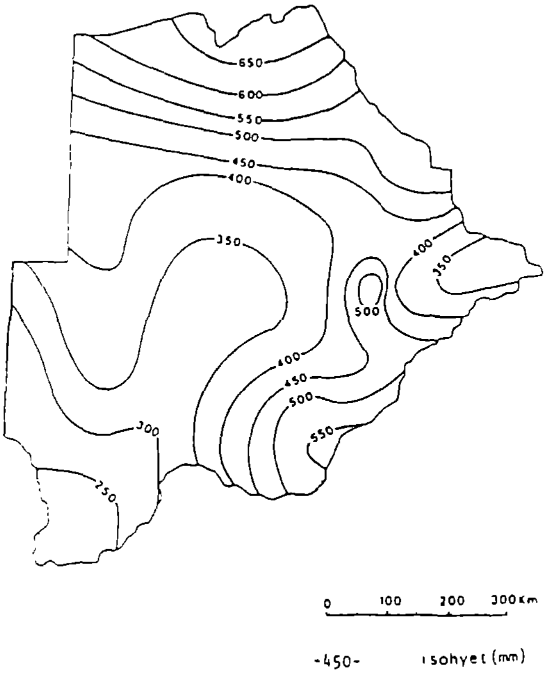

Figure 2b.
Rainfall Stations Sampled

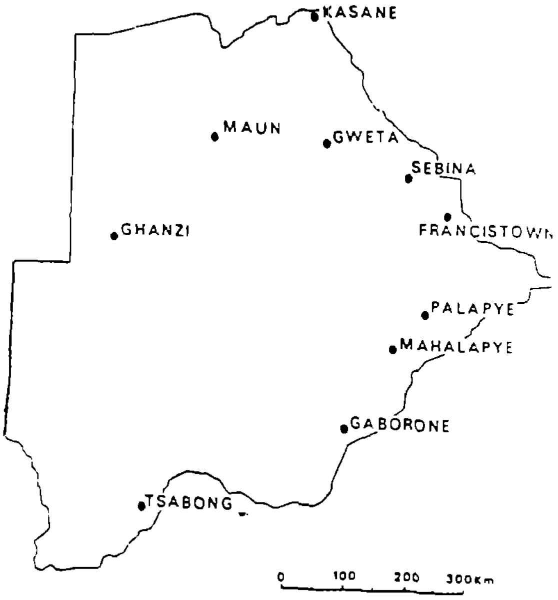

Figure 2c.
Appropriate Rainwater Tank Volumes in Botswana in litres/m² of roof area

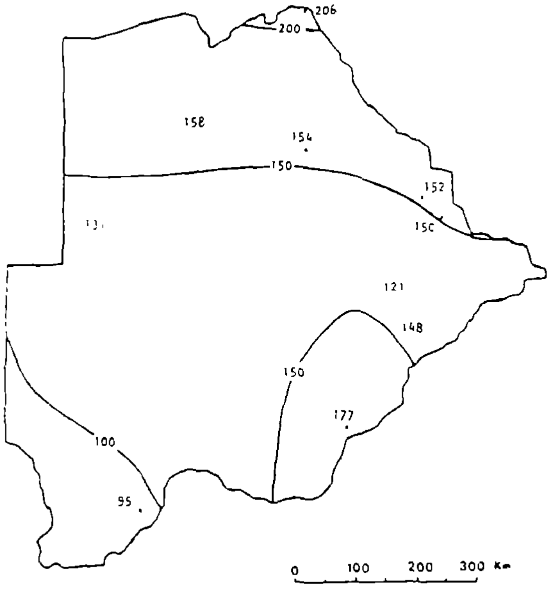

Figure 2d.
Corresponding Rainwater Supply in litres/m² of roof area (95% reliability)

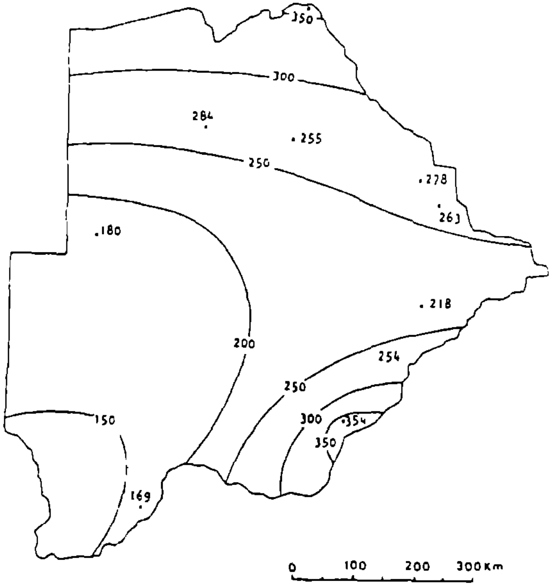

Figure 2. Maps of Botswana Relating to Rainwater Collection

total useful runoff provides a reasonable estimate of the most appropriate tank size for providing the greatest amount of water at the least cost. This storage capacity would supply at least 0.7 (70%) of the useful runoff in all but the very driest years,(i.e. 5% of the time). Larger storage capacities of greater than 0.4 (40%) of the useful runoff would result in deminishing returns for the increased investment,(Fig. 3).

On the basis of these results it was possible to calculate the most economically feasible maximum roof rainwater supply for the study villages. This was done by determining the total available roof runoff for private and public buildings by multiplying their roof area by the mean annual rainfall and a runoff coeficient taken as 0.8.

$$\text{Total Available Roof Runoff} = \text{Total Roof Area} \times \text{Mean Annual Rainfall} \times 0.8$$

By multiplying the total available roof runoff by 0.7 the most economically effective maximum supply volume can be determined:

$$\text{Maximum Feasible Rainwater Supply} = \text{Total Available Roof Runoff} \times 0.7$$

Table 4 shows the results of these calculations for the study villages. Although only 29% of current domestic water requirements could be met by roof rainwater supplies at present, the on going transition from thatched grass to corrugated iron roofs indicates a growing potential for roof catchment supplies. The average metal roofed household with a $46m^2$ roof area, would require a $7.7m^3$ storage tank. This would supply at least $13.3m^3$ annually (with 95% reliability) which would provide more than half of the households domestic water requirements, and all of the drinking, cooking and washing water needed. Apart from the convenience of such a supply the potential health benefits would be considerable.

Although, a roof area in excess of $70m^2$ or $10m^2$ per capita would be required for providing a total rainwater supply, a few households already possess roofs of this size. It is likely that average roof areas will continue to increase in future, since the cost of having a grass roof constructed is now more than for a corrugated iron roof. In the past people built their own grass roofs, but as people increasingly find temporary work in urban areas they have less time to do this and are in a better position to buy more durable corrugated iron roofs.

Using the results from the model it was also possible to construct maps indicating the most efficient storage requirements in mm per m^2 (litres/m^2) of roof area and the associated levels of supply, for the whole of Botswana, (Fig. 2c and 2d). Interpolation for constructing these maps was possible because the flat landlocked nature

Table 4 Calculation of the Potential Rainwater Supply for the Study Villages.

VILLAGE	NATA	THINI	SELOLWANE	BOROLONG	MEAN	Calcul^{n}
Mean Roof Area (m^2)	52	45	45	42	46m^2	a
Mean Rainfall (mm/year)	550	520	520	480	518 mm	b
Runoff Coefficient	0.8	0.8	0.8	0.8	0.8	c
Useful Roof Runoff (m^3/a)	23	19	19	16	19 m^3	d =axbxc
Feasible * Potential (m^3/a) Supply	16	13	13	11	13 m^3	e e=dx0.7
Present Domestic (m^3/a) Consumption	31	25	21	22	25 m^3	f
Household Rain-water Supply as a % of Daily Consumption	52	52	62	50	54 %	g g=e/fx100%
% of Households with Iron Roofs	14	18	30	70	33 %	h
Potential Rainwater Supply as a % of Domestic Consumption for :-						
1. All Households	7	9	19	35	17.5 %	i i=gxh
2. All Public Buildings	9	7	15	12	11 %	j
3. TOTAL	16	16	36	47	29 %	k k=i+j

*the most economically viable maximum potential supply of Botswana results in a regular isohyet pattern with no abrupt local variations due to orographic or coastal influences. Maps of this type (Fig.2c and 2d) represent a useful tool for those planning and implementing rainwater catchment systems in Botswana.

Currently, the most common type of large roof catchment tanks used in Botswana are galvanized corrugated iron ones (2.25m^3, 4.5m^3 and 9m^3) imported from South Africa. Although these provide good quality water they are not very durable. Recent, experiments with locally constructed ferrocement tanks are proving sucessful and these locally produced more durable tanks based on the design provided by Watt(1978) will probably be used in increasing numbers in the future. Unlike the corrugated iron tanks , however, which come in fixed sizes, the ferrocement tanks can be built to any specification upto 100m^3 or more. This makes the appropriate sizing of tanks to specific roof areas and local rainfall conditions relatively easy to accomplish.

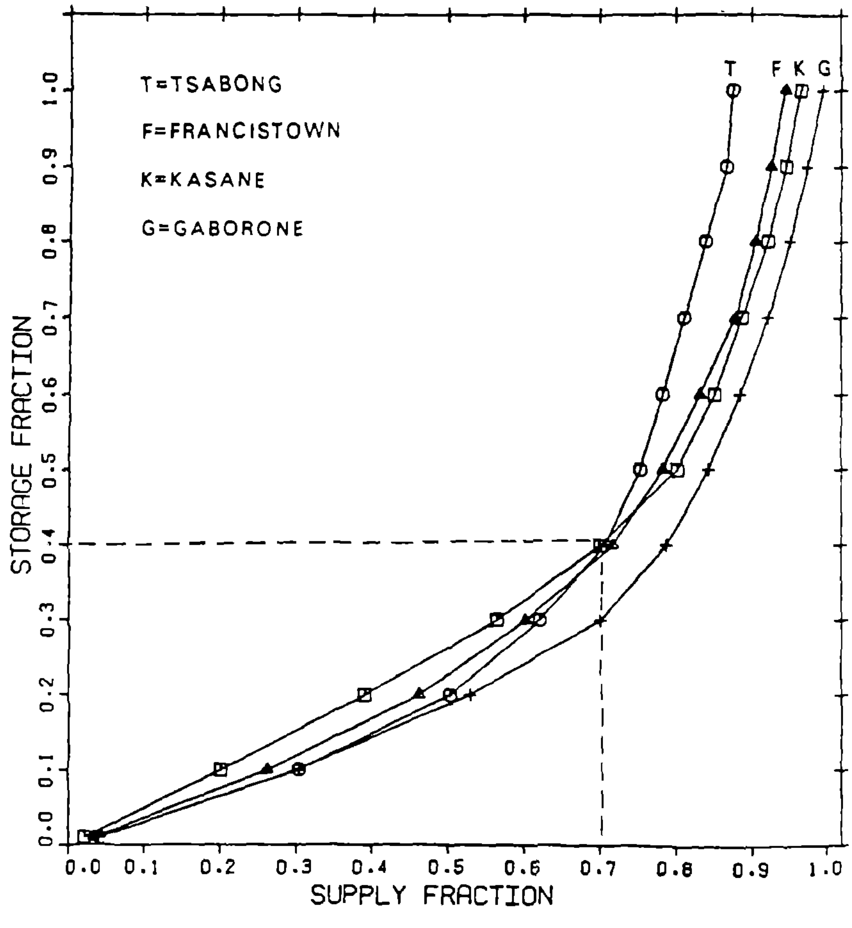

Figure 3. Storage-Supply Curves (95% Reliability) for 4 Stations in Botswana.

CONCLUSIONS

Although, rainwater catchment systems still only play a minor role in domestic water supply in Botswana efficiently designed roof catchment systems could provide a convenient clean reliable supplementary water source for many rural families and institutions. Bacteriological analysis revealed that while roof runoff from corrugated iron roofs stored in covered tanks is of acceptable quality for drinking, the water from ground catchment tanks represents a serious health hazard if left untreated. While the vast majority of villagers had a very positive attitude towards rainwater usage most felt that runoff from thatched roofs was unsuitable for consumption. This counters proposals by some researchers (Hall 1982, Fortmann and Roe 1981) that rainwater collection from thatched roofs should be promoted.

Despite the low rainfall and its unpredictability in Botswana, lack of suitable alternative water sources makes the collection and storage of rainfall feasible in many rural locations. Efficient sizing of storage tanks is particularly important since the rainfall regime in Botswana demands large storage capacities. Effective design based computer modelling techniques can thus lead to significant cost reductions. Corrugated iron tanks imported from South Africa are currently the most common roof tank used in Botswana, although these provide good quality water they are small and not very durable. Locally produced "made to measure" ferrocement tanks would appear to provide a better alternative for roof tank projects.

RECOMMENDATIONS

1. The Government of Botswana and external agencies should continue to fund the ALDEP ground catchment project, as this is the only realistic, affordable way of supplying water to remote, isolated farmsteads within the foreseeable future. Nevertheless, methods to improve the quality of this water using simple sand filters are urgently required.

2. The construction of large ferrocement roof tanks at primary schools and clinics presently lacking reliable, convenient water supplies should be initiated by the relevant ministries. These tanks should be incorporated in the designs for all public buildings in water short rural areas. The possibilities for a roof tank project for private households should also be explored.

3. For the greatest efficiency in terms of maximizing rainwater supply while minimizing costs, a storage capacity equivalent to 40%(0.4) of the useful runoff is suggested for rainwater tanks in Botswana. This would yield on average a supply of at least 70%(0.7) of the useful runoff, with 95% reliability.

ACKNOWLEDGEMENTS

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RAINWATER TANK SUPPLY FOR HOUSEHOLDS IN SOUTH AUSTRALIA WITHOUT MAINS WATER SUPPLY

K.C. Tai and T.D.B. Pearce *

ABSTRACT

In association with a study to give guidance on the domestic use of rainwater for South Australian households without a mains water supply and therefore dependent upon rainwater as the sole source of supply, graphic results of tank size and roof area combinations, as depicted by iso-demand curves, have been produced.

These iso-demand curves reflect a more realistic approach in assessing the degree of security or reliability of supply, through the use of the counting rule for complete and partial 'successes'. In addition, a more conservative approach to the test for spill results in a larger tank storage capacity, equivalent to one extra month's demand.

Through sensitivity analysis, it is found that the results obtained in this study are consistent with the results of an alternative 'optimistic' approach adopted for households with both public mains supply and rainwater tank supply. For this category of households, a supply failure is expected to be of lesser consequence than for households which are dependent solely upon rainwater tanks.

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LIST OF SYMBOLS

S_t	is the storage at the end of the t^{th} month period;
S_{t-1}	is the storage at the end of the $(t - 1)^{th}$ month period;
RO_t	is the roof runoff during the t^{th} month period;
D_t	is the constant demand during the t^{th} month period;
TS'	is the tank size selected on the basis of a conservative rule on storage spill.

P_t	is the monthly rainfall in mm;
A	is the projected flat roof area in sq. m.
c	is the roof runoff coefficient,, assumed to be 0.85. (The value of 0.85 is taken from International Reference centre,WHO,1981).

INTRODUCTION

In South Australian households, the use of rainwater is strictly on a needs basis, mainly because South Australia is the driest of the Australian States and Territories. Four-fifths of the State receives an average rainfall of less than 250 mm.

Households dependent upon rainwater tanks as the sole source of supply were seen to follow an ordered sequence of priorities for rainwater use: first, for food preparation and/or drinking; second, for clothes washing; third, for bathing and fourth, for other inside domestic uses. In the area of food preparation and/or drinking, there were twice as many households (120,350) exclusively dependent upon rainwater supply as households (64,400) dependent upon both mains and rainwater supplies.(ABS,Adelaide, 1983). The number of households reporting in this category was 213,700 out of a state total of 406,950.

Information had been made available mainly to households in urban areas, where both mains water and rainwater supplies are used.(T.J.Martin, 1980). A booklet titled, 'Rainwater Tanks ..... their Selection, Use and Maintenance', had been published by the Engineering and Water Supply Department and the Department of Environment and Planning.(October, 1983).

Recent study by the authors on the use of rainwater tank supply as a sole source of supply has resulted in a publication, titled 'Rainwater Tanks for Households without a Mains Water Supply ..... their Selection, Use, and Maintenance.'(July,1986). This publication was prepared by the Engineering and Water Supply Department with advice from the South Australian Health Commission.

The significant results of this study are highlighted in this paper.

ANALYSIS

In the analysis, it is assumed that households dependent upon rainwater tanks as a sole source of supply have a greater need for a higher level of security than households supplied with mains water and rainwater.

For the former, the consequences of a supply failure are greater.

It is further assumed in the analysis that the pattern of domestic water use would follow the sequence of priorities mentioned above - food preparation and/or drinking; clothes washing; bathing and other domestic inside uses.

Model

Since a greater degree of security or reliability is called for in the analysis for domestic supply solely dependent upon rainwater, it is proposed to use a conservative approach in the test for spill from rainwater tank storage, and a realistic approach in the test for 'success' or tank non-emptiness. These two states, spill and non-emptiness, control the size of the storage capacity to be established from computer simulation for a given roof area and a given rainfall for a specific location.

The model uses the linear mass balance equation for the simulation of the monthly performance of the roof-tank system:

$$S_t = S_{t-1} + RO_t - D_t \qquad (1)$$

subject to:(1) $0 \leqslant (S_{t-1} + RO_t) \leqslant TS'$

(2) $RO_t = (c.P_t - 2).A$

The value of 2 mm in the second constraint is the assumed loss due to evaporation and spill from gutters.

The test for 'success' in tank storage is derived from the linear mass equation given by eq.(1).

(1) A complete success is said to occur when

$$S_t = S_{t-1} + RO_t - D_t > 0 \qquad (2)$$

or

$$(S_{t-1} + RO_t) > D_t \qquad (2A)$$

(2) A partial success would occur when

$$S_t = (S_{t-1} + RO_t - D_t) \leqslant 0 \qquad (3)$$

(3) From eq.(3), it is easy to deduce that a complete failure would occur (defined as tank being empty of water), when

$$(S_{t-1} + RO_t) / D_t = 0 \qquad (4)$$

Storage level in the rainwater tank would fall into one of these three categories, and the tests enable the reliability of supply to be estimated. The reliability, or the security of supply is defined as the total number of months (inclusive of fractions of a month) in a given period in which constant demand is being met. The given period is taken to be the length of rainfall record used in the simulation.

The test for spill from tank storage involves setting storage S at time t without the demand D being taken out, against the tank storage capacity TS'.

From eq.(1), the question asked is whether:

$$S_t > TS$$

If it is, then: $S_t = S_{t-1} + RO_t - D_t > TS$ (5)

or $(S_{t-1} + RO_t) > (TS + D_t)$ (5A)

Let $TS' = (TS + D_t)$ (5B)

then $(S_{t-1} + RO_t) > (TS' = TS + D_t)$ (5C)

From eq.(5C), tank sizes TS' selected in the conservative approach in the test for spill would be greater than tank sizes TS selected in a non-conservative approach, by an amount equal to the constant monthly demand.

Sensitivity Analysis

A sensitivity analysis is made of three counting rules for successes which would affect the selection of the combination of roof with tank capacity.

The sensitivity analysis carried out for this study has been tested against rainfall station no. 23733 at Mount Barker, 30 km south-east of Adelaide, with a rainfall record covering a period of 122 years.

The first rule is an ultra-conservative rule, which states that the tank is 'empty', when storage is below demand:

$$S_t < D_t \tag{6}$$

The second rule is after T.J. Martin (1980), where 'failure' is defined as the inability of the rainwater tank to supply half the required monthly demand.

$$S_t = (S_{t-1} + RO_t - 0.5D_t) < 0 \tag{6A}$$

The third rule defining 'failure' used by the authors in this paper, is deduced from eq.(3) and eq.(4). A partial 'failure' occurs when a available storage is less than demand:

$$\left[1 - (S_{t-1} + RO_t)/ D_t\right] > 0 \tag{6B}$$

and a complete failure occurs when the tank is technically empty:

$$(S_{t-1} + RO_t) / D_t = 0 \tag{6C}$$

The third rule also allows for a test of spill against storage which results in a storage capacity greater than that found by the test of spill accompanying the second rule. The difference in storage capacity derived from the two tests for spill is equal to the constant monthly demand. This is evident from eqs.(5) and (5C).

RESULTS

Figures 1 and 2 display, as typical examples, the iso-demand curves for demands of 200 and 400 litres/day for average annual rainfall from 150 to 1200 mm for the State of South Australia.

To use the graph, one needs to know the average annual rainfall for the given location; the average constant demand per houshold; the projected roof area and the degree of reliabililty or security of supply required. Three levels of security, 80, 90 and 99%, have been analysed.

Graphs of the above pattern have been produced for constant demands of 60, 100, 200, 400 and 600 litres/day/household for the whole of South Australia.

Average annual rainfalls of 800 to 1200 mm are found in the Mount Lofty Ranges, immediately east of Adelaide - this being the wettest part of the State.

Rainfall averages fall off rapidly to less than 250 mm between 150 and 250 km inland, and then decrease more gradually to below 125 mm in the vicinity of Lake Eyre, this area being the driest part of Australia.

Sensivity Analysis

In figure 3, curve 3 depicts the effects of the ultra-conservative rule on the counting of successes and curve 2, those effects of the moderately conservative rule of the authors.

The inclusion of the fractional rule for counting partial successes shifts the postion of curve 3 to curve 2. The test for spill is the same for both curves, i.e. demand is not taken out before checking for spill.

Curve 2 shows a combination of smaller roof area and tank size is feasible with the adoption of the fractional rule for counting 'successes' rather than the use of the integer rule in the ultra-conservative approach.

The difference between curve 2 and curve 1 in figure 3 is du e solely to the test for spill. In the authors' test for spill for curve 2, monthly demand D is not taken out, whereas for curve 1, monthly demand D is taken out. (T.J. Martin,1980).

RAINTANK YIELD
DEMAND 200 L/DAY

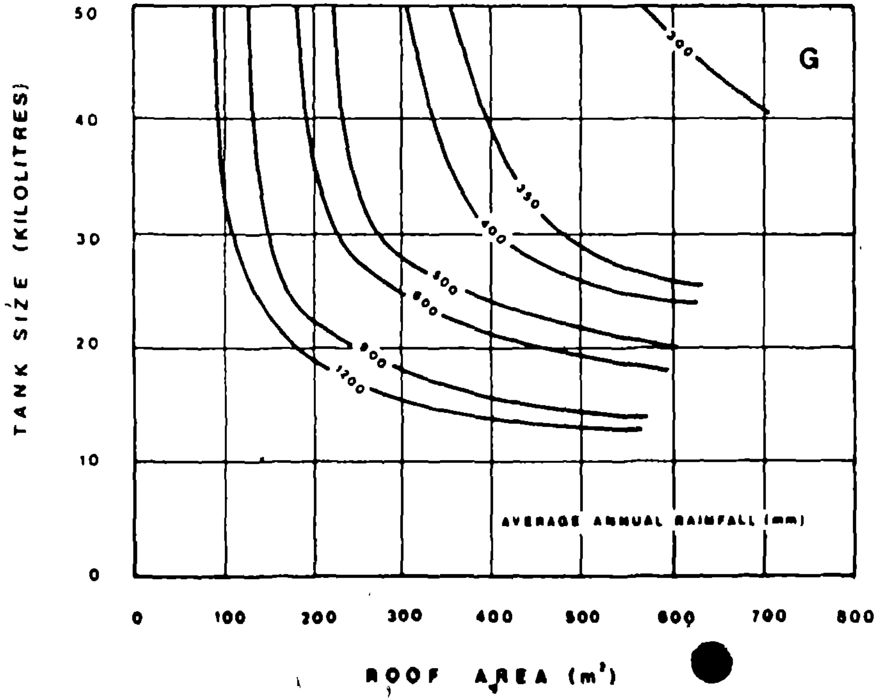
DEGREE OF SECURITY 99 % GRAPH G

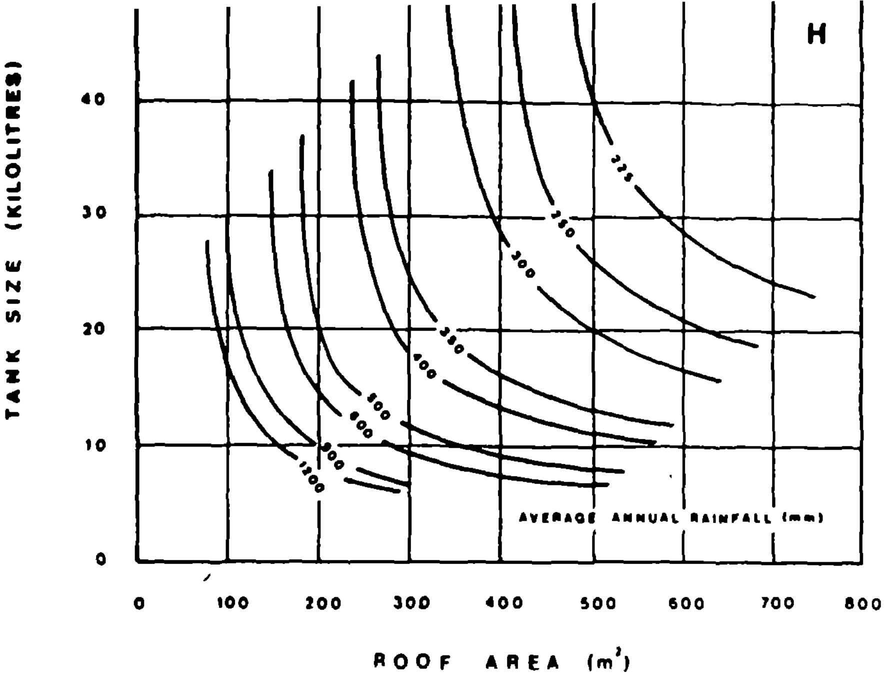
DEGREE OF SECURITY 90 % GRAPH H

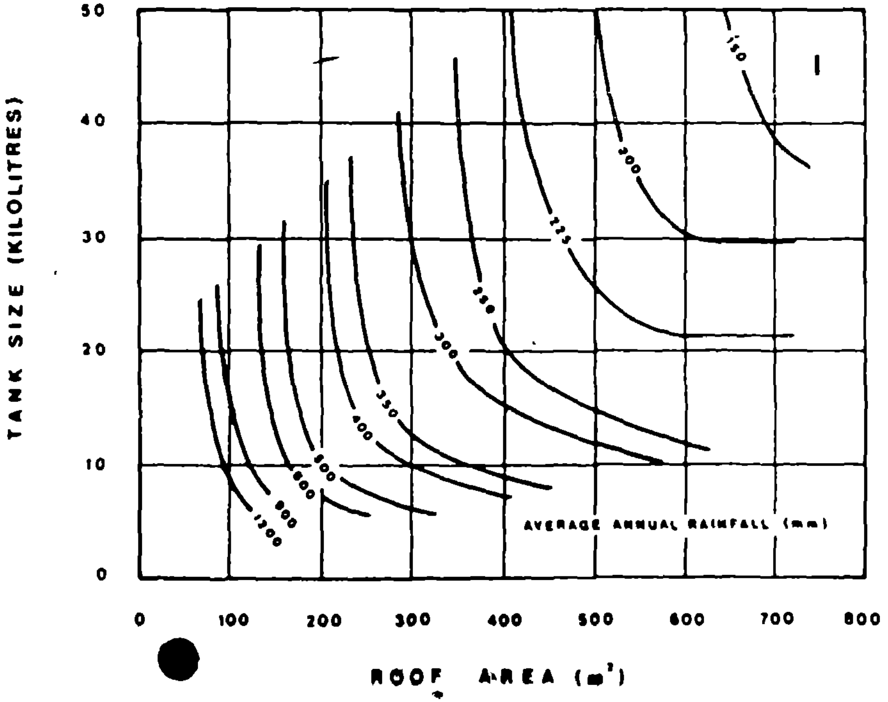
DEGREE OF SECURITY 80 % GRAPH I

FIG 1

ISO- DEMAND CURVES OF RAINWATER TANK SIZES AGAINST ROOF AREA FOR A CONSTANT DEMAND OF 200 L/DAY AT THE DESIGNATED DEGREE OF SECURITY







RAINTANK YIELD
DEMAND 400 L/DAY

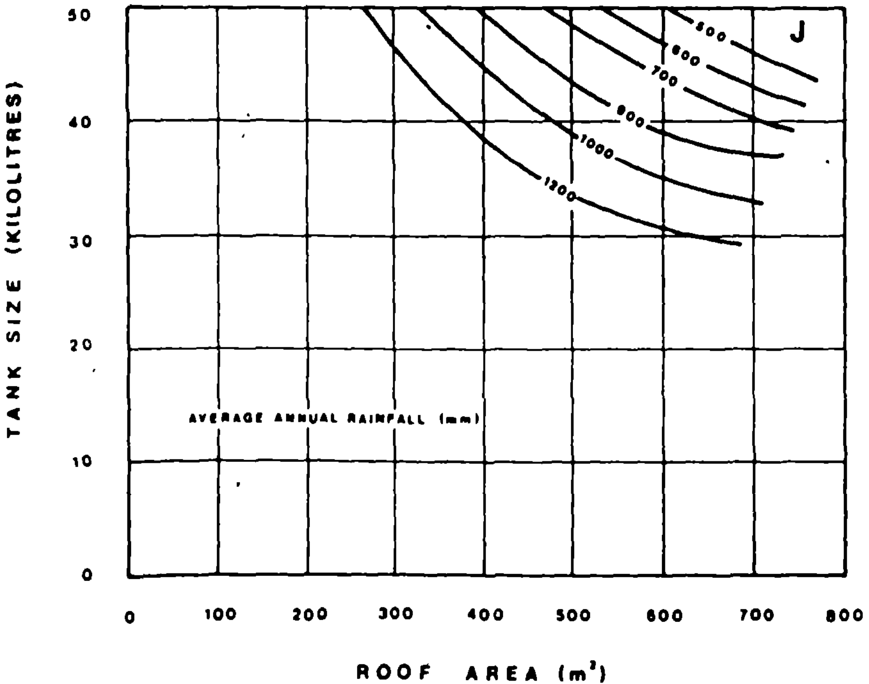
DEGREE OF SECURITY 99 % GRAPH J

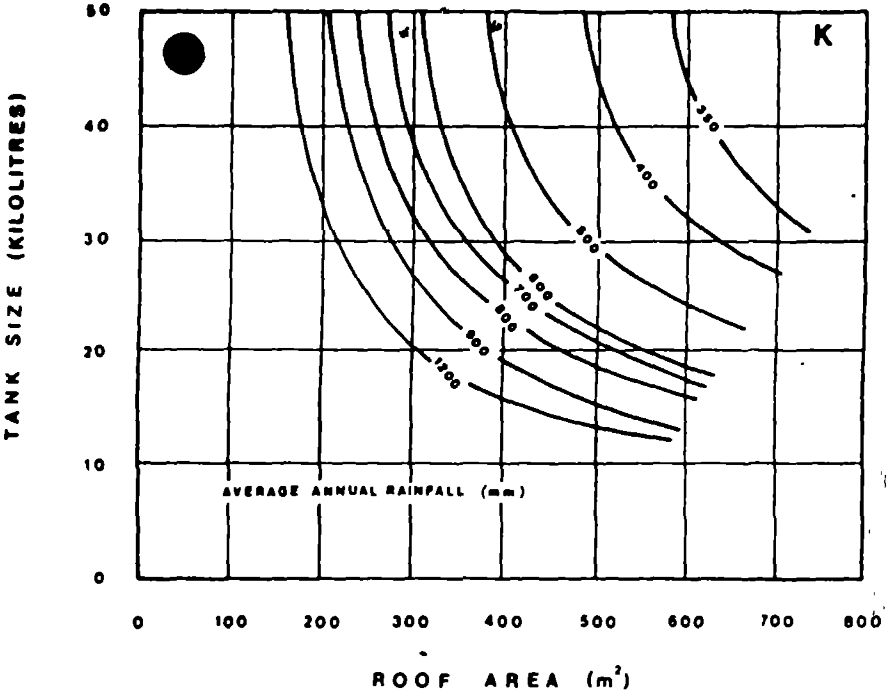
DEGREE OF SECURITY 90 % GRAPH K

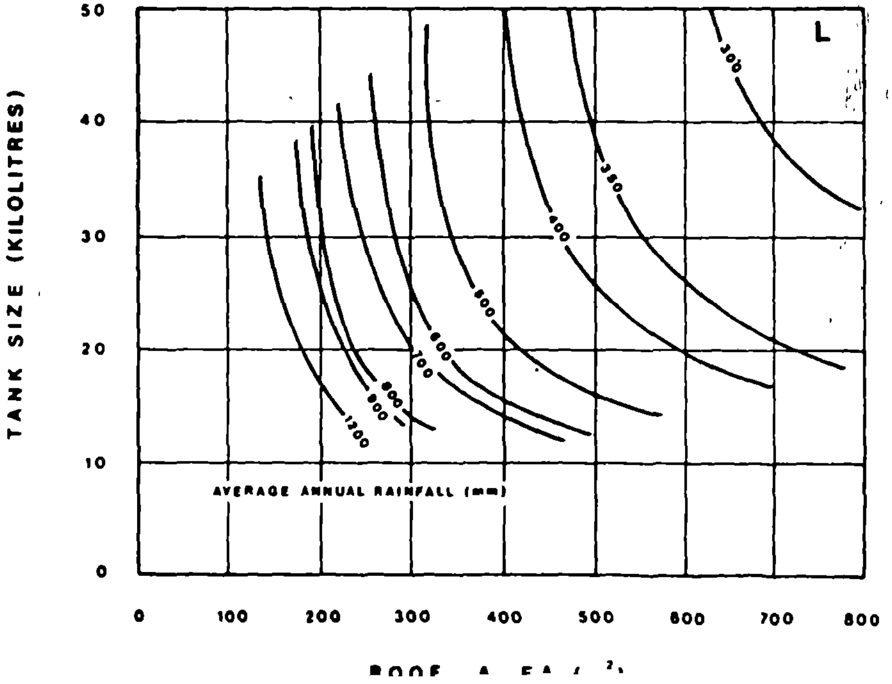
DEGREE OF SECURITY 80 % GRAPH L

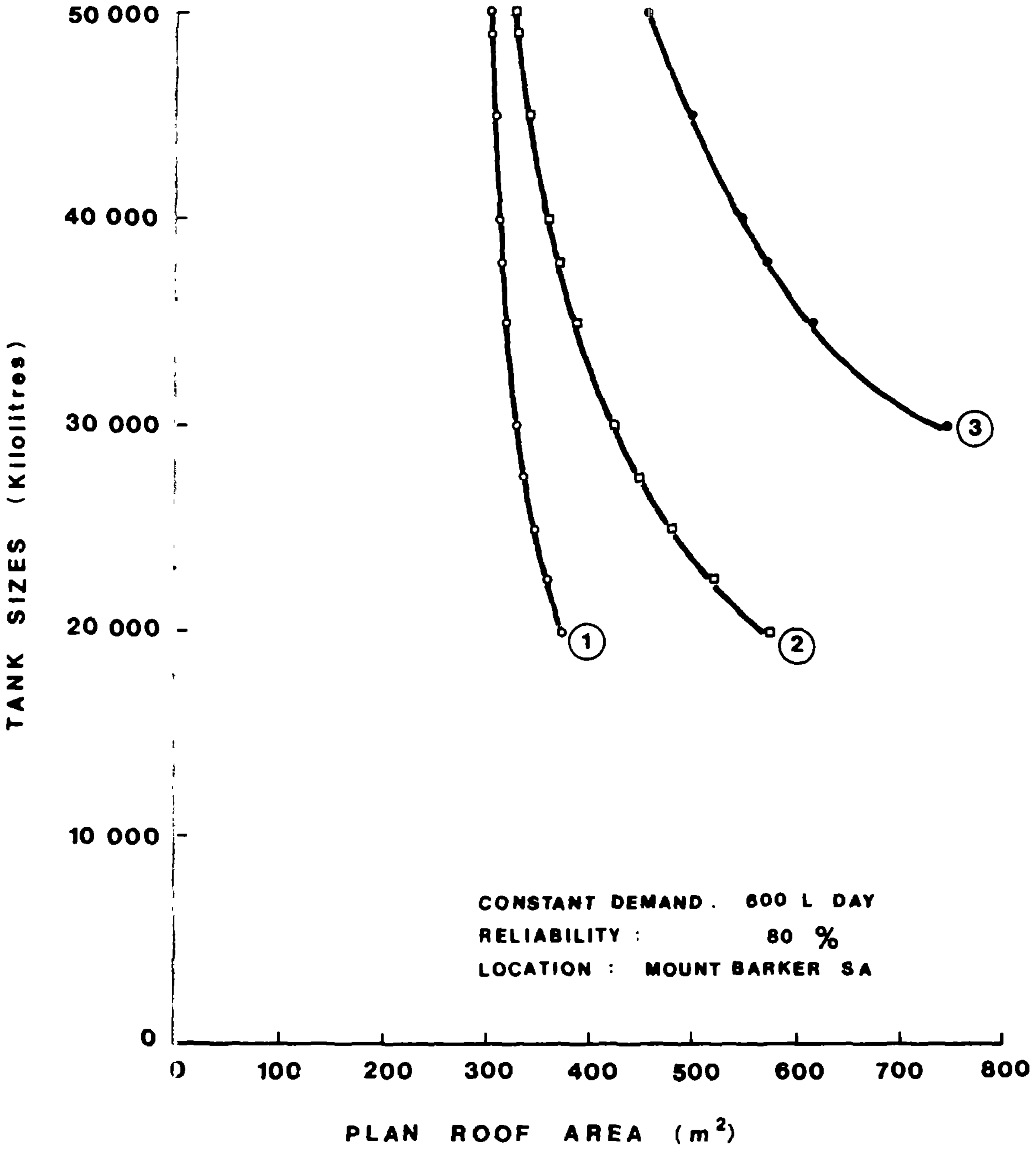
FIG. 2

ISO - DEMAND CURVES OF RAINWATER TANK SIZES AGAINST ROOF AREA FOR A CONSTANT DEMAND OF 400 L/DAY AT THE DESIGNATED DEGREE OF SECURITY









CONSTANT DEMAND . 600 L DAY
RELIABILITY : 80 %
LOCATION : MOUNT BARKER SA

FIG. 3
ULTRA – CONSERVATIVE MODEL — CURVE (3)
MODERATELY CONSERVATIVE MODEL — CURVE (2)
AND OPTIMISTIC MODEL — CURVE (1)

The conservative counting rule of curve 2 produces the same reliability as the counting rule of Martin in curve 1, using 0.5D as the truncation level for assessing either a failure or a success. This agreement is possible when the length of rainfall record is sufficiently long.

DISCUSSION

Graphic results have been produced that show the relationship between projected roof area and tank size for given average rainfall in South Australia. For a given constant household demand and a given degree of security, appropriate combinations of roof area and tank size may be selected from the graphs.

The graphic results are applicable to households which depend upon rainwater as the sole source of domestic supply, with the pattern of domestic water use severely restricted.

Since the consequences of failure are expected to be greater for households dependent solely upon rainwater supply, a realistic approach has been adopted in applying the counting rule for success, which includes total, partial and no successes.

In addition, a moderately conservative rule for testing against spill has been adopted. It is found that tank sizes selected by this moderately conservative rule are greater than those selected by the 'optimistic' rule of Martin by an amount equivalent to one month's demand.

Sensivity analysis of three separate counting rules indicate that selection of tank size and roof area is sensitive to the nature of the assumptions used, the various counting rules for success and the testing rules for spills. The testing rule for success used by the authors gives satisfactory results because the reliability is the same in terms of time reliability or volumetric reliability.

CONCLUSIONS

In association with a study to provide guidance on the use of rainwater for households in South Australia without mains water supply and therefore dependent upon rainwater as the sole source of supply, graphic results as depicted by iso-demand curves have been produced using a combination of tank sizes and roof areas.

These iso-demand curves reflect a more realistic approach in assessing the degree of security or reliability of supply. The degree of security defined in the study by the authors produces the same figure of reliability whether it is expressed in terms of time or volume.

In addition, a more conservative approach on the test for spill results in a larger tank storage capacity equivalent to one additional month of demand. This conservative approach is adopted by the authors because the consequences of a failure in supply are expected to be greater for households dependent upon rainwater supply.

In general, the sensitivity analysis had indicated that the results obtained in this study are consistent with the results of an alternative 'optimistic' approach adopted for households which have the benefit of both public mains water supply and rainwater tank supply.

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RURAL WATER SUPPLY PROJECT, NUSATENGGARA TIMUR-INDONESIA

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ABSTRACT

Rainwater collection from roofs has been a common mode for providing drinking water supply to remote rural areas in South East Asian countries, and is quite a viable, acceptable and reliable method of drinking water supply to these rural communities. The paper discusses the components of rainwater collection tank system, water supply requirements, review of the various practices, hydrometeorological analysis, computation of storage requirements for various roof areas and a detailed proposal for the rural water supply for Nusa Tenggara Timur province of Indonesia. Cost estimates for ferrocement tank design and masonry design are also provided.

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INTRODUCTION

The province of Nusa Tenggara Timur (NTT) Indonesia is located between 8°31' S to 11° 1' S latitude and 118° F - 125° E longitude and is spread on Timor, Flores, Sumba groups of islands. The area is divided in 12 regencies and sub-regencies The population of NTT province is Timor-1002828, Flores-1368610 and Sumba-354925. Many inland and coastal areas are dependent on rainwater for domestic purposes This is because either ground water is saline, or it is not available or ground is rocky, therefore, difficult to dig wells and spring/rivers are far from the villages The population of such areas is usually scattered in a range of population varying from 100 to 500 and is economically poor Due to very high cost of construction and operation and maintenance of pumping or gravity water supply system from a far-off spring source or other sources, the rainwater collection system for individual houses or commune are often planned to meet the drinking water requirement for such areas. This paper, therefore, attempts to develop an approach to the design of optimal rainwater collection and storage systems The paper covers and examines the relevant design parameters for the development of optimal solution for NTT.

COMPONENTS OF THE RAINWATER COLLECTION TANK SYSTEM

The system components are · roof surface (of tiles or galvanised mild steel sheets), rainwater gutters (of galvanised mild steel sheets), rainwater drain pipes (of fabricated mild steel sheets or AC or PVC non-pressure pipes or large diameter bamboo pipes), small straining filter, storage tank with overflow, wash-out and outlet pipe with a tap for withdrawal of controlled/restricted daily water requirement as and when required

The rainwater after falling on the roof surface partly evaporates specially during dry periods at low intensity showers, some part may overflow from the rainwater gutters while the remaining would flow down to the storage tank. Not all the water flowing into the storage tank is, however, available for drinking water use, because part of it overflows, part leaks or evaporates from the tank. The remaining quantity left is available for withdrawal through the tap daily for meeting the drinking water needs.

PRESENT DESIGN GUIDE LINES OF THE DEPARTMENT OF HEALTH

The following guide lines issued by the Ministry of Health to all the provincial Departments of Health for the construction of rainwater collection tank systems, are at present being followed :

(i) Per capita daily water requirement : 5 - 10 litres
(ii) Dry spell period - 3 months
(iii) Number of persons per tank - 100 (20 families)
(iv) Capacity of masonry tank 45 m^3 or alternatively ferrocement tanks 10 or 20 m^3 capacity.

(v) Roof area to suit local rainfall - To collect sufficient rainwater for filling the tank, roof and gutter system of three houses is to be utilised to fill a tank of 45 m^3.

(vi) Designs - Following designs are being adopted :

- (a) Nominal capacity 45 m^3 :
  - Masonry tank 5 m x 5 m x 1.75 m deep(43.75 m^3)
- (b) Nominal capacity 9 m^3 or 10 m^3 :
  - Ferrocement tank 3 m in diameter 1.3 m deep (9.10 m^3) or 1.42 m deep (10 m^3).

(vii) Designs are for guide and could be modified to suit the local conditions and availability of local materials.

(viii) The work is not to be contracted but to be constructed with people participation under the supervision of Health Department Staff.

PARAMETERS INFLUENCING STORAGE CAPACITY

Following parameters affecting the storage capacity have been considered while evaluating the design:

(i) rainfall and its distribution
(ii) per capita daily water requirement
(iii) dry spell period in a year
(iv) number of persons per family
(v) nature of roof surface and effective roof area
(vi) run-off losses and evaporation cum leakage losses
(vii) Safety from short spell of no rain in a month preceding or succeeding the dry no rain period in a year.

The attempt here is to delineate the possible combinations of roof area and tank size required to meet a specified per capita daily water demand for a selected probability of failure.

Rainfall and Its Distribution

A study of the rainfall data of the NTT province reveals that the annual rainfall varies from a spatial maximum of 4321 mm at Manggarai agency to a minimum of 481 mm at Sumba Timur with inter annual variations. There is a large variation in the monthly rainfall pattern. Three to four months in a year are generally dry. The available rainfall data for 10 stations varied from 26 years to 9 years of record. Summary of mean annual rainfall and standard deviations of the data available is tabulated (vide table 1).

TABLE - 1

Rainfall Statistics of Various Regencies

Regency	Station	No. of year of data	Mean annual rainfall	Standard deviation
Sumba Timur	Mauhau	26	839.78	245.89
Kupang	Mapoli	18	1717.28	610.21
Sikka	Waioti	9	1242.56	393.80
Flores Timur	Larantuka	9	1402.44	476.33
Ngada	-	11	1800.73	996.14
Manggarai	-	11	3220.55	742.86
Endo	-	9	1726.22	578.71
Alor	-	11	1265.18	350.19
Sumba	-	11	2167.64	536.57
Belu	Atambua	21	1451.62	364.81

Spatial Average and Standard Deviations

Regency	No. of stations	Spatial Mean	Standard Deviation
Kupang	14	1531.43	436.31
Belu	18	1694.06	572.92
TTS	9	1561.11	427.76
TTU	7	1133.00	234.02

Per Capita Daily Water Requirement

Storage capacity is a function of per capita water supply and the variations in precipitation. Higher the per capita supply more is the storage needed, consequently higher is the rainwater storage cost. Therefore, storage for drinking water requirement only has to be provided for designing a rainwater storage system.

Following per capita water requirement have been adopted elsewhere for the design.

West Java	5 lpcd	By rural water supply project West Java OTA 33/5-7
Central & East Java	5-6 lpcd	Program for rainwater collection tank in Madura, East Java by DIAN DESA
Thailand	4 lpcd	" The potentials of Ferrocement and related materials for rural Indonesia" prepared for USAID by Dr. Ricardo Pama and C. Phramratapongsi.

Sikka Regency, Flores-NTT	4 lpcd	Actual field survey by this project in Oct. 1980

The aim should be to provide as high a rate of supply as feasible at a reasonable cost. To determine the quantity of water being actually collected and transmitted by families during summer for meeting their drinking water requirement, a survey was conducted by the project staff in Sikka regency in October 1980. It was found that every family transports about 2 bamboo full of water daily for meeting their drinking water needs. The actual quantity per bamboo was measured and found to be 12 litres. The average number of persons per family was found as 5.5 to 6. Actual per capita water requirement transported, therefore, works out as 4 litres per day.

The paper, therefore, analyses the system storage capacities required for a per capita supply of 4 and 5 lpcd.

Dry Spell Period in a Year

From the rainfall data it is also clear that the dry period in a year varies from 3-8 months.

Number of Persons Per Family

Regency and Subregency wise number of persons per family as per 1980 census is given in Table No. 2.

TABLE NO. 2

Regency Population & Number of Persons per Household

Regency	Population	No. of Households	No. of persons per household
Alor	125,006	24,254	5.15
Belu	180,417	39,241	4.60
Ende	195,047	36,537	5.33
Flores Timur	240,747	43,889	5.48
Kupang	403,013	78,915	5.10
Manggarai	398,774	64,873	6.15
Ngada	121,749	18,042	6.74
Sikka	219,944	35,778	6.15
Sumba Barat	231,959	39,070	5.94
TTS	283,555	60,563	4.68
TTU	159,052	26,205	6.07

Further, the population is rising and hence the number of persons per household is likely to increase in future. For computations of required storage per family, the numbers of persons per family has been taken as six for all regencies.

Nature of Roof and Roof Area

Nature of roof surface : Rural housing in NTT is classified into permanent, semipermanent and temporary. Semipermanent and temporary houses have thatched roof. A large percentage of houses in a desa are usually thatched. Such houses are unsuitable for rainwater collection system. This is because fine organic particles of thatched roof straw are found to flow along with the rainwater, imparting colour, smell, taste and pollution to water, rendering it unfit for storage and subsequent human consumption. Only those houses which have galvanized mild steel sheet roofing or tile roofing are, therefore, considered for the development of rainwater collection systems.

Gross roof area : The housing improvement and resettlement programme of the Government of Indonesia for NTT envisages following four types of houses :

Type	Plinth area mxm	Roof size mxm	Roof area m^2
Type I	6x6	8x8	64
Type II	6x7	8x9	72
Type III	6x8	8x10	80
Type IV	7x8	9x10	90

Due to limited financial resources, most of the houses planned for resettlement are however of type I or type II. All these houses have galvanised corrugated metal roof. The height of the lower edge of the roof varies from 240 to 250 cm above ground level. The roof areas of houses of Puskesmas doctor and employees of Puskesmas are as tabulated below:

	Plinth Area m^2	Roof Area m^2
For Puskesmas Doctor		
Type I	70	103
Type II	70	103
For Sanitarian/midwife	50	84

Effective area : The effective area of the roof draining rainwater to rainwater gutters and then to the tank will depend upon the type of house, the location of the tank, capacity of the gutters and the arrangement of rainwater pipes conveying roof water from gutters to the tank. Any corner bend on the rainwater gutter, reduce its capacity by 25%. The length of the gutters, the effective roof area percapita draining to the filter assuming number of persons per house as six is tabulated below.

Standard House type, plinth area mxm	Storage tank located at side corner				Storage tank located at the back			
	Effective roof area - m^2		Gutter length (m)		Effective roof area m^2		Gutter length (m)	
	Total	Per cap	Total	per cap	Total	per cap.	Total	per cap
Type I, 6x6	32	5	16	2. 66	48	8	24	4
Type II, 6x7	36	6	17	2. 90	54	9	25	4. 16

Very few heads of families are however fortunate to have a house even of 6mx6m size as being adopted for the resettlement areas. Due to joint family system many houses have more than one family in one house. A roof area of more than 3 to 4 m^2 percapita contributing flow to the tank is, therefore, hardly likely to be available.

In West Java a roof area of 2. 0 sq.m. percapita was adopted for design evaluation. For analysis of storage capacity however, calculations have been worked out with roof area as 2 m^2, 3 m^2, 4 m^2 and 5 m^2 per capita for calculating the rainwater flow to the tank to determine the effect of area on the tank capacity.

Runoff Losses and Evaporation Losses

Runoff and evaporation losses with galvanised metal sheet roofing may be quite small in rainy season, but may be appreciably high during the period of very low rainfall when atmospheric temperature is high. Based on the data of temperature and evaporation, a runoff cum evaporation loss from the roof surface as 15% is adopted for storage design calculations. Storage tank is covered and water proof, not much water stored is therefore likely to be lost from the tank. A leakage cum evaporation loss from the tank surface at 5% is however adopted for design evaluation.

Safety Against Short Spell of No Rainfall Preceding and Succeeding a Long Dry Spell

The analysis of storage required for a selected roof area and supply percapita in a year is based on the monthly rainfalls. However, storage may fall short due to daily variations in the precipitations. This is clear from a detailed analysis based on daily rainfall for Sumba Timur regency, wherein it is computed that the storage required is about 7% more than that computed based on monthly data dry spell. To cover such an eventuality 7% extra storage has been provided on the storage computed on monthly rainfall data. A provision of 10 cm in height of the tank is provided as a dead storage.

STORAGE TANK CAPACITY

Maximum average percapita supply possible : It may be of interest to know as to how much percapita gross storage (including evaporation and leakage quantity from the tank) is feasible if every drop of rainwater (after evaporation losses etc., from the roof) is retained in the tank. This has been analysed and the percapita supply figures have been computed for various regencies. It is clear from this analysis that to provide 4 to 5 lpcd even in drought year, a maximum roof area of 3 to 4 m^2 (more than 2 m^2) is necessary.

Storage Capacity : As the rainfall is concentrated in a period of 4 to 8 months in a year, if attempts to retain every drop of rainwater available is made, balancing storage capacity becomes considerably higher in comparison to the case when storage is provided to meet the maximum no rainfall dry period requirement at a restricted supply of 4 or 5 lpcd. This is because total rainfall is much more than required to provide a continuous supply of 4 or 5 lpcd. This difference will be more noticeable in caseof Kupang than Sumba Timur because average rainfall for Kupang is higher than Sumba Timur, where as dry spell period remains almost same.

Storage for longest dry spell : Maximum dry period of no rainfall in NTT is 7 to 8 months in the area with total annual rainfall of 1500 mm or less. The most critical storage to meet the dry period (no rainfall months), works out to be as follows :

Most critical storage required for the dry period of 8 months :

(i) At 4 lpcd required 4 x 30 x 8 = 960 litres per capita
(ii) At 5 lpcd requires 5 x 30 x 8 = 1200 litres per capita

Thus about 25% more storage is required if one adopts dry period daily per capita supply as 5 lpcd.

The storage calculations have, however, been performed on year to year basis to meet the requirement at 4 and 5 lpcd for a roof area of 2, 3, 4 and 5 m^2 per capita for all the stations using the available data. The storage capacities required have been analysed for different dependability levels. These are given in tables 3, 4 and 5. It is clear from this that about 170 to 847 litres storage capacity per capita is required with a roof area of 4 m^2 to meet water requirement at 4 lpcd with 90 percent dependability.

Storage analysis : Total storage required for all the regencies for 90% dependability is worked out for 4 lpcd and 5 lpcd supply respectively. The storage so computed includes adjustment for daily variations in rainfall (7 percent) and leakage and evaporation from tank (5 percent) and a summary of the same is given below :

Regency	Total storage required (litres) for 4 lpcd	5 lpcd
Sumba Timur	948	1207
Flores Timur	932	1040
Kupang	814	1030
Sikka	796	1054
Ngada	784	1349

Belu	651	822
Alor	553	723
Sumba Barat	411	582
Ende	321	458
Manggarai	191	278

Storage capacity per family : Based on the analysis of storage requirements, it is found that some regencies require less storage than others even for higher rate of supply as they have less variations in the monthly rainfall. Hence it is desirable to divide the regencies into two broad categories :

Group I - Sumba Timur, Flores Timur, Kupang Sikka, Ngada, Belu and Alor: These are to be provided with a family storage of 6000 litres. Leaving a dead storage height of 10 cm and maximum height of tank limited to 1.6 m, these regencies are to be provided with a tank 2m x 2m x 1.6m for each household. With this the regencies Belu and Alor will have capacity to supply of 5 lpcd whereas the others will have a capacity of 4 lpcd.

Group II - Sumba Barat, Ende and Manggarai : These are to be provided with a family storage of 3600 litres. Again making provisions for dead storage and size 1.55m x 1.55m x 1.6m has to be provided for each household in these regencies and it will have a capacity to supply at 5 lpcd.

SUGGESTED DESIGN CAPACITY OF STORAGE TANKS

In deciding this the existing practice and the past experience are relevant.

(i) The rainwater collected in the rainwater tanks constructed for communal use soon gets exhausted within 2 - 3 months after the rains, mainly due to uncontrolled draw off by too many people.

(ii) The rain water tanks of 45 m^3 capacity require a large roof area and an elaborate arrangement and long lengths of the rainwater gutters which often is not available, as a result tank is not always full up to the design level.

(iii) The construction of the rain water tank has to be sturdy and water proof to prevent loss of water after collection.

It is, therefore, suggested that the construction of smaller tanks of $5m^3$ for individual household use should be encouraged to provide 4 to 5 lpcd supply throughout the year wherever feasible.

The larger capacity tank 10 m^3 (preferably) and 20 m^3 should be provided at Puskesmas, residences of Puskesmas staff, Gereja, Masjid, Schools, Balai Desa Office, Police Station/Military Office and joint family households provided sufficient roof area is available in preference to a single tank of 45 m^3 capacity. As a thumb rule roughly 4 m^2 roof area should contribute (2m gutter length) flow per cubic meter of water intended to be stored in the

TABLE NO. 3

ABSTRACT OF STORAGE REQUIREMENT FOR DIFFERENT DEPENDABILITY

Regency and station	Dependability	Per capita storage in litres with supply 5 lpcd roof area				supply 4 lpcd roof area			
		$2m^2$	$3m^2$	$4m^2$	$5m^2$	$2m^2$	$3m^2$	$4m^2$	$5m^2$
Regency : Sikka	100%	x	x	1081	1046	876	871	837	818
Station: wioty	88.9%	x	1038	926	870	809	763	896	656
	77.8%	x	952	910	815	616	736	651	549
Regency: Sumba Barat	100%	612	581	525	504	490	428	403	382
	90%	530	546	520	459	457	424	367	309
	80%	340	296	232	175	280	197	140	124
Regency: Belu	100%	854	823	793	765	671	640	612	612
	90%	798	637	734	727	597	589	581	574
	80%	750	742	544	452	554	458	368	368
Regency: Alor	100%	x	840	740	669	x	610	535	485
	90%	967	739	646	588	723	525	493	471
	80%	849	665	510	471	635	523	414	355
Regency: Ende	100%	x	733	629	559	x	519	450	395
	90%	554	460	409	360	401	338	287	238
	80%	529	387	209	155	381	208	124	124
Regency: Manggarai	100%	590	579	569	559	468	457	447	437
	90%	473	329	249	212	321	210	170	150
	80%	375	258	154	113	253	139	90	82
Regency: Ngada	100%%	x	x	x	1195	661	563	986	950
	90%	x	x	1205	874	528	418	700	661
	80%	875	776	679	855	499	385	523	502
Regency:Sumba Timur	100%	x	x	1128	1105	x	x	886	861
Station: Mauhau	96%	x	x	1098	1067	x	921	854	843
	92%	x	x	1091	1057	x	884	847	835
	88%	x	1128	1065	985	x	879	846	823
	84%	x	1100	1021	974	x	856	788	771
	80%	x	1049	992	974	x	828	778	750
Regency: Kupong	100%	1166	1138	1111	1084	922	894	867	840
Station: Mapoli	93.3%	1072	998	924	915	877	754	732	732
	86.7%	1061	950	915	902	828	736	722	719
	80%	990	948	910	870	776	734	696	656
Regency: Flores Timur	100%	1087	1062	1060	1057	851	848	846	843
Station : Larantuka	88.9%	994	948	915	915	774	734	732	732
	77.8%	958	915	907	873	732	732	699	689

TABLE NO. 4

STORAGE ANALYSIS FOR 5 lpcd

Conditions	Sikka	Sumba barat	Belu	Sumba Timur	Kupang	Flares Timur	Alor	Ende	Manggarai	Ngada
90% dependable storage from 4 m^2 area in litres	941	520	734	1078	920	929	646	409	249	1205
Adjustment for daily flow variation 7%	66	36	51	75	64	65	45	29	17	84
5% for Evapn. and leakage	47	26	37	54	46	46	32	20	12	60
Total storage per capita in litres	1054	582	822	1207	1030	1040	723	458	278	1349

TABLE NO. 5

STORAGE ANALYSIS FOR 4 lpcd

Conditions	Sikka	Sumba barat	Belu	Sumba Timur	Kupang	Flores Timur	Alor	Ende	Manggarai	Ngada
90% dependable storage for 4m^2 area in litres	710	367	581	847	727	743	493	287	170	700
Adjustment for daily flow variations 7%	50	26	41	59	51	52	35	20	12	49
5% for evap. and leakage losses	36	18	29	42	36	37	25	14	9	35
Total storage per capita in litres	796	411	651	948	814	832	553	321	191	784

tank. Gutter length draining to the tank to the one side of drainpipe should not exceed 10 - 12 m units.

Keeping in view the above considerations following designs of 5 and 10 m^3 capacity tank has been suggested for individual household and community rainwater tanks in NTT.

Masonry tank :

(i) Size : 1.8 m x 1.8 m x 1.6 m deep or twin unit each 1.8x1.8mx1.6m

(ii) Nominal capacity : 5 m^3 or twin units with 10 m^3 capacity. Actual capacity 5.184 m^3 or twin unit of 10.368 m^3 capacity.

(iii) Foundation : Local stone compacted under the floor with masonry foundation under the walls.

(iv) Walls : Masonry in cement mortar 1 : 3, plastered in cement mortar 1 : 2, 18 mm thick in 2 layers.

(v) Floor : Ferrocement floor with chicken wire net 5 cm thick in 1 : 2 cement mortar (water cement ratio 0.4).

(vi) Roof : Ferrocement roof slab 6 cm thick with MS reinforcement and 2 layers of chicken wire mesh.

(vii) Filter : Perforated slab with sand and gravel topped with open jointed bricks or big size stones to prevent disturbance of sand underneath.

(viii) Overflow chamber (optional): The tank is sized for failure of one in 10 years. Therefore, in most of the years more rainfall is available at least during the rainy season than 4 to 5 lpcd for which the tank is limited, the rainwater will naturally, overflow to waste.

(ix) As the height of the roof is limited, the tank floor cannot be raised above ground. The tap being almost at the floor level, a pit has to be constructed to place the bucket under the tap. The pit has to be provided accordingly with the open jointed floor so that spilled out or rainwater may soak into the ground, if it cannot be drained. If topography permit a drain should be provided to drain the waste water. Site should be dressed and sloped away from the tank to prevent rainwater finding way to the foundation of the tank.

(x) A water level inspection pipe is to be provided with a cap.

(xi) For entry into the tank, manhole for large capacity tank is to be provided.

Ferrocement tank : The design of ferrocement concrete tank is circular in shape with domical or flat roof. The details are :

	As per West Java Domical roof	As per project	Alternative design flat roof
Nominal capacity	5 m^3	10 m^3	10 m^3
Size	2 m dia	2. 9 m dia	2 94 m dia
Water depth	1. 6 m	1. 6 m	1 6 m
Capacity actual	5. 02 m^3	10 m^3	10. 86 m^3

The structural design reinforcement is based on the designs developed by the West Java rural water supply project. The alternative design of ferrocement tank is based on the structural Engineering Research Institute, Madras,India and International Ferrocement Centre, Bangkok. Other design features are similar to those mentioned earlier under masonry tank. A comparative cost estimate is provided in Appendix A.

CONCLUSION

Based on the detailed studies the following conclusions are drawn :

(i) Per capita daily water supply of 4 to 6 litres during the dry spell is feasible for NTT province with reasonable storage.

(ii) The dry spell period in NTT varies from 3 to 8 months (6 months being quite common) in a year. The criteria of 3 months dry spell for sizing of storage is therefore not applicable. A detailed analysis of storage required is advisable with rainfall data preferably of long duration.

(iii) At present storage tank 45 m^3 is provided to meet the requirement of 100 persons (20 families). This criteria which is practice now is very large. Such a large system is obviously not feasible due to :

(a) Non-availability of roof area of about 300-400 m^2
(b) Elaborate arrangement of rainwater gutters required to convey rainwater to the storage tank.

The capacity of the tank is too big to fill under the NTT rural housing and rainfall conditions.

(iv) As per the analysis 1 m^3 capacity requires a roof area of 4 m^2. The 45 m^3 capacity tank will therefore require a roof area of 180 m^2 . Normally more than 50 m^2 roof area per family of 5 persons may not be available. Thus roof area more than 3 houses will be required to fill the tank of this capacity. The rural houses in NTT are very much scattered and distance between houses is several meters in most cases. Even in case of schools and gereja's it may be difficult to collect roof water from a roof area greater than 40 sq. m. without having to make elaborate arrangement for the support of rainwater gutters.

(v) A smaller tank of 5 m^3 for individual household and 10 m^3 (preferably) and 20 m^3 should be provided at public places and joint households wherever feasible.

ACKNOWLEDGEMENT

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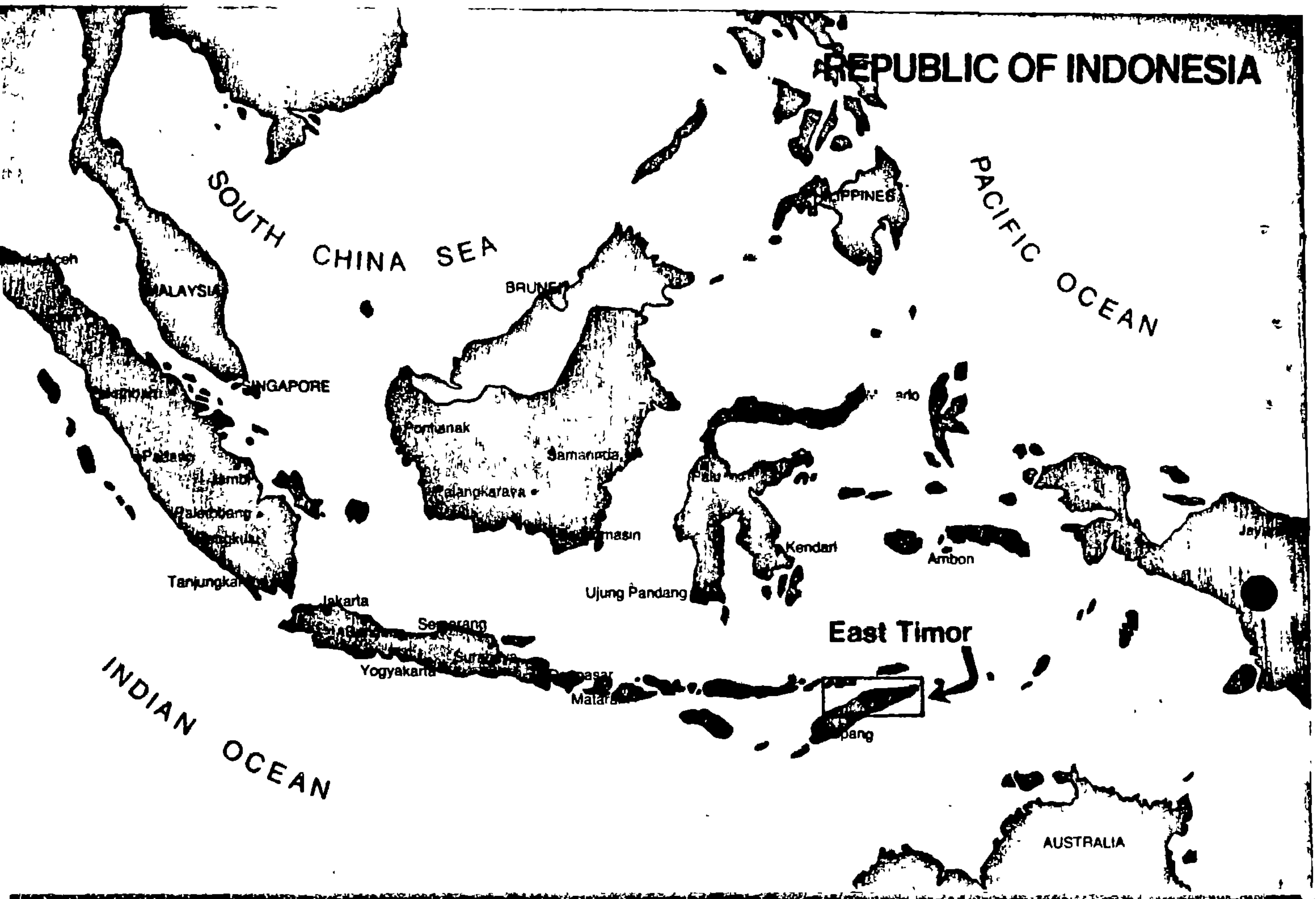
APPENDIX - A

COMPARATIVE COST ESTIMATES OF 10 M^3 CAPACITY TANKS OF DIFFERENT DESIGNS

Item	Unit rate	Ferrocement Tank Design								Masonry Design	
		As per West Java Project		Design by the Project		Design as per SRI Madras India		Design as per F.C.R.I. Bangkok		Design by the Project	
		2.9mϕx1.6m Design No. 5		2.94mϕx1.6m Design No. 6		2.4mϕx2.3m Design No. 3		2.2mϕx2.63m Design No. 4		1.8mx1.8mx2 Design No. 7	
		Quan.	Amount	Quant.	Amount	Quant.	Amount	Quant.	Amount	Quant.	Amount
1	2	3	4	5	6	7	8	9	10	11	12
1. Cement	3000/bag	18	54,000	18	54,000	18	54,000	14	42,000	38	114,000
2. Clean sand	4500/m^3	1.4	6,000	1.8	6,300	1.0	4,500	0.9	4,050	4	18,000
3. Galvanised rod	1000	74.0	74,000	120	120,000	152	152,000	95	95,000	45	45,000
4. Binding wire	1200/kg	2 kg	2,400	2.5 kg	3,000	2.5	3,000	2.5	3,000	1/2 kg	600
5. Chicken wire net	1000/m^2	50	50,000	-	-	-	-	-	-	24	24,000
6. Steel wire mesh 10x10m of 20SWG	1000/m^2	-	-	150	150,000	160	160,000	160	160,000	-	-
7. Water tap	5000	1	5,000	1	5,000	1	5,000	1	5,000	1	5,000
8. G.I. outlet pipe	1500	1,3/4"	1,500	1,1/2"	1,000	1,1/2"	1,000	1,1/2"	1,000	1,1/2"	1,000
9. Drain out pipe	1500	1,1 1/2	1,500	1,1"	1,000	1,1"	1,000	1,1"	1,000	1,1"	1,000
10. Galvanized overflow pipe		1,1 1/2	2,000	1,3"	5,000	1,3"	5,000	1,3"	5,000	1,3"	5,000
11. Water depth measurement pipe	5000	1	5,000	-	-	-	-	-	-	1	5,000
12. Filter plate of RCC		1	3,000	1	3,000	1	3,000	1	3,000	1	3,000
13. Filter sand			300		300		300		300		300
14. Filter gravel			400		400		400		400		400
15. Coconut husk for filter			200		200		200		200		200
16. Brick or large stone for filter			200		100		180		180		200

1	2	3	4	5	6	7	8	9	10	11	12
17. Gutter of galvanised Iron sheet 20 cmø with F.I. stays		10m	10,000	10m	10,000	10m	10,000	10m	10,000	10m	10,000
18. Rainwater pipe of sheet iron		1/2m	1,000	1/2m	1,000	1/2m	1,000	1/2m	1,000	1/2m	1,000
19. Water proof epoxy paint		4	10,000	4	10,000	4	10,000	4	10,000	4	10,000
20. Mosquito net			200		200		200		200		200
21. Nails			500		500		500		500		500
22. Planks	Local		Local		Local		Local		Local		Local
23. Bamboo	Local		Local		Local		Local		Local		Local
24. Brick or stone for wall	-	-	-	-	-	-	-	-	-	3750m^3	Local
25. Plywood for shuttering 1.2x2.4m	3750/sheet		5,250		5,250		5,250		5,250		-
26. Total			232,450		376,250		416,530		347,080		240,400
Reason for variation in cost		Dome roof comparative less reinforcement		Flat roof more reinforcement		Flat roof More reinforcement as per structural institute		Dome roof More reinforcement		Brick work RC roof excluding cost of brick or stones	
Overhead charges Labour 30%			69,735		112,875		124,959		104,124		72,120
incentive transport material etc.			302,185		489,125		541,489		451,204		306,900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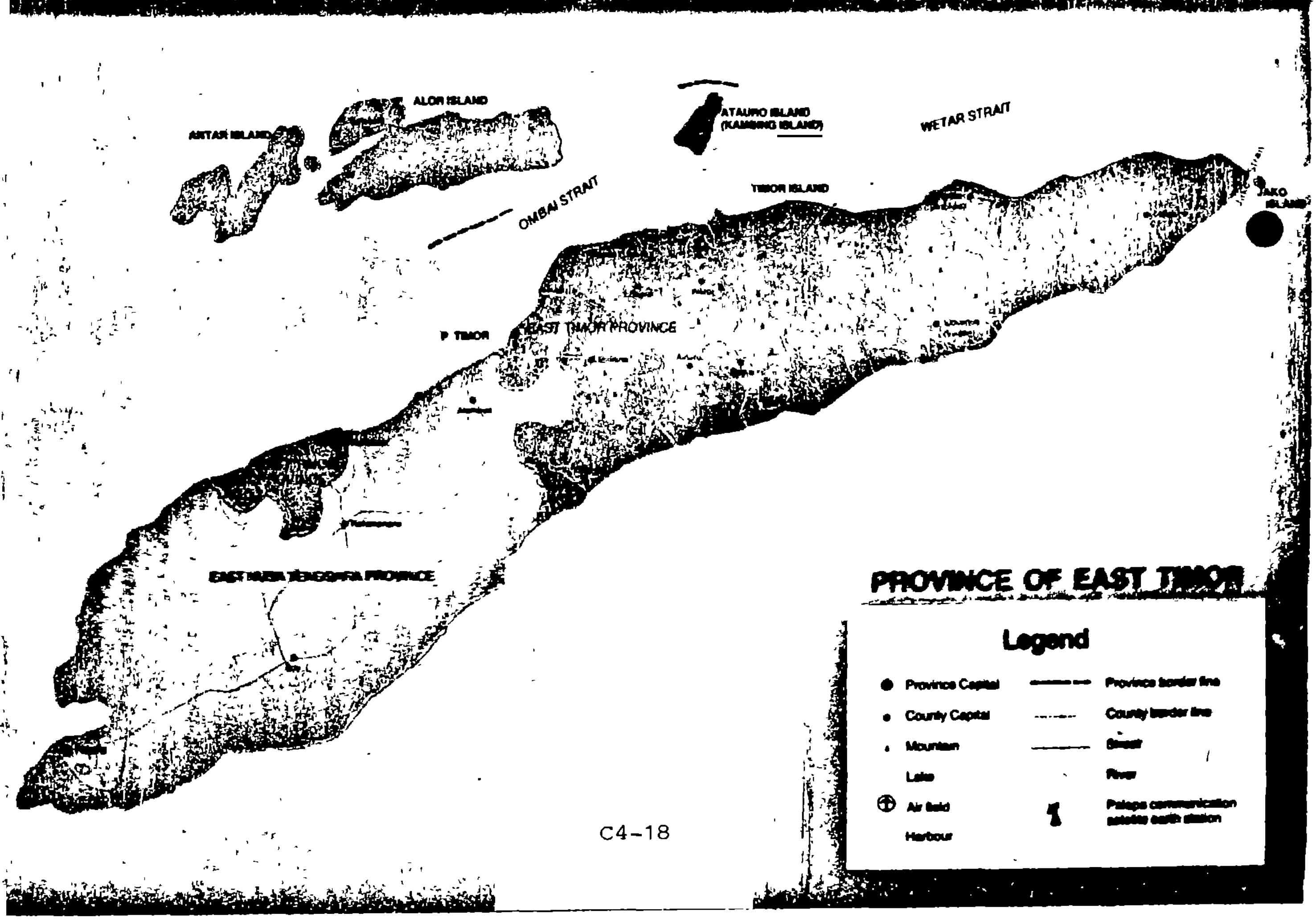
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ATAURO ISLAND (KAMBING ISLAND)
WETAR STRAIT
OMBAI STRAIT
TIMOR ISLAND
P TIMOR
EAST TIMOR PROVINCE
EAST NUSA TENGGARA PROVINCE
JAKO ISLAND
PROVINCE OF EAST TIMOR
Legend
Province Capital
County Capital
Mountain
Lake
Air field
Harbour
Province border line
County border line
Street
River
Palapa communication satellite earth station

RAIN WATER CISTERN SYSTEM
FOR THE RURAL AREAS OF KEDAH, MALAYSIA

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ABSTRACT

Rural water supply has been given prominence in the various development plans of Malaysia. However, the pace at which the rural communities are supplied with potable piped water lags far behind the urban counterparts. A significant proportion of the rural population has to depend on traditional sources and in Kedah especially, the problem is compounded by regular shortages due to dry spells. This paper examines the possibility of introducing rain water cistern system as a reliable system of water supply for the villages in Kedah. The design of a cylindrical tank has been proposed taking into consideration several relevant factors. This rain water cistern system has been shown to be economically cheaper than piped water installation. With government assistance, the cost will be significantly reduced. The only problem that may arise with the introduction of this system is purely a psychological one which is to convince the rural people that rain water is as good as piped water in terms of its potability.

INTRODUCTION

Malaysia has had reasonable success in her efforts at providing potable water supply to the population. Increasing allocations have been set aside for the development of water supply infrastructure and piped network over the past two decades. Thus by 1985, 73.1% of the population has been served with piped water supply. The percentages of the total population that have been served with piped water system for the various parts of Malaysia and the break down in terms of urban and rural are shown in Table 1.

TABLE 1
Percentage of Population Served with Piped Water System in Malaysia, 1970-85
(Source: Fourth Malaysia Plan 1981-85)

	1970		1980		1985	
	Urban %	Rural %	Urban %	Rural %	Urban %	Rural %
Pen. Malaysia	83.0	39.0	90.0	47.2	100	63
Sabah	95.0	-	99.0	18.0	100	39
Sarawak	90.7	13.0	93.0	25.0	100	35
Malaysia	46.1		59.4		73.1	

Table 2 indicates the number and percent of occupied housing units with piped water supply by state, 1970-1980. The latest figures that indicate the measure of success in potable water supply seem impressive by Third World standards. However, these figures do not express the true water supply situation with regard to the rural communities. A high percentage of these figures represent the urban areas. On the basis of districts, high percentages of housing units served with piped water coincide with districts in which are located the state capitals or other main towns (Goh, 1984). This is borne out by Fig. 1. Districts which are predominantly rural in character

TABLE 2

Number and Per cent of Occupied Housing Units
with Piped Water Supply by State, 1970 and 1980
(Source: Census of Housing, Malaysia - Summary
Reports, 1980, p. 2)

State	Number of occupied housing units with piped water supply		Per cent of occupied housing units with piped water supply		Per cent point diffrence	Average annual per cent increase
	1970	1980	1970	1980	1970 - 80	
Federal Territory	-	142,961	-	92.5	-	-
Selangor	173,852	216,263	70.2	86.1	18.4	10.7
Penang	76,478	120,220	69.2	84.2	15.0	5.7
Malacca	30,527	61,585	49.6	81.0	31.4	10.2
Negeri Sembilan	46,814	77,047	59.3	76.0	16.7	6.4
Johore	109,125	201,222	55.9	74.5	18.6	8.4
Perak	125,736	229,903	51.2	74.4	23.2	8.3
Pahang	35,470	94,455	40.3	66.6	26.3	16.6
Kedah	55,864	108,984	31.7	51.8	20.1	9.5
Perlis	5,566	13,500	22.8	43.4	20.6	14.2
Trengganu	9,459	30,478	11.6	29.4	17.8	22.2
Kelantan	18,499	39,278	13.4	22.8	9.4	11.2
Pen. Malaysia	687,390	1,335,896	47.5	68.0	20.5	9.4
Sabah	-	81,620	-	50.3	-	-
Sarawak	-	98,810	-	47.8	-	-
MALAYSIA	-	1,516,326	-	65.0	-	-

are the ones with very low percentages and some of these are found in Kedah. For most rural areas, water supply comes from traditional sources such as shallow wells, rivers, canals and rain. Table 3 shows the percentage of households without piped water and the proportion of this accounted for by non-piped water supplies.

TABLE 3
Percentage of Households and Water
Supply Source in Malaysia
(Source: Census of Housing, Malaysia, 1980)

		a	b	c	d	e
		% of household without piped water	Well water as % of (a)	River water as % of (a)	Canals/ drains as % of (a)	Others as % of (a)
Johore	1970	44.2	76.9	3.4	5.1	14.5
	1980	25.4	59.4	4.8	3.0	32.8
Kedah	1970	68.3	84.6	11.4	2.3	2.9
	1980	48.2	87.8	8.2	1.2	0.2
Kelantan	1970	86.6	91.0	8.3	0.4	0.2
	1980	77.2	92.9	6.6	0.3	0.2
Melaka	1970	50.4	97.5	0.6	0.6	1.3
	1980	18.9	96.5	2.1	0.8	0.7
Negeri Sembilan	1970	40.7	89.7	6.3	2.2	1.7
	1980	24.0	86.4	7.8	1.8	4.1
Pahang	1970	59.7	58.1	37.3	2.6	2.0
	1980	33.4	65.0	31.6	2.1	1.3
Pulau Pinang	1970	30.8	88.4	5.8	2.0	3.8
	1980	15.8	89.3	5.9	3.3	1.5
Perak	1970	48.8	73.2	15.5	7.3	4.0
	1980	25.6	71.6	15.2	3.8	9.4
Perlis	1970	77.2	92.7	2.9	1.0	3.4
	1980	56.6	83.2	1.8	0.2	14.8
Selangor	1970	29.8	76.9	5.2	4.7	13.2
	1980	13.9	56.6	9.1	4.6	30.0
F. Territory	1980	7.4	83.3	9.9	4.5	2.24
Trengganu	1970	88.35	88.8	10.2	0.4	0.5
	1980	70.6	93.2	6.3	0.1	0.3

In this paper attention is focused on the State of Kedah which by 1980 has about 48.2% of households which are not supplied with piped water. Most of these households are located in the rural areas. Although a significant proportion of the 48.2% of households depends on well water, it must be stressed that the wells are generally shallow not deeper than 6 metres. They become highly susceptible to drying for at least three to four months of the year due to seasonal dry spells. River and canal water is generally unwholesome which during normal times are already affected by agricultural activities and domestic wastes. The water quality greatly deteriorates during the dry spells. Rain water as the sole source of water supply for household use plays a very negligible role in Kedah. Crude forms of storage from roof runoff do exist to augment other sources but they are totally inadequate especially during the dry periods. Under these conditions it is pertinent to consider the possibility of introducing proper rain water cistern systems to the rural areas of Kedah as a means of supplying potable drinking water during both normal times and during dry spells when all other forms of supply, including piped system, fail to provide the potable water requirements of the communities. This study is also a logical extension of a more detailed investigation on the water supply problems in four villages in Kedah (Goh, 1983).

RAINFALL IN KEDAH

The dependability of any rain water cistern system to a large extent depends on the rainfall characteristics of the locality in which such a system is to be introduced. The need for a rain water cistern system in Kedah is justified on the basis of the rainfall regime which will be discussed below.

Kedah lies in the north west of Peninsular Malaysia (see Fig. 1) and is well known for its distinctive dry spell during the first few months of each year. Nowhere else in Malaysia does such a feature exist. Within the state of Kedah, the severity of dry spells increases to the north and this is reflected in the annual rainfall distribution from south to north (Fig. 2). Annual rainfall decreases from the south which receives about 3300 mm to the north which receives about 1549 mm per year - a difference of 1751 mm.

The occurrences of dry spells of varying magnitudes have been studied by Dale (1960), based on rainfall records prior to 1956. Dale used 0.2 mm as his criterion for a rain day. While that value is adequate for purely climatological considerations, it is hardly meaningful for any consideration of water supply from roof runoff. Based on the criteria of 2, 5 and 10 mm of rainfall, an analysis of the daily rainfall records over a 9 year record (1975-83) shows varying lengths of dry spells as indicated in Table 4. From the

TABLE 4
Lengths of Dry Spells, Alor Star

Year	Longest period with rainfall less 10 mm (days)	Longest period with rainfall < 5 mm (days)	Longest period with rainfall < 2 mm (days)
1974/75	26	17	17
1975/76	68	66	44
1976/77	53	53	53
1977/78	63	46	46
1978/79	80	80	80
1979/80	92	88	78
1980/81	54	54	54
1981/82	80	73	73
1982/83	74	72	51

table it is clear that except for 1974/75, all other years experienced dry spells of more than one and a half months (i.e. days with less than 2 mm of rainfall). In 1978/79 and 1979/80 the periods lasted for two and a half months. It is in such an extreme case that the rain water cistern system that is to be introduced is to be measured to test its efficacy and reliability. As far as the other months of the year are concerned, dry spells do not exceed more than a week. Rainfall during these wet months are reliable and more than sufficient to guarantee water supply into the cistern for domestic requirements, provided the system is sufficiently designed.

ROOF CATCHMENTS AND RAINWATER CISTERN SYSTEM

The majority of Malaysia's population and that of the state of Kedah reside in the rural areas and a high proportion of this belongs to one ethnic group, the Malays whose houses are unique in their architectural style and therefore the roof structure. Houses are generally raised above the ground. The two most common roof structures in Kedah, their dimensions and viewed from various angles are shown in Fig. 3 and Fig. 4. There are other variations of roof structure as well as their dimensions which probably reflect the economic standing of the owners.

In spite of the recurring problems of water shortage during the dry spells and concomitant health implications and although the roof structures of houses are amenable to rain water cistern construction, proper cisterns have not been installed by the villagers. Cisterns take crude forms such as old oil drums or vases which are placed below the roofs to collect water for incidental uses such as for washing of feet before entering the homes. On the part of the government, no conscious effort has been made to encourage villagers to install properly designed cistern system. Several reasons can be cited to account for this absence of cistern system. Firstly, rain water is not perceived as wholesome by villagers and this is partly due to the over emphasis on the part of the authorities to develop water supply projects in terms of piped water system. Secondly, the development of water cistern will benefit households individually, while the development of piped water supply will benefit a larger group of people simultaneously. There is also a tendency to perceive the installation of water cistern system as being more expensive and relatively inconvenient as compared with the piped water system. It must be admitted that it is impossible to achieve 100% coverage of piped water supply not only because of the exhorbitant allocation needed but where money is available adequate catchments for water supply are not easily available in Kedah. In Kedah especially, many villages are far from access roads and some are isolated within paddy growing areas, while others are located along the coast where river water is most polluted, well water is brackish and piped water is not easily accessible. Rain water cisterns would be a good alternative means of water supply.

RAIN WATER CISTERN - PROPOSED DESIGN

Fig. 5 shows the design of a cylindrical ferrocement tank proposed to be introduced in the rural areas of Kedah. It must be admitted that no system is perfect. However, the proposed tank with indicated dimensions has been designed after taking into consideration several factors:

(a) The longest period of dry spell with days less than 2.0 mm is 100 days.

(b) For the duration of dry spell the tank will provide only drinking water on the basis of 36 litres per household per day. The assumption here is that the family size is 6 and drinking and cooking requirement is 6 lpcd.

(c) The capacity of the tank is approximately 4.7 kl but at the start of the dry spell which is assumed to be mid-December, the volume of water within the tank must not fall below 3.6 kl. A float valve will be installed to indicate the water level at 3.6 kl.

(d) 1.1 kl excess capacity will be sufficient to meet the requirements of drinking and cooking and for certain other uses during the other months of the year which are generally wet.

(e) The average Malay house has a roof area of between 35-38 m^2 (see Fig. 3 and Fig. 4). On the basis of this roof area, it is quite certain that the tank could be continuously filled prior to mid-December. Assuming that the water is well depleted by end of October, the November rainfall alone is able to replenish any shortfall, even if the tank becomes empty by that period. It takes about 92-100 mm of rainfall to fill the empty tank to 3.6 kl (refer to Fig. 6). This amount of rainfall is well below the November average for Alor Star which is 200 mm.

The roof runoff will be collected in the gutter along the perimeter of the roof. The gutter is to made of 150 cm semi circular galvanised iron to be painted with epoxy paint to slow down the effect of corrosion. The roof gutter will be connected to the tank by a downpipe.

ECONOMIC CONSIDERATIONS

In order to appreciate the economic advantage of installing the proposed cistern system, one has to compare it with the installation of piped water system. Several enquiries with private hardware agencies and concrete pipe manufacturers show the following costs.

The tank with the dimensions given in Fig. 5 will cost approximately M$600 each* while the gutter will cost another M$400. Assuming the life span of the tank to be 20 years, this works out to be M$30 per year and assuming that the gutter will last for ten years the average cost will be M$40 per year. The combined average cost per year will be M$70 per year which averages out to approximately M$5.80 per month.

The installation of mains and feeder pipes to a cluster of homes approximately 1 km from access road will initially cost about M$4000 - $5000. Assuming that there are ten houses, the average installation cost is M$400 - $500 per home. Average monthly consumption per household costs M$8.00 - $10.00 per month which comes to M$96 - $120 per year. Experience in Kedah indicates that due to shortage of impoundments and low water pressure, pipe connections often fail to provide water during certain periods of the year.

It is evident from the above that it is cheaper to install rainwater cistern system than to install piped water system to homes in Kedah.

In any installation of water supply system whether rainwater cistern system or piped water system, the initial costs will no doubt be exhorbitant to the villagers whose average monthly income is less than M$250. This is where the role of the government becomes important. The Malaysian government in the various five year development plans, has made concerted efforts to raise the standard of living of the rural population. If the government departments could take it as their responsibility of constructing and supplying the tanks and

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* M$2.54 = US$1.00

gutters at reduced cost and to provide incentive for self help in installing these items, then the actual costs would be greatly reduced. Alternatively, the government could provide interest free loans or subsidies to the villagers.

WATER QUALITY

Kedah is basically free of industrial pollutants, as the mainstay of the economy is paddy growing. Except for some occasional rust on zinc roofs, rain water that is collected in the tank is potable. Under the present circumstances where the quality of river, canal and well water is questionable and the quality of piped water during the dry periods leaves much to be desired, tank water is certainly of a higher quality than the other alternatives. Some treatment, nevertheless, could be carried out by providing the villagers with powdered chlorine. Because of the recurrent outbreaks of cholera during the dry spells, villagers will normally boil water before drinking and this in itself is effective in eliminating any biological contaminants.

CONCLUSION

Rain water cistern system has great potentials as a reliable means of supplying potable water to the rural areas of Kedah in particular and to the rural areas of Malaysia in general. This potential has not been seriously explored by the water supply agencies of the government. From the discussions above it can be seen that tank system is economically feasible and viable and in the long run cheaper than piped water system unlike the experience in Australia (Heeps, 1977). The only problem, and which is not insurmountable, is purely a psychological one, i.e. how to change the attitude of the rural people towards accepting tank water as at par with piped water in all aspects of reliability of supply, relative convenience and of equally good quality. The rural communities in Malaysia have all along perceived piped water as being the best and no other system could substitute it. In no small measure, the government is to be blamed for this mistaken perception. It is opportune that under the present down turn in the economy where investments on large scale piped water supply projects will be greatly slowed down that the villagers be introduced to this rain water cistern system. For a significant proportion of the rual communities, the reality is that they will have to be content with a different and not necessarily worse system of water supply.

It is hoped that a pilot study of the efficacy of this proposed cistern system be conducted in a village in Kedah under the auspices of a rural development agency of the state government. It is the authors' hope also that the seminar will provide some positive suggestions, comments and criticisms to this paper before it is tabled to the relevant authority for consideration and experimentation.

ACKNOWLEDGEMENT

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FIGURE 1

Percentage of Households with Piped Water by District in Malaysia, 1980

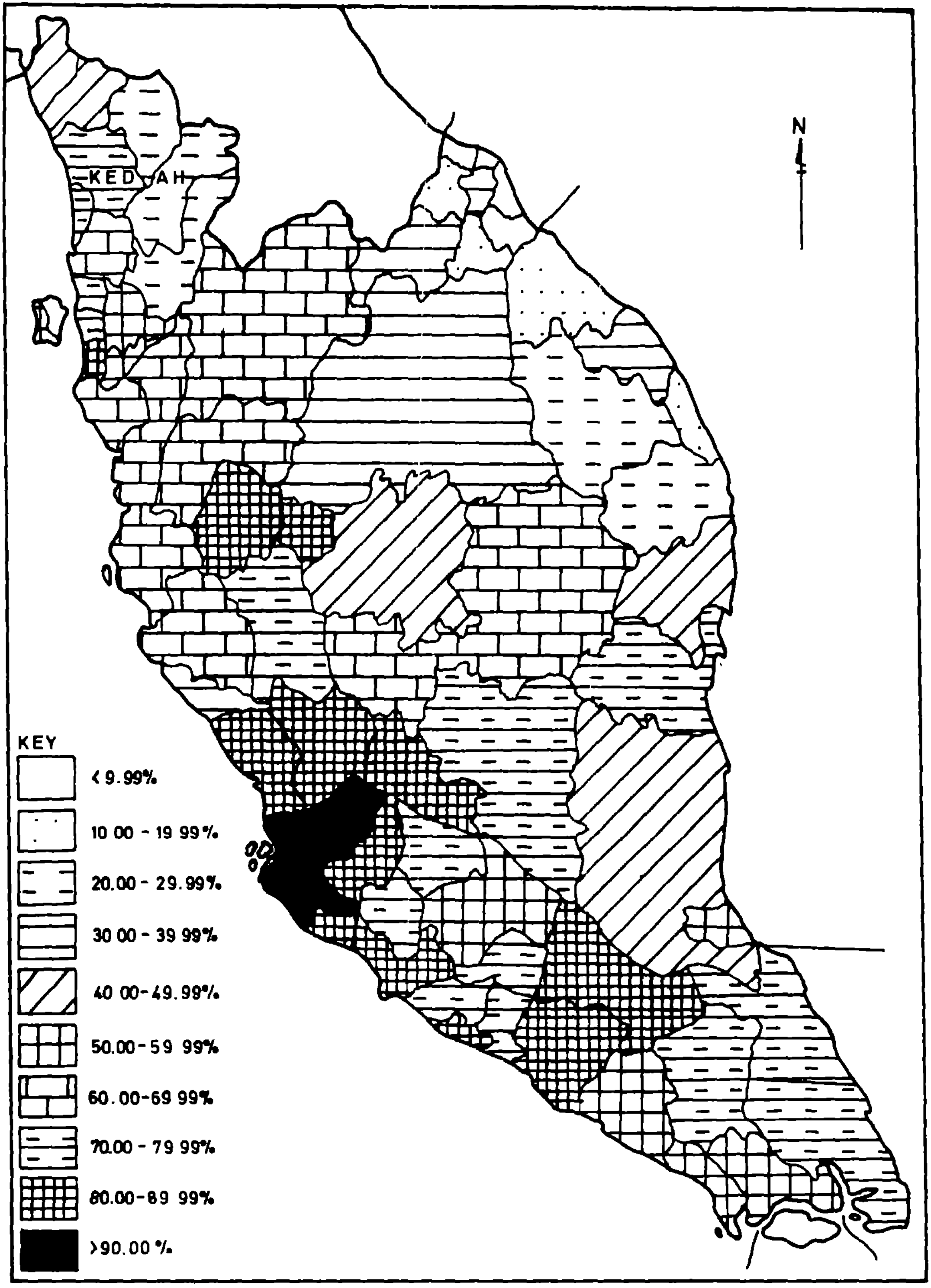


FIGURE 2
Mean Month by Rainfall for selected stations in Kedah

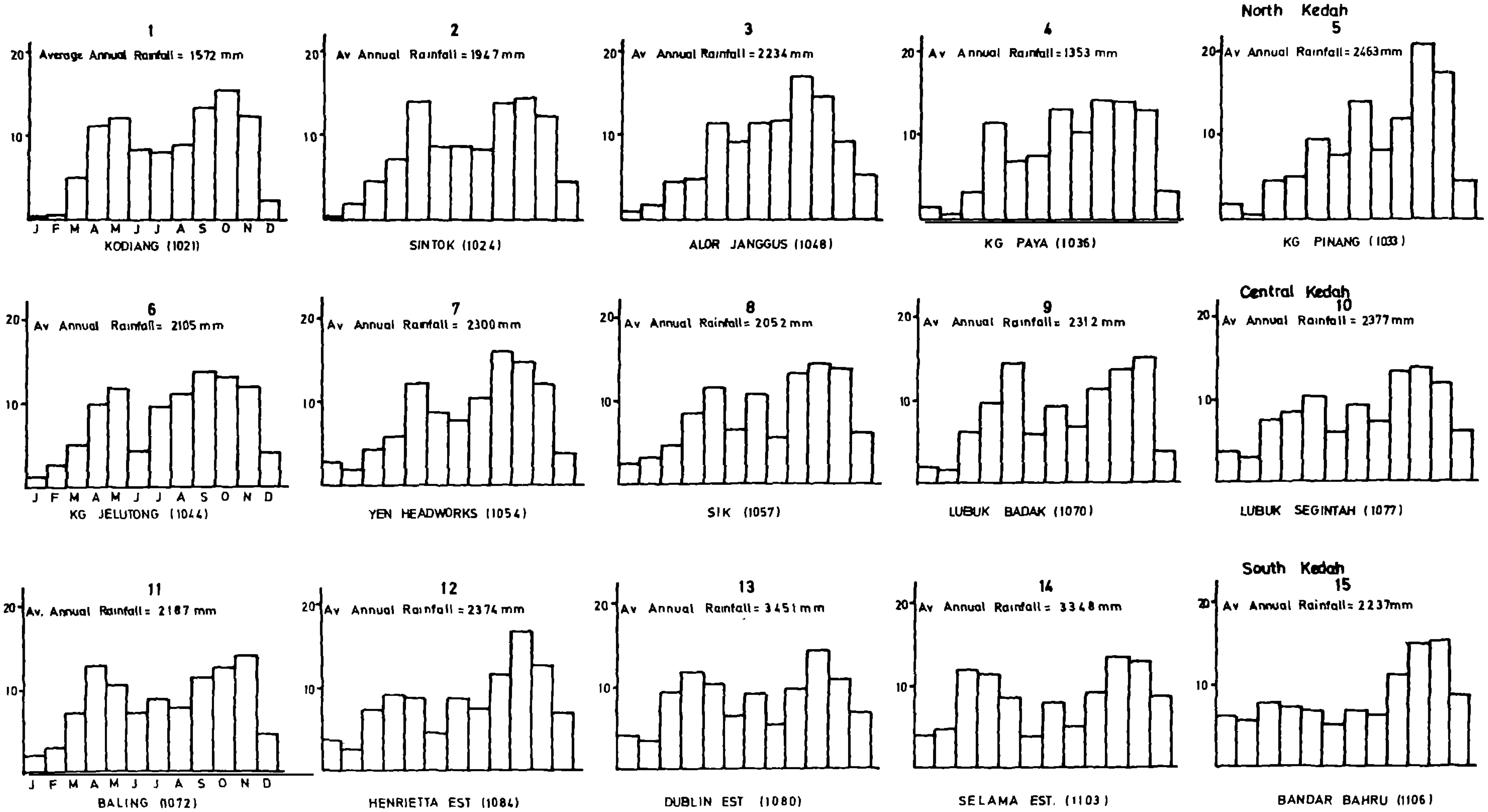


FIGURE 3
Malay Roof Structure-Type (a)

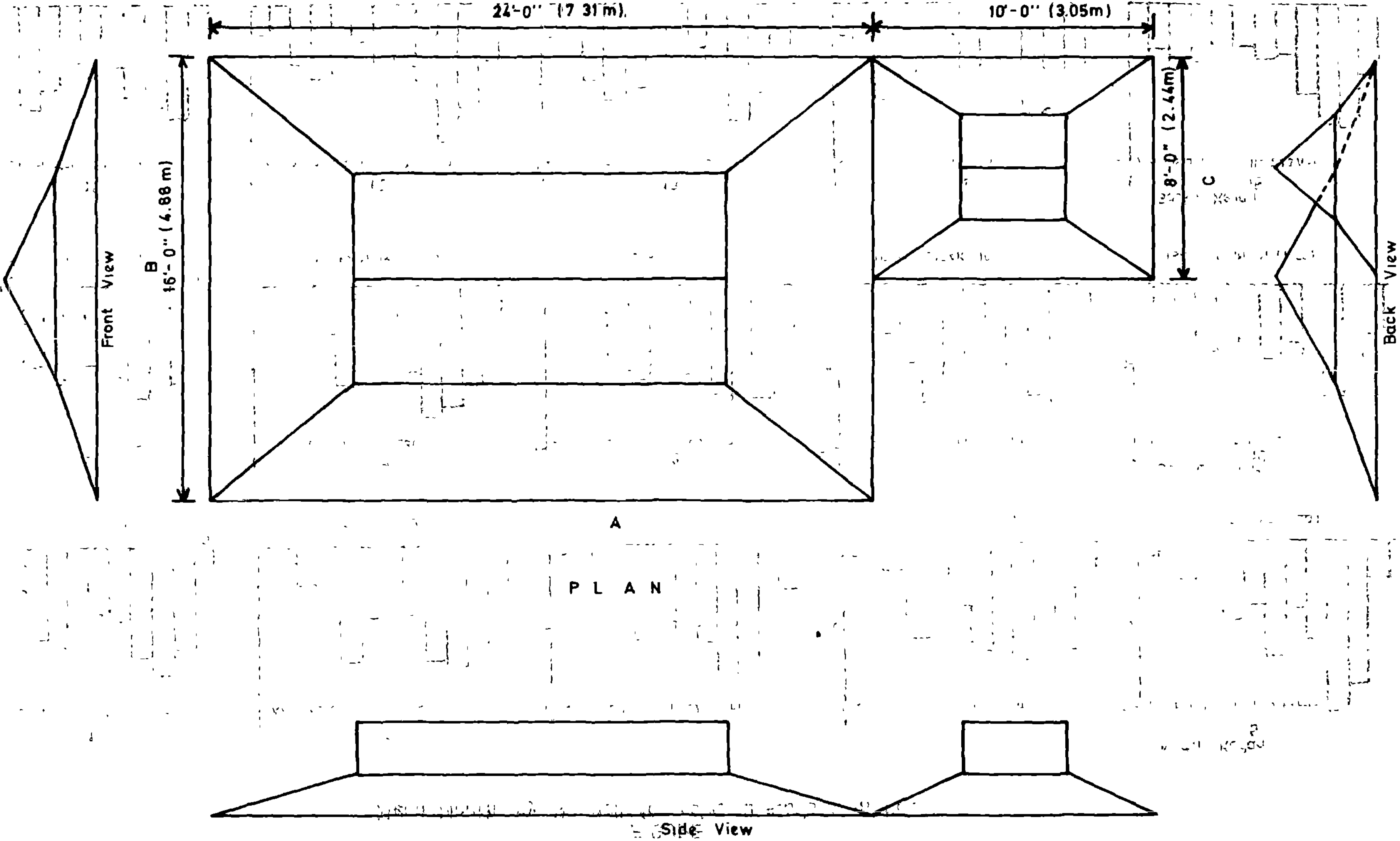


FIGURE 4
Malay Roof Structure - Type (b)

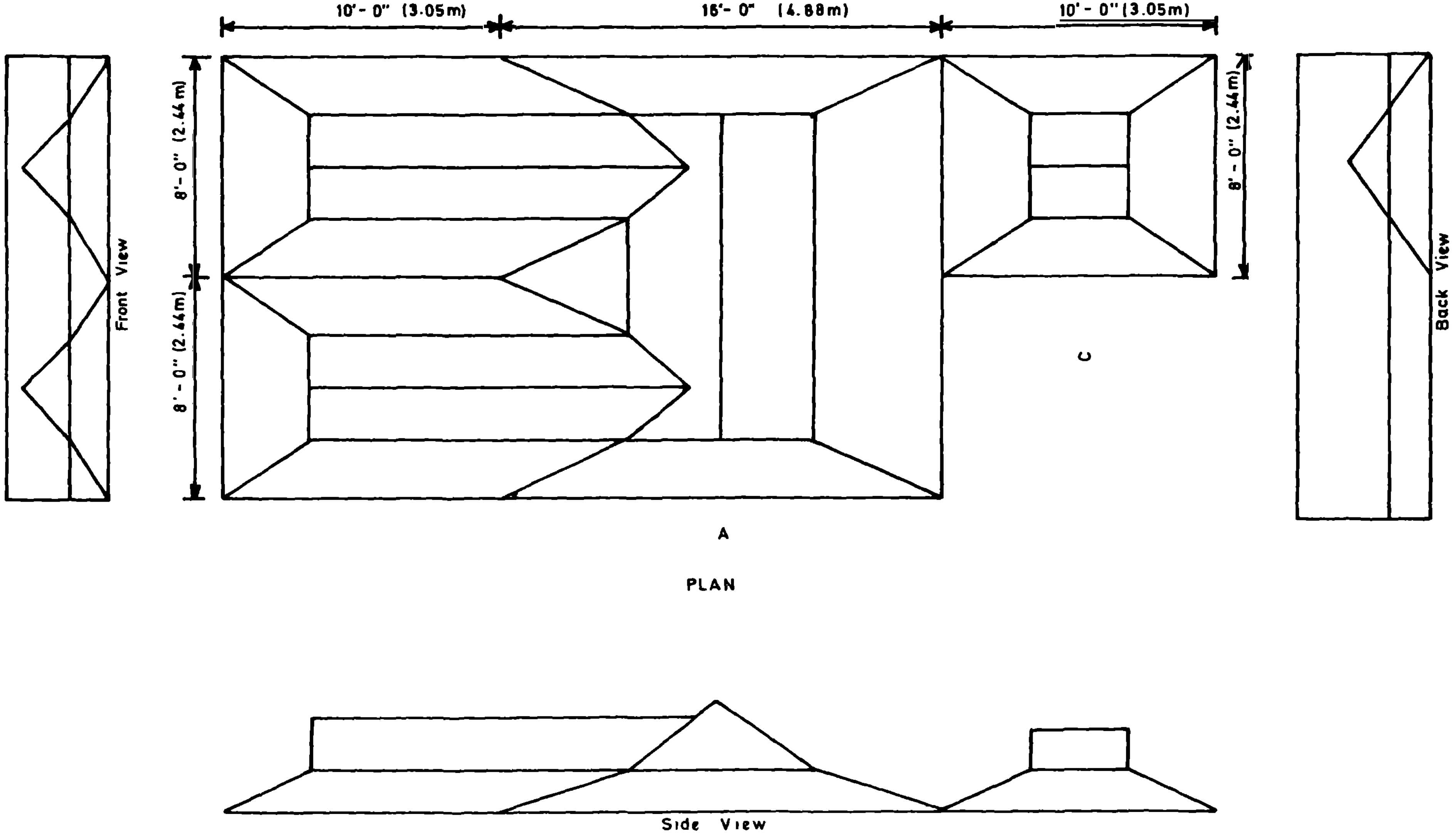


FIGURE 5
PROPOSED DESIGN OF CYLINDRICAL TANK

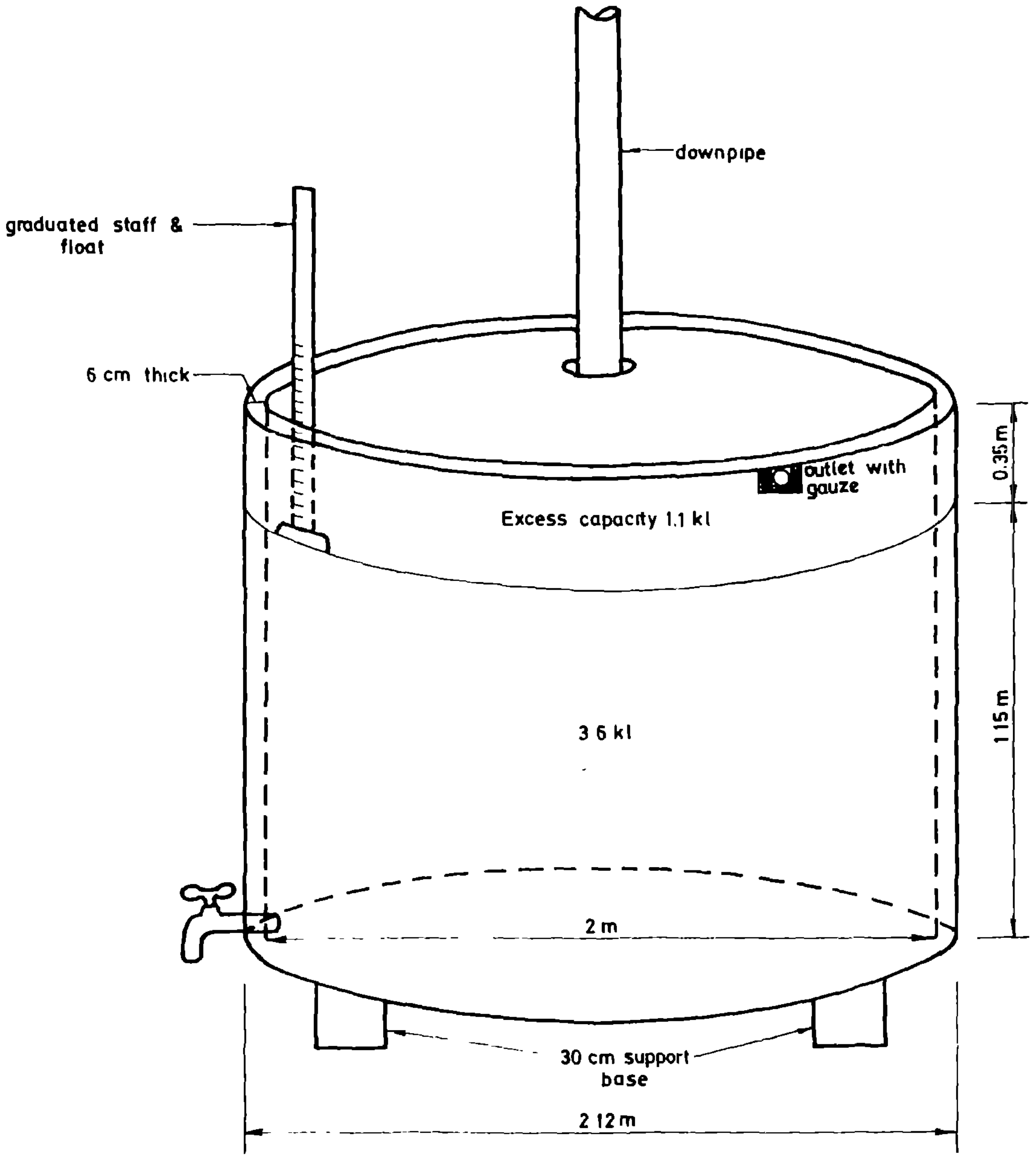
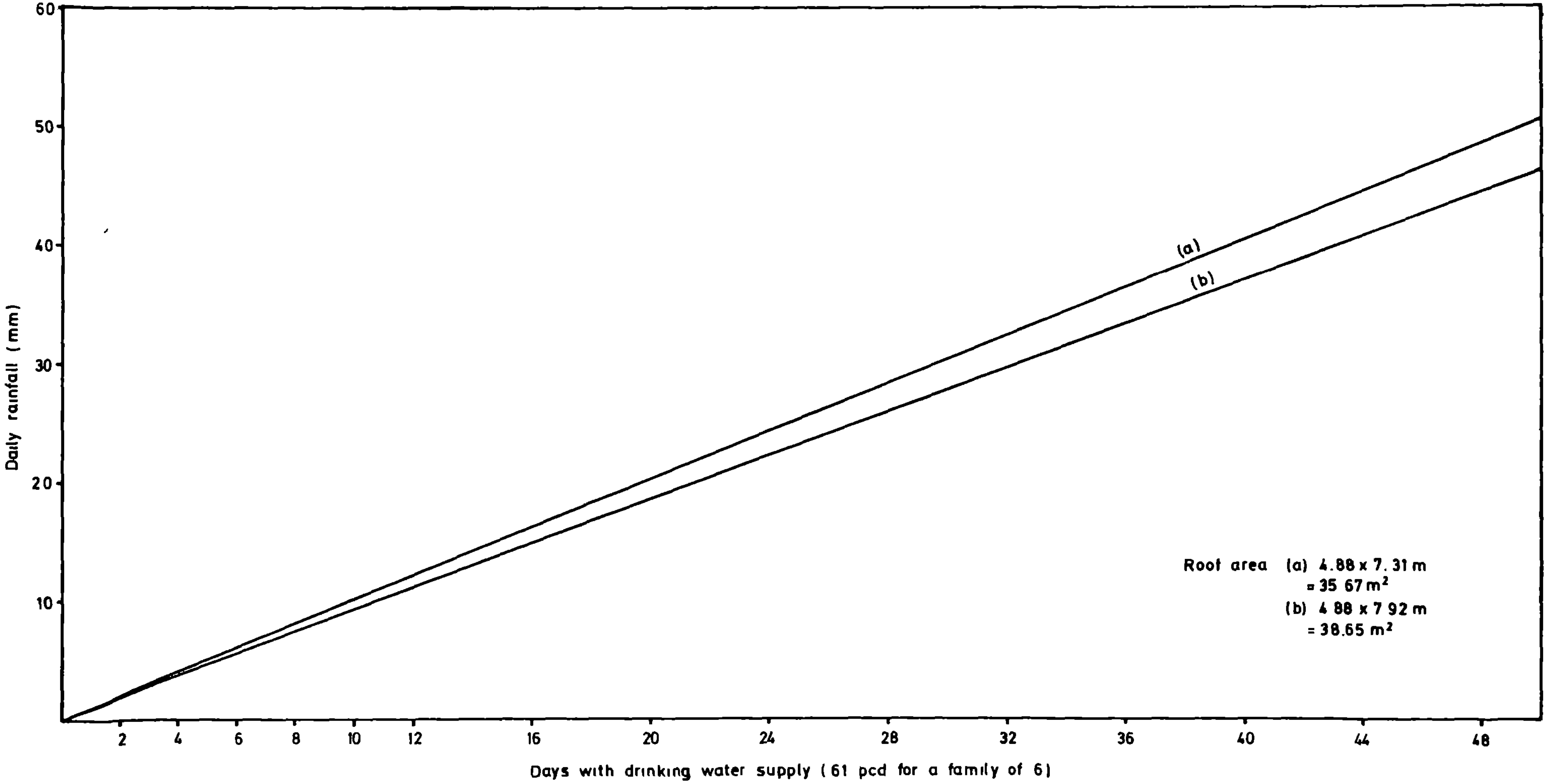


FIGURE 6
Drinking water supply as a factor of roof size and daily rainfall



INTEGRATION OF RAINWATER HARVESTING WITH OTHER SUPPLY SYSTEMS IN RODRIGUES

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ABSTRACT

An investigation of rainwater harvesting and other water supply practices was carried out for the island of Rodrigues in November 1985. The field investigation consisted of a user questionnaire, a technical survey and bacteriological testing for various sources. Information on rainfall patterns, types of roofs, and population and settlements was collected for the whole of the island. For various design factors and various localities on the island, the storage capacity required to satisfy certain water demand figures was calculated. The importance and benefits of rainwater harvesting for Rodrigues are discussed. Specific recommendations for planning, water quality optimisation, ways to increase storage and for development of community rainwater harvesting systems are proposed.

THE ISLAND OF RODRIGUES

Rodrigues is a dependency of Mauritius and is the largest of the Outer Islands of Mauritius. It is situated 400 miles to the east of Mauritius, at 63°25′ East and 19°43′ South. Rodrigues has an area of approximately 40 square miles and the population in July 1983 was estimated at 33000 (CENTRAL STATISTICAL OFFICE, 1985). The island is mountainous and is subject to a tropical marine climate.

PUBLIC WATER SUPPLY

Water in Rodrigues is used mainly for domestic purposes and livestock. The scarcity of water does not allow for other uses; little surface water is available for irrigation. According to the last Census (CENTRAL STATISTICAL OFFICE, 1985), users were served as follows in 1983: piped water inside housing unit 7% of the population; piped water outside but on premises 28%; piped water outside from public fountains 14%; wells or rivers 51%. Unfortunately there are two mistakes. One is a mistake of approach: classifying rivers and wells in the same category. Secondly, there is no mention at all of RWH which is actually common in Rodrigues.

Projects in the past concentrated on the pipe distribution network which is quite extensive. Surface water and borehole groundwater feed the pipes. There are also sources where users can abstract water directly: handpumps (groundwater), streams, springs and rainwater harvesting (RWH) schemes. Details on the existing systems and recommendations for improvement are included in the final report on the Rodrigues investigation (MICHAELIDES, 1985d).

HOUSE QUESTIONNAIRE AND TECHNICAL SURVEY

A survey of water supply practices and in particular RWH in Rodrigues was carried out by Messrs. G. Michaelides (Dundee University), M. Allybokus (University of Mauritius) and F. Mowlabucus (C.W.A of Mauritius) in November 1985. It was the first time that a site investigation and a desk survey (MICHAELIDES and YOUNG, 1985a; MICHAELIDES, 1985a) on the potential of RWH in Rodrigues were carried out. A total of 48 private houses in 28 settlements were surveyed.

Availability And Distance To Sources

In most cases the sources available to a household were more than one. Of the houses surveyed, 92% practised and 6% were preparing to practise RWH. 83% had some form of access to piped water including standpipes. (Note: The sample should not be taken as representative of the proportion of each water supply of the total). In all cases of availability of piped water, water was flowing in the pipes intermittently. There was water every day, and that for a few hours, in only 15% of the cases. Some people complained that the water pressure is very low. The problems spring users faced were the distance to, and the lack of protection of most springs. Several journeys had to be made to reach streams and handpumps too.

Uses Of Water

Mixing of water from various sources is undesirable. There was mixing of rainwater (RW) with other sources in 55% of the cases. In 71% of known cases, RW was used for drinking (in 29%, it was used for drinking and cooking only), showing a clear preference of using RW for drinking rather than other purposes.

Water Quality Perceptions

Comparisons were made in one-third of the cases. 60% considered RW as being better than other sources and 27% other sources better than RW. Users considered the quality of RW as satisfactory and piped water as generally unsatisfactory.

Water Consumption

In 40% of the cases users gave figures of their consumption for all domestic purposes. Consumption rates were in the range of 11-67 l/c/d, including washing, with an average of 30 l/c/d. The average number of persons using the water supply per household surveyed was 8.

House Roofing

The total roof area available in each of the households surveyed is in the range of 15 to 307 m^2, the average being 66 m^2. Of the houses surveyed, 48% possessed a flat concrete roof, 37% a sloped corrugated galvanised iron roof, and 15% a combination of both. (Note: The concrete roofs are 23% and the iron roofs 71% in the whole of the island). The average concrete roof of the surveyed houses is 64 m^2. The roof area used for RWH is 96% of the total available. The average iron roof is 50.5 m^2. The roof area that is guttered and is utilised for RWH is 46%. All iron roofs were adequately sloped.

Inflow System

There is no need for gutters in concrete slab roofs and hence the roof area available is almost entirely utilised for RWH. It appears that people could not afford or were not aware of how to install more and better gutters. In certain cases, the size and condition of gutters were inadequate for RWH.

Storage

Rainwater was stored exclusively in 44% of the storage containers; RW and piped in 26%; intending to store RW in 5%; and other combinations in 6%. The types of storage employed were as follows: recycled 200 litre drums 43%; concrete blocks 17%; reinforced concrete 13%; various concrete tanks of unknown composition 13%; limestone bricks 7% and others. The average capacity available for RW and combinations of RW with other water sources was 1.8 m^3 (excluding 3 households exceeding 10 m^3 capacity).

Only 7 systems had an overflow pipe. 37% of all storage units had an outlet pipe.

Water Quality Features In Systems

No RWH system incorporated a foul flush <u>diversion</u> mechanism. In two cases, however, the water of the first storm at the beginning of the rainy season was not stored. There was only one case where the <u>inflow</u> pipe's connection to the storage tank was <u>sealed</u>. 63% of the storage units for which information was collected had some form of <u>cover</u>. 87% of the uncovered storage units were drums. Only 14% of the covered storage units had a <u>sealed</u> cover but even in those cases, the manhole cover was not sealed. No <u>overflow</u> pipe was <u>screened</u>. There were 5 cases where the <u>inflow</u> pipe was <u>screened</u>. 23% of the storage units had a <u>drain</u> pipe. There were only 5 cases of a drain pit and/or drainage channel.

Maintenance

Roofs were cleaned in 51% of the households and not cleaned in 9%. For the rest of the cases, no information was provided. Roofs were cleaned when they looked dirty; at the beginning of the rainy season; "regularly"; some during the rainy season and others during the dry season. In 52% of the known cases either no information was provided whether storage was cleaned or it was not applicable. In one case it was never cleaned and in another case it "could not be cleaned". The frequencies of cleaning for those households practising it were: "by visual inspection" 30%; "whenever empty" 30%;

"regularly" 10%; "when empty and by visual inspection" 10% and other cases.

Water Treatment

The household treatment of water for drinking purposes was boiling. There was no boiling at all in 31% of the households. The water was boiled, or at least boiled for most of the time, in 31% of the cases; water was boiled during severe droughts and epidemics by 13% of the households; and other cases.

Health

Records of diseases were obtained from Queen Elizabeth Hospital of Rodrigues. The records cover the period of 1/1 to 21/7/85. The most frequent water-related diseases that could be identified were: gastroenteritis (diarrhoea and vomiting) 94 cases, enteritis (diarrhoea) 60, dysentry 20 and others. Records of where these occurred were also kept.

SURVEY OF PUBLIC BUILDINGS

Buildings Surveyed

The public buildings surveyed were two schools, two offices, a church, a police station, a Cooperative, a fuel station, the harbour stores and the Hospital. Information for the Hospital has been kept separate.

Roof Catchment

Two-thirds of the roofs were made of corrugated galvanised iron and were sloped. The remaining were flat concrete roofs. The roof area available for each building varied from 64 to 972 m^2. 86% of the total catchment area was utilised for RWH.

Storage

In 63% of the 24 tanks, RW was stored exclusively. The mean capacity for each building was 18.4 m^3 varying from 1.2 to 88.2 m^3.

Piping

All inflows consisted of pipes: two of them were in disuse. All storage tanks had a drain pipe but one of them was in disuse. Half of the tanks had no overflows. All storage units possessed outlet pipes.

Water Quality Features

The inlet pipe was well sealed where it entered storage in 40% of the storage units. All but two tanks were fully covered but only 21% were well sealed. No overflow pipe was screened. The inflow pipes to 6 tanks were not screened and for 3 tanks they were screened; no information could be obtained for other systems. Six tanks had a good drainage system.

Maintenance

Information on maintenance was given for 5 of the 9 buildings. The roof was cleaned in 3 cases and the storage in 4 cases (but one case "very rarely").

Queen Elizabeth Hospital

The hospital consists of 13 buildings. All roofs are sloped corrugated iron except one that is flat concrete. They are all fully guttered. The total roof area is 2170 m^2,of which 41% was connected to storage tanks. Some of the inflow systems, however, were partly damaged.

There are 7 concrete rectangular tanks with a total capacity of 113 m^3 (16 m^3 on average) and 16 concrete circular tanks each of 0.7 m^3. Of the latter, only 5 were meant to store RW. All but 3 tanks were fully covered. Only 3 covers were well sealed. No overflow pipe was screened.

WATER QUALITY EXAMINATION

Samples from 5 RWH systems and one groundwater handpump were collected for bacteriological analysis. One sample (RWH) was found to be fully satisfactory (0 faecal coliforms / 100 ml). Two other samples (RWH and handpump) could be condemned because of the existence of faecal coliforms (of unknown number). The other three

RWH samples had no faecal coliforms and thus they should not be condemned. Sampling was limited and the results offer only some indication of the water quality. The RWH systems used need some basic improvements: covering, sealing covers, sealing inflow into storage, screening inflow and overflow pipes, and maintenance. A bigger slab and drainage facilities should be provided for the handpump.

THE POTENTIAL OF RWH FOR RODRIGUES

Rainfall Pattern

Monthly rainfall data was collected for the following stations: Marechal (18 years of data), Pointe Canon (33), La Ferme (31), Oyster Bay (33), Solitude (33) and Lataniers (29). The mean annual rainfall at these stations varied from 1145 to 1679 mm (average=1344 mm), and the minimum rainfall in a year varied form 433 to 647 mm. This type of rainfall distribution is compatible with the use of RWH.

Roofing

In Rodrigues there were 7790 buildings in 1983 (CENTRAL STATISTICAL OFFICE, 1985) of which 89% were residential. The type of roof materials was as follows: iron sheets 71%, concrete slabs 23% and vegetation 6%. If an iron roof is free from rust and corrosion, then it is an excellent rainwater collection surface (MICHAELIDES and YOUNG, 1984). The increasing proportion of flat concrete roofs (it was only 1% in 1972) is not a problem because people <u>utilize</u> most of the available catchment surface from RWH since no gutters are required. No figures are available for an "average" roof size in Rodrigues. Excluding 5 houses exceeding 100 m^2, the average roof area of the houses surveyed is 48.5 m^2 which is adequate for RWH. For the purposes of the design that follows, the catchment surface is taken as $A=30$ m^2 or 40 m^2.

Population And Settlements

RWH has been identified as economical for dispersed population patterns and small populations (MICHAELIDES and YOUNG, 1983a). The density of buildings in Rodrigues was 195 per square mile in 1983, and that of population 827. It may be claimed that Rodrigues is a densely populated place; but, as observed by the researchers, houses are scattered. There are 137 settlements. In 31% (47% in 1972) of them the population is less than 100, in 21% (24%) it is between 100 and 200, and in 17% (12%) it is between 200 and 300. The number of small settlements has been decreasing over the years. Even so, the proportion of small settlements (even though some could be close to each other) is still high, for which individual or community RWH systems (or community wells or springs) would be suitable. Because of the scattered nature of village houses and the ragged relief in Rodrigues, individual RWH schemes would achieve easier access to water than other sources. The advantage of piped water over RWH is that there is already an extensive distribution network of pipes on the island, at least in the places visited by the researchers. At the present time, however, this factor is invalid because for most of the time there is no water flowing in the pipes, as was found out during the field investigation

The number of persons (N) per housing unit is a factor in designing the dimensions of a RWH scheme. In 1983 the average number of persons per dwelling was 5. This N is to be used in the design that follows.

Design Of Storage Capacity Required

The OTTRAIN Model for rainwater collector reservoir sizing which is a hydrologic model that analyses rain data to determine appropriate combinations of demand and storage for that data, has been applied to Rodrigues (LATHAM and MICHAELIDES, 1986). OTTRAIN was developed by B. Latham at the University of Ottawa (LATHAM, 1985). Monthly rainfall data from the six stations in Rodrigues were used. The number of consumers (N) and the runoff coefficient (F) were kept constant at N=5 and F=0.8. The options in effect had been: no rationing and standard reliability levels of 90%, 95%, 99% and 100% based on volume. The results of the design show that the water demand that can be satisfied for A=30 or 40 m^2 is 13.6 to 17.4 l/c/d for Solitude and 10.0 to 13.7 for all other stations if reliability is 95% and storage capacity 4 m^3 (or 5 m^3 for one-third of the cases).

The average consumption excluding washing, of 25 households (as found during the survey) was 21 l/c/d. If one case of over 100 l/c/d is excluded, then the average is 18 l/c/d. RWH can, thus, supply an important proportion (71%) of the domestic water needs in Rodrigues. The situation can be improved through several ways in critical periods and/or cases of inadequate storage capacity.

a) The use of RW could be rationed.
b) Alternative water supplies could be used. Indeed, most households in Rodrigues have more than one supply available, though not continuous if piped water.
c) The RW supply could be restricted to some uses.
d) If water demand is varied throughout the year, then storage required would be less than if demand is kept constant.

As far as storage capacity is concerned, the field investigation revealed that the existing capacity is 1.5 to 2 m^3 per household on average. This should at least be doubled to provide a satisfactory water supply.

Benefits From RWH

The characteristics of RWH, in particular the use of resources, the development process, the proximity to the user, water and energy conservation, reduced possibility of infections and minimum water treatment required (MICHAELIDES, 1985b and 1985c), are particularly valuable for Rodrigues which is a small island of limited resources, 400 miles away from Mauritius.

RECOMMENDATIONS FOR RWH

Catchment Surfaces And Guttering

Undoubtedly a sloped corrugated galvanised iron roof is more efficient as a rainwater catchment surface than a flat concrete roof. Bearing in mind, however, that a) the proportion of concrete houses is increasing, and that b) Rodriguans utilise more available roof space if it is concrete because gutters are not required, the idealised system for Rodrigues would be: to keep the present trend of building houses with reinforced concrete beams and columns and concrete block or limestone walls but, instead of a flat concrete roof, a single-sloped (to reduce length of guttering) iron roof should be installed.

The majority of the existing houses with iron roofs still need manufactured or ready-made metal or plastic gutters to be installed to utilise more roof space available. It should be noted that the quality and size of existing gutters for iron roofs in Rodrigues is unsatisfactory in most cases.

Storage

Each individual household needs storage for both RW and piped water. Piped water flow is intermittent at the present time and only 13% of the houses surveyed received piped water every day and that for an average of 3 hours. The storage capacity per household for RWH should, as a general guideline, be of the order of 4 m^3 (at least) for an important contribution of RWH.

Various aspects of existing (and also rock tanks which are no longer built) types of storage had been examined. The conclusion is that the most promising storage types for Rodrigues are: limestone tanks, rock tanks, concrete block tanks, cylindrical concrete tanks and cement jars.

In Rodrigues cement, reinforcement, timber, formwork, iron sheets and pipes are imported. Reinforcement is 30% more expensive than in Mauritius. Aggregate plants where rocks are crushed exist in Rodrigues at two places. Limestone bricks are bigger (1.5 times) and less expensive than concrete blocks and are cut locally; it is indeed a very promising type of storage. Also, building of rock tanks should be revived.

It has been observed by the researchers that many tanks had too much reinforcement or walls that were too thick.

People, depending on their financial capabilities, can increase the available storage capacity incrementally. Two or more of the jars or standard size cylindrical tanks can be joined together by a pipe to achieve the desired storage capacity.

Water Quality Optimisation

A full analysis on this subject has been dealt elsewhere (MICHAELIDES and YOUNG, 1983b, 1984 and 1985b). Here only some observations and recommendations specific to Rodrigues are included.

Rodrigues is not an industrialised area in which air pollution might constitute a problem. Also, there are no sugar cane leaves in the air that would accumulate on catchment roofs.

In Rodrigues awareness of foul flush diversion mechanisms does not exist. There is no starting point to build although some people were not collecting the first rainfall of the rainy season. Households with relatively large storage systems could introduce a diversion mechanism if advised. For householders with limited storage and resources, the simple practice of moving the downpipe into position after the first flush, would be effective.

Requirements like storage covering and pipe screening are very important and necessary but were inadequately or improperly done in Rodrigues. No system was properly sealed and no overflow pipe screened. Some inflow pipes in Rodrigues discharge into a funnel which is attached on the tank cover. This is useful if both the end of the inflow pipe and the funnel are screened. After each rainfall event, the screen and/or cloth may be cleaned with ease without having to climb on the roof for cleaning a screen attached on top of the downpipe.

People in Rodrigues are aware of the maintenance requirements and if the information they provided in the survey is accurate, they do practise cleaning frequently enough, if it is supposed that the other requirements were met (that is, if design and construction were proper).

Planning And Implementation

Planning and design of RWH systems is quite simple but needs to be correct the first time to avoid waste of resources. It is a matter of some basic awareness, knowledge and motivation and, of course, a matter of minimising costs. Local planning groups formed to determine systems based on local needs and potential would improve the chances of success. External support in terms of materials and an adviser on design choices would be useful.

What needs to be done is a) provision of guttering, b) increase of storage capacity, and c) provision of features optimising water quality. All these recommendations are equally important. The measures optimising water quality could be given greater priority because they are simple. These, together with some remedial action to put systems in disuse into good working order, can mostly be incorporated at little or no cost. An immediate plan of action for initiating or upgrading existing RWH schemes could include the following:

a) The Administration and in particular the Works Division can supply to village committees or individuals technical information.

b) Since water is very important for Rodrigues, schools and community societies should offer classes on various aspects of water supply including technical matters on a regular basis. This would also aid in motivation.

c) A group or groups of technicians and skilled labour could go from house to house advising and actually installing or improving features optimising water quality.

Public Buildings

Public buildings, such as schools, churches and governmental buildings, usually possess large, good quality roofs with gutters that can be used for community water supply. Many of these catchments already possess storage capabilities. As was identified by the survey, the potential of these existing RWH systems could be enhanced by minor remedial action to a) optimise water quality, and b) put systems in operation.

Using average rainfall data of each locality, a demand of 30 l/c/d and the actual roof area of each public building and assuming that no water is lost, the following number of persons would be served throughout the year for all their needs: Queen Elizabeth Hospital at Creve Coeur about 230 persons, the Harbour store roof at Port Mathurin 100 persons, Saint Gabriel church 85 persons, La Fouche School 80 persons, and the Onions Cooperative at Citronelle 70 persons.

There are no figures of the total roof area of public buildings available. According to the 1983 Census, there were 324 institution and non-residential buildings. If the average roof is taken as 400 m^2 (note: 422 m^2 was the average of roofs surveyed excluding the Hospital) and the average annual rainfall of Rodrigues as 1350 mm, then half the population of Rodrigues would be supplied with 30 l/c/d!

Thus, public buildings should receive high priority. Additionally, the covers of large water reservoirs could be used as catchment surfaces and the rainwater collected be stored in the reservoirs themselves.

Additional storage would be required. A rough approximation for storage capacity needed would be to divide the roof area by 10. Thus the harbour stores would need V=97 m^3 (available now 88 m^3); Saint Gabriel church 72 (now 33); La Fouche School 64 (now 12); Onions Cooperative 49 (now 3); and Hospital 217 (now 124). The storage capabilities would roughly need to be doubled. A full design procedure would be required if a project is to be initiated.

CONCLUSIONS

RWH is being practised in Rodrigues but the systems are generally inadequate in terms of storage capacity and construction features to optimise water quality. Moreover, though usually enough for RWH purposes, not all the available roof area is utilised. The renaissance and further development of RWH from large non-residential buildings should receive high priority.

The present domestic water supply in Rodrigues calls for more and better individual storage units for both rainwater and other water sources, because almost all sources are either of intermittent flow or at a distance from the consumer. It is believed that rock and limestone tanks and cement jars are the best storage options for Rodrigues. Further research into water storage techniques appropriate to the environment of

Rodrigues is required. The experience of other developing countries would be valuable. Features optimising water quality are simple and inexpensive unless there is no storage cover at all.

Though the authorities are more concerned with public supplies involving other sources, it is hoped that RWH would be integrated into the policies and programmes for water supply.

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RAINWATER AS A SOURCE OF DOMESTIC WATER SUPPLY IN THE COASTAL AREAS OF BANGGLADESH

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ABSTRACT

Rainwater has a great potentiality for use as an alternative source of domestic water supply in the coastal areas of Bangladesh, where there is no organized water supply system. To analyse the feasibility of using rainwater as a source of domestic water supply a field study on the existing socio-economic, housing and water supply conditions has been conducted in a sample area of this problem zone. Using the 'yield after storage' approach, the storage volume required for rainwater collected from rooftop has been calculated under various constraints, viz. catchment area, demand, family size and reliability. It has been found that one fourth of total families in this area would be in a position to collect rainwater using rooftops. But only about 6 percent of the families can afford to pay the high construction cost of a permanent type of storage tank required for the system.

INTRODUCTION

In the coastal area, the problem of fresh water supply for domestic purposes is acute. The surface water in coastal regions (Figure 1) has a severe salinity problem during the dry season. As the fresh water draining from the landward side deminishes, tidal inflows enable saltwater to penetrate into land and make both surface and ground waters saline. Another problem of drinking water in these areas arises from floods. In the wet season, most of the areas become flooded and the water become heavily contaminated due to mixing with domestic and other wastes from the densely populated villages.

In this area, heavy rainfall occurs during the months of April to July. So a water supply system designed on the basis of rainwater may solve the acute water supply problem in the coastal area of Bangladesh. To calculate the amount of rainwater required for a family throughout the year, the following information will be required:

(i) Information about the socio-economic conditions, existing water supply system, water consumption pattern, family size and housing system in the area of interest through a field survey.

(ii) Rainfall, evaporation and other relevant data of that area.

(iii) The percentage of population in the coastal area that can be covered by the rainwater supply system and the required storage facilities to ensure uninterrupted supply throughout the year.

FIELD SURVEY

Sample Area

For estimating the storage facilities required for rainwater collection, data related to the water consumption pattern, the roof sizes as well as the family sizes of the coastal area are relevant. To collect these data, a field study is conducted in a sample area in Hatiya Upazila* (Figure 2), situated in the south

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*Upazila is a lower level administrative unit; literally mean a sub-District.

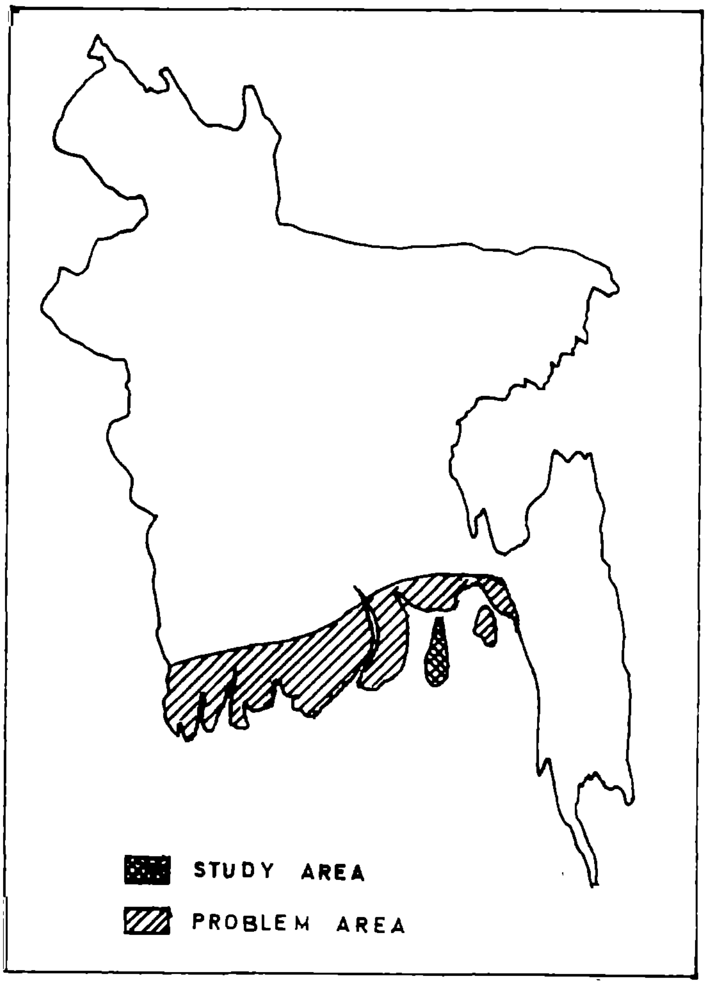

Figure 1. Water supply problem area in Bangladesh

coast of Bangladesh (latitude $22^{\circ}21'$ North and longitude $91^{\circ}6'$ East). The climate of this is characterized by a mild, dry winter and a hot, wet summer. On the basis of monthly incomes, families living in the sample area were divided into four groups (Figure 3). According to the distribution of their incomes, 12 families were selected for the detailed survey.

Population

Population is the most vital factor in the design of water supply system. In the area surveyed, family size varies from 3 members to more than 10 members per family. The average family size in the area is 6.3, which is higher than the average family size of 5.8 for Bangladesh as a whole (Bangladesh Bureau of

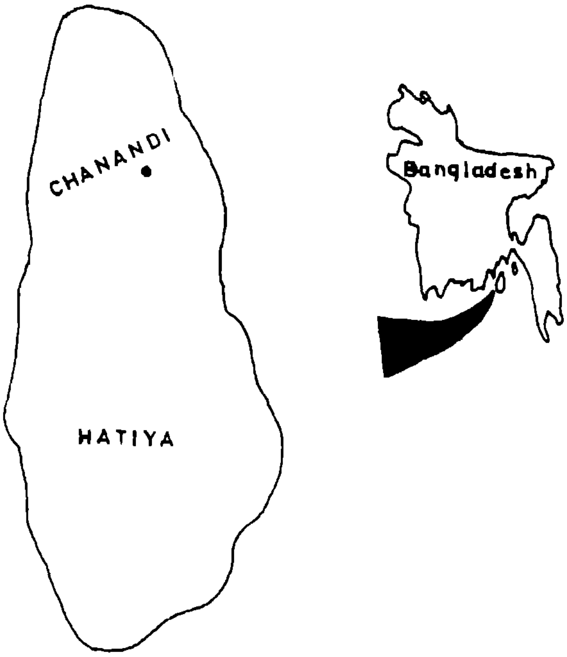

Figure 2. Field study area

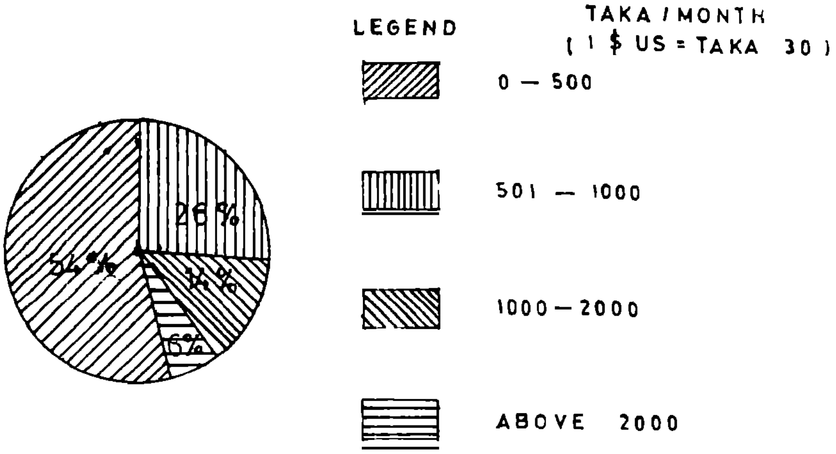

Figure 3. Distribution of families according to monthly income

Statistics, 1984). Although the variation of family in this sample area is 3 to 14, in the design of storage tank for rainwater collection the family size varying from 4 to 8 has been used.

Housing Condition

The housing conditions in the area are very poor. The houses* are small in size and very congested in pattern. On the basis of building materials used, the houses can be classified as pucca (brick/concrete), semi-pucca, kutcha (mud soil), mixed etc. The roofs of most of the houses are made of straw, and only 3.7 percent have pucca construction in the village Chanandi in the sample area as shown in Table 1. About 18 percent of the houses covering about 26 percent of total families surveyed have roof made of CGI(Corrugated Galvanized Iron) sheet and R.C.C. with more than 50 m^2 roof area which can be available for rainwater collection. Roof area ranging from 50 to 90 m^2 per family may be considered for design purpose.

TABLE 1. ROOF AREA OF THE HOUSE FOR A FAMILY IN CHANANDI

Roof material	Area, m^2	Percentage of houses in the area surveyed
Pucca	81-90	3.7%
CGI sheet	51-80	14.8%
Straw	31-80	70.4%
Bamboo & others	31-40	11.1%

Socio-economic Condition

These areas are predominantly Muslim areas; as more than 90 percent of the total families are Muslims. And therefore, the cultural pattern inevitably follows the Islamic values. The economy of these areas is overwhelmingly based on agriculture. Most of the families have a low income often below the subsistance level except a few families who have monthly income more than Taka 15,000.00

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*House is a structure having one or more rooms for sleeping and taking rest. A house does not include toilet and kitchen.

Water Source, Quality and Use

The type of water sources are identified as unprotected (pond and ditches, river and stream) and protected (hand pump, deep and shallow tubewell). Most of the families have access to both protected and unprotected sources. Although there are 20 ponds and ditches, a small stream, 2 deep tubewells and 4 shallow tubewells in the area surveyed, local people face severe shortage of fresh water in both dry and wet seasons. People complain about the presence of excessive iron and chloride in the existing waters available for domestic purposes during the dry season.

The water requirement for domestic purposes includes water required for drinking, cooking, washing clothes and utensils, bathing, sanitary purposes, house cleaning and polishing. The per capita water consumption is estimated on the basis of litre per capita per day (Lpcd). Figure 4 represents the per capita water consumption under various socio-economic and field conditions. An average of 40 Lpcd consumption was found with standard deviation of 11.00. Whereas per capita water consumption of the households who have roof made of CGI sheet and R.C.C. and are capable of collecting rainwater was found to be 52 Lpcd with standard deviation of 10.09. This value of 52 Lpcd may be used in the design of storage facilities for rainwater.

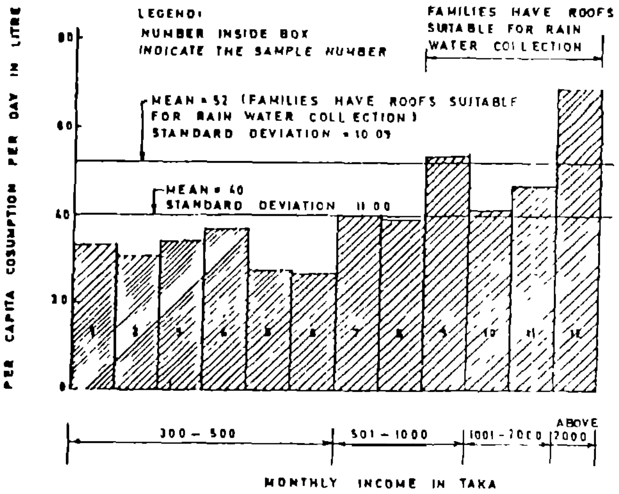

Figure 4. Water consumption of various surveyed samples
(Arranged in order of monthly income)

Rainfall

The coastal area is situated in the monsoon zone. Heavy rainfall occurs in this zone. Monthly mean rainfall ranges from 680 mm in July to 10 mm in January. The mean annual rainfall is 3280 mm with a range from 4,402 to 2,861 mm/yr (Manalo, 1976). The rainfall pattern of this area has been shown in Figure 5.

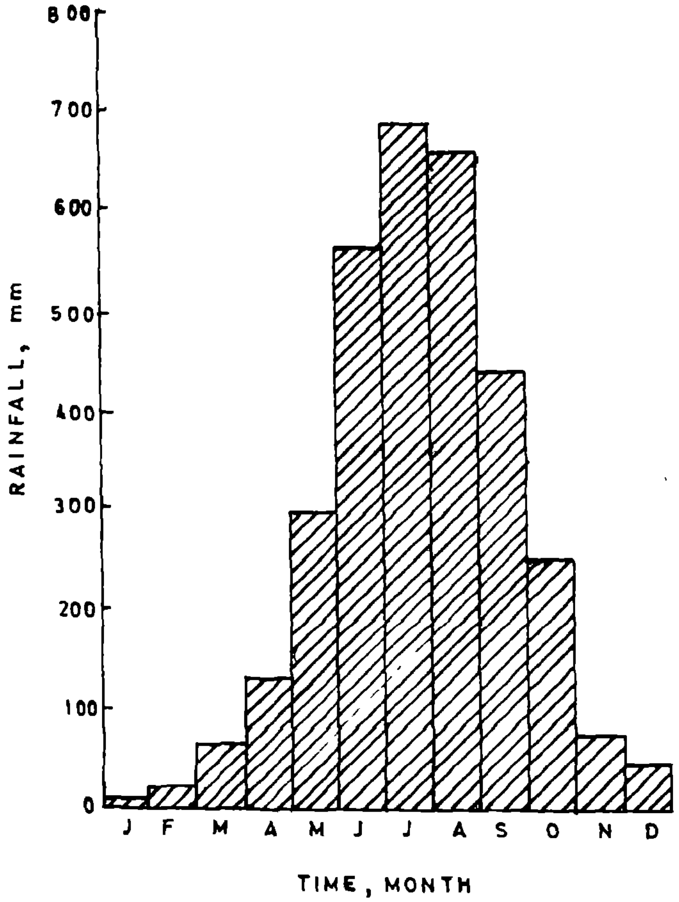

Figure 5. Rainfall pattern in Hatiya

STORAGE CALCULATION

There are various methods available to calculate the rainwater to be stored. Among these, the conservative approach of 'yield after storage' is used. This method was proposed by Jenkins et al (1978). It is a modified form of the mass curve in which assumption has been made that maximum demand for each month is limited to the initial quantity in storage. The demand is satisfied after the addition of rainfall causes a 'spill' condition. The calculation is illustrated in Figure 6. And this can be expressed as follows:

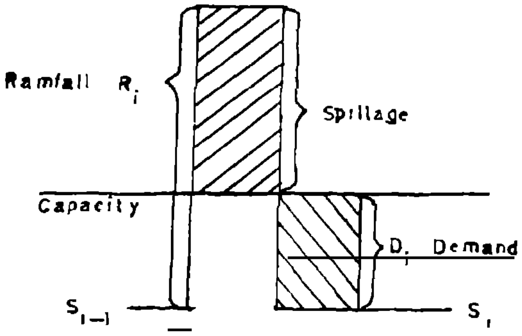

Figure 6. Yield after storage calcualtion

The storage required at month K is

$$S_{j,k} = \sum_{i=j+1}^{k} (A \times ROF \times MR_i)$$

$$S_{i,k} = \sum_{i=j+1}^{k} (S_{j,k} - D_i)$$

where

A = roof area

ROF = runoff factor

MR_i = rainfall in month i

D_i = the demand for month i

To determine the storage volume, the following values of data as obtained from field study and metrological data were considered:

Water consumption per head per day = 52 litre

Catchment area varies from 50 to 90 m^2

Average family size = 4 to 8 persons

Runoff factor = 0.90 (assumed)

Evaporation per month = 130 mm (in coastal area)

Fifteen years of monthly rainfall data for the Hatiya Upazila of Bangladesh was taken in this study (1966-1980).

RESULTS AND DISCUSSION

In view of large volume for rainfall data handling, repeated calculations and application of this approach in other conditions, a computer program was developed and run for demands of 4, 5, 6, 7 & 8 persons in a family; roof top areas of 50, 60, 70, 80 & 90 m^2 and reliability values of 80%, 85%, 90%, 95% and 97.2%. To provide a better understanding of this computation, catchment area/ storage/ performance curves as determined by the yield after storage are presented in Figure 7.

It became apparent from the analysis that the approach was suitable for system of any size in which the major determining factor of the tank size was the demand placed on the system. Once the demand was defined for a required reliability of a particular catchment area, the minimum storage volume required to satisfy this demand over a design period and given rainfall data, may be calculated and represented as shown in Figure 7.

In the last three curves of Figure 7, there are no storage volume values of catchment area of 50 m^2, because the storage needed is greater than the available rainfall over a month due to high demand and small catchment area for required reliability. For a given reliability it can be seen that the curve is approximately asymptotic to limiting values of the storage and collection area. These represent the two basic limitations of any water supply system - sufficient area to generate run-off and sufficient storage to ensure supply in periods of low or zero run-off. It can be also seen that for increased reliability, an increase on storage volume or catchment area is required.

The smaller the catchment area, the larger is the storage volume required for the same degree of reliability. In the analysis, it is found that the variation of storage volume is very wide i.e. from 34 to 221 m^3. For a average family size of 6 persons, the range of storage volume is from 49 to 122 m^3. Considering average storage volume of 85.5 m^3, and storage area of 24 m^2, height of storage tank would be 3.56 m. The construction cost of that storage tank would be about Taka 110,000. This is obviously outside the financial capability of middle income group, which

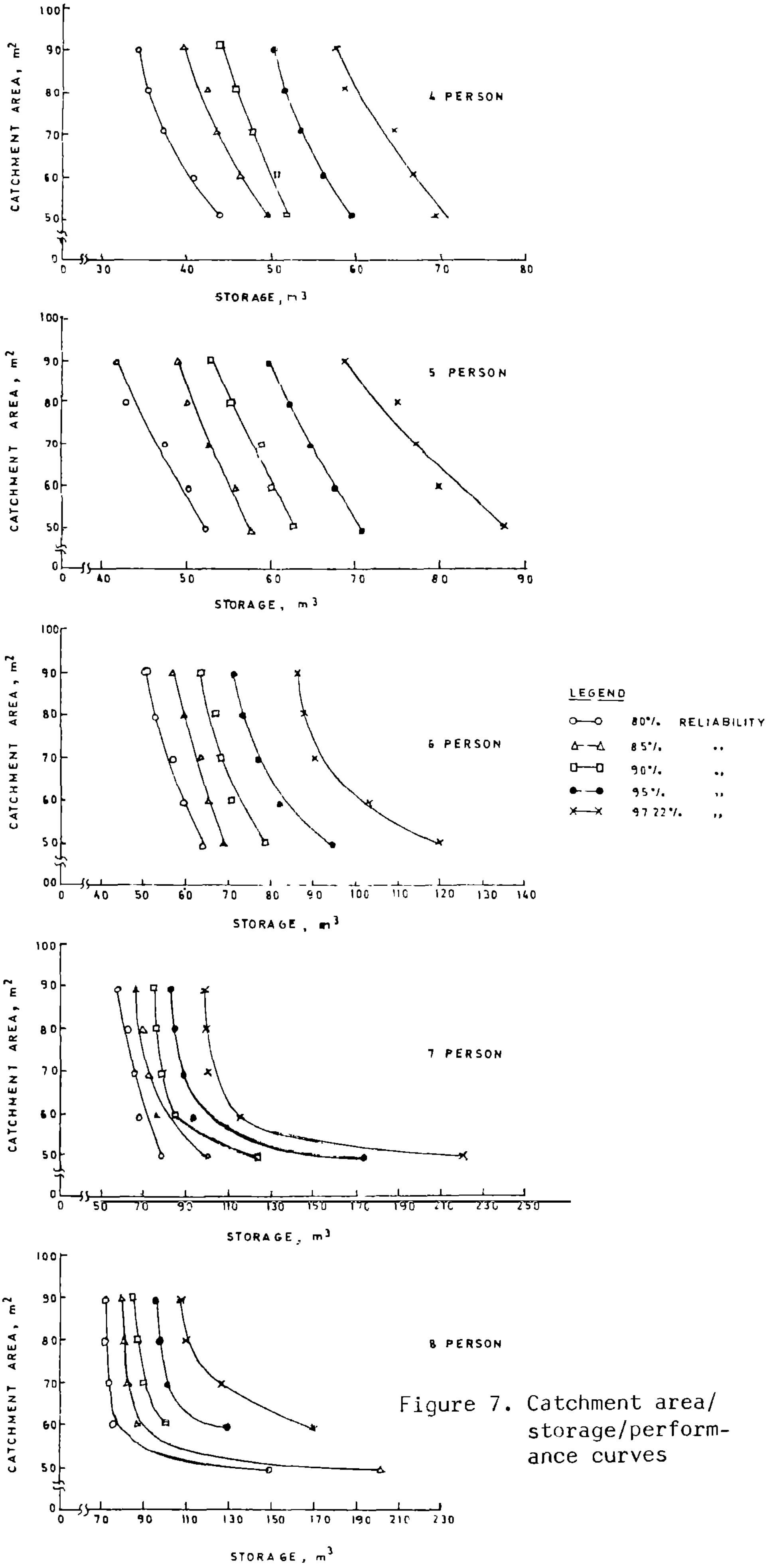

Figure 7. Catchment area/storage/performance curves

has a monthly average income of Taka 1,500 per family. Again from the housing configuration, the space for storage tank construction is very limited particularly for four or more families living in a place. Only about 6 percent of the total familes can afford to invest in this type of water supply system.

CONCLUSION

Results of this study indicate that only 18 percent of total roofs made of CGI sheet and R.C.C. which cover about 26 percent of the total families is suitable for rainwater collection. Larger storage volume is required for a larger family having smaller catchment area when higher degree of reliability is required. A family having low income can not afford to construct a large storage tank due to high cost involved. Only about 6 percent of the families can afford to have rainwater supply system for all domestic uses.

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WATERSUPPLY OF KARSTIC ISLANDS BY HARVESTING THE RAIN

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ABSTRACT

Most islands on the Adriatic sea are covered by karst, which means they have very scare surface or underground water. Consequently the water supply presents a serious problem, particularly with the current trend of developing tourism. The small islands have solved this problem by using a traditional method of water supply, i.e. by harvesting the rain water quite abundant during the wet periods. However, the increasing demands for water, resulting from the higher standard of living, call for an application of better systems.

The paper deals with a solution of water supply for the island Silba. It presents the methodology used for the selection of solutions, the procedure of dimensioning, the water quality and other essential features of the proposed solution.

INTRODUCTION

The island of Silba is one of a thousand islands of the Adriatic sea. It is situated in the north part of the Adriatic sea, between $44^{0}12'$N and $14^{0}40'$E ca 35 km from land. The surface of the island is ca 15 km^2, and the maximum height is ca 80 m. The mean annual rainfall is 948 mm. The essential geological composition of the island consists of the calcium rocks and thus makes impossible the formation of the surface flows, Fig. 1.

The main branch in economics, as in most Adriatic islands, is the tourism of seasonal character. The number of permanent inhabitants is 200, whereas the number of seasonal ranges from 50 in winter (during the week-ends) to 600 in summer; whereas the number of tourists ranges from 0 in winter to 2400 in summer. According to some planning materials the number of tourists and inhabitants should be doubled by the year 2015. The great oscillation in the number of inhabitants in the course of the year significantly influence the functioning of a whole series of community services, including the watersupply.

The main problem of the island consists in providing sufficient quantities of water for the present and for the future.

The watersupply is provided by individual cisterns and by communal cisterns linked into a single watersupply system. The capacity of the cisterns are not satisfactory in the summer periods, and thus the watersupply in high season is provided by transporting water from the land by tankers. As the points for the filling of the tankers are at a significant distance from the island (ca 150 km) the costs for water are high and affect the inhabitants and the tourists.

Since it is not possible, for a longer period, to connect the island to the regional watersupply system on the land, by means of a pipeline, the water authorities have ordered a study for a watersupply solution which should be based exclusively on the local conditions (sources). The further text presents the main characteristics of that study and the suggestion for the solution of the watersupply problems for the island Silba.

MAIN CHARACTERISTICS OF THE ISLAND

Meteorological and Hydrological Characteristics

On the island there is a meteorological station which started working in 1963, while the pluviograph was installed in 1955. Owing to this fact there are relatively satisfactory data which can be used to obtain the necessary information.

On the island there is constant relative humidity of ca 75% which is to be expected, because of its limited size and height.

The mean air temperature during several years is 15.2^{0}C. The temperatures below zero occur rarely and last 2.5 days on the average, whereas the summer temperatures are about 25^{0}C.

Winds are frequent, but the strongest winds occur in winter and never exceed the speed of 37.2 m/s.

Since the island is affected by the winds and is relatively low, there are maximum expected evaporations from the free surface, ranging according to Pennman, from 28 mm in December to 178 mm in

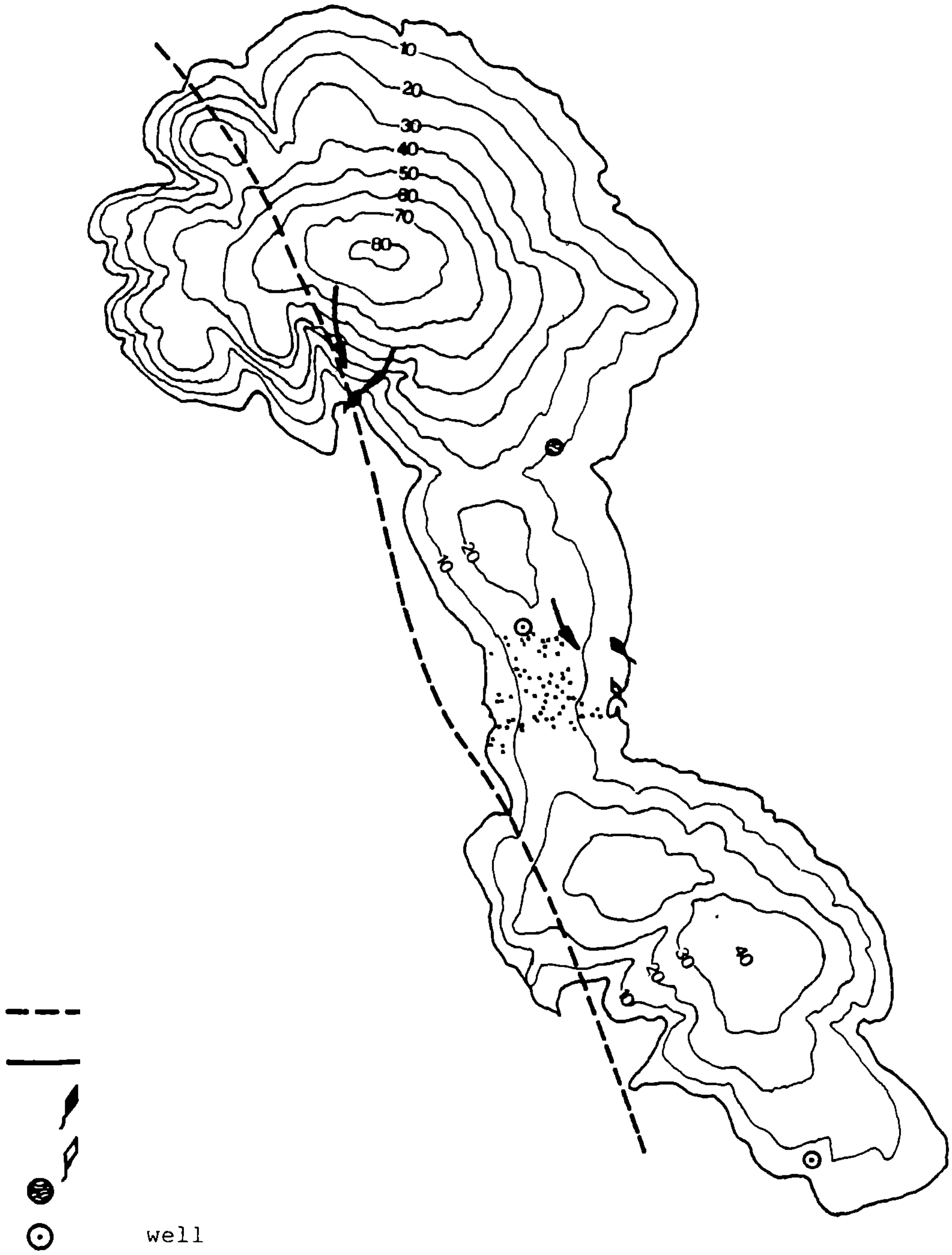


Figure 1. **Map of the Island**

July.

This process is closely connected with cloudy weather, being rare in summer, and more frequent in winter.

Special attention is paid to the processing of the data obtained by pluviographs, which includes the basic statistical analysis, duration, repeated occurrence and intensity of precipitation. There is a favourable circumstance that only a few months in the previous period of observations, have been completely without precipitation. Table I presents the basic data obtained by an analysis of series covering several years.

TABLE I Main Characteristics of the Rainfall

	Month												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
Max	367	184	285	134	152	142	157	159	327	303	348	242	1891
Min	4.00	9.00	8.00	20.0	0.00	5.00	0.00	0.00	7.00	0.00	12.0	8.00	680
Mean	95.3	78.3	80.9	67.0	65.0	57.2	42.4	67.8	107	103	138	111	1013
STD	64.0	48.2	54.6	30.1	37.8	37.1	41.0	40.0	71.6	85.5	79.3	70.1	241
CV	0.67	0.61	0.68	0.45	0.58	0.65	0.97	0.59	0.67	0.83	0.57	0.63	0.24
CS	2.34	0.51	1.64	0.47	0.30	0.72	1.32	0.43	0.90	0.81	0.64	0.54	1.49

According to these data it can be concluded there are favourable conditions for solving the watersupply by rainfall harvesting.

Geological Compostion and Hydrogeological Relations

The island has a uniform lythological composition. It consists only of limestones. They belong mostly to the upper kreda (touron and senon). The limestone is often covered on the surface by terra rossa or by humus.

The island is anticlinal.The anticlinal axis passes approximately through the middle part of the island. The main hydrogeological characteristic of the island is that it consists of porous limestone. The precipitation which does not evaporate relatively quickly sinks into the underground. Due to the relatively dense vegetation the evapotranspiration is significant, especially after rains of lower intensity. The porosity of the limestones is secondary, and it depends on the degree of cracking and of karstification. The karstification of limestones in time leads to the formation of terra rossa which in the course of time progressively fills the underground cracks (fissures) and pores. As the sea level has been raised in the course of time there are certain areas in the submarine part where the rock pores are filled with earth, and as such today they function as barriers and prevent the fast outflow of the groundwater at the sea level. Owing to this phenomenon in the middle of the island there are small quantities of the fresh water, which thus accumulated have been used since the 15 century. This situation makes it possible to use small quantities of the groundwater in the course of the year, and particularly in winter.

Economic Characteristics

During the last 50 years there have been continuous migrations of inhabitants from the island, so that today there are only 200 inhabitants living there. During the last 20 years the island has become a well-known tourist resort for the week-ends and for seasonal tourism so that the number of inhabitants varies from 200 - 2400.

The main economic activity on the island is tourism, so that the only activities and services being developed are related to tourism. In the development plans of the island the greatest emphasis is placed on tourism and its accompanying activities with special attention paid to agriculture related to tourism (vineyards, vegetables, citrus). It is supposed that by 2015 the number of inhabitants will increase to 1200 during the season, and the number of tourists to 4200. Consequently numerous facilities for tourism, accompanying infrastructure and marinas will be built.

It has been established that the factor limiting the development of the island is its watersupply, and thus special attention should be paid to the solution of this problem.

The Existing Watersupply System

The present watersupply is provided by individual cisterns and three greater communal cisterns. The communal cisterns are linked by an underground system into a single system covering the needs of the greater part of the setlement and having a connection for the tankers. All these cisterns are old and in the past were sufficient to satisfy the demands of the inhabitants who also used the groundwater from the wells. However, when the tourists come during the summer the stored quantities of water are not sufficient and the water has to be delivered from the land using the tankers. (1985. - 3500 m^3). The water is pumped from the tankers into the cisterns and then using the distribution system it is possible for the inhabitants to fill their individual cisterns. Consequently the distribution system is not used for the direct watersupply, but only for delivering water for the filling of the individual cisterns, and for the protection against fire.

The existing cisterns are old and they leak, and the surfaces for the collection rain are in the very settlement, so they get polluted; hence the quality of the collected water is not satisfactory. Furthermore the volume of the communal cisterns filled by the water from the tankers is small, so that large tankers cannot be used, which significantly increases the cost of the transported water. Therefore the existing system has to be abandoned and the reservoirs should be built.

THE SOLUTION ALTERNATIVE

Since it has been established that by 2000 no regional solutions can be expected it has been decided to provide the watersupply from the local sources: a) rain harvesting; b) groundwater exploitation; c) combination of the groundwater and rain harvesting.

Since the capacity of the groundwater cannot satisfy all the demands, the only solution consists in the combination of the two sources or only rain harvesting. In this case it is necessary to build the surfaces for rain harvesting and to ensure the appropriate volume of the reservoirs. Since these volumes are relatively large it is not economical to build firm concrete structures, but to construct a small reservoir or several small reservoirs (basins).

On the island there are several natural depressions which can be exploited as storage places if they are made impervious to water. As today such depressions can be made impervious by placing plastic pholias at a low cost, this solution has been accepted. In addition to these depressions there is enough available space for harvesting rainfall so that it appears to be a relatively simple solution for both collecting and storing of rainfall. The situation is even more favourable since these depressions and the available surfaces are situated on the levels higher than the town so that the water can flow to the town by a gravitational flow.

The only problem that arises is whether the reservoirs should be built as open or coveres. The two important factors affecting the configuration of the solution are: 1) evaporation intensity = losses; 2) water quality = treatment plant. In evaluating these solutions several essential criteria have been considered: a) economy; b) efficiency; c) technology; d) exploitability; e) reliability. The characteristic of each variant have been defined in advance. The open reservoirs have significant evaporation, and the suitability of the location for each region essentially depends on the ratio volume/water surface. The situation is more favourable if this ratio is higher. Thus the reservoir should be as deep as possible. Since the natural depressions are ca 12 m deep they are considered to be relatively shallow and not very suitable for the open storage of water. The available active volume is, namely, 60% of the total volume, since the surface layer (epilimnion) is not suitable for exploitation, neither is the bottom layer which encures the lasting biological and physical duration of the reservoir. If the reservoir is covered then the required volume is ca 50% smaller. Another factor to be considered is the cost of the construction. The open reservoirs are cheaper if there is enough space without additional excavations, and the covered reservoirs are more expensive because of the roof structure construction. All these costs vary from one region to another, depending on the local characteristics and the construction possibilities. In this actual case the solution with a covered reservoir proved to be more expensive.

Before making a final decision another factor should be analyzed, i.e. the effect of the water quality on the solution. The water quality is affected by: - seasonal variations of the surface temperatures with a relative stagnation of the deep water; - variation in the quality and quantity of plancton developed in water; - variations of the water level; - local conditions (wind, vicinity of the sea, etc).

The selection of the treatment plant will depend on the changes in the water quality. The covered basins eliminate the atmospheric influences, the temperature change and plancton, so that the water has only to be disinfected and the concentration of alkalic metals has to be increased. The open reservoirs are exposed to external influences, temperature change and have a biocenosis typical for the lakes of the Mediterranean region. Therefore the water should treated by sedimentation,filtration and desinfected. Taking into account the personnel engaged and the attitude of people towards such structures it is considered that the most efficient solution is the one which is at the same time simpler and more reliable considering the management problems. Consequently the solution with the covered basin was selected, although it is generally speaking more expensive.

The groundwater can be used for additional filling of the basin, but only after its quality has been ensured. The construction of the septic tanks on the islands the groundwater has been polluted so that it cannot be used for the watersupply until a municipal sewer system has been built and until its quality has been improved. Therefore this water was not taken into account for the watersupply but for the other purposes which do not require the sanitary safe water quality.

Thus the configuration of the solution presented in Fig. 2. is obtained.

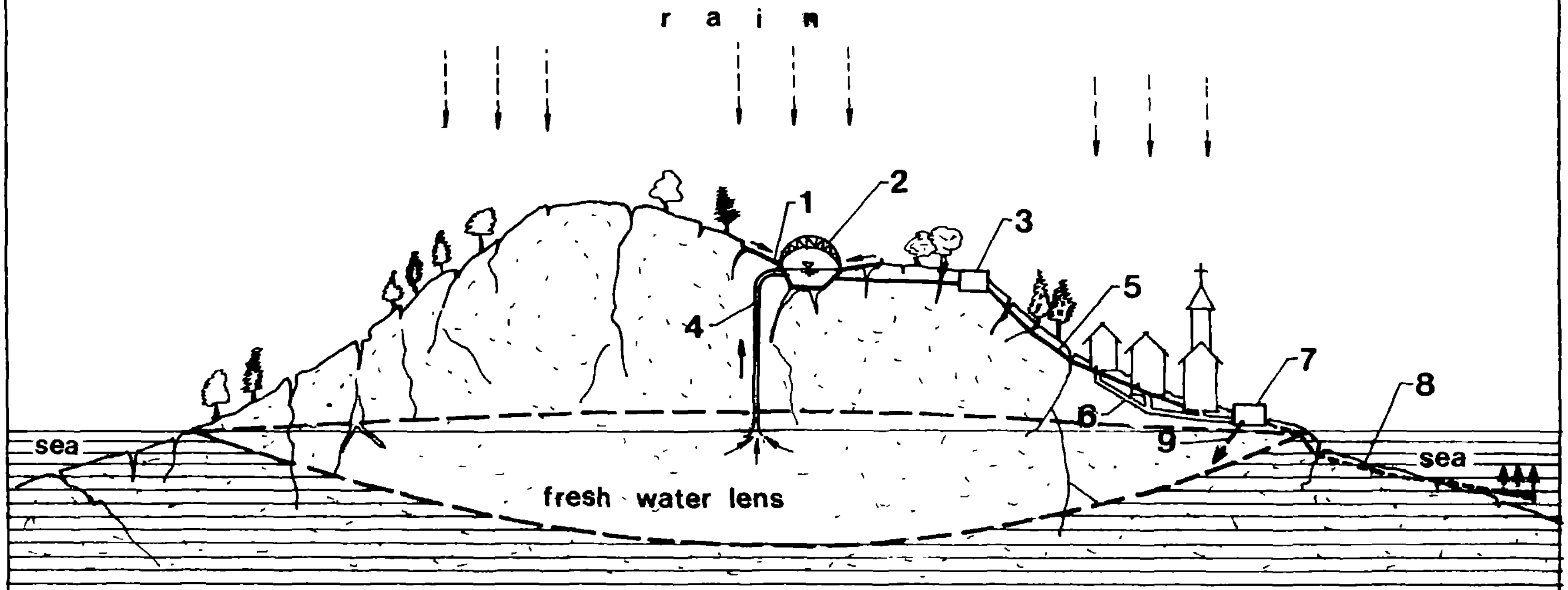
In the selection of the structure construction the following facts were considered: 1) great quantities of cheap stone aggregate on the island; 2) that there are no roads on the island, and hence the traffic including vehicles of large size and engineering machines is not possible; 3) the whole necessary material should be transported by ships from the land to the island; 4) the manpower is not expensive. Accordingly it has been decided that the surfaces for rainfall collection should be built of concrete, since it can be produced on the site and its placement can be carried out without any highly specialized machinery.

The reservoir should be built with plastic lines placed on the suitable foundation consisting of crushed stones and protected by crushed stone of appropriate granulometric composition. Thus only the plastic pholias have to be transported from the land. The roof structure of the reservoir should be an inflated semispherical air chamber fixed for safety reasons (wind) to a light aluminium structure. The layout surface of the reservoir is a circle surrounded concentrically by a surface for collecting of rainfall. The roof structure of the reservoir also serves for rainfall harvesting. This layout of the structure, brought about the characteristics of the natural depression makes it possible to obtain an efficient structure occupying the minimum space of the site.

The communal solution of the island watersupply can be realized in this way. All the individual cisterns, as well as the already existing communal cisterns, should be kept for safety reasons and in case of long dry periods, as well as because of the substitution of the consumption using the water for the demands not requiring high water quality.

DIMENSIONING OF THE COLLECTING SURFACE AND THE RESERVOIRS

The method suggested for solving the problems is based on the variation of the collecting surface and its respective smallest volume satisfying the requirements that the tank is never dry. The factors influencing the dimensions of the tank and of the collecting surface are: a) intensity and distribution of rainfall; b) initial quantity of water in the tank; c) specific consumption; d) runoff coefficient from the concrete surface.



1 - collecting surface
2 - cover reservoir
3 - disinfection
4 - pumping ground water (II phase)
5 - water distribution system
6 - sewer system
7 - wastewater treatmant plant
8 - marine outfalls
9 - ground water recharge

Figure 2. CONFIGURATION OF WATER SUPPLY SOLUTION

The input data are the monthly data on rainfall for the years between 1955 to 1984. The water consumption per month has been planned according to the specific consumption and the predicted number of consumers. The computation results are presented in Table II.

TABLE II The Water Demands Expressed in 1/s

Period	Out of season I,II,III,IV,XI,XII	Pre-seasonal V,VI,IX,X	Seasonal VII and VIII
Period of development 1985	0.4211	1.3169	5.8889
Period of development 2000	0.5040	2.2723	13.1942

The runoff coefficient from the concrete surface has been adopted as a constant for single months. The review of outflow coefficients is presented in Table III.

TABLE III Presentation of the Outflow Coefficient

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Runoff coeff.	0.9	0.9	0.7	0.7	0.5	0.5	0.3	0.3	0.5	0.5	0.7	0.9

After defining all the influential factors, it is possible to choose, for a previously supposed value of the collecting surface, the smallest volume satisfying the condition that the tank is never empty during its operation.

The volume which will satisfy the above presented requirements for a given surface has been studied according to the criterion expressed as

$$V_{i+1} = V_i + \varphi_i A P_i - Q_i \qquad \ldots(1)$$

where V_{i+1} should be greater than zero so that the planned volume is suitable. The expression uses the following notations:

A - collecting surface
V_i - the quantity of water in the tank in month i
φ_i - the runoff coeffieciient for the month under consideration
P_i - monthly rainfall
Q_i - consumption in month i.

In order to solve the described task a computer programme has been developed. The computation was designed in the following way: Starting from an initial surface we compute the water volume this surface can ensure and subtract the consumption from it, then an initial volume of water in the reservoir is added to it. At the beginning the reservoir was chosen to be full, which was a correct assumption for the years (series) under consideration, i.e. 1955 to 1984, since the reservoir was full only at the beginning and was emptied through rainfall, as inflow into the reservoir and through consumption as outflow. The computation is carried out for all the months during all the years and if the volume appears to be negative for a certain month (i.e. the consumption cannot be satisfied) then the initial volume is increased until we obtain the smallest possible volume which ensures the supply for all those years for a given surface. Then the volume for another surface is sought in the same way. The results are the pairs of areas and volumes which satisfy the watersupply; they are presented in Fig. 3.

The mentioned figure shows the difference in the required reservoir volume for a single collecting surface, related to the increased consumption (development period until 2000).

Thus we can obtain a whole series of possible combinations related to the collection surface and the necessary volume. Taking into account the limited capacity of the space the alternatives were evaluated and compared from the economical standpoint and thus an optimum solution was obtained (Fig. 3).

DISCUSSION AND CONCLUSION

The presented study served to establish the fact that the normal watersupply for the island Silba can be provided by rainfall harvesting and by a single watersupply system. The accepted solution is cheap and simple for the maintenance and construction, as its makes the best use of the local conditions. This paper, however, does not pretend to give all the details and explanations of the analyses carried out in order to select the optimum solution. It can, however, present the essential characteristics of the suggested solution. It has been proved once more, in our practice, that the traditional methods of watersupply for our islands can be used even nowadays, introducing the new achievements of technology into the solutions.

The positive result of this study is an encouragement for a greater number of our islands since we live in the time when it is impossible to provide the financial means for the construction of expensive regional systems of watersupply using the water from the land.

A simple budget method was used in dimensioning as it gives efficient solutions using the computer calculations. This method is not applicable for hand calculations, as it would entail a great deal of time. This method uses a historical series, but in the planned conditions of consumption. Better results can be obtained if the historical series is used for modelling the predicted time series of a given safety level. According to our experience this effort is not necessary if the series is long enough and if there are no additional data on the same processing level (the planned consumption). We believe that the presented method can be successfully used for efficient dimensioning of the structures.

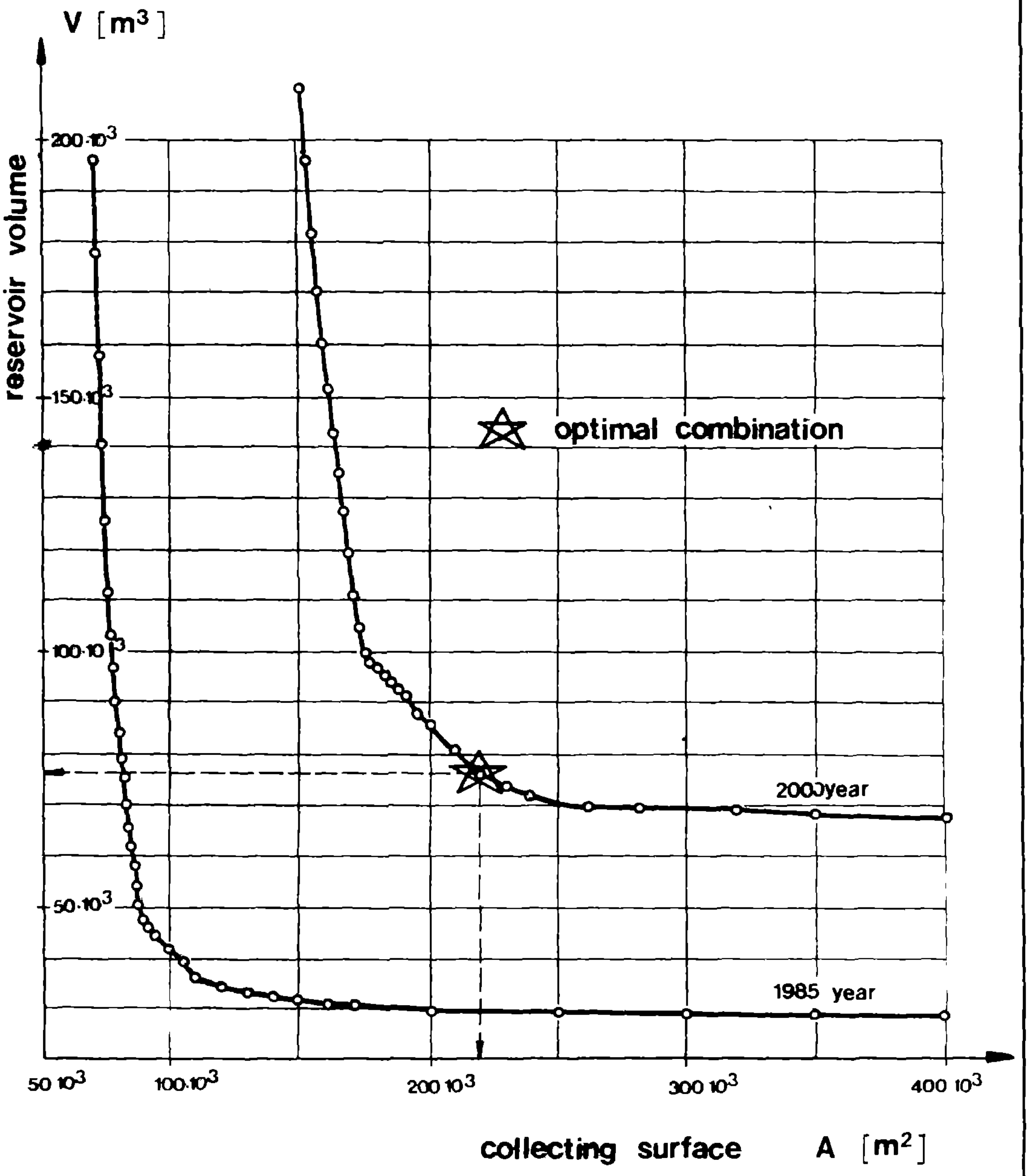


Fig. 3. **Envelopes of possible combination which satisfy demand**

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ANALYSIS OF RAINFALL PATTERNS FOR THE DESIGN OF RAIN CATCHMENT WATER SUPPLIES IN A TROPICAL WET / DRY SEASON CLIMATE

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PAPUA NEW GUINEA

ABSTRACT

In Papua New Guinea extensive rainfall records are available but they are not computerized. A method was needed which allowed a sufficiently thorough analysis yet kept data coding at a manageable level.

A two phase approach was adopted: In phase one monthly rainfall totals for 38 representative stations and continuous record lengths of around thirty years were analysed to yield probability distributions of the occurrence and severity of dry periods. The whole country was then zoned into seven distinctive dry period rainfall regimes. Phase two of the analysis consisted of numerical simulations of rain catchment supplies using actual daily rainfalls for representative periods for each of the seven zones identified in phase one. Two types of simulation were run: One for standalone systems the other for systems with supplementary topups from external sources.

The results are a map of Papua New Guinea showing the seven zones and sets of design tables for each zone. Tabulated are the percent reliability of a standalone system and the number of topups required, both as functions of catchment area and storage volume.

The computer programmes used could be run on most microcomputers using the CP/M80 operating system.

INTRODUCTION

In many areas of Papua New Guinea rainwater catchments are the predominant source of water supplies both in rural and urban areas. Yet although experience has shown that their performance varies widely as a result of the high degree of variability in rainfall patterns throughout P.N.G. there has been little attempt so far to vary the design of such supply systems in response to the differences in rainfall.

A map produced for the National Water Supply and Sewerage Board based on average monthly rainfalls and average durations of dry seasons (Beca Gure Pty.Ltd. 1984) differentiates zones of poor, satisfactory and good suitability for rain catchment supplies. This map helps in deciding where such supplies could be built but does not address the problem of tailoring a system to the rainfall pattern in a particular location.

According to estimates from the Department of Works and Supply the annual replacement cost of rainwater tanks in urban areas alone is in excess of $1,000,000. Clearly a proper hydrologic design is justified where expenditures of this magnitude are concerned.

Several approaches to the problem were studied. The approach finally adopted consists of using actual monthly rainfalls to identify dry periods of specified severity for representative locations throughout the country and then to simulate the performance of a rain catchment in response to the actual daily rainfalls as a function of rain catchment size and tank storage volume.

IDENTIFICATION OF DRY PERIODS BY AREA

Dry period definition

If any water supply is to function continuously but draws on a source which varies in time then it has to be designed to cope with periods when the source is low by providing sufficient storage. For any wet/dry season climate it is the identification of dry periods of specified severity and duration which is critical for the design decisions.

Climatic tables for Papua New Guinea (McAlpine et al 1975) provide statistical data on monthly rainfall totals. However such data can not be used for constructing typical dry period rainfalls for durations other than one month. Both the rainfall amount and the duration of a dry period would be nonrepresentative. To obtain dry periods of realistic length and severity the analysis has to be based on the original monthly records where the natural sequence of events is preserved. Such records are available for a large number of stations throughout P.N.G. many of which are continuous for 20 years or more.

The second problem is to find a suitable definition of a dry period or dry season for the purposes of this study. A careful distinction has to be made between dry period and dry season since the latter implies a regular annual occurrence of such event. In many parts of this country the two types of events will coincide but even then the "wet" season during one year may occassionally be dryer than the "dry" season during another. For determining the performance of a rain catchment water supply we therefore use dry periods regardless of whether they coincide with the dry season.

It remains to decide on the length of such periods and on how many should be extracted from each record. As for the definition of dry season also for the definition of dry period it is possible to arrive at different criteria which depend largely on the intended application. In our case practical considerations on the economical size of tank storage provide convenient criteria.

Carting water from alternative sources can be more economical than providing for the extra storage to last through a long dry period. From the data available it appears that to provide storage capacity in tanks for more than three months can be considered excessive in all but a few exceptional situations, e.g. on small islands where no alternative source is available. Three months was hence selected as the standard length of dry periods for this study. The available data were also analysed for dry periods of six months for comparison. The number of dry periods to be extracted from the records was chosen as equal to the record length in years for each station.

Processing of monthly rainfalls

A total of 38 rainfall stations with sufficient record length and representing different areas of Papua New Guinea were selected and dry periods for each were calculated as follows:

1. Starting with the first month of record up to the last minus two running totals were calculated for each month consisting of the monthly rainfalls of the current month plus the next two to yield a three month total.

2. The running totals were sorted in ascending order each remaining labelled with the month and year in which it started.

3. Starting with the second lowest each running total in sequence was compared with all preceding ones and if its three month period overlapped a previous period it was flagged as a duplicate and was removed from the set.

4. The first N, where N was the record length in years, running totals from the remaining set were extracted as the N lowest three month rainfall totals for the record from that station. These were tabulated together with the month and year when the particular periods started and the cumulative frequency in percent. This method of extracting extreme events is called the method of exceedences (Hudson and Hazen 1964).

Some comments are in order here concerning the type of computer and the processing language used. Considering the quantity of data normally involved in processing meteorological data it is natural to assume that a large mainframe computer is necessary. In fact however the quantity of data involved in this study - around 300 monthly rainfalls and 180 daily rainfalls per station - is well within the capability of even a modest microcomputer. Since the author did not have easy access to a mainframe but had an Apple II microcomputer on his desk it was natural to try the microcomputer first.

The programmes for data entry, file management and the processing steps listed above were all written in BASIC for ease of programme development. The processing time for the 38 stations selected was four overnight runs. The tables and graphical representations were also produced with the same computer.
Table I is an example of the result from the town of Kavieng. The same analysis was also done for dry periods of six month duration for the purpose of studying the correlation between dry periods and the conventional definition of dry seasons.

TABLE I
Occurrence and Frequency of 3 Month Dry Period Rainfalls for Kavieng

Period occurred starting in month	year	Rainfall during period in mm	Cumulative % probability
August	1972	178	4
July	1982	198	7
May	1975	332	11
August	1984	360	15
July	1965	384	19
December	1983	420	22
August	1974	421	25
August	1971	430	30
July	1966	445	33
July	1970	447	37
June	1964	453	41
April	1974	462	44
June	1968	467	48
August	1976	484	52
December	1973	488	56
April	1984	488	59
September	1973	489	63
December	1978	497	67
September	1975	506	70
May	1967	507	74
January	1963	508	78
September	1964	554	81
July	1960	555	83
May	1969	556	89
June	1958	560	93
April	1978	573	96
January	1962	583	100

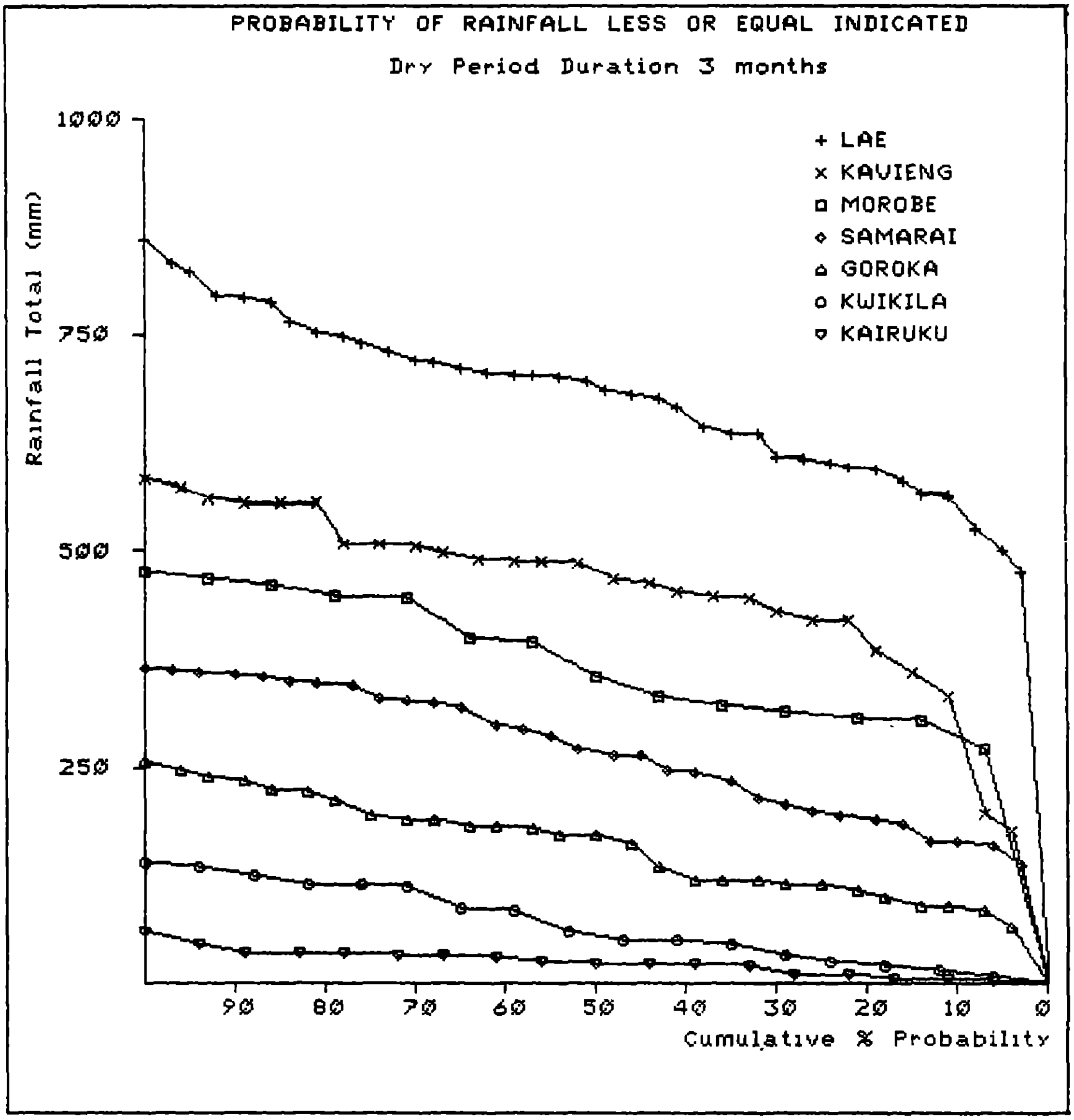


Figure 1
Result from three month dry period analysis for seven stations each representing a different rainfall zone.

The seven rainfall zones referred to in Fig. 1 will be defined next in the chapter on correlation and mapping.

Correlation and mapping of dry period rainfalls

From the tabulations and frequency plots for the 38 stations the 10% probable (very dry) and the 50% probable (median) three month dry period rainfalls were extracted. The results are on Table II.

TABLE II

3 Month Dry Period Rainfalls for the 38 Base Stations

Station name	50% probable (median) mm	10% probable mm	Ratio 50%/10%
Kairuku	22	3.6	6.1
Port Moresby	46	7	6.6
Kwikila	55	12	4.6
Daru	98	38	2.6
Tapini	169	87	1.9
Goroka	172	88	1.9
Awar	185	33	5.5
Cape Nelson	214	12	17.2
Bulolo	217	162	1.3
Rabaul	231	110	2.1
Popondetta	240	89	2.7
Samarai	268	165	1.6
Kandrian	281	166	1.7
Abau	292	208	1.4
Kundiawa	293	145	2.0
Finschhafen	308	227	1.4
Bamu River	314	63	5.0
Hoskins	316	161	2.0
Lumi	317	210	1.5
Wewak	324	183	1.8
Mt.Hagen	325	264	1.2
Buka	330	235	1.4
Namatanai	332	184	1.8
Madang	341	119	2.9
Morobe	354	286	1.2
Ambunti	373	256	1.5
Vanimo	391	256	1.5
Bwagaoia	413	141	2.9
Pomio	464	278	1.7
Kavieng	475	299	1.6
Kerema	478	313	1.5
Mendi	478	271	1.8
Kieta	479	362	1.3
Kokoda	491	263	1.9
Momote	507	368	1.4
Telefomin	596	452	1.3
Lae	690	550	1.2
Kikori	706	448	1.6

It was expected that the variation in rainfall between stations would be higher for dry period rainfalls than for annual rainfalls, but the extent of the differences exceeded the expectations. The median rainfall totals for the three month dry periods vary from 22 to 706 mm, a ratio of 32. By contrast the annual rainfalls for the same stations are 1147 and 6541 mm respectively, a ratio of only 5.7. This allows two conclusions: Firstly constructing rain catchment water supplies without taking these variations into account leads to an enormous waste of resources, secondly basing such design on on annual rainfalls or a derivative therefrom, e.g. long average monthly rainfall (L.A.R.) is not sufficient.

The 38 stations analysed were selected for a representative areal coverage and it was hoped that this would be sufficient to define the dry period rainfall pattern throughout the country. However the degree of variations between adjoining stations made it doubtful whether any pattern derived from these 38 stations alone could be depended on for areas between these stations. An objective and hydrologically sound correlation was required between the the dry period rainfalls determined for the 38 stations and some other more readily available rainfall data.

The only suitable data available for a significantly larger number of stations are annual and monthly rainfall averages. From the climatic tables referred to already before (McAlpine et al 1975) were extracted the averages for annual, January, July, and dryest month for the same 38 stations and were subjected to a curve fitting and correlation analysis.

Some correlation existed in all cases but only that with the averages for the dryest month was really useful having a correlation coefficient of 0.95. The equation for the best fit line was

$$r_p = r_m \times 2.50 \qquad (1)$$

where: r_p = predicted median three month dry period rainfall
r_m = average rainfall during dryest month

For comparison the correlation coeffient using annual averages instead was 0.73 and using the L.A.R. values employed by Beca Gure (1984) in compiling their map was 0.83.

Rejecting all stations with less than 5 years of record for most of P.N.G. and with less than 3 years in the extreme West where data are particularly sparse left a total of 406 stations for which monthly averages could be used. Equation (1) was applied to the averages for the dryest month for these 406 stations. The resulting predicted three month dry period rainfalls were plotted on a map together with the previously determined values for the 38 base stations and this map was superimposed onto a topographic map of the country.

It was expected that orographic effects would have a large influence on rainfall distribution in a country as mountainuous as P.N.G. but it was also expected that they would be too complex for use as a factor in prediction (Gilman 1965). However in many cases it was possible to estimate a known dry period rainfall from neighboring ones merely by following the elevation contours. As a result it was decided to use elevation contours as a guide for interpolating between stations and in defining hypsometric contours. The final map of median three month dry period rainfalls can hence be defined as being based in the first order on measured values for 38 stations, in second order on quantitative estimates based on a correlation with averages of measured values for 406 stations, and in third order on qualitative correlation with elevation contours.

The complete map is too large and complex to be reproduced within the confines of this paper but a portion of it is shown as figure 2. A total of seven rainfall zones is defined on the map ranging from less than 50 mm for zone 1 to more than 500 mm for zone 7. These zones correspond to seven sets of design tables developed from the simulation of daily rainfalls which is described next.

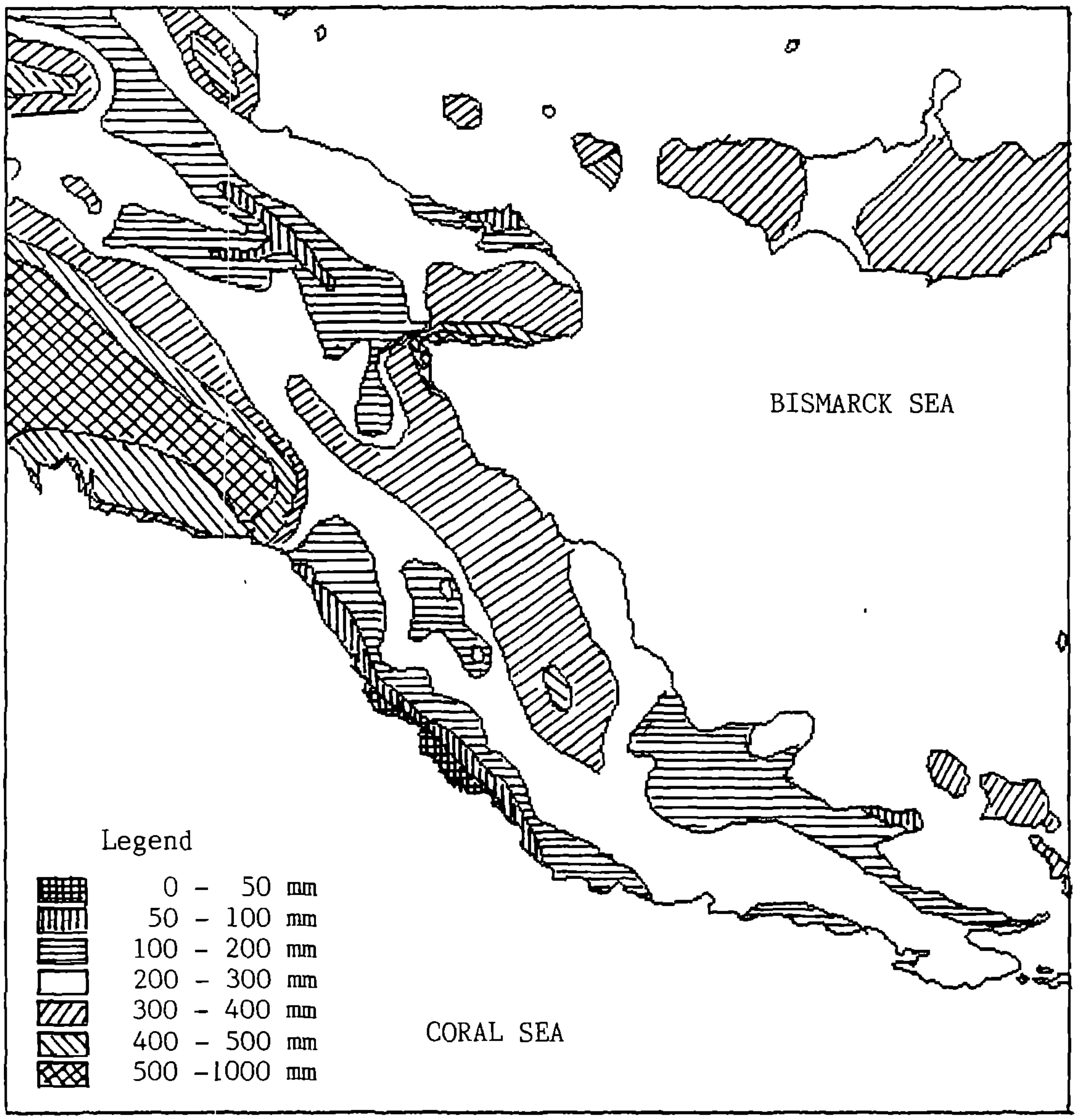


Figure 2
Partial map of Papua New Guinea showing three month dry period rainfalls as seven zones

NUMERICAL SIMULATION USING DAILY RAINFALLS

Simulation method

Data Selection

The analysis of monthly rainfalls alone is not enough to study the performance of a system where the storage component is designed to compensate for variations counted in days. And even daily rainfall data are not totally satisfactory since falls of the same magnitude but different intensity can result in different amounts of water recovered due to effects of gutter overflow or evaporation losses. But hourly or even more frequent data are rarely available so daily data will have to do.

In countries where rainfall data are routinely recorded on a mainframe computer the period analysis based on monthly totals as described above would not be necessary. The simulation could be based on full records of daily falls.

For Papua New Guinea only part of the records is computerized and this part is not accessible from within the country. However the period analysis of monthly data apart from identifying the total amount of rainfall during dry periods also identified the times during which these actually occurred. Consequently daily data needed to be entered into computer only for those identified periods.

Determination of initial storage

The numerical simulation of a rain catchment water supply is nothing more than a form of bookkeeping which records day by day how much water comes in, how much is used, and how much is left in storage. The result depends in part on how much was in storage at the beginning of the period being simulated. This dependency on initial storage reduces every time the storage container becomes either empty or overflows and is totally eliminated after both has occurred.

Obviously the result of a simulation is not very useful if it depends heavily on an arbitrary initial assumption. The method used here to eliminate or at least reduce the effects of initial storage was to set the initial storage for the period under study through simulation of a leadup period. To keep any residual effect on the conservative side the storage at the beginning of the leadup period was assumed to be empty.

Simulation procedure

The objective of the simulation stated in simple terms is to maintain a book on what would have happened during a specified period to a rain catchment water supply given a specified sequence of rainfall events. Such a simulation could be made to reproduce real events very closely by including every component of the natural process. This would not only require an adequate understanding of every component but also sufficiently detailed data.

In practice most simulations are a compromise determined by what detail is necessary to obtain results sufficiently accurate for the application intended and also by what data are available.

The application of this simulation was to provide design data on what catchment size and what storage size would be required to satisfy a specified daily water consumption given a particular rainfall pattern. For a standalone system the simulation proceeds as follows:

1. The decision variables are defined.
   These are the catchment size, storage size, consumption rate.
2. The boundary condition is set.
   This is the volume of water in storage at the beginning of the leadup period.

For each day in sequence of the leadup and period under study:

3. If any rainfall is recorded for the day then 1 mm is subtracted as wetting loss on the catchment.
4. The remaining rainfall in mm is multiplied by the catchment size in square metres. The result is the yield in litres.
5. The yield if any is added to the water in storage.
6. If the amount in storage exceeds the storage size then it is cut back to the storage size. If this occurs during the leadup period then the count of overflows is increased by one.
7. If the amount in storage is sufficient to meet the consumption rate then the consumption is subtracted.
8. If the amount in storage is insufficient to meet consumption then the remainder if any is used leaving zero storage. If this occurs during the period under study then the count of days with insufficient supply is increased by one.

The simulation for the same periods is repeated for a system with supplementary topups with the following differences:

The topup volume becomes an additional decision variable for step 1.
There is no count of overflows in step 6.
Instead of recording insufficient supply in step 8 an additional topup is recorded and the topup volume is added to the storage but becoming effective on the next day.

As defined previously the simulation during the leadup period serves to more realistically define the initial storage for the period under study. The count of overflows during the leadup period serves to indicate whether the storage at the end of the leadup period has become independent of the initial storage defined as boundary condition. If the initial storage was set to empty and overflow occurred then the final storage of the leadup period which also is the initial storage for the period under study is independent of that boundary condition.

The two simulations are done for a range of practical combinations of catchment size and storage size. Only one representative consumption rate is used because the results can be used for other rates simply by multiplying the consumption rate, catchment sizes, and storage sizes by the same common factor.

Implementation

The simulation procedure described is quite simple and for a small data set could be done by hand or calculator.

The length of the dry period for design purposes had been defined as three months or 90 days. The leadup period was selected as the 90 days preceding the period under study. A longer leadup period had been considered, but it would have to be very much longer to make a significant difference to the outcome. The extra effort required in obtaining and entering the data mitigated against it. This of course would not apply in cases where daily data are on computer already.

Each simulation had hence to be done for 180 days, once for a standalone system and once for a system with supplementary topups. Catchment sizes and storage sizes were defined in sixteen steps through their practical ranges yielding 256 possible combinations. For each of these combinations the two simulations over 180 days had to be repeated. The number of operations required is beyond being practical if done by hand or calculator. It also raised doubts whether a microcomputer would be sufficient.

A trial programme operating on a reduced data set and written in BASIC executed 2000 balances in 4 minutes. The extrapolated execution time for the full set is more than three hours per station. Although this was not entirely impractical it was decided to try a faster approach. The critical part of the programme was rewritten using the native language of the microprocessor used, in this case a Z80 and taking full advantage of the increased speed when operating with small integer numbers. Instead of three hours the execution time per station became 48 seconds.

On the negative side the time required to write and debug the machine language programme was almost three weeks. It remains an open question whether this extra effort was really justified, but it proves that if used in the appropriate way a microcomputer can do a lot of work normally assigned to a large mainframe computer.

Apart from the main simulation programme the implementation package includes a series of programmes to enter and edit daily rainfall data and to present the results in tabulated and graphical form.

Simulation results

The advantage of simulation over other approaches of systems analysis is its simplicity and transparency. Errors are easily identified and corrected. But one of its most serious disadvantages is its frequent sensitivity to nonrepresentative historical data when used in design optimization (Ven Te Chow 1964).

The simulation as used in this study produces results by summing the occurrence of certain events, e.g. days when the supply was insufficient. When the individual event occurred within the period is not relevant to the result. Summation of this nature tends to reduce the effect of non-representative distributions of events within the historical record. Nevertheless a residual effect can be expected to persist.

Other likely sources of errors are the accuracy of the daily data themselves, errors caused by evaporation/wetting losses different from the 1 mm assumed, errors due to gutter overflow. Due to the absence of relevant data it was not possible to calculate these errors. However all of them combined are likely to be small compared to the final design error inherent in chosing catchment size and storage size from a limited range of standard sizes available to the designer.

The output from the simulation is three arrays of values with the individual values a function of catchment sizes and storage sizes and the arrays themselves a function of the selected simulation parameters, in particular consumption rate, topup volume, and optionally a non zero storage at the beginning of the leadup period. These arrays are:

1. The number of days with insufficient supply (first simulation)
2. The number of topups from a supplementary source (second simulation)
3. The number of days during the leadup period when overflow occurred (counted during the first simulation)

TABLE III
Percent of Days when Supply was met for Different Storage (Tank) and Catchment Sizes, Town of Kundiawa
Median 3 Month Dry Period, Consumption Rate 100 l/day

Tank (m^3) Catchm. m^2	0.4	0.7	1.0	1.3	1.6	2.0	2.4	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	19	20	20	20	20	20	20	20	20	20	20	20	20	20	20
16	26	27	27	27	27	30	36	41	41	41	41	41	41	41	41
20	32	36	36	36	38	42	48	57	63	71	79	79	79	79	79
24	37	40	42	43	47	53	59	69	78	86	100	100	100	100	100
30	57	63	68	71	77	83	89	98	100	100	100	100	100	100	100
35	62	71	78	82	88	94	100	100	100	100	100	100	100	100	100
40	69	81	90	93	98	100	100	100	100	100	100	100	100	100	100
50	77	91	97	100	100	100	100	100	100	100	100	100	100	100	100
60	78	92	99	100	100	100	100	100	100	100	100	100	100	100	100
70	78	93	100	100	100	100	100	100	100	100	100	100	100	100	100
80	82	96	100	100	100	100	100	100	100	100	100	100	100	100	100
90	82	98	100	100	100	100	100	100	100	100	100	100	100	100	100
100	90	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Subtracting the values in array 1 from the period length yields the number of days when the full supply was met. Table III is an example listing the days when the supply was met as a percentage of the period length. The black line dissecting the table separates those combinations where overflow occurred during the leadup period from the ones where no overflow occurred. The combinations in the top right hand corner are those where overflow did not occur, i.e. where the storage at the beginning of the leadup period still affects the result. Because the storage at the beginning of the leadup period was assumed to be empty the performance of these combinations is under-estimated by the simulation.

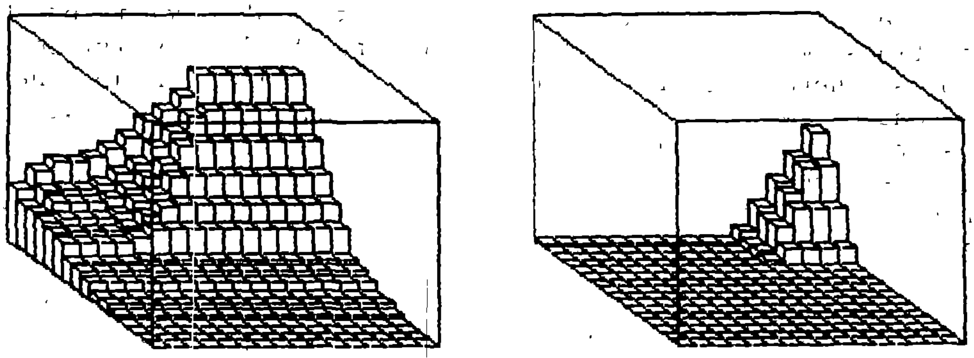
The simulations were carried out for the 38 base stations both for the 50% probable (median) and the 10% probable dry periods. Figure 3 is a 3D-bar graph comparing the results for three representative stations.

The number of topups for the town of Kundiawa obtained from the second simulation are shown on Table IV.

TABLE IV
Number of Times when Supply was topped up for Different Storage (tank) and Catchment Sizes, Town of Kundiawa
Median 3 Month Dry Period, Consumption Rate 100 l/day, Topup 1000 l

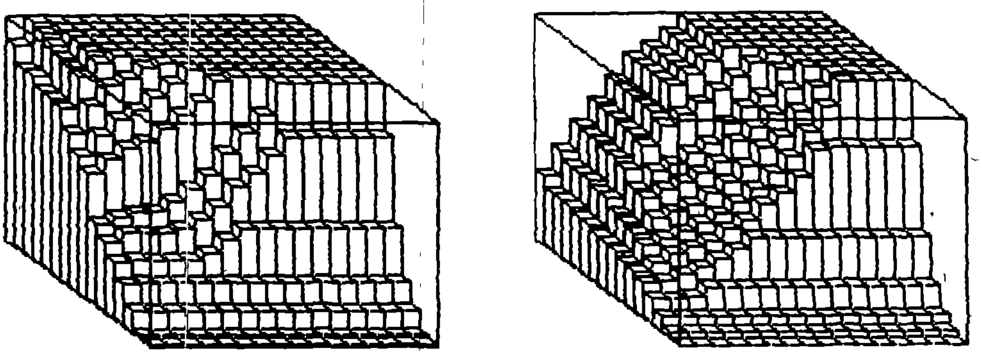
Tank (m^3) Catchm. m^2	0.4	0.7	1.0	1.3	1.6	2.0	2.4	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0
4	18	11	8	8	8	8	8	8	8	8	8	8	8	8	8
7	17	10	7	7	8	8	8	8	8	8	8	8	8	8	8
10	16	10	7	6	6	6	6	6	6	6	6	6	6	6	6
13	14	9	6	6	6	6	6	6	6	6	6	6	6	6	6
16	13	8	6	5	5	6	5	5	4	4	4	4	4	4	4
20	12	6	5	4	5	4	4	3	3	2	1	1	1	1	1
24	12	6	5	4	4	3	3	2	2	1	0	0	0	0	0
30	10	4	4	2	2	2	1	1	0	0	0	0	0	0	0
35	9	4	2	2	1	1	0	0	0	0	0	0	0	0	0
40	9	4	2	1	1	0	0	0	0	0	0	0	0	0	0
50	7	2	1	0	0	0	0	0	0	0	0	0	0	0	0
60	7	2	1	0	0	0	0	0	0	0	0	0	0	0	0
70	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0
80	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0
90	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0
100	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Economical optimization of design could be carried out using the results from arrays 1 and 2 produced by the simulations. However since the costs of catchments and tanks vary considerably it was not practical to include it in this general analysis.



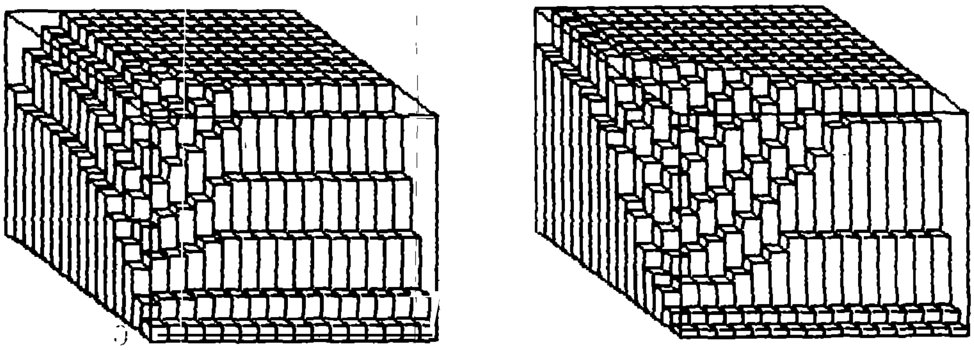
PORT MORESBY NORMAL DRY PERIOD

PORT MORESBY VERY DRY PERIOD



KUNDIAWA NORMAL DRY PERIOD

KUNDIAWA VERY DRY PERIOD



KAVIENG NORMAL DRY PERIOD

KAVIENG VERY DRY PERIOD

Figure 3

Bar graph showing simulation result from three different stations for 50% probable (normal) and 10% probable (very dry) dry periods. Axes represent: Left to right increasing storage, front to back increasing catchment size, height of bars percent reliability.

APPLICATION EXAMPLES

Application to base stations

A base station in this case is any rainfall station for which the full analysis has been carried out, i.e. identification of dry periods from monthly rainfalls followed by simulation using the daily rainfalls for the identified periods. Any of the identified periods could have been used for the simulation resulting in design tables for the corresponding probability of occurrence. The simulation for the median dry period for the town of Kundiawa is used here as example (Tables III and IV).

If the designer has complete freedom in chosing both catchment size and tank storage and if during the normal year the water supply is to provide 100 litres every day without interuption or topup from alternative water sources then any combination from Table III showing a 100% reliability can be selected.

If the catchment is a roof of predetermined size e.g. 30 m^2 then the smallest tank size offering 100% reliability is 3,500 litres. If however one topup with 1000 litres is acceptable then Table IV shows 2,400 litres as the minimum tank size. Similarly a matching catchment size may be selected if the size of the storage is predetermined.

Application to other locations

Applications to locations other than base stations are based on the dry period rainfall map developed from the monthly data (Figure 2). Design tables for base stations which are in the same zone on the map as the location considered can then be used. It should be remembered however that orographic effects are strong and some adjustments to design values obtained from the tables may be appropriate after taking in consideration the aspect of a particular location. Overall the results can be expected to be less reliable than for the base stations themselves but provide an adequate guide if a conservative design policy is adopted.

Application for different rates of consumption

Analysis of the simulation process shows that different compatible units of measurement produce identical numerical results. The design tables may be used for different consumption rates by corresponding scaling of the values on the table margins. For example: the values on the tables as presented were calculated for a consumption rate of 100 litres/day. To use the same tables for a consumption rate twice as high, i.e. 200 litres the roof catchment sizes and tank sizes on both the table margins are multiplied by two.

Larger changes to the scale may cause too much of the catchment and storage sizes to be moved out of the practical range. In that case the simulation should be repeated using the same rainfall data but substituting more appropriate sizes and the desired consumption rate.

CONCLUSIONS

There are very large variations in dry period rainfalls between different areas of Papua New Guinea which are due to orographic effects and orientation of features towards prevailing winds. The common conception that tropical climates have very consistent rainfalls does not necessarily apply.

The magnitude of these variations make it mandatory that the design of rain catchment water supplies takes them into account. An unacceptable waste of resources develops otherwise.

Analysis of monthly data for identification of regimes or zones and of dry periods for these followed by simulation using daily rainfalls from the periods identified allows compilation of design tables. These tables can be made simple enough for application by personnel of intermediate technical training.

The method used requires relatively little entry of data and is suitable for countries where meteorological data are not routinely entered and processed on computer.

A common microcomputer was found adequate to handle the task. This is particularly important in situations where access to a mainframe computer might be difficult or impossible to arrange.

ACKNOWLEDGEMENTS

Data used in this study were made available by the Papua New Guinea National Weather Service, Port Moresby and the Bureau of Meteorology, Melbourne, Australia. The author also wishes to thank Mr. E.S. Webber of the National Water Supply and Sewerage Board and Dr.E. Dekel of the World Health Organization, Port Moresby for their constructive comments and suggestions. This paper was published with the permission of the Secretary, Department of Health, Papua New Guinea.

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THE UTILISATION OF HIGH-RISE BUILDING ROOFTOPS FOR DEVELOPMENT OF A DUAL-MODE OF A WATER SUPPLY IN SINGAPORE

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ABSTRACT

In this study, rainfall data of a new town in Singapore was analysed and a computer program developed to relate rainfall to roof area and demand. The main objective was to develop a dual mode of supply ensuring that the rainwater is used for non-potable purposes like flushing of water-closets. If the rainwater is depleted, an electrically operated mechanism will activate pumping from the cistern containing potable water to the rainwater cistern and the non-potable requirements will be satisfied.

From the computer runs, it was ascertained that in the representative 12 storey high-rise buildings, 5.5% of the domestic demand can be saved by implementation of this dual mode of supply. It is also shown that such a system is more effective in a 4 storey building. The water from such systems will be cheaper but it has to be ensured that the mechanism developed should be very reliable and ensure effective and continual water supply to the rainwater cistern.

INTRODUCTION

Singapore lies about 1° 19' north of the equator and has a total land area of 620 km^2. It has a population of 2.5 million that is growing at a rate of 1.1% (Statistics Department, 1984). It is hence conceivable that the domestic demand of water will also escalate.

The production cost of water in Singapore has been progressively increasing over the years to the extent of 30% between 1979 and 1982. Besides, a sum of S$362 m has been spent on new water projects between 1973 and 1984 (Foo, 1983). There is thus an urgency to look for possible other cheaper and alternative sources of water supply.

As 80% of Singapore's population lives in high-rise buildings, (Housing and Development Board, 1983), a study on the use of rainwater as a supplementary source of water in such buildings is being looked into.

FACTORS AFFECTING RWCS IN HIGH-RISE BUILDINGS

In Rain Water Cistern Systems (RWCS), the parameters that bear major significance are the stochastic pattern of rainfall, the catchment (or roof) area, output (or draft/demand) and storage (size of cistern). The adequacy of cistern size will be closely related to the established relationship amongst the rest of the parameters.

The major constraint in harnessing water falling on roofs of high-rise buildings is the limited catchment area that is available. Besides, the abstracted water may have to be treated or, alternately, the water can be used only for non-potable uses. In either case, if the abstracted volume of rainwater is insufficient at any point of time, there arises the need to have an alternate source of supply. In the Singapore context, there is an existing water supply system which will have to come into operation in case the stored rainwater is depleted. Thus there is the need for a dual-mode of supply.

This type of problem has been previously identified by integrating RWCS with existing supply systems (Ikebuchi and Furukawa, 1982) and by reusing a combination rain and wastewater (Fewkes and Ferris, 1982), in both cases the water being used for flushing purposes only.

In Singapore it is prohibited to have the inlet of the existing potable water supply system submerged in a cistern containing an alternate source like rainwater (Public Utilities Board, 1977). There is thus the need to develop the dual mode of supply to also cater for this requirement. Using a simple input/output concept developed earlier (Appan, 1982) a computer programme was formulated and a rainwater-priority system developed. Besides this system which was applicable to conditions where the roofwater inlet is at a higher level than the inlet of the potable water, a proposal was also made for a system wherein both the potable and rainwater tanks are at the same level (Appan, 1983).

OBJECTIVES

The main objectives of this study are:

(1) To develop computer programs and a working system for a dual mode of supply in high-rise buildings such that the current supply of potable water can be augmented by the rainwater being collected on roofs.

(2) To calculate the percentage of rainwater that can be used for non-potable purposes, the volume of potable water to be supplemented and the frequency of spillage in relation to an optimum cistern size for a representative block of flats.

(3) To carry out a sensitivity analysis for the major parameters.

(4) To do a cost analysis on the implementation of dual mode of supply in high-rise buildings in Singapore.

FLOW CHART AND COMPUTER PROGRAM

The flow chart developed was geared to suit the available data and meet specific output requirements (see Figure 1). The algorithm ensures that parameters printed out are percentage of draft satisfied, percentage of rainfall collected, frequency of failure of system, spillage, spillage volume, volume to be supplemented by existing water supply system and number of pumping operations required. Sufficient flexibility is provided in terms variable cistern volumes, number of storeys and roof areas.

PRINCIPLE OF THE RWCS DUAL SYSTEM

Rain falling on the roof of a high-rise building enters the cistern. If the capacity of cistern is exceeded, water overflows and is wasted. Water is then withdrawn to satisfy the water demand. If the water level falls to a predetermined low level in a situation where supply from the potable water tank is gravitated to the rainwater tank, the simple rainwater priority system developed earlier (Appan, 1983) can be used.

If the two cisterns are in the same level, there is need for a system to activate flow from the potable water tank to the rainwater cistern when the latter does not have enough water to meet the demand. In the electrical system developed, when the water level falls to a low level, the electrodes will cut in and an inflow (by pumping) from the existing water supply system will be activated. The cut out will be effective when the top water level is reached. The simple electrical system involving control of pumping by means

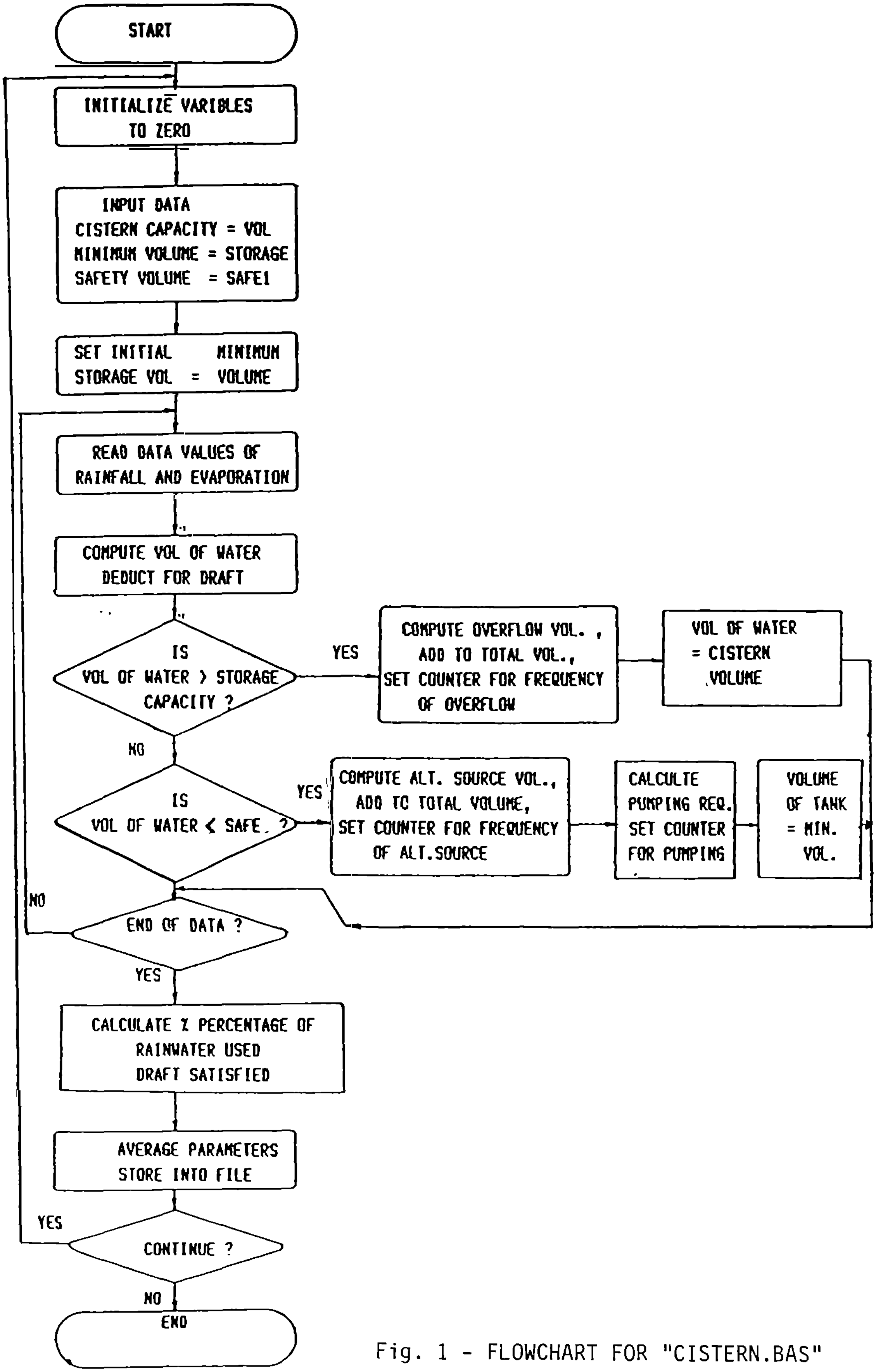

Fig. 1 - FLOWCHART FOR "CISTERN.BAS"

of a solenoid valve is shown in Figure 2.

Water left at the end of the day will be carried over to the next time interval. For all practical purposes the discrete time interval of one day has been considered.

CASE STUDY

The study area chosen was Ang Mo Kio, a fully developed new town in Singapore. Ten years' rainfall data was obtained from the nearest rainfall station at Lower Peirce Reservoir (Meteorological Service, 1983) and analysed.

A block of high-rise flats 12 storeys in height was considered to be representative. Its roof area of 1250 m^2 was used in the computer analysis. The estimated number of flats is 168 per block with an average of occupancy of 4.8 persons per flat (Tan, 1982).

Average water consumption of 140 lpcd and a flushing volume equivalent to 24% of the per capita usage have been used to represent the local requirements (Lim, 1983).

COMPUTER RUN RESULTS

Using the program that was developed, a series of outputs was generated for the available field data. For the representative 12 storey high-rise building, varying the cistern size from 40 to 90 m^3 and using a calculated draft, characteristics of the system were generated. The values obtained for this range of sizes (see Fig. 3) indicate that there is only an increase of 3.2% in the rainwater used corresponding to an annual frequency of failure of 242 to 231. The optimum cistern volume of 60 m^3 has been ascertained by comparing marginal increases in the percentage of rainwater used.

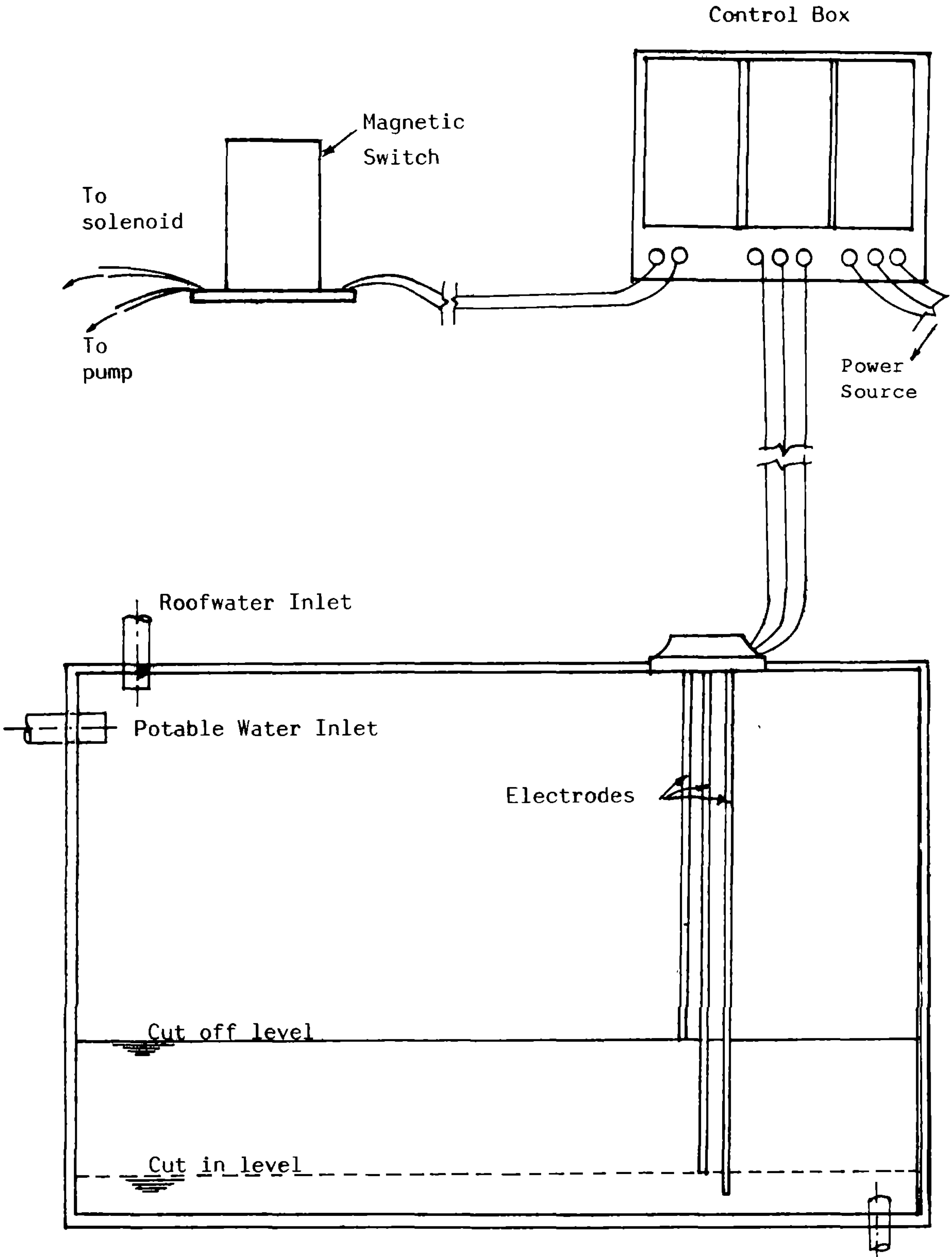

Fig. 2 : RAINWATER - PRIORITY SYSTEM
(Electrical Control for cisterns at same level)

Roof area = 1250 m²
Number of storeys = 12
Percentage of water used for flushing = 24%

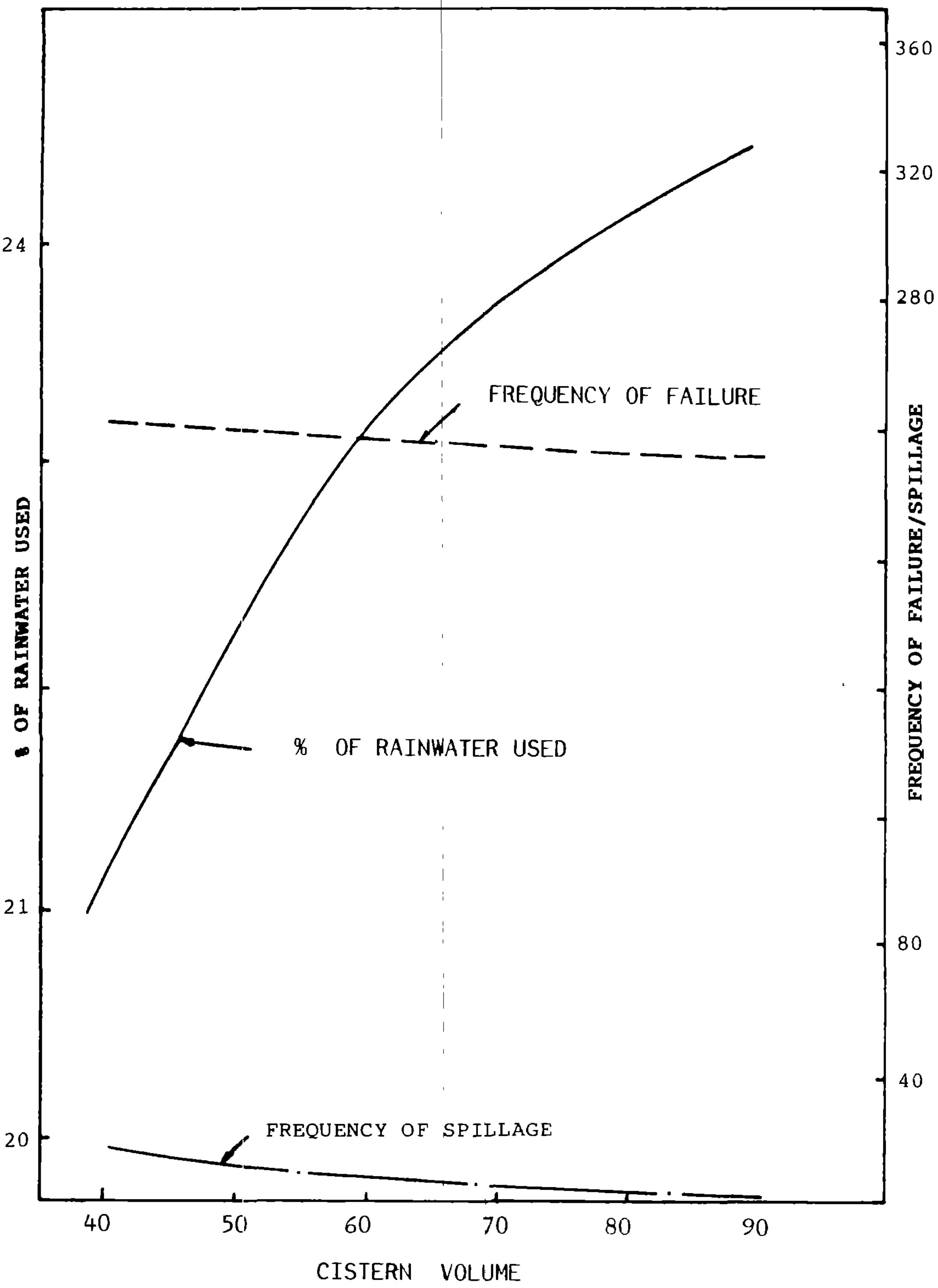

Fig. 3 : VARIABLE CISTERN SIZES AGAINST OUTPUT

As the draft will change with number of storeys, a sensitivity analysis was carried out to check the response (see Fig. 4). The considerable increase in 57.4% of rainwater used in the case of four storeyed flats against 17.9% for 16 storeyed flats, indicated that the system is more effective for the low-rise flats.

Another analysis carried out was to assess the effect of overall savings in water usage per capita in relation to variability in flushing volumes. The results (see Fig. 5) are quite conclusive in that by a changing the flushing volume from 15% to 30%, the corresponding savings in water usage was only marginally significant as it varied from 5.2% to 5.7%.

COST ANALYSIS

The investment cost consists of an initial capital outlay involving construction and materials cost of the cistern, light-roofing (above the flat roof of the block of flats), a rainwater-priority electrical system and installation of separate piping systems.

The benefit of the dual system consists of savings in the operational cost of existing water facilities and the interest saved due to deferment of capital schemes, the unit cost of leakage approach (Department of Environment, 1980) being used to determine the latter.

Based on a 20 years loan repayment scheme, the present worth of RWCS investment for dual system is calculated to be S$85.95 million. The current cost of water being supplied is 53.5 cents. The cost of rainwater based on current loan interest of 10% was 39.5 cents.

CONCLUSIONS AND RECOMMENDATIONS

(a) For a representative 12 storey high-rise building, the computed

Volume of cistern = 60 m^3
Percentage of water used for flushing = 24%
Roof area = 1250 m^2

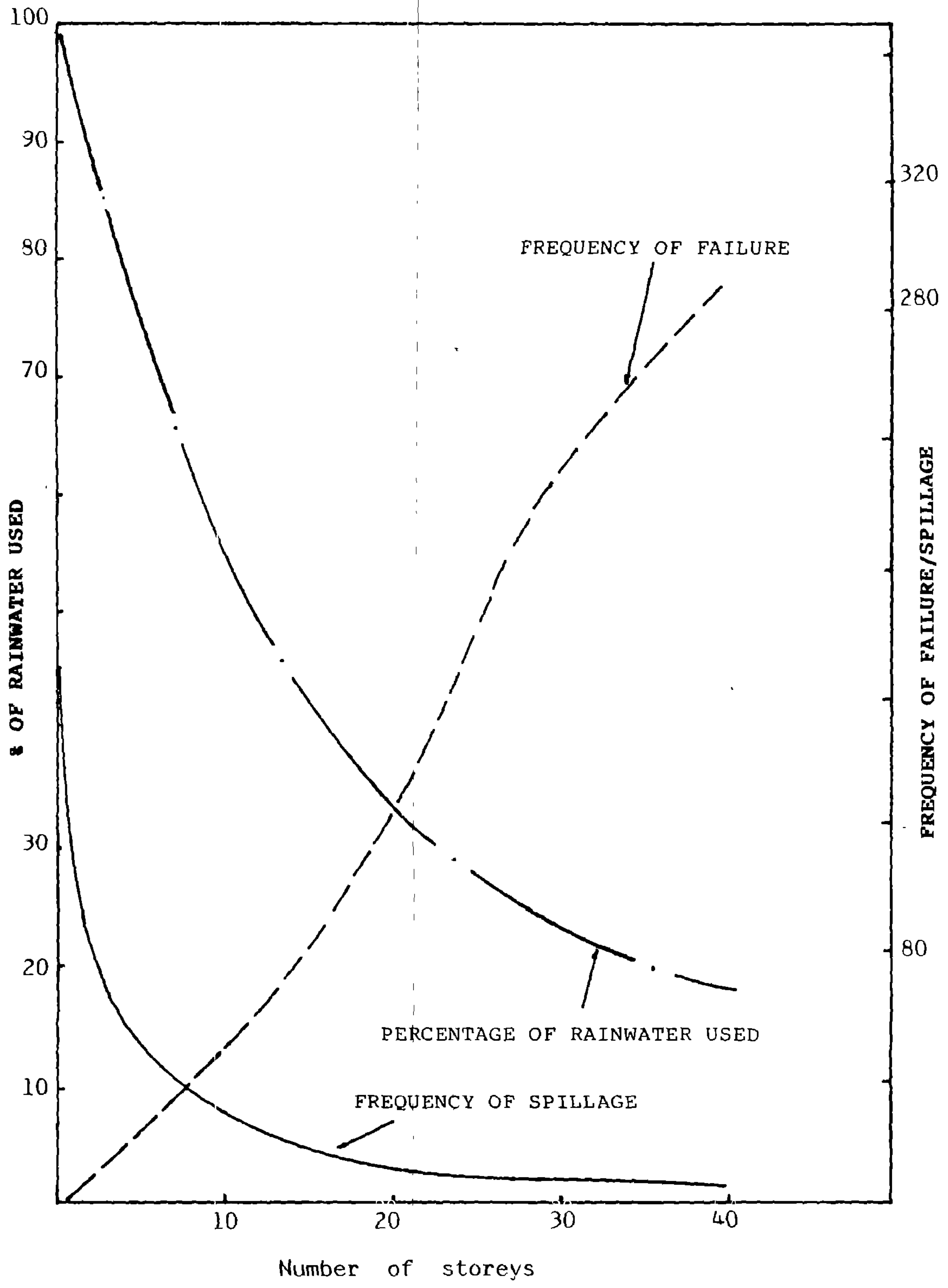

Fig. 4 : NUMBER OF STOREYS AGAINST OUTPUT

Cistern volume = 60 m^3
Roof area = 1250 m^2
Number of storeys = 12

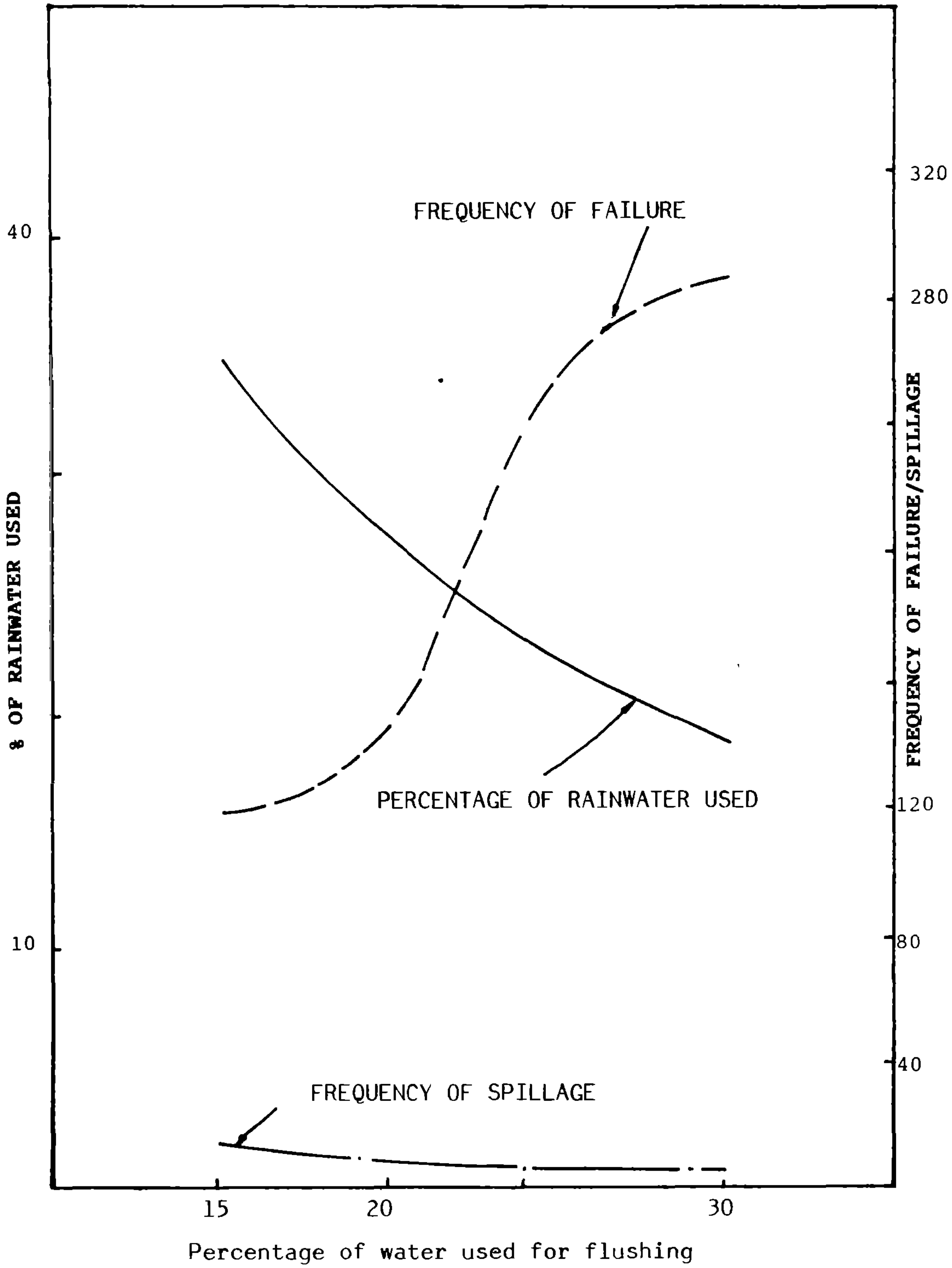

Fig. 5 : VARYING DRAFT AGAINST OUTPUT

storage volume is 60 m^3, which will result in savings of 5.5% of domestic demand.

(b) If roof areas of blocks remain unchanged, the prospect of RWCS looks brighter in low-rise buildings which have an overall savings of consumption of water 13.7%.

(c) In cases where the rainwater-priority system is to be activated by an electrical system, special care has to be taken that the system is well-maintained and is foolproof.

(d) The dual system is capable of collecting 5.7 million cubic metres of rainwater per year in the existing 12 storey flats. Based on the current interest loan of 10% and 20 years repayment scheme, the cost of rainwater is calculated to be 39.5 cents per m^3 against the current cost of potable water which is 53.5 cents per m^3.

(e) Besides the economic considerations, intangible benefits such as further development of limited water resources and attenuation of floods in highly urbanised areas should be considered in the overall evaluation of RWCS.

(f) If such dual systems are to be installed, the structural stability of existing flats have to be investigated (Appan, 1983). This is due to the vast differences in the structural design of the existing high-rise buildings and the need to cater for the additional load of RWCS.

(g) The potential of RWCS can be further investigated for use in factories, schools and, preferably, in any type of buildings which have large roof or land areas. Besides, with some pre-treatment of collected roofwater, there is also potential for establishing RWCS in industries which are high consumers and do not need a water having potable quality standards.

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THE TERRACE-CISTERN SYSTEM

A CALL FOR EXPERIMENTATION

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ABSTRACT

The paper recalls that the terrace-cistern system described in earlier works (Nascimento, 1982) is the association of two very old techniques: land cultivation in terrace and cistern storage of rainwater caught from terraces.

Potential advantages to be taken of the system are also recalled: best use of water, protection against erosion, struggle against desertification, flood control, etc.

An analysis is made of the mechanism of water drainage above the groundwater level, and new advances are reported that provide for better adaptation of the system to the existing ground: catchment with geotextiles, and possibly cisterns outside terraces.

The development of the system calls for experimentation in different conditions of climate and terrain, from which construction specifications and operation outputs could be derived.

There is the description of a first experiment though on very limited scale, and the need for other experiments in different regions is emphasized.

INTRODUCTION

The terrace-cistern system (TC), a research project already presented in earlier works (1982), is the combination of two very old techniques: the terraces, for land cultivation and defense against erosion; and the cisterns, for rainwater storage.

The rainwater that drops in the terraces is collected and conducted to cisterns where it is stored and protected from evaporation to be later used in those terraces.

Rainwater is so collected in the source of runoff, merely a few meters downstream of the rain droping position; and it can also be used in the very terraces where it was collected, that without necessity of significant elevation or transportation.

The combination of terrace and cistern technologies to form the TC system so opens much wider land and water management prospects than either of the technologies alone might provide.

In effect, the system chief potentialities are the following:

a) Making feasible exploitation of lands whose survival depends on small amounts of water provided by the cisterns in periods of drought;
b) Improving the profitability of certain already existing exploitations, with the help of the water supplied by the cisterns;
c) Protecting against erosion, because the collecting of water and its storage in cisterns reduces the runoff;
d) Contributing to fight flooding, because, if the area where the TC system is installed is an important part of the drainage basin, it will significantly abate flooding;
e) Contributing to fight desertification, by the joint effects of some plant coverings (a), defense against erosion (c) and flood reduction (d).

As can be seen, the potentialities of the TC system are especially promising in low rainfall, arid or semi-arid regions, where rainwater, though precious it may be, is often wasted and a cause of damage.

Nevertheless, the TC system relatively high cost, as well as some doubts about its technology, are the main drawbacks to its application.

However, the fast evolution of various factors such land degradation, desertification, development of urban zones, demographic pressure makes it increasingly necessary and urgent to improve land and water management in a significant way.

In this changing times the always growing value of land and water will certainly, in a short while, balance the system's cost.

Moreover, the system's construction may begin and be tested in small pilot areas, without great investments. After experimentation of its workings in those small areas, the system can then be spread to other areas.

That is to say, investments in the system can be made by stages in order that the experience obtained in a previous phase may be integrated in the following phase.

In the present paper two advances in the technology of the system are reported that can ease its application: the collecting with geotextiles and the terrace-independent cisterns. Questions put by the corresponding technology are also referred to, which only experience can answer.

That's why a call for experimentation is here made.

CATCHMENT WITH GEOTEXTILES

In previous works referred to above, about the TC system, it was considered that cisterns would be integrated in terraces and the catchment of water be made by trenches and gutters.

However, the recent geotextile technology allows for other solutions in catchment.

Fig. 1 shows a catchment in trench in which a drain pipe was set. That pipe already available in market is made of PVC grooved and perforated tube, with a diameter of 50 mm or 60 mm, covered with a geotextile. This geotextile works as a filter, stopping soil grains, dragged by water, from penetrating the pipe, blocking it up. As the pipe is very flexible, it can easily be adapted to any trench design.

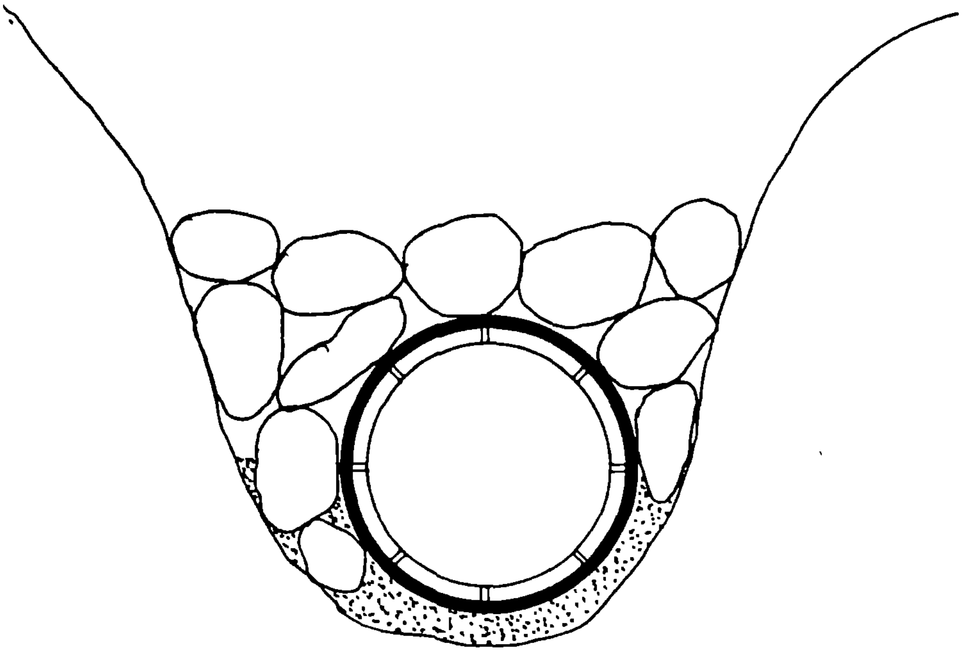

Fig. 1 - Catchment by drain made of a geotextile covered tube

Pebbles or crushed stones are placed over the pipe for various purposes: steadying the pipe, without hindering easy admission of water; avoiding that runoff along the trench reaches erosive speed; and protecting pipe against detrimental actions (footings, animals, ect.).

An inconvenience in this catchment could be the voids of pebble being filled with sediments from soil erosion in the terrace.

As a matter of fact, while in the pipe zone in contact with clean pebbles water is directly collected from the runoff, not yet infiltrated into the sediments between pebbles, the water that comes from percolation through the referred to sediments is collected on completely different conditions.

For better elucidation of those conditions, some aspects of the drainage mechanism over the groundwater level follow.

In Fig. 2 let us consider water infiltration of runoff in a soil where the groundwater level (NF) is found at a certain depth.

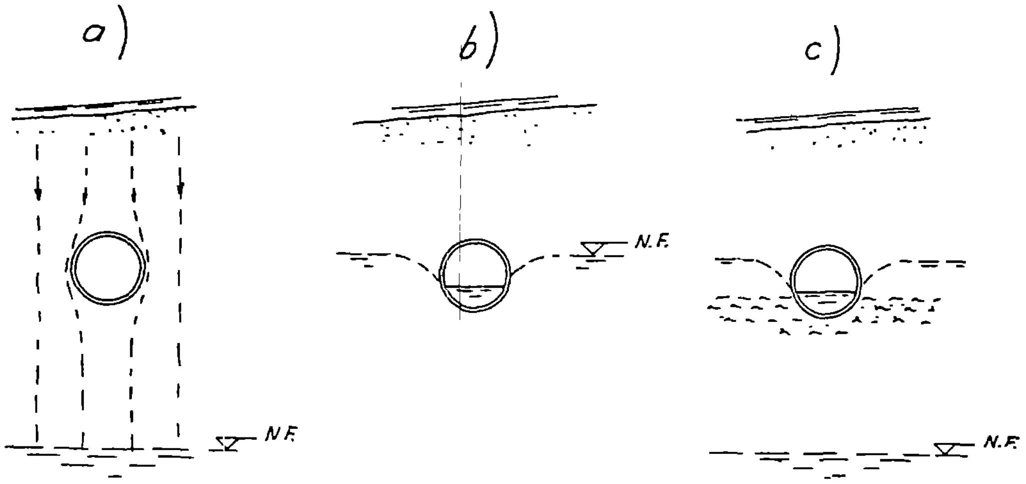

Fig. 2 - Water collecting above the groundwater level

If a drain is put in the ground above NF (Fig. a), it will collect no water because the flow lines will get round the drain by effect of soil capilar suction. The drain will only retain water if the NF raises to the drain level (Fig. b).

A drain above the NF will also collect water if there is a less permeable layer in the soil that will temporarily retain a suspended water nappe (Fig. c).

In Fig. 3 an experiment is sketched that makes completely clear such mechanism (1953).

Other, still simple experience is the following (Fig. 4):

Waterfeed the top of a cloth hanged as shown in the figure. If there is a hole in that cloth, the water dripping down it will get round that hole in a way similar to Fig. 2 and Fig. 3. In the bottom of the cloth, however, the accumulation of water, making drops, reduces the capilar suction and allows that it outs the cloth, dropping.

In light of this mechanism, in Fig. 5 are sketched situations that may occur in the drain.

In Fig. a) with the pebble all clean, the drain captures water directely from the runoff, so obtaining the maximum rate of flow Q_d.

In Fig. b) the fractions of the perimeter of the drain contact with sediment more permeable than the ground. The water infiltrated in the sediment remains there, suspended as in Fig. 2c. The total

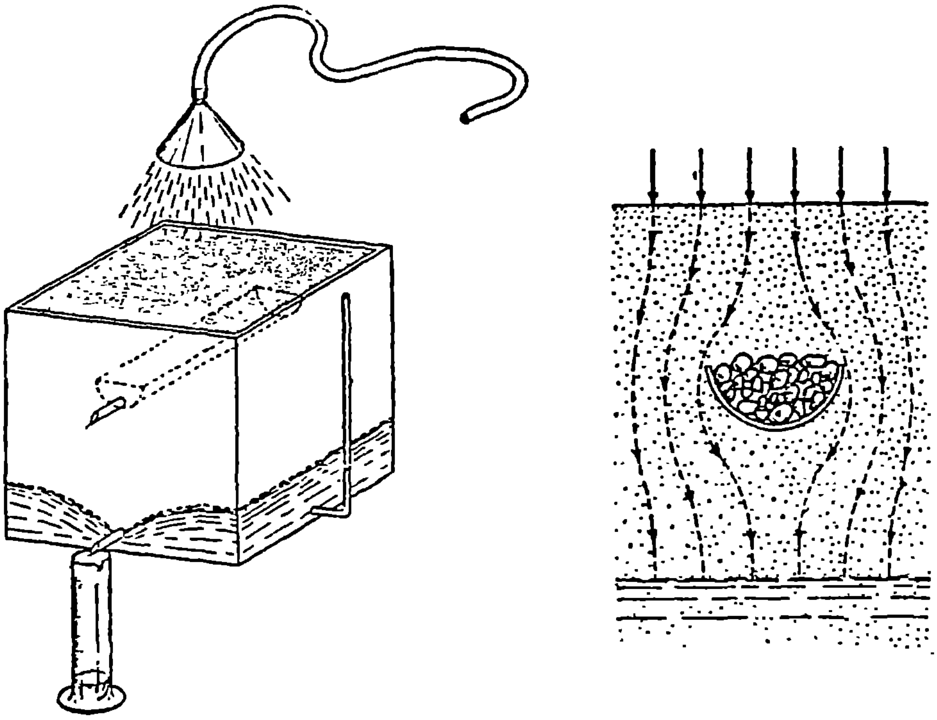

Fig. 3 - Above groundwater level, water trickles away in sand and does not go into the drain.

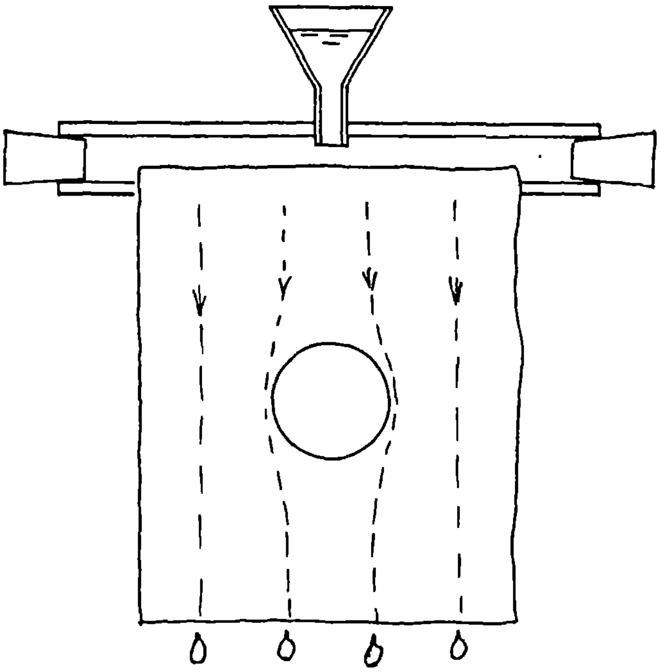

Fig. 4 - Water dripping from a hanged cloth gets round the hole in that cloth.

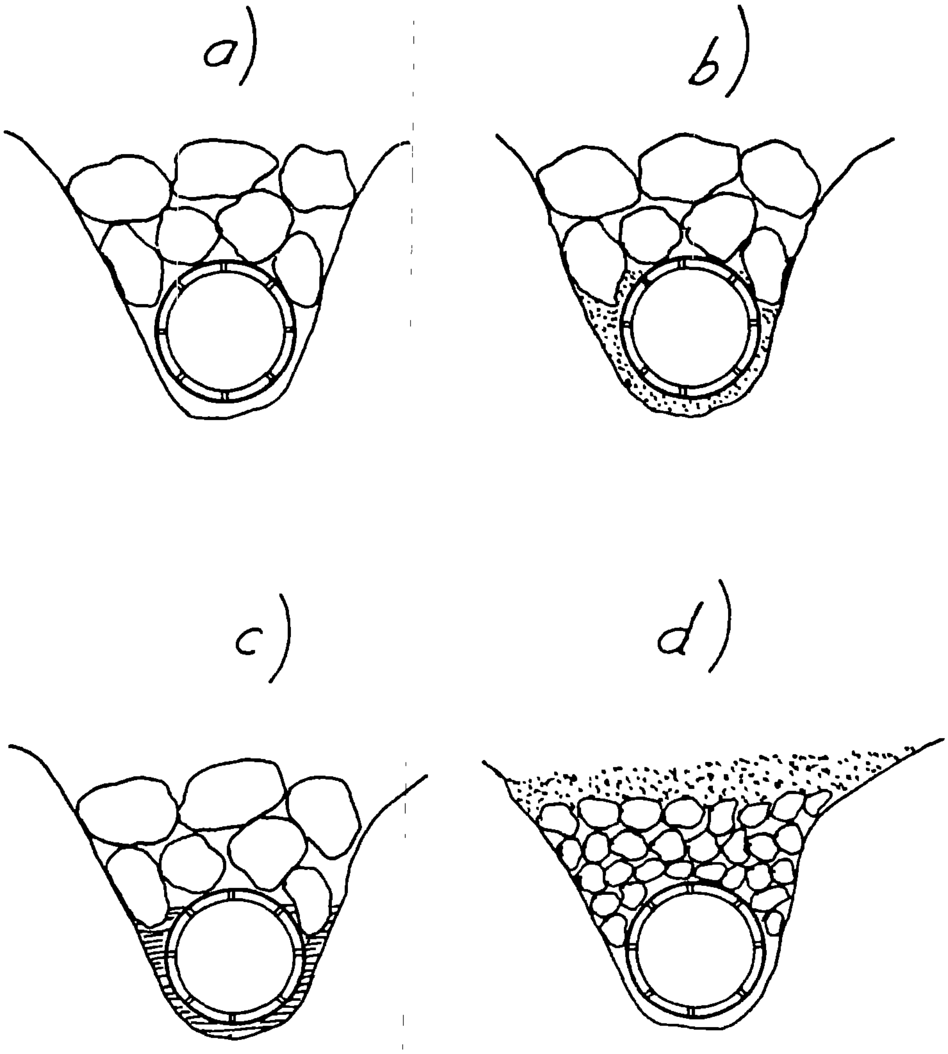

Fig. 5 - Sediments effect in catchment

rate of flow will approximately be the sum

$$Q = (1 - S)\, Q_d + S\, Q_s \qquad (1)$$

Q_s being the flow the drain would retain if it were completely wrapped in sediment.

Fig. c differs from Fig. b) only because the sediment is less permeable than the ground. Consequently the infiltrated water gets round the drain as in Fig. 2a. The total flow retained by the drain is also given by (1) but for $Q_s = 0$.

In this case, however, two situations have to be distinguished: if the geotextile capilar suction is greater than that of the sediment some water will enter the geotextile and will drip down it until the lower generatrix of the tube, without entering the tube. Water accumulation there reduces capilar suction and thus water can be absorved by the underlying sediment and then infiltrates into the ground. In other conditions, with the geotextile capilar suction lower than that of the sediment, water there infiltrated goes down, and does not penetrate into the geotextile.

In Fig. d) the sediment stores up over the pebbles for one of two reasons: either it was accumulated by runoff but, being too coarse relatively to the pebble, could not accomodate between the pebbles; or it was not deposited by runoff but by any other action (wind, animals, men).

In this situation the drain retains only water that has infiltrated in the sediments, remains suspended in the trench and then goes into the pipe. The collected flow depends on the percolation through the sediment, and certainly will be very different from Q_s.

The effective life of this type of drain so depends on how fast the pebble is sediment-filled, that is, on the intensity of erosion upstream. To increase that life, erosion in terraces must be reduced as much as possible. And, on that account, the shape and width of the terraces must not exceed proper values, depending both on the nature of ground and of crops therein cultivated.

However slow as it may be, sediment deposition will always make the drain useless. The problem of how to recover it will then be put, involving repair or replacement works.

To increase the drain effective life, one can resort to another conception sketched in Fig. 6.

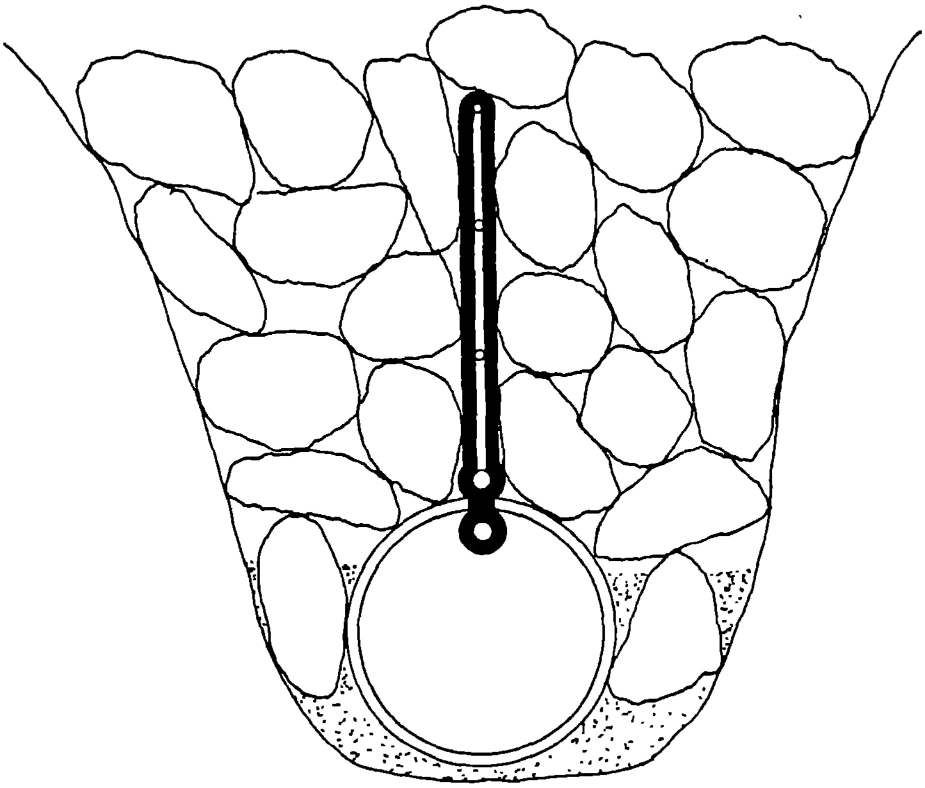

Fig. 6 - Catchment by drain made of a tube with a geotextile curtain.

The water, collected by a geotextile vertical curtain, drips down to the inside of a tube. With this finality the curtain goes into the tube by a slit opened longitudinaly in it, by its upper generatrix.

To assure that the curtain is kept upright, chiefly during the installation, the geotextile must present a certain rigidity, either because it contains reinforcement (composite geotextile), or because its characteristics of manufacture by themselves make it stiff.

In the drain shown in Fig. 1, detrimental efects of sedimentation are felt since the beginning. On the other hand, in the drain of Fig. 6 those effects are felt only later, when the sediment surpasses the tube and reaches the curtain. In other way, even when the curtain was already reached by the sediment some infiltrated water can still be collected if, as mentioned above, the geotextile suction exceeds that of the sediment. On the contrary, in the same situation, drain of Fig. 1 will collect no water.

Still another drain conception is the one sketched in Fig. 7.

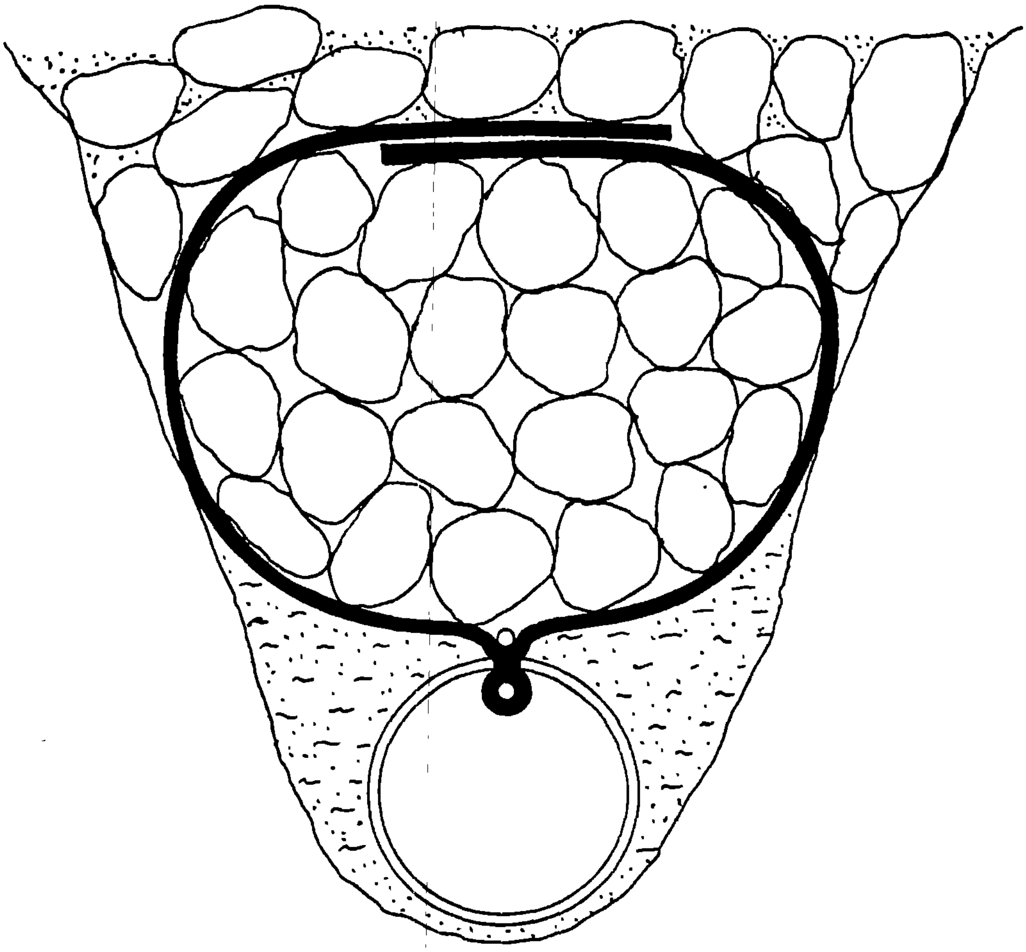

Fig. 7 - Catchment by drain made of a tube with a double flexible curtain.

The geotextile makes two flexible curtains that joint in the tube slit. After the tube has been placed in the trench and covered with soil, pebble is put in such a way as to be enveloped by the curtains. Some pebble is also put over it.

In this case the curtains stop the sediments, and so avoid the filling up of the voids of the underlying enveloped pebble, though the overlying pebble is filled up. In this way, however, drain maintenance will possibly be easier provided that sediments are periodically removed.

CISTERNS INDEPENDENT OF TERRACES

In preceding works on the TC system, cisterns were presented integrated in terraces.

The system will however be more adaptable to the various ground conditions if cisterns were independent of terraces.

In effect, in this way neither terraces are conditioned by cisterns, nor these must have shapes and sizes compatible with those.

Terraces can so be any already existing terraces, in which catchment drains are installed, as in Fig. 8a, or new terraces reduced to an assembly of ridges to intercept the runoff, as in Fig. 8b.

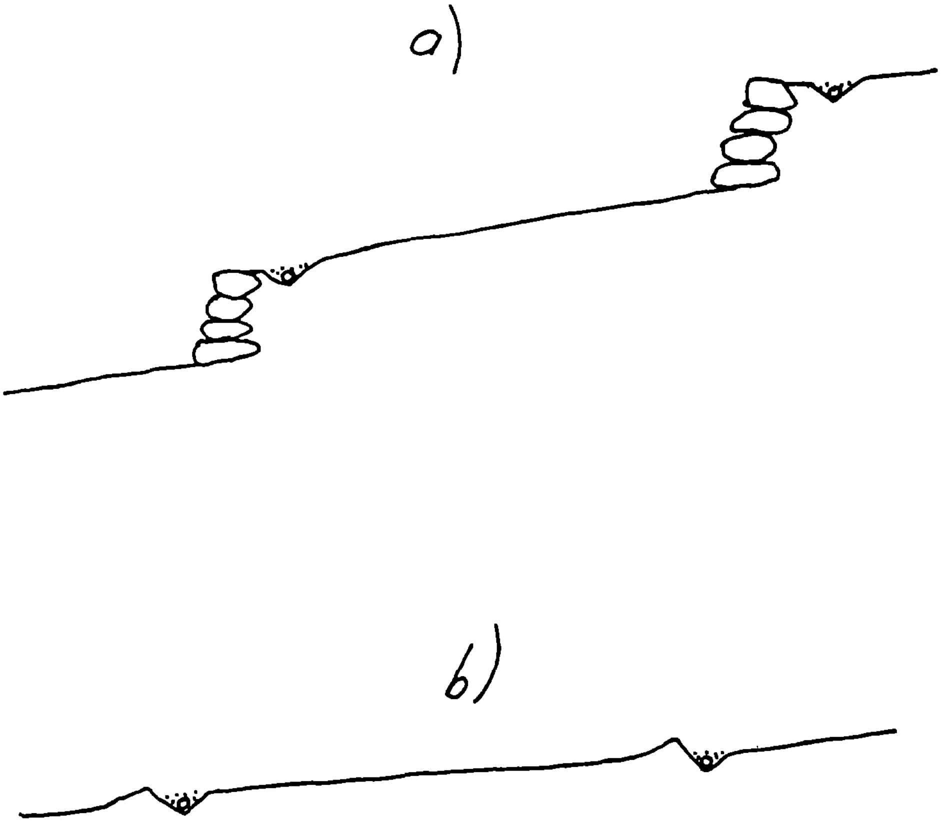

Fig. 8 - Catchments in already existing terraces (a) or in new terraces simply made out of ridges (b).

For the cisterns, in their turn, several traditional solutions are possible.

Besides masonry cisterns in ancient military and religious works other solution of a more rural character exist all over the world.

For example: China underground cisterns and those in Negev desert, attaining about 10 m3, and covered in masonry; Australia underground concrete cisterns, generally of 100 m3, masonry cisterns with a galvanized iron sheet cover supported by a wood structure; fired clay pots in Africa, Asia and Latin America; pots made by moulding cement inside and outside over a large granary basket (Ghala tank); wooden barrels in Europe, North America and Australia; etc. (United Nations Environment Programme, 1983).

Besides these traditional solutions lots of others are possible resorting to more recent materials, such as: prestressed concrete, prefabricated concrete, cement-gun, etc.

Modernly membrane technology still allows for other solutions, as nylon-reinforced butyl bags, already available in market with capacities reaching 228 m3 (U.N. Env. Prog. 1983).

Cisterns independent of terraces make it possible on the other hand, to install them in places where the terrain is less favourable for cultivation or more favourable for cistern construction.

A GEOTEXTILE SMALL EXPERIMENT

Hereinafter is described a small experiment still in progress, related to catchment with curtain-drain.

It is carried out in Algarve, in Manta Rota, between Tavira and Vila Real de Santo António.

It is a curtain-drain with a length of 5 m, which collects the water from a terrain with about 10 m2, near a house (Fig. 9).

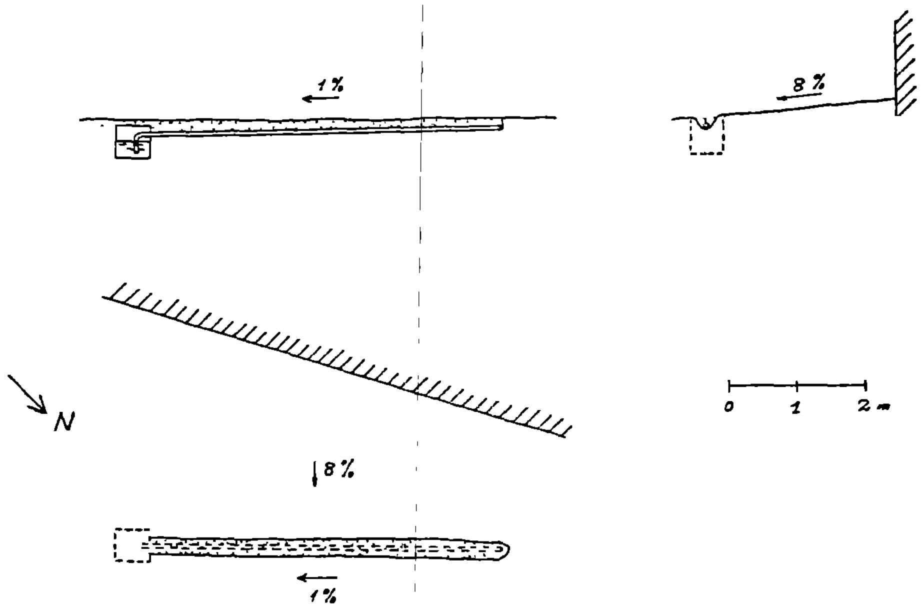

Fig. 9 - Sketch of the experimental terrace-cistern

The curtain-drain, with a pipe of 50 mm diameter, is of a type sketched in Fig. 6, the geotextile being reinforced with a plastic netting. The collected water is driven to a cement cistern, of a cubic shape, with a nominal capacity of 100 l. Its effective capacity is however of only 87 l, because above that volume, the water is discharged to the terrain by the admission aperture of the drainage pipe.

The cistern has a cover, also in asbestos cement, which in turn is covered with soil with the thickness of 5 cm to 10 cm.

In the cover there is a small hole of 1 cm diameter, normally plugged with a cork, that is used to allow the water volume to be measured inside the cistern. That measurement is made by withdrawing the soil in the cork zone, removing this and introducing in the hole a rod graduated for the effect.

In Fig. 10 the results until the present date are shown.

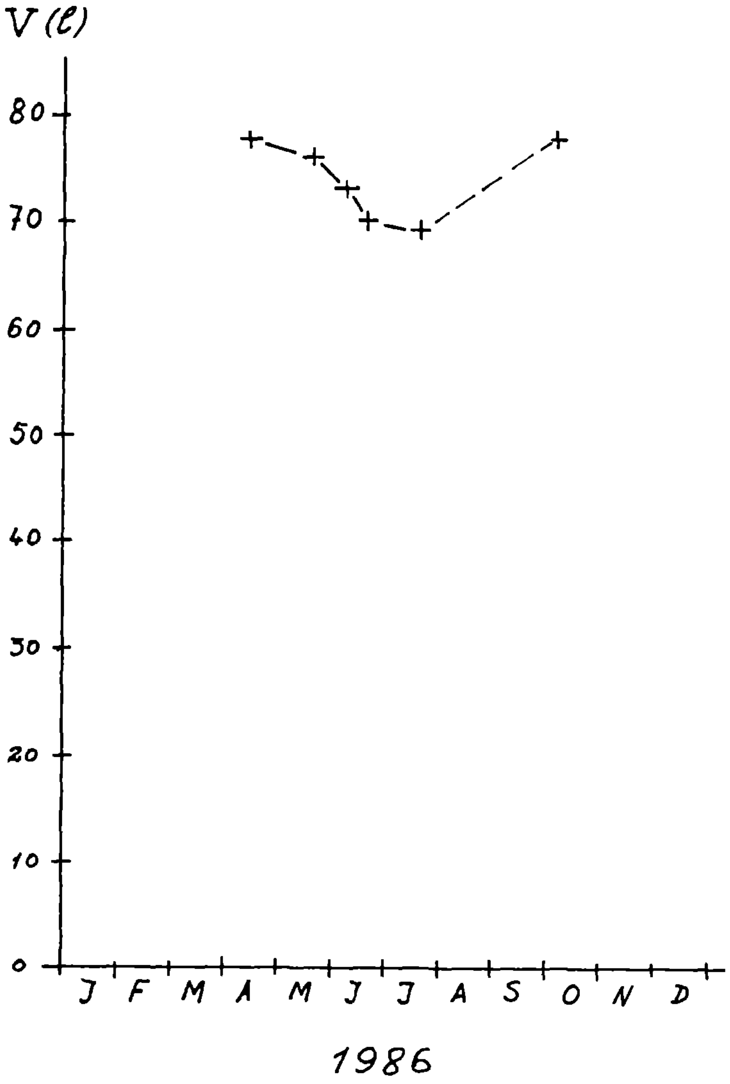

Fig. 10 - Water volume of cistern versus time.

The figure shows that from April, during drought, the cistern has already lost some water. The rate of lost decreased after July because, inside the cistern, the pipe was extended and plunged into water.

The drought being over in October, the water raised again in the cistern. It is too early, however, for drawing conclusions from the experiment.

APPEAL TO EXPERIMENTATION

The main questions about TC system are the following:

- What are the types of catchments and cisterns more appropriated to a certain region?
- What is the water volume the system can provide in the period of the year where it is more necessary?
- What is the system cost?

But the following questions can also be made about the eventual system benefits:

- What will be the benefit obtained if TC system makes the exploitation of certain terrains more profitable?
- What will be the benefits resulting from exploitation by the TC system of certain non-cultivated terrains?
- What benefits will be obtained with the contribution of TC system in the reclamation of certain terrains degraded by erosion, flood or desertification?

Answers to this questions would certainly be of interest.

But only by experimentation can we have those answers.

By this very reason, in this paper an appeal to experimentation is made.

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FERROCEMENT CYLINDRICAL TANKS FOR RAINWATER COLLECTION IN RURAL AREAS

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ABSTRACT

In rural areas of many developing countries, rainwater is collected for drinking and washing purposes. The need for simple, economical and durable storage facilities which can be constructed by means of locally available construction skills and builidng materials is self evident. The main objective of this paper is to propose a ferrocement water tank design and attendant construction technique that will ensure durability and long service life. Based on an analysis of the water tanks and test results of the mechanical properties of ferrocement elements, the reinforcement details of two cylindrical tanks of $5m^3$ and $16m^3$ capacities are presented. The tanks were constructed and tested. The test results together with illustrations and photographs showing the construction sequence suitable for rural applications, are presented in this paper.

INTRODUCTION

In the rural areas of many developing countries, there is a scarcity of water for drinking and washing. Traditionally rainwater is collected for such usage and the problem is to provide simple and economical storage facilities which can be constructed with unskilled labour. Toward this end, the International Development Research Centre (IDRC) funded a project on 'Rainwater Collection' for the rural areas of the Philippines. This paper is based on a study (3) carried out for the IDRC on the design and construction of cylindrical ferrocement water tanks for rainwater collection.

Ferrocement is defined by ACI Committee 549(1) as a thin-walled reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small diameter wire mesh. Extensive investigations have been carried out on practically all aspects of the mechanical properties, construction techniques and various possible applications of ferrocement and the basic technical information for the design and construction of ferrocement structures is now fairly well-established (1, 4 - 7). In recent years, a great deal of interest has been created within the Southeast Asian region on its potential applications in the fields of agriculture, housing and industry (5).

Ferrocement construction is labour intensive and suitable for rural applications in developing countries. It does not require heavy plant or machinery and being a low-level technology, the construction skills can be acquired fairly quickly. Ferrocement is ideally suitable for the construction of thin-walled structures such as water tanks and ferrocement tanks of $20m^3$ capacity have been in use in New Zealand since the late 1960's (2).

In this study, two ferrocement cylindrical tanks of $5m^3$ and $16m^3$ capacity were analysed, designed, constructed and tested. The test results and construction techniques are discussed.

ANALYSIS AND DESIGN

Analysis

The adopted water tank design consists of a cylindrical wall rigidly connected to a circular base plate at the bottom and covered by a truncated conical roof on top as shown in Fig. 1. Two tanks denoted as Tank A and Tank B were analysed using the linear elastic theory for thin shells. Each of these tanks has a wall height of 1.8m, the internal diameters are 2.0m and 3.6m for Tank A and Tank B respectively. Both tanks have a wall thickness of 35mm whilst the base thicknesses are 35mm and 50mm for Tanks A and B respectively. In each case, the roof has a thickness of 25mm and a slope of 1:3. An opening of 0.8m diameter is provided at the centre.

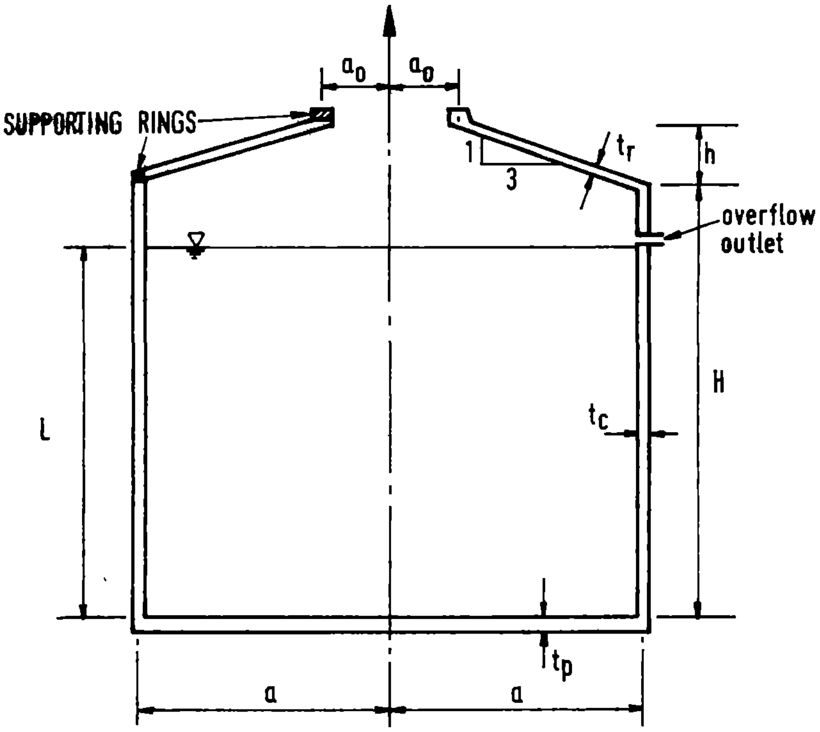
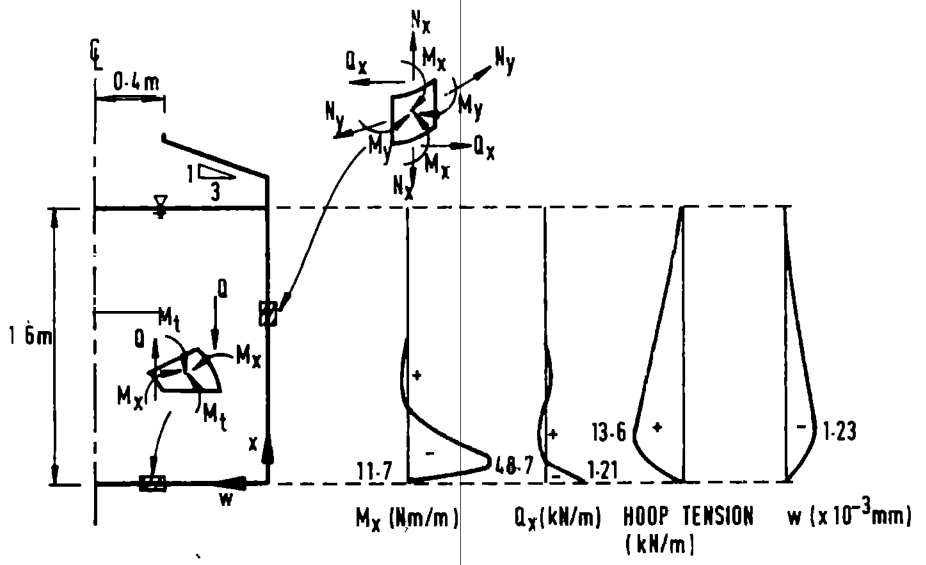
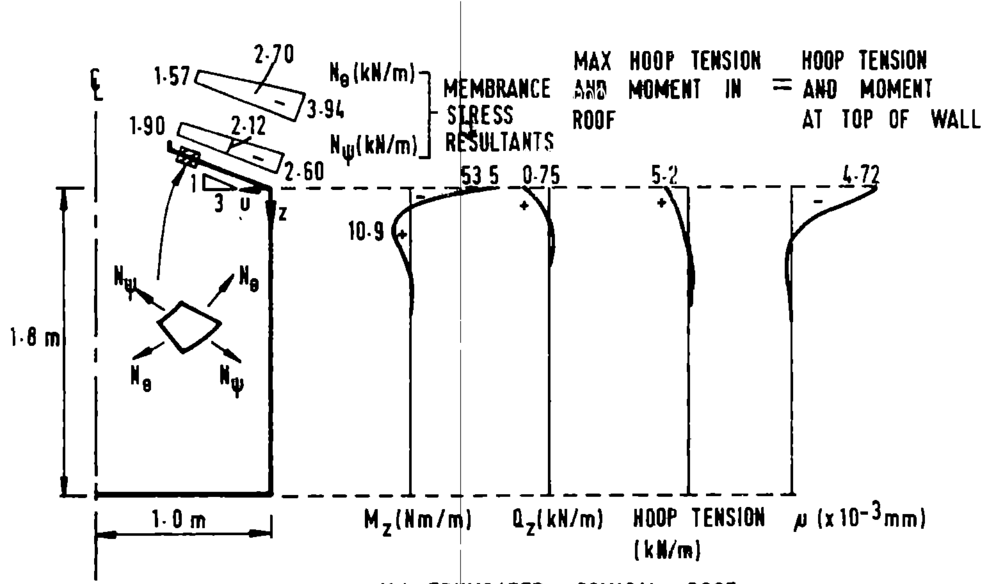


Fig. 1 Cylindrical Tank with Truncated Conical Roof

When the tanks are filled to a height of 1.6m, they satisfy the condition of a long cylinder. The analysis was divided into two parts. The first part dealt with the analysis of the cylindrical wall by imposing appropriate boundary conditions on the junction with the base plate. The second part dealt with the analysis of the truncated conical roof by considering the compatibility conditions governing the displacement and rotation of the junction between the roof and the cylindrical wall. The imposed loads on the roof consist of a uniformly distributed load of 0.75 kN/m^2 and a ring load at the top supporting ring of 0.6 kN/m. The detailed analysis is given in Reference (3) and the results are presented in Figs. 2 and 3.



(a) CYLINDRICAL WALL

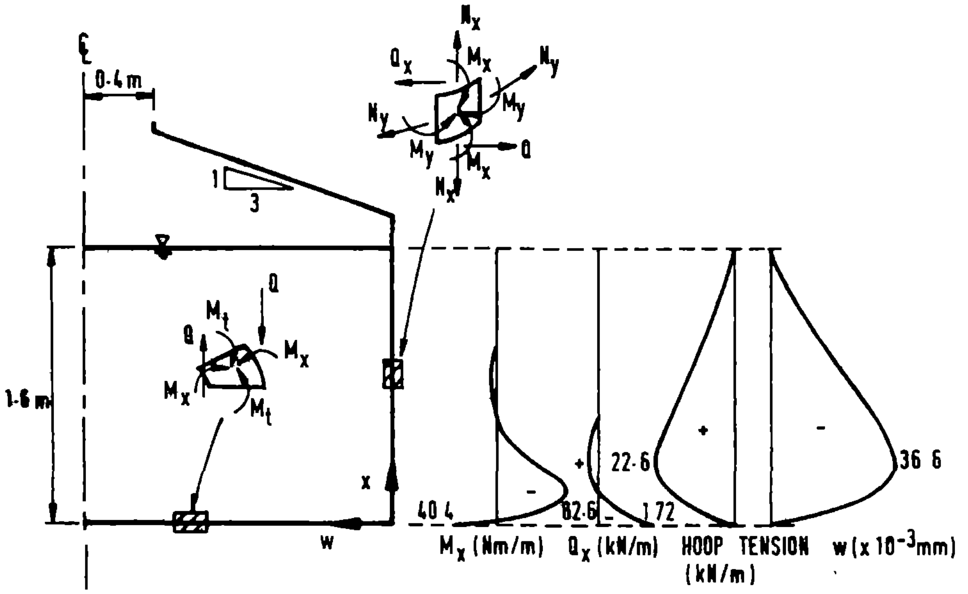


(b) TRUNCATED CONICAL ROOF

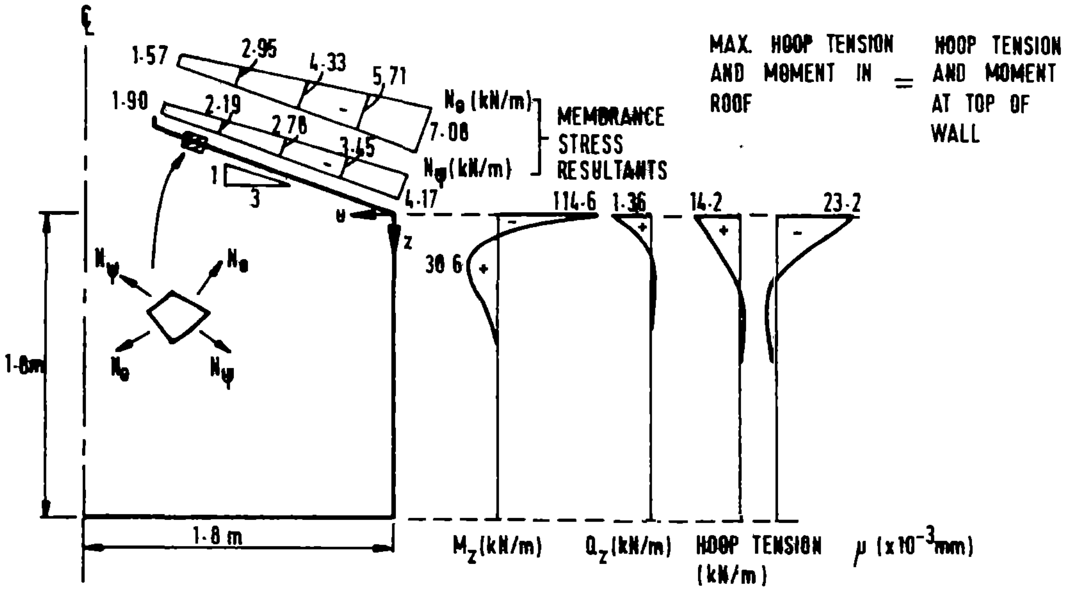
Fig. 2 Analytical Results for Tank A

Design

For the ferrocement water tank to fulfill its intended function, not only must it be watertight, its structural components must also be proportioned to provide adequate resistance against cracking under service loads. The design should ensure durability and long service life of the tanks as funds for maintenance and replacement may not be forthcoming and disruption caused by non-serviceability may impose great inconvenience to the users. This may be achieved by satisfying the recommendations of ACI Committee



(a) CYLINDRICAL WALL



(b) TRUNCATED CONICAL ROOF

Fig. 3 Analytical Results for Tank B

549(1) which recommends a minimum volume fraction, V_f, of 1.8% for water retaining structural elements. In addition, the design strategy adopted should take into account the construction sequence suitable for rural application.

The diameter and height for a tank can be fixed by taking the required capacity and availability of ground space and height at the site into account. A wall height of 1.6m to 2.2m has been recommended to facilitate plastering work. To provide easy access into the water tank for the purpose of cleaning as well as sufficient rigidity of the roof, a roof slope of 1:3 and an opening of 800mm diameter are recommended.

From the strength as well as practical viewpoint, a thickness of between 25mm to 40mm is recommended for both the roof and the cylindrical wall. The thickness for the base should be slightly larger than the wall since a greater rigidity is needed and a value of 35mm to 50mm is recommended.

EXPERIMENTAL INVESTIGATIONS

In view of the above recommendations on the thicknesses of the various elements and ACI recommendation of a minimum volume fraction of steel reinforcement of 1.8% for water retaining structures, test specimens were prepared with the amount of steel reinforcement as shown in Table I. The properties of the constituent materials are shown in Table II. The mortar mix with a cement-sand-water ratio of 1:1.5:0.4 was selected in view of its porosity, desired compressive strength and excellent workability (7).

The specimens were tested for tensile and flexural strengths and the results are summarized in Tables III and IV. The required thicknesses for the base, wall and roof of each tank are determined by checking the strength of each component against the maximum stress resultants acting on it.

From Figs. 2 and 3, it can be seen that the bending moment and hoop tension are two main factors which determine the sectional properties of the base, wall and roof. Thus, for an element subjected to bending moment M and axial force N, the following design criterion should be satisfied.

TABLE I: Details of Ferrocement Test Specimens

Specimen	Thickness (mm)	No. of Layers of BRC Weld Mesh	No. of Layers of Wire Mesh	Volume Fraction of Steel Reinforcement (%)
S25	25	1	2	1.4
S35	35	2	3	1.8
S50	50	3	4	1.8

TABLE II: Properties of Constituent Materials

Plain Mortar		
Cement:sand:water	:	1:1.5:0.4
Crushing strength	:	35-40 N/mm^2
Modulus of elasticity	:	2.8×10^4 N/mm^2
Fine Wire Mesh		
Grid size	:	12.5 x 12.5mm
Diameter	:	1.22mm
Yield strength	:	365 N/mm^2
Modulus of elasticity	:	2×10^5 N/mm^2
Welded Steel Mesh (BRC Mesh)		
Grid size	:	150 x 150mm
Diameter	:	5.40mm
Yield strength	:	550 N/mm^2
Modulus of elasticity	:	2×10^5 N/mm^2

TABLE III: Results of Tensile and Flexural Strength of Ferrocement Specimens

Specimen	Tensile Strength		Flexural Strength	
	First Crack Tensile Force (kN/m)	Ultimate Tensile Force (kN/m)	First Crack Bending Moment (Nm/m)	Ultimate Bending Moment (Nm/m)
S25	60	162.5	738	2560
S35	109	212.5	1449	5310
S50	-	-	3120	11810

TABLE IV: Proportioning of Components

Tank	Component	Thickness (mm)	Steel	Location	Meridional Direction			Circumferential Direction		
					N_1(kN/m)	M_1(kNm/m)	$(\frac{N_1}{N_c}+\frac{M_1}{M_c})^{+*}$	N_2(kN/m)	M_2(kNm/m)**	$(\frac{N_2}{N_c}+\frac{M_2}{N_c})^*$
A	Roof	25	S25	Base of Roof	Compression	53.5	0.07	5.2	10.7	0.10
	Wall	35	S35	Top of Wall	Compression	53.5	0.04	5.2	10.7	0.06
				Max. Bending Moment	Compression	48.7	0.03	9.6	9.7	0.09
				Max. Hoop Tension	Compression	22.0	0.02	13.6	4.4	0.13
	Base	35	S35	-	-	11.7	0.01	-	-	-
B	Roof	25	S25	Base of Roof	Compression	114.6	0.16	14.2	22.9	0.27
	Wall	35	S35	Top of Wall	Compression	114.6	0.08	14.2	22.9	0.15
				Max. Bending Moment	Compression	82.6	0.06	17.2	16.5	0.17
				Max. Hoop Tension	Compression	44.8	0.03	22.6	9.0	0.21
	Base	50	S50	-	-	40.4	0.01	-	-	-

* Values of M_c and N_c are given in Table III.

** $M_2 = \nu M_1$ ($\nu = 0.2$).

\+ Value of N_x is neglected in calculations.

$$\frac{N}{N_c} + \frac{M}{M_c} \leqslant \frac{1}{3} \qquad (1)$$

in which N_c and M_c are the values of tensile force and bending moment at first crack of the element (see Table III). A safety factor of 3 has been included in the design criterion.

The inequality (Eq. (1)) is checked for the three components of the tank at critical sections in Table IV. For the assumed thicknesses and steel reinforcement, the design criterion is satisfied for all the components of the tank. The safety factors for the base are high but are reasonable in view of uncertain local ground conditions. It is noted that the roof section has a volume fraction of only 1.4% (see Table I). Although ACI Committee 549(1) recommends a minimum volume fraction of 1.8%, the roof section is considered satisfactory as it is not subjected to the requirements of water-tightness. The reinforcement details for Tank A and Tank B, including the details of connections and roof opening, are shown in Fig. 4. It is anticipated that this design should ensure durability and long service life of the tanks.

CONSTRUCTION OF TANKS

Materials

Type I ordinary Portland Cement should be used. Sand used should be clean, hard, strong and free of organic and deleterious substances. Typical properties of fine wire mesh and skeletal steel (BRC Mesh) are shown in Table II In case the reinforcements recommended are not available, equivalent reinforcement satisfying the specifications may be selected.

Site Selection and Preparation

The site chosen for the water tank should have adequate bearing capacity to ensure uniform support of the base and should not be uncompacted backfill. All vegetation and loose top soil should be removed and the exposed firm ground levelled to the desired slope (1:40 to 1:100) to provide for natural drainage of the tank through the scour pipe for cleaning purposes. A layer of lean concrete,

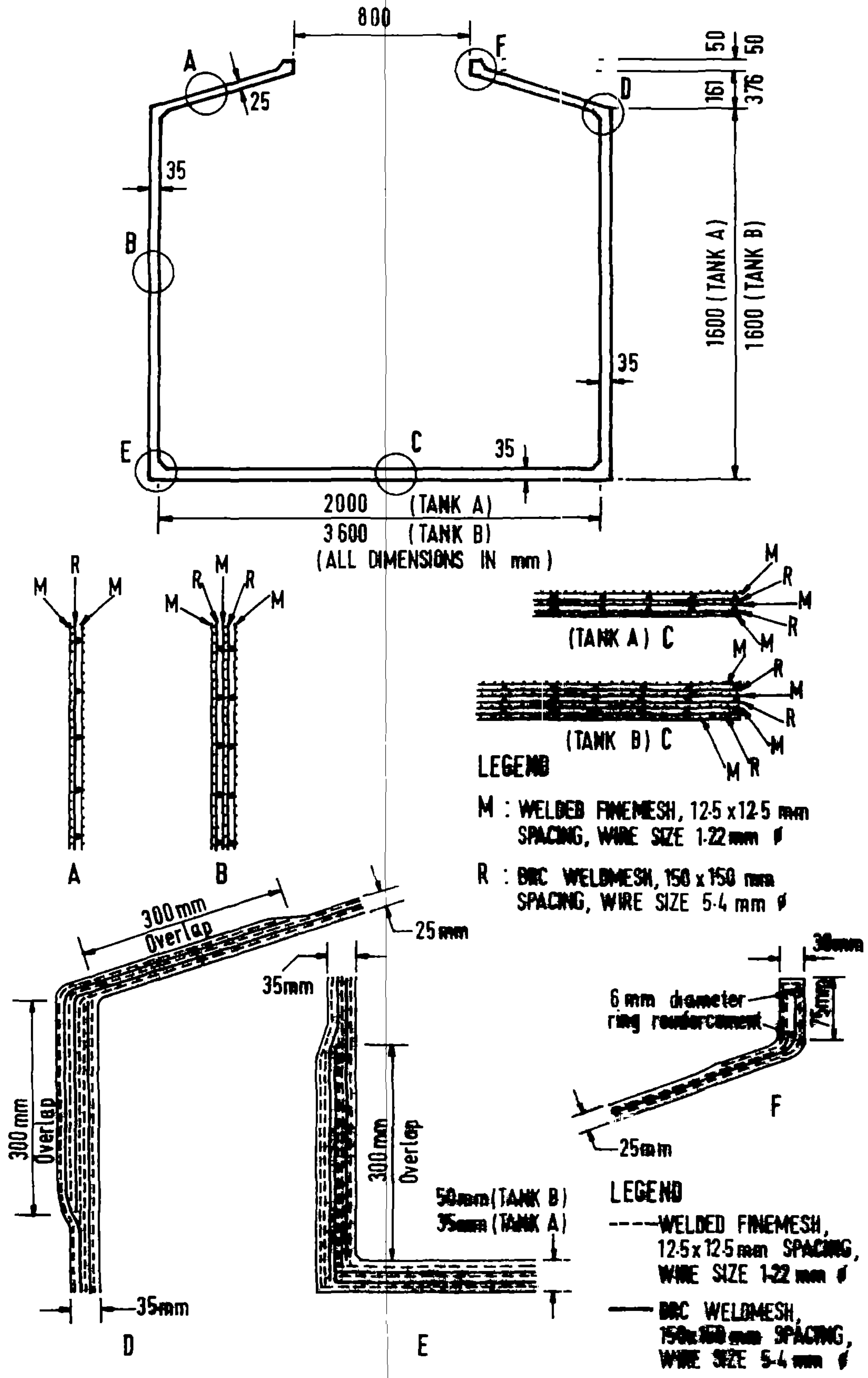


Fig. 4 Reinforcement details of Tanks A and B

Fig. 5 A Layer of Lean Concrete on the Soil

Fig. 6 Base Bars bent up to form Starter in Cylindrical Wall

Fig. 7 Assembled Reinforcement for the Base

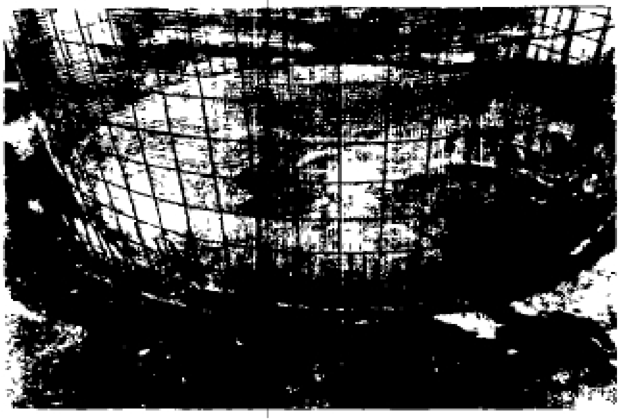


Fig. 8 Wall Reinforcement in place after the Base has been Cast and Cured

Fig. 9 Bending Outer Layer of BRC Mesh in Wall on to Conical Roof

Fig. 10 Wall and Roof Reinforcement of Tank A

Fig. 11 Wall and Roof Reinforcement of Tank B

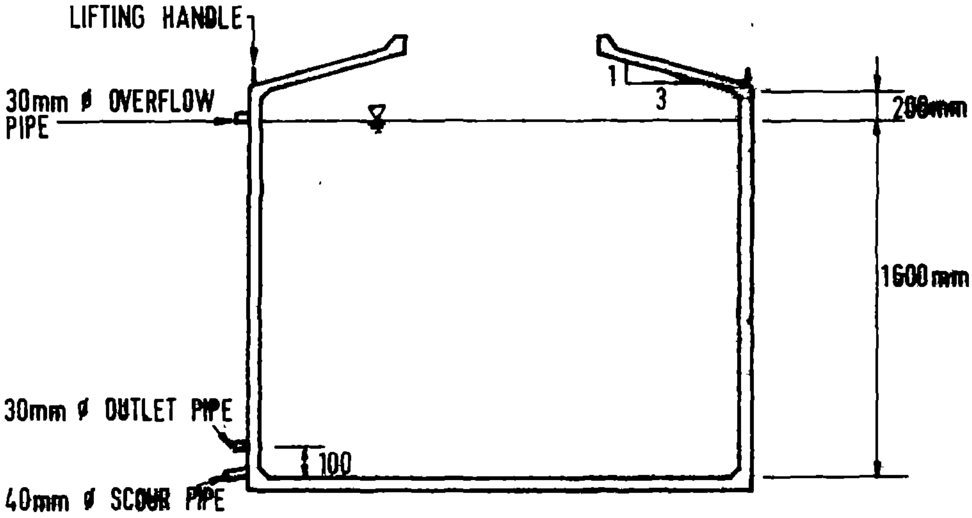


Fig. 12 Positions of Auxillary Fittings

Fig. 13 Auxillary Fittings

Fig. 14 Plastering of Wall

Fig. 15 Completed Tank A

Fig. 16 Completed Tank B

30mm to 50mm thick should be placed on the soil to provide a clean bed for laying reinforcement (Fig. 5). Polythene sheets or waterproof cement bags are to be spread over the lean concrete before the reinforcement for the base is laid. Besides preventing direct contact of wet mortar with the lean concrete this will provide the additional option of ease of moving the tank to another location nearby if so desired later.

Preparation of Base Reinforcement

The BRC mesh is rolled out, flattened with a mallet and cut to the required length and shape. After a circular BRC mesh is obtained superfluous transverse bars are cut away and the bars bent up using a pipe section as shown in Fig. 6. This process is repeated with the other layers of BRC mesh making sure that they will fit over one another. It may be noted that only the base bars of the inner and outer layers of BRC mesh project into the cylindrical wall.

Once the skeletal steel has been prepared the required number of layers of 1.22mm diameter fine wire mesh of 12.5mm mesh size is tied to it after they are stretched taut. The tie wires used should be properly cut, bent inward and flattened with a mallet. The meshes should be misaligned to provide for a more uniform distribution of reinforcement. It is recommended that the outer layer of fine wire mesh be wrapped and profied using mallets but left untied to the other layers as it will be wrapped over the reinforcement cage of the wall before plastering of the wall begins (Fig. 7). The base-wall joint details are shown in Fig. 4.

Plastering of the Base

After the site is prepared properly, the reinforcement for the base is placed onto the polythene sheets or waterproof cement bags with spacers to ensure proper cover. With the outer layer of fine wire mesh of the base untied, the base is plastered to the required thickness, making sure the cover to the reinforcement and the slope of the base is maintained. Before plastering the scour pipe should be in place and sealed with plumbing sealant to prevent clogging. The entire base should be plastered, making sure that the mortar penetrates into the bottom layers of meshes. The recommended mix proportion by weight of the mortar is 1:1.5:0.4 for cement, sand and water (Table II).

The base should be properly cured for 3 days. Curing should commence 24 hours after application of the final layer of mortar. During the first 24 hours of plastering, the surface should not be permitted to dry out. Fig. 8 shows the completed base of the tank.

Preparation of Wall Reinforcement

The outer layer of BRC mesh for the wall reinforcement is rolled out and trimmed to the required height and length. The height of the BRC mesh should be trimmed such that the top transverse ring is located at the wall-roof joint (Fig. 9) with provision for starter bars in the conical roof. The inner layer of BRC mesh is prepared in a similar manner except that there are no starter bars projecting into the roof.

Three layers of fine wire mesh are used in the wall. They are wrapped and tied to the skeletal steel as shown in Figs. 10 and 11. It may be noted that the height of the outer layer of fine wire mesh is extended for subsequent wrapping around roof reinforcement (Fig. 9).

Preparation of Roof Reinforcement

Reinforcement for the conical roof (of slope about 18^{0} to the horizontal) consists of two layers of fine wire mesh and one layer of BRC mesh. A circular BRC mesh is cut, and overlapped to develop the conical roof. The resultant opening in the conical roof should be at least 800mm in diameter to allow access for workmen into the tank for plastering to be carried out.

Two rings of 5.4mm diameter bars are provided at the opening in the roof. It is generally more convenient to completely fabricate the reinforcement of the wall and roof of the tank before plastering of the wall commences.

Auxiliary Fittings

Fig. 12 shows the positions of the auxiliary fittings. These consists essentially of a 30mm diameter PVC overflow pipe, 30mm diameter PVC outlet pipe and 40mm diameter PVC scour pipe. The details of these fittings are shown in Fig. 13. Additional layers of fine wire meshes may be added around auxiliary fittings.

In addition four lifting handles are provided at the wall-roof junction of the tanks. These consist of 5.4mm diameter bars bent and placed equidistant from each other along the circumference of the tank. The reinforcement for the lid consists of one layer of BRC mesh and 2 layers of fine wire mesh. Handles may be incorporated to facilitate lifting. An appropriately sized and positioned hole may be incorporated to accommodate the inlet pipe.

Plastering of the Wall and Roof

After proper curing of the base, the reinforcement for the wall and roof may be assembled on to the base. For tanks of larger diameters it may be more convenient to fabricate the reinforcement cage in-situ after the base has been plastered and cured properly. The untied, extended outer layer of fine wire mesh of the base (Fig. 8) is then wrapped over that of the wall and tied. Plastering of the wall may now commence using mortar of the recommended mix proportions (Table II). Mortar application should be accomplished from both sides of the wall using trowels or hands (Fig. 14).

The plastering should be carried out in tiers starting from the base and advancing upwards. After each tier was completely plastered from the outside the remaining parts was plastered from the inside ensuring proper compaction and a proper cover (about 5mm) for the reinforcement is provided on finishing both the inside and outside surfaces of the tank.

For smaller tanks the plastering of the wall and roof may be carried out in one operation. In the case of larger tanks the roof ma be plastered 3 days after the wall has been properly cured. In this case, the wall should be plastered up to the wall-roof junction. Some propping of the roof may be necessary for the larger tanks. The props should only be removed after the roof has been cured properly for 3 days (longer if possible).

The tank should be cured properly. A curing period of 28 days is suggested starting 24 hours after application of the final layer. Moist jute or burlap bags soaked in water should be used to cover the tank. After curing the tank should be filled and thoroughly inspected and tested before being used. Painting if required should only be carried out after the tank has completely dried out.

TEST RESULTS

Two tanks A and B of $5m^3$ and $16m^3$ (Figs. 15 and 16) capacities were constructed in accordance to the procedures recommended earlier. After proper curing for 28 days, the outlet, overflow and scour pipes were sealed temporarily with plugs or plumbing sealent. Water was filled to the brim of the tank and the exterior surfaces inspected carefully 24 hours later.

In this study, no leakage was observed for both tanks. The tanks were kept filled for seven days and the performance of the tanks was monitored carefully. The water height was marked and observed for any reduction. It was noticed there was no leakage and reduction in height of the water.

The tanks were instrumented with electrical strain gauges on the exterior surfaces of the cylindrical wall and transducers also were used to measure horizontal deflections. The hoop stresses determined from strain readings agree closely with the theoretical calculations as shown in Fig. 17 for Tank A and Tank B. The deflections at capacity were also very small (less than 0.3mm). It is of interest to mention that no waterproofing compound was used in this project.

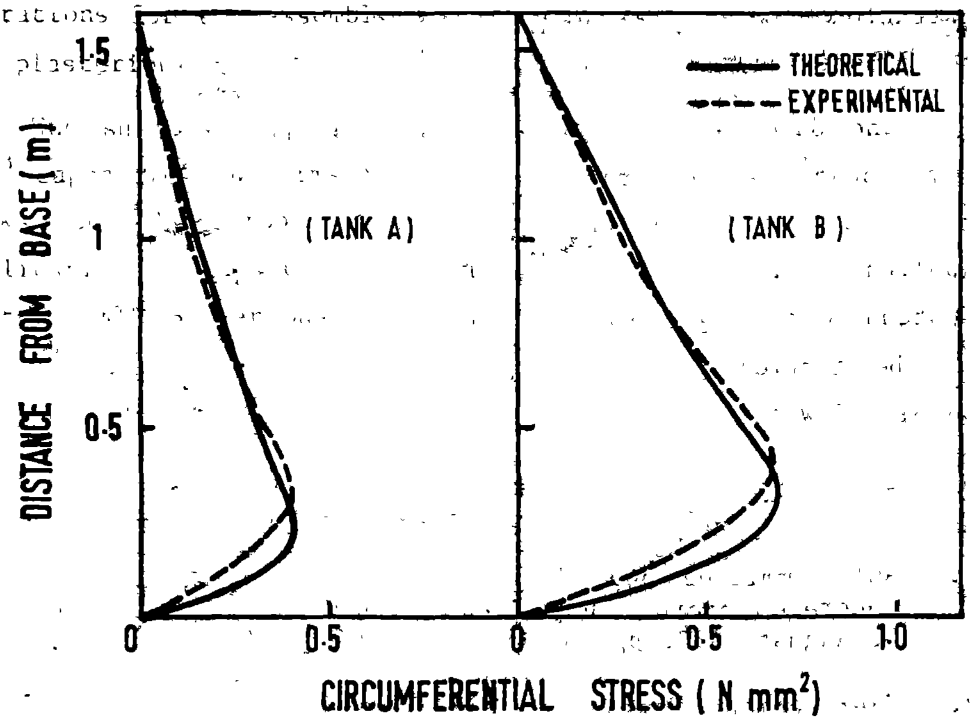


Fig. 17 Comparison of Theorectical and Experimental Circumferencial Stress

SUMMARY AND CONCLUSIONS

In this study, the analysis of the cylindrical shell wall rigidly connected to the circular base plate and conical shell roof was carried out. Based on the analysis and experimental results of the mechanical properties of ferrocement elements, the reinforcement details for Tank A (5m^3) and Tank B (16m^3) are proposed. The strength of the ferrocement tanks is much higher than the required strength from analytical considerations. However, the minimum volume fraction of 1.8% is provided as recommended for water retaining structures by ACI Committee 549 (1). This design will ensure durability and service life of the tanks as funds for maintenance and replacement may not be available and disruption caused by non-serviceability may impose great inconvenience to the users.

One of the objectives of this study is to develop simple construction techniques for the proposed ferrocement cylindrical tanks suitable for rural applications. Being labour intensive, special attention is paid to the development of a sequence of operations for the assembly of the reinforcement cage for the tanks and plastering.

The successful performance of the prototype tanks of $5m^3$ and $16m^3$ capacities confirms the feasibility of using ferrocement water tanks of the proposed design which is suitable for rural applications. It may be advisable to construct two smaller tanks instead of a bigger one of the same total capacity so that cleaning may be carried out to ensure water quality without disruption of supply of water.

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INVESTIGATIONS

OF

BAMBOO REINFORCED CONCRETE WATER TANKS

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ABSTRACT

Bamboo reinforced concrete water tanks have been constructed and used in many countries. In Thailand alone, it is estimated that over 50,000 bamboo reinforced concrete water tanks have been built and the investment has been over 300 million baht (US $ 11.5 million). Some of them are still in use while others fail by cracking or bursting. In addition to the loss of investment, the failure may be dangerous to lives.

Five bamboo reinforced concrete tanks and three bamboo cement tanks of capacity ranging from 4.3 to 11.3 cubic meters and age ranging from 1.5 to 6 years old were investigated. The investigation involved testing of concrete and bamboo specimens obtained by cutting of sections from the tank walls. It was found that the bamboo rods in these tanks were badly deteriorated and became ineffective as reinforcement. As a result, the tanks are left practically without any reinforcement and may eventually burst and be dangerous to lives and properties. Thus if bamboo is to be used as reinforcement for concrete water tanks, appropriate measures to avoid the decay problem is necessary.

INTRODUCTION

One of the highest national priorities for rural development is to provide drinking water of an acceptable standard for people in rural areas. Several organizations, both governmental and nongovernmental, are actively involved in this by encouraging villagers to construct water tanks for storing rain water for drinking purpose. Some of these organizations are the Department of Health, the Office of Accelerated Rural Development, the Office of the Secretary of the Prime Minister, the Population and Community Development Association (PDA), and several universities.

Several different types of water storage tanks with different types of reinforcement are constructed and supplied to villagers in Northeast Thailand. These include unreinforced water jars, bamboo reinforced concrete (BRC) tanks, and ferrocement tanks. The type of reinforcement used depends on many factors, such as the size and cost of tank, the speed of construction, and the skill of the implementing agency etc.

Bamboo reinforced concrete tanks are popular in Thailand and some other countries. They are relatively economical as they employ bamboo which is an indigenous material as reinforcement instead of steel.

Some bamboo reinforced concrete tanks are over ten years old and are still in use. However, some others burst and their bamboo reinforcement rotted. In a survey conducted in 1983 at Tom-Na-Ngarm Village and Tom-Na-Dee Village, Amphur None-Sa-Ard, Udornthanee Province, it was found that about 60-80 (30-40%) of the tanks constructed in 1977 had burst and the bamboo reinforcement deteriorated. These tanks were constructed by the villagers without good engineering practice. The concrete aggregates were of poor quality and the mixture was lean, producing low concrete strength.

This finding has prompted this investigation into the long term behaviour of bamboo reinforced concrete water tanks by the Faculty of Engineering, Khon Kaen University, and the Population and Community Development Association under the financial assistance of the Canadian Embassy in Thailand.

OBJECTIVE

The main objective of this study is to investigate the long term condition of the bamboo used as reinforcement in concrete or cement water tanks in order to assess its suitability for such application.

TESTINGS

Concrete sections with a width of 1-1.20 m and a height of 1.20 m were cut from water tank wall at a height of 0.3-0.5 m from the base. The tanks tested were between 1-6 years and laboratory tests in engineering and biological aspects were conducted on bamboo rods.

RESULTS

Engineering Tests

The tensile and bond strength of bamboo from the tanks are presented in Table 1.

The average tensile strength of bamboo from tank no.1 which is the youngest, is only 27% of their average original tensile strength. For tanks no. 2 and 3 which were 2.5 and 3.5 years respectively, some bamboo rods were completely decayed and the average tensile strength of the bamboo rods that could be tested are 10% of their original strength. Tank no. 4 which is the only tank that Pai Ruak was used, the average tensile strength of bamboo is 15%. For tank no. 5, the bamboo rods which were put through an open fire prior to construction have the average tensile strength of 11%. For tanks no. 5,6 and 7 which are bamboo cement tanks, the horizontal reinforcing bamboo rods were only 2-3 mm thick, were mostly disintegrated. The tensile strength of the bamboo rods presented are those of the larger vertical ones which have the average of approximately 39%. For tank no. 6 the bamboo rods were coated with bituminous emulsion. It would be interesting to see the effects of the emulsion on the bamboo properties. However, it is a pity that all the bamboo rods were destroyed by termites.

The bond strength between bamboo and concrete is from zero (bamboos were completely destroyed) up to 18.9 kg/sq.cm. The magnitude of the bond strength depends on the degree of deterioration of the bamboos, knots, taperness of the bamboo rods etc. Since the bamboos deteriorate, their bond strength is not of much interest.

Biological Tests

From bilogical tests, it was found that all the bamboo samples have micro-organisms which destroy the bamboo tissues. These micro-organisms were fungi and bacteria and they were aerobic (can grow under normal condition) and facultative aerobic (can grow under the condition with limited oxygen) types.

DISCUSSION AND CONCLUSION

From the test results, the tensile strength of bamboo reduced markedly within 1-2 years. Some of the bamboo rods were completely decayed. The deterioration rate of bamboo depends mainly on the age of the tanks, the thickness and the locations

Table 1 Tensile and Bond Strength of Bamboo from the Water Tanks

Tank Type	Tank No.	Age (years)	Tensile Strength (ksc.)	Percentage of tensile strength (%)	Bond strength (ksc.)	Moisture content (%)	Note
Bamboo Reinforced Concrete	1	1.5	334,344 (339)	26,27 (27)	18.9 (18.9)		Attacked by termites, only two samples were availab for testing.
	2	2.5	141,121,97 (120)	11,10,8 (10)	8.7,4.3,6.8 (6.6)	33,32,29 (31)	Some bamboos were completely decayed.
	3	3.5	146,65,161 (124)	12,5,13 (10)	4.0,3.5 (3.8)	44,41,32 (39)	Some bamboos were completely decayed.
	4	4	266,353,297 (305)	13,17,15 (15)	5.7,19.2 (12.5)	41,33,28 (34)	Bamboos were soft but none was completely decayed.
	5	4	189,155,97 134 (144)	15,12,8,11 (11)	1.8,7.0,6.7 (5.2)	55,61,58,48 (56)	Bamboos were put through an open fire, none was completely decayed.
Bamboo Cement	6	1.5	696,664,321 707,253,308 (492)	55,53,25,56 20,24 (39)	-	61,57,61,55 52,48 (56)	Some bamboos were completely decayed especially the thin ones for hoop reinforcement.
	7	1.5	360,597,290 637 (471)	29,47,23,51 (37)	-	67,106,70 77 (80)	Same as tanks no.6
	8	6	-	-	-	-	Bamboos were coated with bituminous emulsion, all were attacked by termites.

Note 1. Average tensile trength of Pai Ban = 1260 ksc., Average tensile strength of Pai Ruak = 2040 ksc.
2. Numbers in brackets are average values

of bamboo rods. Thinner bamboo rods tend to deteriorate more quickly than thicker ones and the bamboos located closer to the tank base appear to deteriorate more quickly than the ones closer to the top.

Micro-organisms, both fungi and bacteria, were found to be the major causes of the deterioration. These micro-organisms require suitable conditions for the growth. These conditions are nutrients, moisture, oxygen and suitable temperature. Cellulose in bamboo is the nutrients for the micro-organisms. Moisture is ample in water tank since the concrete is wet. Oxygen is somehow available in concrete and is observed by the rusting of tying wires used to tie the bamboo rods together. The temperature in Thailand is also in the suitable range for the growth of these micro-organisms.

Hence, all the factors for the life sustenance of the micro-organisms are present in water tanks.

Besides these micro-organisms, other factors that may contribute to the deterioration of bamboo which were not investigated are wet and dry cycles and the effects of chemical in concrete to the bamboo.

From this investigation, it is obvious that if bamboo is to be used as reinforcement for concrete water tanks appropriate measures to prevent the decay problem is necessary.

What will happen when the bamboos deteriorate?

The behaviour of bamboo reinforced water tanks when the bamboo rods deteriorate can be classified into 2 categories.

1. For the tanks that concrete or mortar strength is low and by itself alone cannot resist the stresses induced in tanks, the bamboos will take some of the stresses and keep the tanks intact. When the bamboo deteriorate, the tanks will fail. The tanks in this category will fail within a few years after construction. Good examples of the tanks in this catergory were found in Tom-Na-Ngarm Village and Ban Tom-Na-Dee Village, Amphur None-Sa-Ard, Udornthanee Province as mentioned previously.

2. For the tanks that concrete or mortar strength is high and by itself can resist the induced stresses occurring in the tanks, when the bamboo rods deteriorate (after a few years) these tanks will still be intact. Although the concrete or mortar strength increases initially as the hydration process of cement increases, it will be reduced after some time by the destroying actions of nature such as weathering, and temperature changes etc. When the strength of the concrete or mortar is too low to sustain the stresses, the tanks will fail.

Because concrete is a brittle material, the failure of bamboo reinforced concrete water tanks when the bamboos deteriorate, will be sudden and dangerous.

ACKNOWLEDGEMENT

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POLICY & PLANNING

RAINWATER CATCHMENT RATIONING

Richard J. Heggen

ABSTRACT

In standard practice, rainwater catchment systems are designed to satisfy a fixed demand. An economic demand function relating consumption to price (the deterministic component of which is related to construction and maintenance costs, the stochastic component of which is related to the consequences of system failure) is not made explicit. Several studies have assumed some scheme of rationing in drought conditions, but little consideration has been given to a common basis for such analysis.

Practices of water rationing are surveyed. Several approaches applicable to small-scale catchment management are identified. A case study in Northern New Mexico is evaluated with a one-parameter demand function. From the perspective of penalty minimization, the more successful rationing plan is identified.

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SYMBOLS

C, capacity, L^3

P_i, deficit penalty

Q_i, release, L^3/T

Q_0, minimum consumptive requirement, L^3/T

S_i, storage, L^3

T, target demand, L^3/T

V, trigger volume, L^3

α, rationing parameter

β, consumptive parameter

γ, storage parameter

INTRODUCTION

Rationing is the decreased rate of resource depletion made to extend the period of resource availability. Rationing depends upon the expected timing and quantity of resource replenishment and the consequences of losing the resource for a period of time. Water rationing is a program of decreased consumption designed to maintain a reserve of water until a future hydrologic event allows return to the normal consumptive level.

Where water is plentiful and distribution systems can be oversized, a liberal demand is projected and the water system is designed to meet that demand with a factor of safety. Water rationing is rarely an issue.

Where water is scarce and supply is severely constrained by cost, rationing must be a real consideration in evaluating the potential performance of a water system. When water reserves dwindle, it must be foreseen how utilization changes. In a region where there is no contribution to water reserves for one month per year, for example, the socioeconomic impact of going without water for that month will not be the same as the impact of consuming water at two-thirds the normal rate for three months, though in both cases the same quantity of water is utilized. A water system that predictably fails for a month might be inadequate, while a system foreseen to meet a rationed demand to survive the dry spell might be reasonable.

Rainwater catchment systems for household supply in developing regions tend to be constrained by cost and technology. The service population is likely to accept the fact that at times water will be scarce and consumption must be curtailed. Selection of a proper system configuration (typically catchment area and cistern volume) depends upon the expected behavior of the users when a drought occurs. Conversely, evaluating a system's performance under alternative rationing plans may help identify a strategy of water use that minimizes the severity of water shortage.

This paper reviews the practice of rationing and proposes a methodology by which a rationing function can be incorporated into system design.

WATER DEMAND

Per capita water demand in developing areas is typically influenced by four factors: facilities (e.g. in-house vs. public taps); user income; custom and tradition; and price. Two-to threefold increases in consumption have been noted as a direct consequence of household plumbing. Larger increases yet may occur when a handpump is replaced by a pressurized system (United Nations, 1976). The unit price of water is significant, as evidenced by elasticities ranging from 0.2 to 0.65 (Saunders, 1969, Cortegoso, 1974, and Grima, 1972). It must be recognized that a simple average of historical consumption may not properly estimate future demands. It is sometimes suggested that rainwater catchment systems are employed to satisfy some minimum demand, thus sidestepping the problem of changing water use. This position may be tenable in some cases, but that requirement itself may be ill-defined. In some 40 papers dealing with catchment design, the author found the minimum demand to range from 2 to 120 liters per capita-day. Minimum demand is thus an elusive parameter, a figure dependent perhaps more on social expectation than on biological need.

Even when the economy, the technology, and customary practices are stable, the supply may vary. Should supply become less than demand, the latter must appropriately decrease. In short, demand is not a number, but a function.

WATER RATIONING

In only nine of the 40-plus papers on the design of rainwater catchment systems was any indication made that rationing might occur. Of the remainder, a perfectly inelastic demand for water seems to have been presumed. As the latter assumption does not well reflect economic evidence when supply becomes short, there is room for improved analysis, particularly in cases where supply may be frequently low and an exhausted reserve may have major consequences.

Numerous approaches to water rationing are practiced. When the water system has multiple users, rationing is generally by regulation of use, time of availability, volume, proportion of historical use, or price adjustment. Use rationing (e.g. no car washing or limited lawn watering) is generally effective for small water shortages. Colorado Springs, Colorado achieved a 13 percent consumptive decrease in that manner (Anderson, 1977). During drought, New York City forbid the serving of non-requested water in restaurants, a use rationing more symbolic than consequential. Time rationing (shutting off the system for alternating periods) has been practiced on Okinawa during major droughts (Garland, 1975). Volumetric rationing (typically a fixed quantity per capita-day) reduced consumption by 75 percent in Ames, Iowa (Rossmiller, 1985). Proportional rationing (some percent of non-drought use) has been used to cut consumption 25 percent in Denver, 75 percent in northern California (Anderson, 1977) and up to 57 percent in the San Francisco Bay area (Hoffman <u>et. al.</u>, 1977). Price rationing (raising the price when supply gets low) has been shown to be efficient by Renshaw (1982).

The key to each of the above approaches is regulatory power and enforcement capabilities. It is not surprising that Ames' plan worked; a 900 percent surcharge was assessed on noncompliants.

None of these approaches is in itself well suited for the individual household catchment system. Catchment rationing more depends on the users' willingness to assume risk, capability of tapping another water source, and/or ability to relocate should the dry spell continue.

RATIONING FUNCTION

A rationing function is a mathematical description of how rationing is to be carried out. For a catchment system, several terms must be defined.

Capacity, C - the volume of the reservoir or cistern. Capacity is in itself not a parameter in the rationing problem, but may be a factor in determining trigger volume.

Trigger volume, V - the volume of reservoir storage at which rationing is initiated. As shown in Table 1, V is frequently taken as a proportion of C.

TABLE 1. Rationing Function Parameters

V	Rationing Function	Q_o/T	Time Increment	Location	Reference
0.5 C	1 Step	0.67	Weekly	Hawaii	Lo and Fok, 1980
Severedry period	1 Step	0.90	Yearly	Nova Scotia	Waller and Inman, 1982
0.5 C	1 Step	0.50	Daily	Puerto Rico	Morris et.al., 1984
1 Month reserve	1 Step	0.75	Monthly	Ontario	Schiller and Latham, 1982
1 Month reserve	3 Steps	0.60	Daily or Monthly	Australia	Perrens, 1982
Unspecified	3 Steps	0.25	Unspecified	Australia	Perrens, 1982
0.714 C	4 Steps	0 50	Monthly	Queensland	Piggott et.al., 1982
C	Linear	-0.05	Weekly	Hawaii	Lo and Fok, 1982
C	Logistic	0.23	Weekly	Hawaii	Lo and Fok, 1982
Unspecified	Logistic	0.33	Unspecified	South Australia	Huey and West, 1982

Storage, S_i - the volume of water stored at the start of time period i.

Target demand, T - the reservoir release satisfying consumptive needs for a time increment.

Release, Q_i - the actual reservoir release for consumptive use in time increment i. When rationing is in effect, Q_i is less than T. When rationing is not practiced, Q_i equals T.

Minimum consumptive requirement, Q_o - the reservoir release necessary to meet minimum needs. Q_o is the release that would be made in the last time increment before the reservoir was empty. As shown in Table 1, Q_o is generally taken as a proportion of T.

Fig. 1 illustrates the parameters. The rationing function is here shown by a three-step decrease from (V, T) to (0, Q_o). Table 1 indicates a variety of alternative rationing functions proposed to connect these bounds.

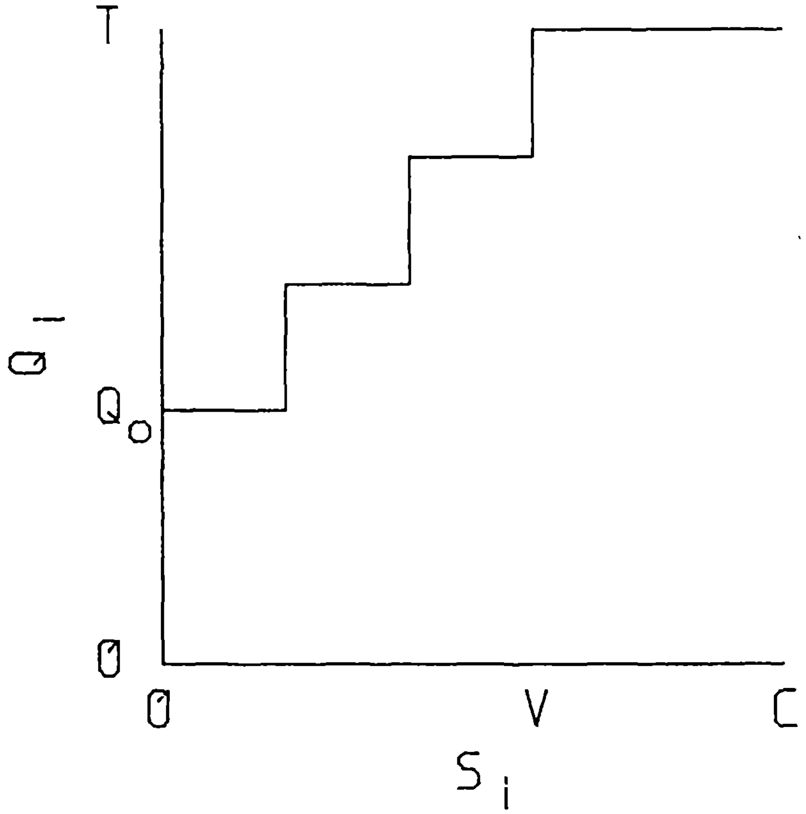

Figure 1. Step Rationing Function

While step functions are easy to use, such noncontinuities do not reflect the way most people regulate themselves. The logistic (or "S") curve is perhaps the best description of human response to shortage (Lo and Fok, 1982). When a shortage begins, there may be little reduction in consumption. At some intermediate point, the gravity is recognized and consumption is significantly reduced. As the shortage continues, consumption levels to a bare minimum.

A weighted logistic function can describe a variety of rationing plans,

$$Q_i = T \frac{1 + \beta \gamma e^{-\alpha}}{1 + \beta e^{-\alpha \gamma}} \tag{1}$$

where α is a constant rationing parameter, β is a consumptive parameter computed,

$$\beta = T/Q_0 - 1 \tag{2}$$

and γ is the relative storage S_i/V. If α is high, the rationing function (illustrated by Fig. 2 where Q_0 is 0.2 T) is concave downward; rationing doesn't become major until storage is slight. A low value makes the rationing function concave upward; rationing is quickly imposed when storage falls below target volume. An intermediate value retains an element of the "S".

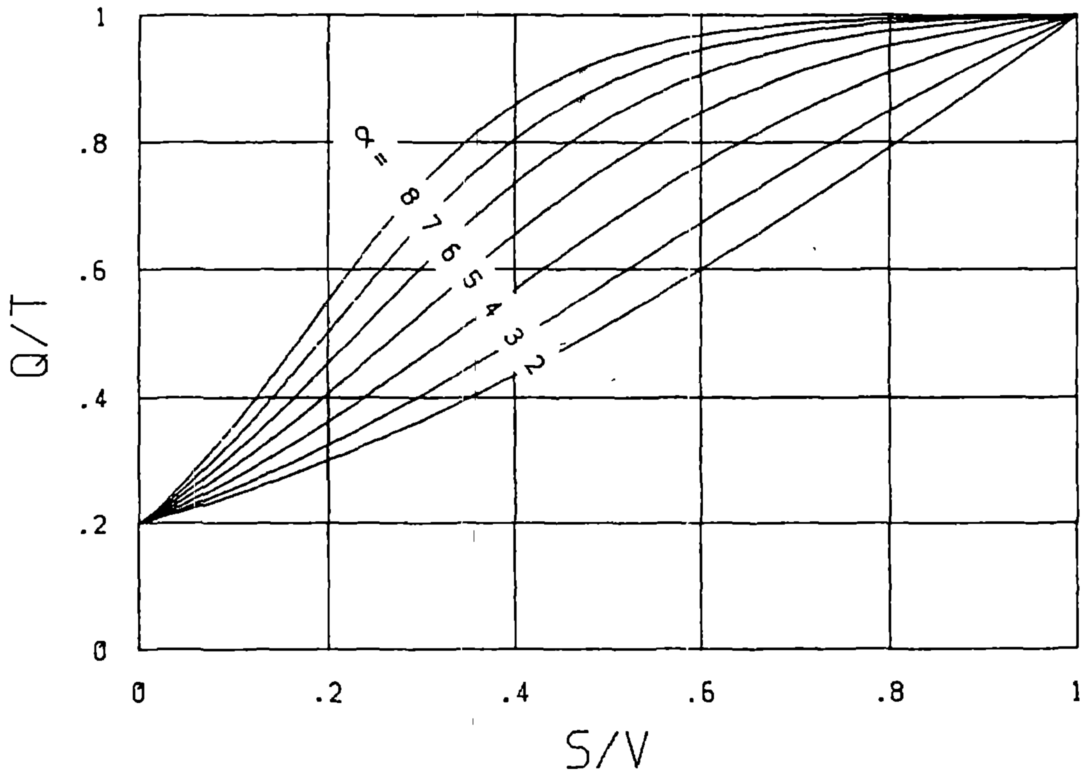

Figure 2. Logistic Rationing Function

PENALTY FUNCTION

While rationing plans may be formulated without an acknowledged objective function, one must exist. In broad terms, the optimal rationing plan is the one that minimizes drought-caused penalties,

$$\text{minimize} \sum_{i=1}^{n} P_i \tag{3}$$

where n is the number of periods (typically days) in the drought and P_i is the default penalty for period i.

Like all economic goods, water has a price (though not necessarily properly determined in the market). P_i might thus be thought of as the value of the water not delivered. In a society where a water truck can be summoned, the price may be a constant. In a society where crops perish or people die when water supply fails, the price for that volume of water which makes the difference is very high. A demand-like function exists; the scarcer the water, the higher its value. Fig. 3 illustrates an exponential assumption for the shape of this curve.

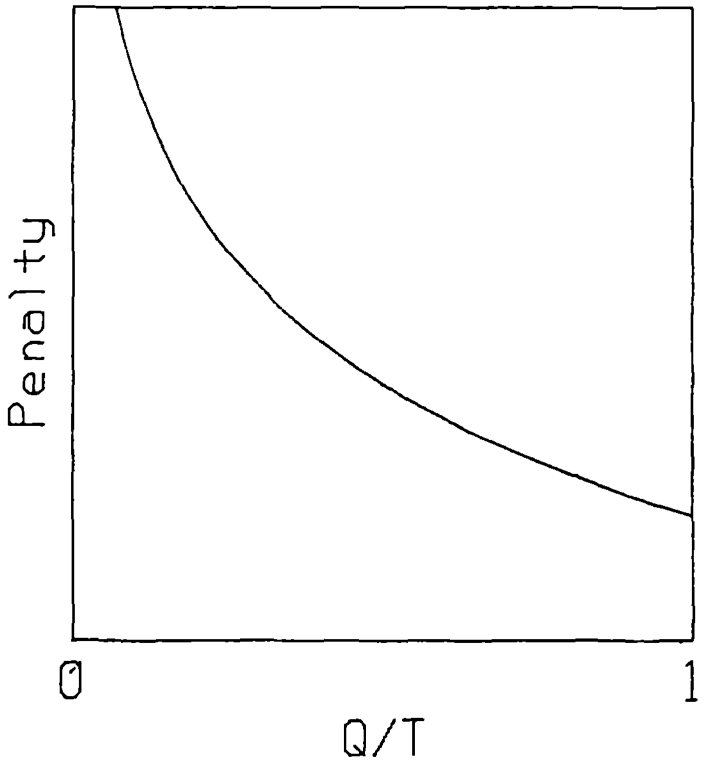

Figure 3. Exponential Penalty Function

$$P_i = P_o - (P_{.368} - P_o) \ln (Q_i/T), \quad Q_i/T < 1 \qquad (4)$$

$$P_i = 0, \quad Q_i/T >= 1 \qquad (5)$$

where P_o is a base penalty incurred for each period where reservoir release Q_i is less than target demand T, and $P_{.368}$ is the total penalty for a period when only 36.8 percent (inverse of the Naperian base e) of T is released. When target is satisfied, no penalty is incurred.

Whereas it may be desired to quantify P in monitary units, there is no analytic necessity to do so. Any relative scale will do.

ANALYSIS

The objective function can be rewritten by combining Eqs. 1, 3 and 4,

$$\text{minimize} \sum_{i=1}^{n} P_o - (P_{.368} - P_o) \ln \frac{1 + \beta \gamma e^{-\alpha}}{1 + \beta e^{-\alpha \gamma}} \qquad (6)$$

for all $\gamma < 1$. The rationing parameter α is the only decision variable. P_o, $P_{.368}$, β and γ are system parameters, each of which can be adjusted with i if they are seasonal. The only state variable, S_i, provides the constraint,

$$S_i = S_{i-1} - Q_i + \text{Input} - \text{Spill} \qquad (7)$$

Eq. 6 is minimized by varying α. Simulation using either the release-before or release-after spill convention is the easiest approach for optimization.

CASE STUDY

Rio Arriba County in northern New Mexico is a culturally unique portion of the United States. Settled by Spanish colonials in the 1700's, the region was in large extent bypassed by the westward march of American development. More than two-thirds of the population today speaks Spanish as the first tongue. Cultural pride is high, making it at times difficult for externally-directed change. Most households retain strong traditional influences, harkening to times when self-sufficiency was a necessity, not just an alternative.

One manifestation of self-sufficiency is the traditional tin roof; the most meager houses and the most lavish haciendas share the same pitched roof of galvanized corregated iron. Rainwater catchment is the traditional method of domestic water supply and for 50 percent of the houses today, a combination of catchment and wells remains the water source.

While precipitation is not high, 20 inches (50 cm) annually, it is distributed throughout the year. Fig. 4 shows seven years of daily record. Measurable precipitation occurs roughly three days in 10. Precipitation exceeds 0.2 inches (0.5 cm) one day in 10. Roughly twice per year, precipitation exceeds one inch (2.5 cm). In a typical year, there are four occasions where precipitation does not occur for 1 to 2 weeks, one occasion where a drought lasts from 2 to 3 weeks, and one occasion where a drought extends for more than 3 weeks.

Domestic water use is not well documented, but several circuitous measures indicate that per capita usage is relatively low. Over 12 percent of all houses lack complete plumbing. Ten percent of rural housing units have no plumbing at all. A quarter of households cook and heat with wood (Bureau of Census, 1980). In Albuquerque, NM, a major metropolitan area to the south, Hispanic households have been shown to use water on a per capita basis at less than 60 percent the rate of nonhispanics of equal income (Lupsha et. al., 1975).

While many households employ rooftop catchment for potable water supply, in most cases there is a backup option, generally a well. During shortage, water can be delivered by truck. Thus the consequence of depleting the cistern is more that of inconvenience than hardship. Rationing is practiced not out of necessity, but rather because a slight modification of water usage is not considered to be a high price. Because rainless periods are rarely for more than a week, rationing is generally not started until reserves are in the range of 7 to 14 days. The actual rationing function is gradual at first, approximating a high α in Fig. 2.

To explore the sensitivity of the system behavior to the rationing function, simulations were made of catchment yield for the precipitation trace of Fig. 4. A monitary penalty function was not defined; rather P_o was simply set at one-quarter $P_{.368}$. While an infinite P for no release may be appropriate for survivors in a lifeboat, it is not proper for the case study. For $Q_i < 0.1\ Q_o$, P_i was set at that corresponding to 0.1 Q_o. T was approximately 40 lpcd, Q_o was approximately 15 lpcd, and V was approximately a two week reserve. Looking at catchment areas and cistern volumes necessary to satisfy even the low T, it became apparent that few households actually could be water-sufficient with rainwater catchment alone.

Simulation indicated several robust observations: most households would benefit from increased catchment area but had little need for additional cistern volume; no reasonably-sized system could eliminate all days where T demand could not be met; and the general behavior of cathment yield was not highly sensitive to small parametric changes. In almost every evaluation, one conclusion was confirmed: that the lower the α , the lower the cumulative penalty. The users who significantly cut consumption early ($\alpha = 2$) tended to incur roughly 20 percent less penalty than those who did not ($\alpha = 8$). In several cases, those of the latter group incurred nearly the same penalties as users who rationed not at all; the practice of mild rationing halved the number of days when Q_o was not met, but doubled the days when Q_i was below T.

A conclusion that the optimal rationing function has a low does not seem to be practically recognized, however. More people appear to delay significant rationing until the tank is nearly dry. Recognition may be attempted by adjusting the penalty function until theory and practice agree. The explanation may be simply that the rationing problem isn't entirely a rational one.

It can be concluded, however, that even when a precise rationing function cannot be fit to user behavior, an approximate one is better than none at all. In Rio Arriba County, rationing does maintain a water supply over short droughts and shortens the days in long droughts when alternative sources must be employed.

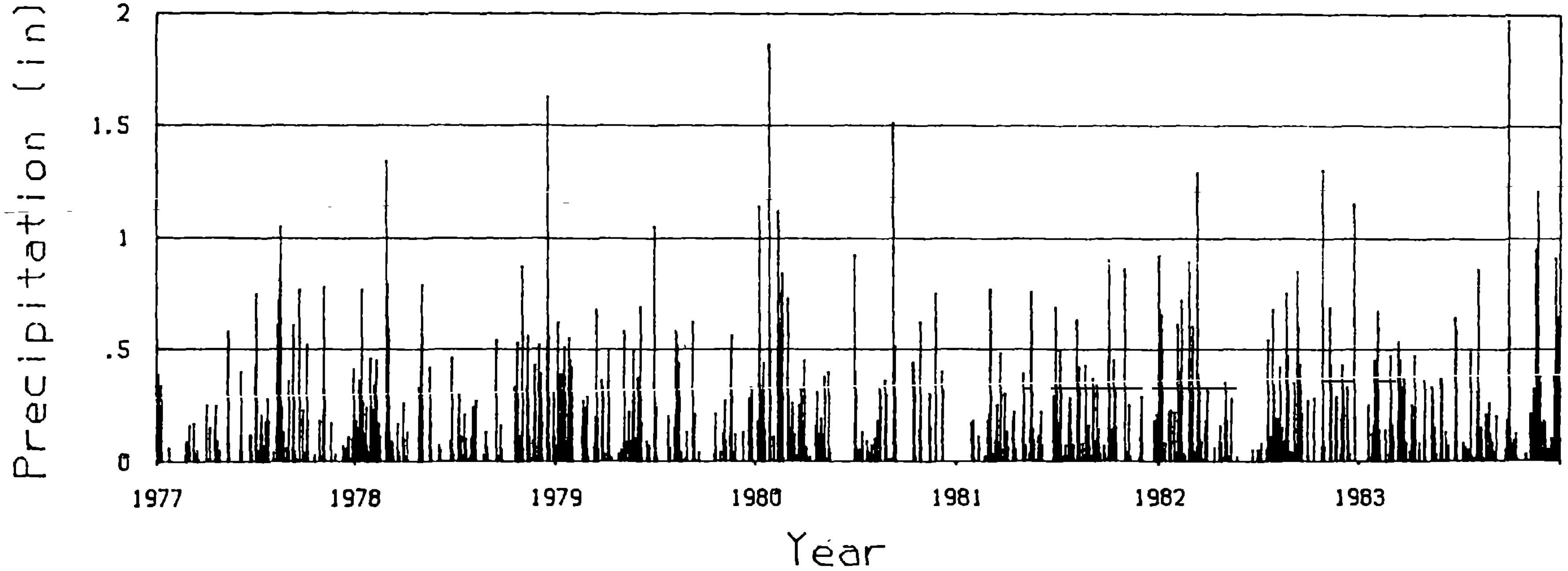

Figure 4. Daily Precipitation, Chama, NM

CONCLUSIONS

In that water rationing is generally practiced when reserves are low, it is reasonable to consider rationing as a parameter in the design or analysis of a rainwater catchment system.

Several rationing functions have been employed in the literature. Most can be approximated by a single decision-variable logistic equation. The value of the parameter can be selected to best fit a preconceived functional shape, or it can be varied in pursuit of penalty minimization.

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ASSESSING THE TRADEOFFS BETWEEN COST AND RELIABILITY FOR WATER SUPPLY ALTERNATIVES FOR MICRONESIAN COMMUNITIES

James J. Geselbracht

ABSTRACT

Objectives which might be important in analyzing water supply alternatives for Micronesian communities are minimizing cost, maximizing hydrologic reliability, maximizing water quality, maximizing central control, and minimizing the organizational requirement. Several water supply alternatives are considered for the community of Colonia, Yap. These options are the existing method of centralized water supply, decentralized rainwater catchment (RWC) systems, and a dual supply approach which uses a centralized system to satisfy the semi-potable demands and decentralized RWC systems to satisfy the potable demands. A computer model which simulates the daily change in storage tank water level is used to design the RWC system. Results indicate that while RWC systems may be more expensive or have lower hydrologic reliability and give the government less central control over water supply, they have a lower organizational requirement which might allow the water quality criteria to be met more reliably.

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INTRODUCTION

Colonia, the population center of Yap State of the Federated States of Micronesia, and Koror, the capital of the Republic of Palau, are two small communities in the Western Caroline Islands of Micronesia. While the rainfall on those islands is high (Yap averages over 307 cm. per year), both communities have had serious problems with their centralized community water systems as both have failed to meet the quantity and quality demands of their residents. An overview of the problems encountered in the centralized water supply systems is presented and a cost-analysis of the use of decentralized rainwater catchment (RWC) systems to replace or to supplement the centralized systems is examined for Colonia.

BACKGROUND ON CENTRAL WATER SYSTEMS

In the past 15 years, many centralized water systems have been built or expanded in the island communities of Micronesia. In some cases, such as Koror, centralized systems had been built under the Japanese administration of the islands (1924-1941) and improvements were made to those existing systems. In other cases, completely new systems were built. Most of the systems that resulted utilized central water sources (impoundments of small streams, wells, etc.) and centrally treated and distributed the water to the community.

Many of those systems, until recently, were unable to consistently meet the community's quantity demands and were required to reduce water demand by supplying water to the distribution system only during limited "water hours". The author has had extensive experience working to improve both the Koror and Colonia systems so that they could supply sufficient water 24 hours a day. They have both sustained 24-hour operation for over 2-1/2 years. Neither system, however, is able to consistently meet the water quality criterion of a finished water turbidity of 1 0 nephelometric turbidity unit (NTU).

The reason that these water systems had operated in a failed state, in the author s opinion, is because of their improper management. While specific structural reasons could explain the failure, the existence of those problems was caused by poor system planning, maintenance, or administration. For example, system consumption was approximately 945 liters per capita per day (Lpcd) which is excessive for a system with very little industry. Water system flow studies revealed that most of that consumption could be attributed to a few residents with plumbing problems at their services (e.g. flush toilet tanks with inoperable flapper valves). In Koror, 3.9% of the metered residential users had consumptions above 5675 liters per day (Lpd) while 66.5% had consumptions below 1685 Lpd (Geselbracht, 1984b). The average residence in Koror has about 5 persons. High consumption caused by negligence can be controlled by metering and billing. However the billing was administered poorly and a flat-rate billing charge was the common response to high meter readings. Similar consumptions were seen after the water system of Colonia had been restored to 24-hour water. There, while each service was metered, bills were not distributed and average residential consumption ranged from 1604 to 2177 Lpd (Geselbracht, 1984a).

While one might point to mis-management as the reason for such system failures, it is not fair to put the blame completely on the managers of those systems. Managing a small water system is not an easy task and the task is made more difficult when set in the Micronesian context. There, budgets are uncertain, the distant location of suppliers may result in a delay of up to a year of a needed repair part, and the systems themselves may be poorly designed or constructed. Additionally, political and family interactions complicate rational management decisions.

WATER SUPPLY OBJECTIVES

Typical objectives of water supply might be to meet a demand for a given quantity of water at a minimum cost, maximum hydrologic reliability, and maximum quality. The reliability and quality objectives might be addressed by setting targets for hydrologic reliability (e.g., design for a ten-year drought) and water quality (e.g., turbidity < 1.0 NTU). Other objectives might also be important in evaluating alternatives to water supply. The water supply scheme should have a minimal sensitivity to organizational or administrative failure. On the other hand, central control of water supply might be more politically acceptable and make the insurance of water quality an easier task.

Minimize Organizational Requirement

Since the supply of potable water is important to the maintenance of a community's health, it is important for that supply to be uninterrupted. Centralized water systems require good management skills for organizing proper operation and maintenance activities which insure uninterrupted service. Since management in the Micronesian context is difficult, it would be beneficial to minimize the level of management skills which the water supply system requires in order to insure the continuation of service. One way of doing this would be to decentralize the system so that the management requirement is dispersed throughout the community. The head of each household would then be responsible for managing the consumption and maintenance of that household's water supply. Failure to properly manage their supply would result in a failure only at that household. RWC systems have been identified as an attractive water supply option where community organizational infrastructure does not exist (Michaelides and Young, 1983).

Maximize Central Control

Those who decide on the method of water supply in the Micronesian islands are typically government officers. One poorly defined objective of the decision makers might be to maximize their political power. In a society where the political power may be divided between government, business, and traditional leaders, there exists an incentive for government leaders to make decisions which keeps power within the government structure. Political power derives from the responsibility of providing the community's water and from the ability to provide (and take away) jobs related to centralized water treatment and distribution. Decentralization of such activities removes power from the government and disperses it among the people. Thus, the political objective of the maintenance of power might call for centralized water supply schemes.

Central control of water supply may also be advantageous because it makes it easier to monitor the community's drinking water. The responsibility of the proper operation and maintenance of decentralized systems, and thus the quality of water they produce, might be given to the general public. It was noted in the context of dual distribution systems that "human ignorance and carelessness are factors which must always be considered in attempting to safeguard the general public from their own follies." (Worth, 1976). It might be advantageous, then, to facilitate central control over potable water supply in order to insure its quality.

RAINWATER CATCHMENT SYSTEMS

Design Method

A RWC system consists of a catchment surface (roof), collection channels (gutters), and a storage tank. It is designed by sizing the catchment area, storage volume, and the consumption to be served by the system. Once those variables are fixed, the rainfall patterns of the region will determine the reliability with which the consumption will be served. A computer model which simulates the change in storage volume in a RWC tank due to daily rainfall and consumption was used for designing the RWC system. Inflow to the storage tank is determined by multiplying the roof area by the rainfall. Using the model, one may determine the tank volume required for a given catchment area in order to meet a consumption over the period of study without failure. Alternatively, one may determine the amount of time that the system will fail to meet the demand for a given catchment design. The model was run with daily rainfall data for 1976 and 1977 collected at the weather station on Yap island. The rainfall pattern during those years corresponds to a 10-year drought and has been used in the design and analysis of the central water system for Colonia.

Costs

To estimate the cost of storage tanks, 1984 material costs for Yap as well as a labor cost of about $2-3/hr were used for several reinforced concrete tank sizes. While the estimate is crude, it should be adequate for planning purposes. Such an estimate yields the following relationship between cost and tank volume:

$$TC=10^{(0.8 \log V + 0.226)} \qquad (1)$$

where V is the tank volume (liters (L)) and TC is the tank cost (US$). While cheaper tanks may be built out of materials such as ferrocement or fiberglass, reinforced concrete seems to be the preferred tank in Micronesia because of its durability.

The catchment area is assumed to include corrugated galvanized iron roofing, its supporting structure, and guttering made of galvanized iron. Catchment areas at ground level are probably not a viable option in Micronesia because of limited land availability. Existing household roof areas are estimated at 70 m^2. The cost of building additional roof catchment is estimated at $26.90/$m^2$.

Results

The cost of a RWC system is dependent on the consumption for which the system is designed. Figure 1 shows how the cost of the least-cost design varies with consumption. These systems are designed for no failures over the study period. If the catchment systems were designed to satisfy the typical residential water demand observed for the Koror and Colonia systems, a consumption of 1685 Lpd might be used. Since a RWC system would operate with a lower water pressure than the centralized system, one could reasonably expect lower consumptions. Additionally, the physical presence of the household's water supply might be expected to make consumers more conscious of their water consumption and reduce wastage, especially during dry periods. A consumption of 950 Lpd (250 gpd) might more nearly represent the demand that would be exerted on a household RWC system (Wagner and Lanoix, 1959). The range of design choice and costs for this consumption are presented in Figure 2. For example, designs which utilize a small roof area (140 m^2) and large tank volumes (100,000 L) will satisfy demand as effectively as those which utilize a large roof area (300 m^2) and a small tank volume (50,000 L).

Figure 2 shows a good deal of flexibility in achieving low-cost designs. Roof areas from about 180 m^2 to 280 m^2

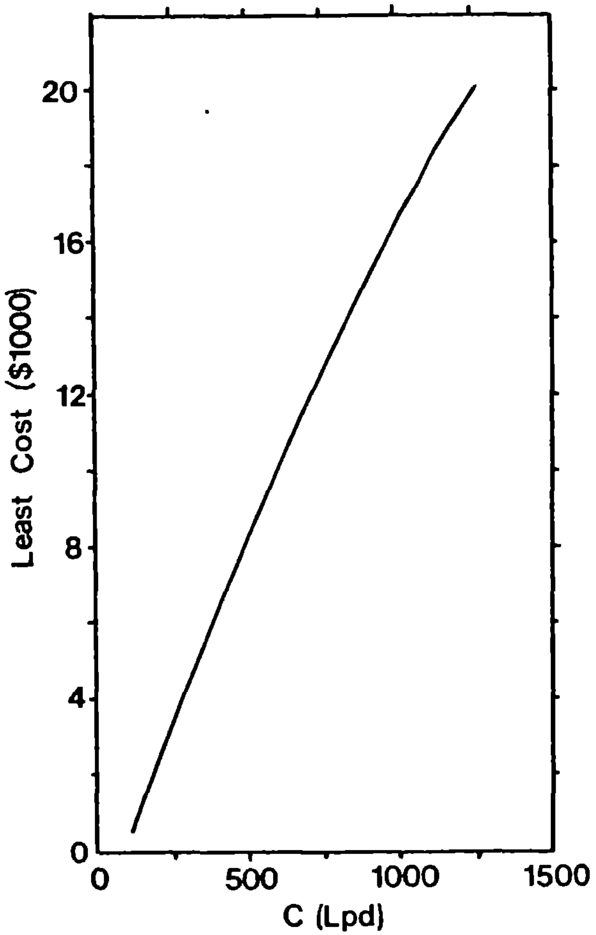

FIGURE 1

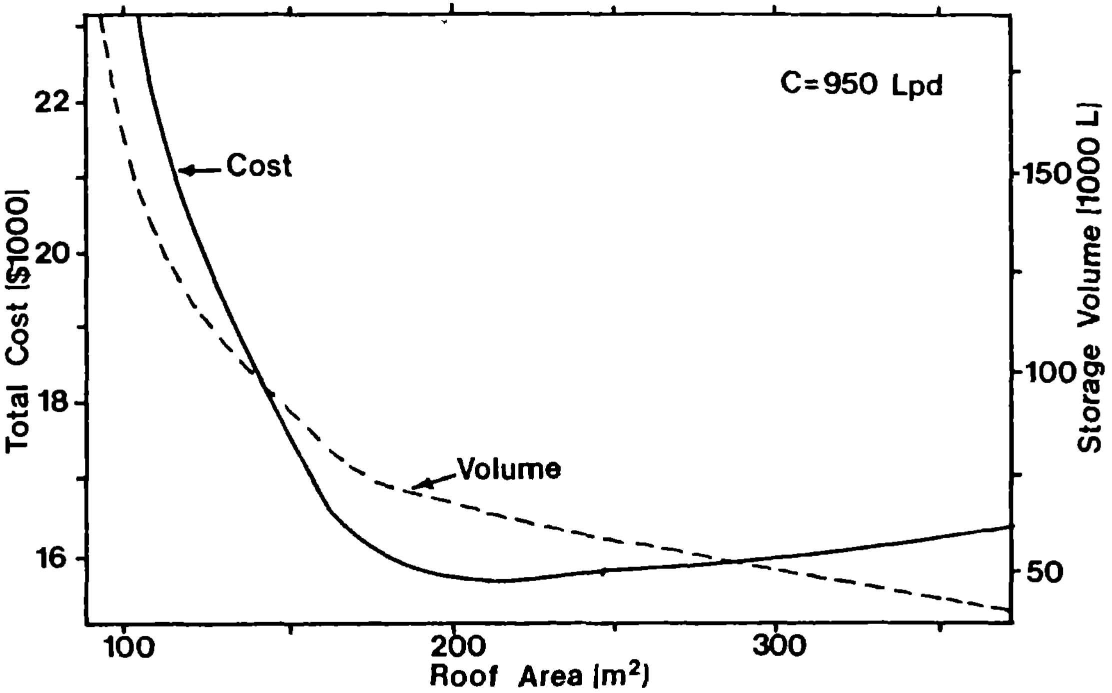

FIGURE 2

at $18,700. Over a twenty year design life and a discount rate of 6.5%, the present worth of the chemical usage is $206,055. Thus the cost of improving and operating the water treatment facilities would be about $171/person, bringing the total system cost to about $1242/person. It would be difficult to quantify the cost of improving the management and technical skills which would insure the proper operation of these facilities.

Figure 2 shows a cost-optimal rainwater catchment design cost of about $3140/person. If that cost is adjusted from 1984 dollars to 1975 dollars using the ENR building cost index, the catchment cost would be about $1700/person. Both the central water system and the rainwater catchment system have been designed for the same hydrologic reliability (10-year drought). A RWC system would be expected to have a lower organizational requirement which, under conditions where management is difficult, might allow the water quality standard to be more reliably met. The decentralized RWC system is more expensive by about $460 person. The value of central control and the cost difference must be weighed against the costs of improving central management to the point where the central system would meet the water quality standard.

DUAL WATER SUPPLY

Because the system fails to provide a good quality water, many of the residents of the community satisfy their potable water demand by utilizing rainwater catchments (O'Meara and Romeo, 1983). These are typically undersized and crudely constructed. One water supply alternative available to Yap would be to formalize and improve the existing practice by utilizing the existing central water system to satisfy the semi-potable water demand (bathing, washing cars, flushing toilets, etc) and to use household RWC systems to satisfy the potable needs (drinking, kitchen uses, washing babies, etc). The quality of water in Micronesian rainwater cisterns is variable reflecting the variability of their design, operation, and maintenance. In general, however, the water is of good quality with low turbidity (Romeo, 1982).

Such a dual supply concept is different from typically proposed dual supply systems in that the potable supply is decentralized rather than independently distributed from a central treatment facility. Estimates of the potable water demand, as defined above, range from 10.6% to 15% of the total average daily use (Haney and Beatty, 1976). If the average daily use is taken as 1685 Lpd (445 gpd), then a potable demand of 189 Lpd (50 gpd) falls within the range presented above. Figure 3 presents the designs and costs of RWC systems which satisfy that demand. The upper cost and design curves represent systems which satisfy the demand without failure during the period of study. The least-cost RWC system could satisfy the potable water needs of a family of 5 for about $457/person. Adding that to the cost incurred to date for the central (and now formally recognized as semi-potable) system gives a total cost of $1527/person. Comparing this to the cost of expanding the central treatment facilities, the RWC option is inferior by about $290/person.

Cost savings can be seen in RWC systems if hydrologic reliability is sacrificed. A majority of the storage volume is used for only a short period of the year. If during the dry season potable water consumption is reduced, the volume of the storage tank may be reduced. The lower curves of Figure 3 show the volume of tank that would be required for a system which normally supplies 189 Lpd (50 gpd) except during dry periods when consumption is lowered. Dry periods are defined by a simple operating rule: when the storage tank falls below

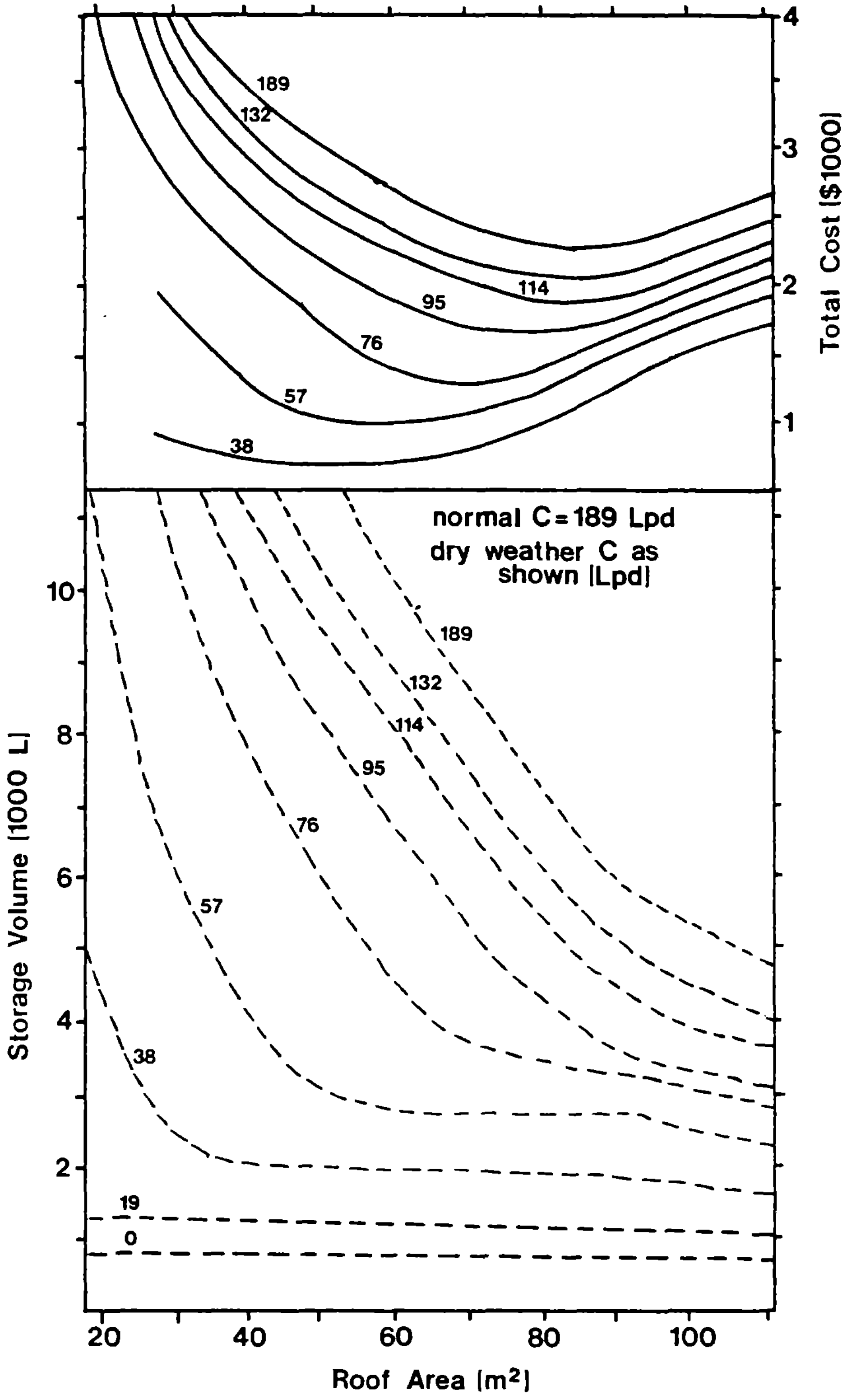

FIGURE 3

RWC Design & Cost

1/4 full, consumption is reduced. Such a reduction could be accomplished by installing two water taps into the tank--one at the 1/4 level for normal use and piped into the household, the other at (or near) the bottom for dry period use and installed outside (to discourage use). The dry weather consumption becomes another design variable of the system.

Figure 4 compares the costs for various designs with the total volume (over the 2 year period) of the water demand which is not satisfied. That comparison is made for a number of different dry weather consumptions. The volume which is not satisfied is the product of the number of days at the low consumption level and the reduction in consumption. That variable can be seen as an intuitive surrogate for hydrologic reliability. The solid curve in Figure 4 gives an indication of the tradeoff between system cost and hydrologic reliability. It is possible that a different operating rule would yield even greater cost savings for the same decrease in hydrologic reliability.

A system with a storage tank of about 1930 L (510 gallons) and a roof area of about 74 m^2 (800 ft^2), requires a consumption of 38 Lpd (10 gpd) for 70 days of the two year period under study. That system would cost $840 which is slightly less than the centralized water treatment option. While the centralized water treatment option would meet the demand with a higher hydrologic reliability, the RWC option would have a higher reliability of meeting the water quality standard because of its lower organizational requirement.

CONCLUSION

A summary of the perfomance of three water-supply alternatives with respect to five objectives is presented

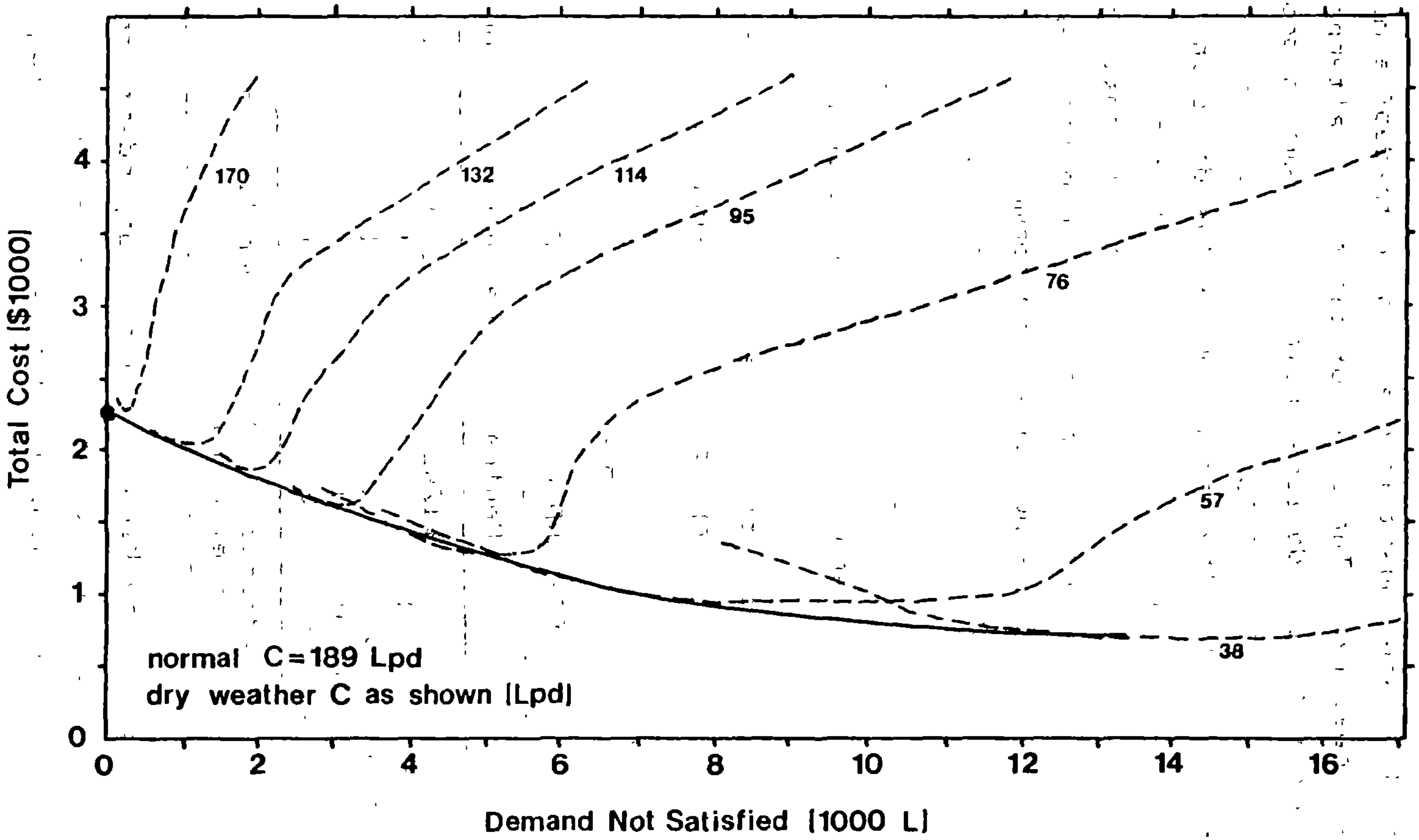

FIGURE 4
RWC Cost vs. Hydrologic Reliability

in Table I. Two of those objectives, cost and hydrologic reliability, are quantified and their tradeoffs may be assessed readily. The costs of the three alternatives are presented for designs with the same hydrologic reliability. The target water quality for each alternative is also the same. While the decision makers may want to maximize central control for political reasons and to control the reliability of meeting the water quality target, such control requires skilled managers and a stable political environment. In their absence, one might want to minimize the organizational requirement of the water supply in order to insure its reliable operation. These last two objectives are conflicting as philosophies of reliable design. The cost differences should be evaluated in light of the existing or projected level of management skills which are available to insure a dependable water supply.

TABLE I

SCORECARD OF ALTERNATIVES

Objective	Central	Decentral	Dual
Min. Cost	$1242	$1700	$1527
Max. Hyd. Reliability	1	1	1
Max. Water Quality	1	1	1
Max. Central Control	1	3	2
Min. Org. Requirement	3	1	2

Note: costs in $/person, other alternatives are ranked in order of preference.

The tradeoffs and rankings are highly dependent on the assumptions made in this study. Less expensive water tank construction methods would make a RWC system more attractive. Water consumption is a very important parameter in the analysis. Lower consumptions would make RWC systems more attractive. Water consumption has, however, been at the focal point of central water system problems in Micronesia and the figures used in this study seem to be acceptable to Micronesian decision makers. Rainfall patterns vary from island to island and will change the RWC system design. For example, Palau averages about 50 cm. more rain annually than Yap. Thus, RWC systems there would be less expensive. An analysis, similar to that presented here, could evaluate the cost effectiveness of RWC systems for those communities.

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USE OF RAINWATER COLLECTION IN URBAN AREAS

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ABSTRACT

Rainwater collection systems are usually considered to be a rural technology. The discussions of cost versus benefit and of feasibility commonly centre on the individual household. However, for studies carried out by and for governmental water agencies, the target area is more likely to be a town or a city. More broadly based estimation techniques for estimating rainwater collection system viability are required in this case.

This paper will show that rainwater collection may contribute to urban water supplies and will provide an outline of some of the calculations that can be done to estimate that contribution based on consideration of the city as a whole.

LIST OF SYMBOLS

A - area of catchment surface (m^2)
D - yearly volume of rainwater used (m^3)
K - runoff coefficient equal to the ratio of the amount of rainfall available for use to the amount falling on the catchment surface.
R - average annual rainfall (m)
S - storage volume (m^3)

INTRODUCTION

Objectives

This paper has two objectives:

1. To present rainwater collection as an attractive supplementary urban water supply option.
2. To present a method of estimating the feasibility of such an urban rainwater program.

Background

Rainwater collection is commonly presented as a water supply option in rural areas (Pacey and Cullis, 1986), particularly in remote areas where the following conditions apply:

1. Alternative sources of water do not provide sufficient quantities of water.
2. The available sources of water are of very poor quality that would require construction and maintenance of expensive water treatment facilities.
3. The cost of bringing distant water supplies to the users is prohibitive.
4. The population requiring water has relatively large impervious areas (here, assumed to be roofs) that can be used as catchments.
5. There is sufficient rainfall annually to permit the collection of adequate amounts of water on the roofs available. A general rule is that approximately 1000 mm or more falls annually and the dry season is less than 6 months duration.
6. Rainwater quality is adequate for direct human usage.

While these conditions are often satisfied by rural locations, it is instructive to note that they can very often be true as well in many urban and suburban areas which one normally associates with centralized piped water systems. The reality of water supply in many large cities is that:

1. Growth of water usage, particularly in urban fringe areas is outstripping the ability of governments to expand existing water treatment and distribution systems. This lag in supply has been brought about because of a decline in government reserves in the past decade as foreign debt has increased, resulting in a reduction in money available for capital projects.
2. Existing treatment and distribution systems are declining in capacity because they are aging and because, in many locations, funds for maintenance have not been available to keep them running at capacity.
3. Where water sources, such as rivers, lakes and ground aquifers are being utilized as urban water sources, they have been developed to a high level of usage and thus there is often very little additional capacity that can be developed without jeopardizing other uses of the water. The available sources for new water will be more expensive to develop as they may be more distant or of lower quality.
4. Adding additional capacity to an existing water distribution system may require complete rebuilding of the distribution system. It is not simply a matter of pumping more water because the system is often at capacity.
5. Centralized systems import water into urban areas. This water does not naturally belong there and thus must be exported via sewers. Thus, an additional water cost is for the expansion of sewer systems.

In short, in areas where centralized water systems exist, the marginal or additional costs of expanded supply can be astronomical although the cost of installed capacity on a per cubic meter basis may be quite low.

Given these conditions, a water supply option that supplies additional water relatively inexpensively compared to existing supplies can be extremely attractive. The authors suggest that household rainwater roof catchment systems may, in many circumstances, fulfill this need for supplementary supplies.

THE CASE FOR URBAN RAINWATER COLLECTION

The advantages of rainwater collection systems for urban use are:

1. After initial capital costs are provided, there are virtually no operating costs and very little maintenance is required. Properly constructed tanks have few leaks and require infrequent cleaning. Most of these costs will be borne by the owner of the unit.
2. The rainwater can always be used as a substitute for piped water. Rainwater generally has a good quality and, particularly in suburban housing estates, will retain this quality. Thus, it can substitute for high quality uses such as drinking and cooking. Near industrial plants, large roadways, or other sources of airborne pollution, or if the water is collected from thatched or tarred (bitumen) roofs, the rainwater will be of lower quality. In this case, it can be used for washing or flushing. However it is used as a supplement to a centralized system, the economic benefits derived will be the same.
3. Since the rainwater collected would otherwise have run off during rain storms but would now be stored and used over a longer period of time, storm runoff is reduced and sewers and storm works are put under less stress at peak flow times. Because the water stored will be released at later dates when the sewer system is more able to handle it, the existing sewers will be able to handle greater storms. Overall, the flow in sewers is more evenly distributed while the total volume is not increased. This can forestall expansion of sewer systems many years.

AN EXAMPLE

The Situation

To illustrate the kind of analysis that could be done, we shall consider a city in a developing country. In this example, the numbers are representative only and are cited in order to illustrate the main factors to be considered in deciding whether large scale implementation of rainwater collection systems systems is feasible.

The city had a population of 500,000 which was growing at 7.5% per year. A river 60 km south of the city supplied most of the water to the city. The water needs for the city averaged 18.3 million m^3 (Mm^3) annually. Overall, this meant a water demand of about 100 litres per capita per day (lcd). Average individual domestic water demand was about 50 lcd.

The pumped water supply system had a maximum capacity of 20.5 Mm^3/year but it was old and losses were estimated to be 25%. It was not able to supply the present water needs. Water shortages were a frequent occurrence and a new rapid filtration plant was planned. To increase water availability, it was determined that a large dam was needed on the river which would cost in the order of $16 million. The cost of past water treatment and supply had been heavily subsidized by outside capital but the current cost for the water system was estimated to be $3.00/$m^3$ (plus $1.00/$m^3$ per year for operating and maintenance costs).

The city has housing with roof types as follows:

HOMES:	corrugated metal	40%
	thatched roofs	30%
	clay tile	20%
APARTMENTS:		10%

Most communal houses, as measured in typical compound housing units, are of size 5x12m, 5x10m or 6x10m. A 60 m^2 roof area with a length 12 m is assumed for this case. It is assumed that existing houses would generally not need to change their roof type solely for rain collection purposes or that increased use of galvanized roofs as opposed to thatched was an established independent trend. Thus the additional cost incurred by use of a rainwater collection systems will not include a roof and the major costs would be for the tanks.

For easy calculation of rainwater system costs on an initial estimate basis, prices of materials for ferrocement-type tanks can be given as approximate costs per m^3 of volume. Detailed costing would need to be more accurate. The cost of some of the basic materials used in building rainwater collectors are as follows:

1. cement - $3 for 45 lb (20 kg) bag. Two bags are required per cubic metre of volume.
2. reinforcement of the tank - $3/$m^3$
3. Galvanized gutter material - about $1.0 per metre of length. The length of gutters could be estimated by twice the length of the roof.
4. The labour costs would be roughly 50% of material costs.

The average annual rainfall in the vicinity averages 1035 mm/year (R = 1.035 m), distributed in the following pattern by months:

J: 63 mm, F: 81 mm, M: 119 mm, A: 246 mm, M: 201 mm, J: 26 mm,
J: 27 mm, A: 23 mm, S: 21 mm, O: 43 mm, N: 97 mm, D: 88 mm.

This was derived from the monthly data for ten previous years from a nearby station. See Appendix A.

Surveys of the housing areas showed the average number of people per house to range from 10.7 to 5.1 with an average of 8 persons in the urban areas.

Physical Analysis

The present water needs for the city were 18.3 Mm^3. The maximum capacity of the conventional water system was 20.5 Mm^3, which becomes 15.4 Mm^3 after losses are deducted. Thus, the shortfall in water supply is 2.9 Mm^3 per year. The annual growth in the water demand is about 1.4 Mm^3/year (7.5% of 18.3).

The number of domestic units is approximately 62,500 (500,000/8).

The installation of rainwater collectors on all metal and clay tile roofs and on one-third of the thatched roofs could provide water to (40 + 20 + 30/3) = 70% of households or 43,750 of them. The total catchment area is 2.6 million m^2 (60 x 43,750). For the houses cited, it is assumed that 80% of the rainfall is collected for use. Thus the runoff coefficient, K, is 0.8, and the average annual rainfall volume available is:

$$K\ A\ R = 0.8 \times 2.6 \times 1.035$$
$$= 2.2\ \text{Mm}^3$$

The yearly domestic demand in houses with rainwater collectors is

$$8 \times 50 \times 43{,}750 \times 365\ /\ 1000 = 6.4\ \text{Mm}^3.$$

Thus the rainfall could, on the average, supply 34% (2.2/6.4) of the water demand in the households where it is used. On a larger scale, the installation of rainwater collection systems could provide up to 12% (2.2/18.3) of the total city water. Given these quantities, it can be seen that the water could be used in this case in the following ways:

1. it could relieve the present shortage of water caused by the losses in the conventional system.
2. it could substitute for over one year's growth in the water demand while providing the same level of service and without taxing the existing system anymore.

However, it is well to note that large quantities of water are not available and it cannot substitute for a full conventional system. At best, it is only a supplementary system and thus could extend the life of any conventional system by a little over 12%.

Economic Analysis

For the present example, assume that rainwater systems will be developed to meet one year's annual growth. Therefore the yearly demand, D, on the rainwater systems is 1.4 Mm^3 which is 0.64 (1.4/2.2) of the total available rainfall. This is a minimum value and during rainy periods, further rainfall may be used without affecting the rainwater systems' operation during dry months.

To estimate the size of the tank required, the rainfall data can be analysed using a recognized method. Hand and calculator methods as derived and applied in Schiller and Latham (1986) can be used but the one applied here is a computerized model (see Appendix B). This results in a non-dimensional plot of demand versus storage for the particular region under consideration as shown in Figure 1. A 95% reliability level will be used as it represents a good trade-off between tank size and service level and takes into account some reduction of demand during certain periods of the year. From Figure 1, it means that 0.19 (say 0.2) of the average annual rainfall collected, KAR, should be stored. Therefore, the storage volume, S, is 0.2 of 2.2 Mm^3 or 440,00 m^3 which is about 10 m^3 per household.

The cost of these rainwater collectors could be calculated as follows:

Costs for 43,750 tanks of total size .44 Mm^3 ($ millions)
    Concrete .44 x 2 x $3 = 2.6
    Reinforcement .44 x $3 = 1.3
    Gutters 43,750 x 24 m x $1 = 1.1
Total materials 5.0
Labour at 50% of materials = 2.5

Total 7.5

The operating costs would be nearly nil and maintenance costs would be relatively small compared to the conventional system. Assume that maintenance costs are 4% annually.

The cost to meet the increased demand by building a new conventional system equal in capacity to the current one would be:

$3. x 1.4 M = $4.2 million for the plant
1.4 / 18.3 x $16 M = $1.2 million for the dam

TOTAL $5.4 million

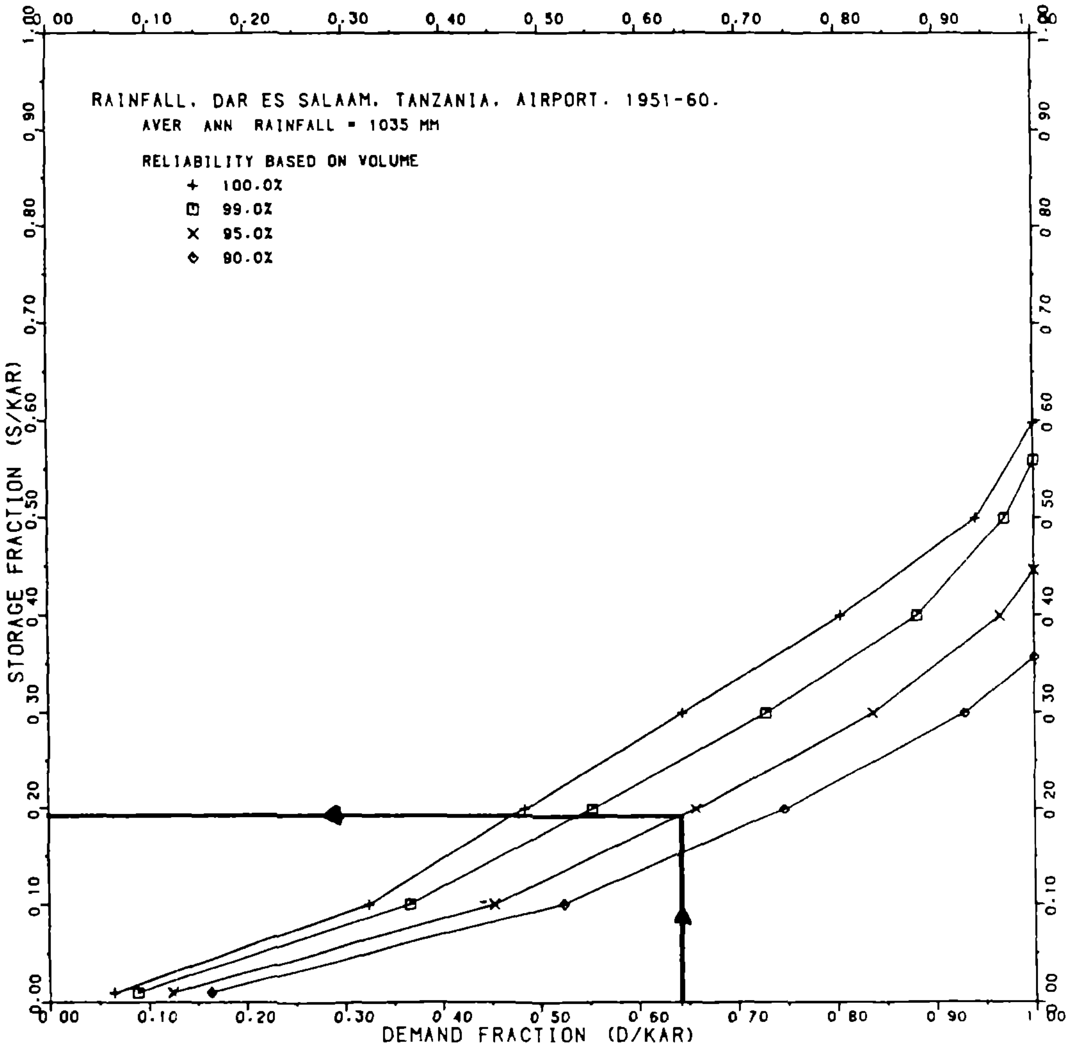

Figure 1: Storage vs. Demand in Non-dimensional Form

In subsequent years, $1.4 million would be spent for operation and maintenance.

Thus, comparing the total cost of both options in $ millions:

YEAR	CONVENTIONAL	RAINWATER
0	5.4	7.5
1	6.8	7.8
2	8.2	8.1
3	9.6	8.4

This shows that within two years rainwater collection supplementary supplies will save money over conventional systems. In other locations, this break even point may take fewer or more years depending on the costs of each component and the rainfall availability. These calculations do not take account of the fact that, since rainwater collectors are built in small household modules, the benefits will begin very soon after construction begins as each tank is completed. On the other hand, a conventional system will take years of construction before any of the water is available. Also, rainwater collectors in new areas are added as required so there are no carrying charges involved in holding unused pumping capacity until a demand develops for it.

However, note that in this case plans will have to be made to develop reservoir capacity on the river to provide for future increases in the demand. But, if rainwater collectors are installed with new housing, the new domestic demand would be decreased by up to 12%, thus extending the lifetime of a conventional system.

CONCLUSION

Rainwater roof catchment systems can be applied in urban settings to complement existing centralized water systems. Depending on the quality of water, this water can be used for human consumption or other purposes. However it is used, it will decrease demand on the existing system and forestall expensive development of increasingly expensive piped water sources.

The authors encourage water boards to consider this option in future plans for expansion and urge them to subsidize directly home owners who develop rainwater collection where this is appropriate.

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Appendix A

DATA USED IN THE OTTRAIN MODEL

The data used for this example were monthly rainfall values for 1951-1960 for Dar Es Salaam Airport, Tanzania. They were obtained from page 442 of the Africa volume of U.S. Department of Commerce (1967) and are reproduced here as a matter of record.

All values are in mm.

J	F	M	A	M	J	J	A	S	O	N	D
39	137	142	242	259	29	28	12	2	79	195	217
6	62	62	159	113	21	3	17	72	34	51	24
17	66	143	284	378	2	61	49	20	67	197	62
54	51	40	275	231	3	15	12	23	107	58	24
35	109	30	202	372	44	31	1	5	13	68	114
216	22	167	243	93	11	9	4	20	24	20	36
144	111	101	269	331	30	16	8	13	30	289	121
8	128	132	234	28	27	61	37	8	18	30	112
35	72	126	232	61	21	45	85	16	19	64	127
76	55	251	315	150	69	2	7	27	34	1	41

Appendix B
THE OTTRAIN MODEL

The OTTRAIN Model for rainwater collector reservoir sizing is a hydrologic model that analyses raindata to determine appropriate combinations of demand and storage (reservoir) size for that data. It was developed at the Civil Engineering Department of the University of Ottawa, Ottawa, Canada (Latham, 1983) and is also known as the Ottawa Model. It is basically a mass-tracking type of calculation in which a combination of storage and demand values is chosen and the operation of the reservoir is simulated by following the water flowing into and out of the reservoir with an appropriate check on whether or not the capacity is being exceeded in each of the time periods for which data are available. These calculations are normally carried out on actual historic raindata.

OTTRAIN offers the following options:

1. MEASURE OF RELIABILITY. The reliability can be measured on either a volume basis (percentage of the demand volume that is provided) or on a time basis (percentage of time periods that the demand is completely supplied).
2. RATIONING. If storage at the beginning of a time period is less than the demand for the period, the demand is reduced to 75% of its normal value.
3. EXTERNAL SOURCE. If water is available, a week's supply of water is imported if the amount in store is less than the demand for the period.
4. TYPE OF DATA. Monthly, weekly or daily data can be used, although monthly is the usual.
5. CALCULATION ALGORITHM.
6. PLOTTING. This can be done in various ways.

In the case reported in this paper, the following options were used: volume reliability of values 100%, 99%, 95%, 90%, no rationing, no external source, monthly data, 0.5 calculation parameter, non-dimensional plotting.

The major achievements of OTTRAIN over other reservoir techniques such as the mass curve model of Rippl are:

1. it allows a reliability level to be set for the storage size. This gives a greater choice of the demand and storage combinations.

2. it uses a storage algorithm family set that has as its extremes the YAS (Yield After Spillage) and YBS (Yield Before Spillage) algorithms described in Schiller and Latham (1982). These two algorithms were unified by the introduction of a parameter which ranges from 0 to 1. Experiments have shown that use of the algorithm with a parameter value of 0.5 and monthly data gives a good approximation to the daily data case.
3. Calculations are carried out for combinations of demand and storage that cover the full range of demand and storage fractions. Thus all possible combinations are considered with a <u>minimum</u> number of cases of calculation.

NOTE:

1. The relationship between demand and storage is not a simple one and depends on the rainfall pattern. Thus the applicability of the curves of OTTRAIN should be restricted to the immediate region of the meteorological station where the data were obtained. If they are to be applied to more distant areas, this should be done only with caution as, strictly speaking, they do not apply.
2. The storage values for 100% reliability are considerably higher than for even 99% levels and are often several times those for 95%. Since the shortages usually occur during droughts and it is known that users cut back water use during these periods as a conservation measure, a reliability level below 100% is viable if the rationing calculation is not being used. When using the rationing option, the 100% reliability should be chosen more often.

A TOTAL APPROACH TOWARDS THE ESTABLISHMENT OF RAIN WATER CISTERN SYSTEMS IN DEVELOPING COUNTRIES

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ABSTRACT

Rain Water Cistern Systems (RWCS) have greater application in developing countries where the capital outlay for the conventional larger water supply systems is not forthcoming. However, only of late has the propagation of such systems on a large scale gained prominence.

To establish RWCS systems, the associated technology involving the sizes of cisterns, types of material to be used, mode of utilisation and the maintenance of quality are factors that have been largely discussed in depth. In this paper, it is emphasised that to propagate such systems besides these salient technological factors, the socio-cultural aspects of the region also have to be taken into account. The total approach towards a successful RWCS should ensure an integration of all associated technological, socio-cultural and economic components such that the final outcome is a long lasting, simple and cheap system that is manageable by rural communities.

Two types of approaches are recommended depending on the existing state of knowledge of RWCS in the region. As such, case studies of the modus operandi in the Philippines and Indonesia are presented.

INTRODUCTION

In the past, development of water resources has been confined to large-scale projects that involved substantial capital outlays and required progressively sophisticated expertise. These twin characteristics hampered the introduction of many water projects in developing countries where there is the need to borrow large sums of money to execute such projects and, very often, engage expert foreign personnel for execution. Consequently, many of these projects never took off. However, the lack of water continues to ravage developing countries to the extent that three quarters of the third world countries in Asia, Africa and Latin America lack drinking water facilities (Morrison 1983).

The introduction of the age old method of using Rain Water Cistern Systems (RWCS) and their propagation in developing countries is of relatively recent origin. The great attraction of RWCS have been the low capital outlay, simple design and construction technology and, in many cases, the sense of communal participation that such projects have fostered. Taking all these factors into consideration, there is the need in developing countries to formulate a methodology for the introduction of RWCS that not only alleviates the problem of a pressing demand for water but, at the same time, helps in developing better understanding, co-operation and unity in communities.

AVAILABLE INFORMATION AND TECHNOLOGY

Considerable published information is available on the design of RWCS, emphasis being placed on sizing of cisterns (Heggen 1982, Appan 1982, Hoey and West 1982), simulated rainfall patterns, (Fewkes and Ferris 1982, Fok et al 1980), rationing of water (Perrens 1982, Lo and Fok 1982), dual modes of supply (Ikebuchi and Furukawa 1982, Lim and Loh 1986), etc. The analytical methodologies developed and the research undertaken have resulted in RWCS being well-characterised and their physical requirements defined with a large degree of confidence. In general, due to the inherent nature of such systems where operational and maintenance functions have been transferred from a central authority to large numbers of individuals or groups of individuals, the quality aspects and control of RWCS need to be addressed in greater depth.

THE NEED FOR A TOTAL APPROACH IN DEVELOPING COUNTRIES

The overall concept of RWCS is quite straightforward and installation of such systems is relatively inexpensive. In fact, the capital-intensive large water supply systems where quality-control, supply and distribution are centrally-controlled, could have been largely instrumental in the progressive lack of use of simple RWCS. But presently, RWCS can be introduced in developing countries where capital outlay is not forthcoming. Also in such systems, there should not arise any insurmountable technical problems that cannot be dealt with locally. An added advantage is that such systems are largely decentralised.

From experience accrued in Thailand (Hayssen 1983, Appan 1984a) and Indonesia (Aristanti 1983), the responsibility of payment for the system ultimately was that of the individual or group of users. The economic status of most of the people in developing countries is very low and thus the system of repayment is a critical element in the propagation of RWCS.

The need for appropriate technology using locally available material is to be seriously considered as the use of indegenous building materials like bamboo, bricks, etc. have proven to be reasonably successful (Vadhanavikkit 1983, Thiensiripipat 1983, Kerkvoorden 1982 and Doelhomid 1982). Such use not only decreases the cost considerably but also helps the potential user to identify his project better as he is using indigenous building materials.

Another factor that influences propagation of RWCS is the attitude of the people. Though there is evidence that rainwater has been used traditionally (Rajapakse 1983, Prempridi 1983), there are instances where there is poor knowledge of its quality (Pathirana 1983) and abuse of cistern storage facilities (Aristanti, 1983). In fact, there needs to be an acceptance of this type of water and the users will have to exhibit a high order of discipline. This is so especially when its use is to be rationed during periods of drought and when it has to be doled out in cases where even drinking water is scarce. Consequently, as this source of water can alter the life style of these people, it is imperative that the socio-cultural aspects of the use of rainwater be an integral part of planning in RWCS technology.

Looking at the propagation of RWCS as a whole, it is clear that the introduction of such systems will have an impact on the quality of life of the users in terms of economic, social and cultural aspects. The need is therefore there for the evolution of a methodology or approach that will take all these factors into consideration. On analysing the historical development and propagation of RWCS in Thailand and Indonesia, developing countries that have adapted RWCS in recent years, it is observed that the success of this system has been largely dependent on an approach that took into account all the above salient factors. This is tantamount to adopting a total approach, an approach that affects the whole lifestyle of the villagers. This total approach has been recognised to be essential for the successful implementation of RWCS in developing countries (Appan 1984b).

MODUS OPERANDI

Primarily when a potential location is identified for establishing RWCS, it has to be ascertained as to whether or not there is any form of such systems in existence. The line of action to be taken is very much dependent on this information as outlined in the flow-chart (see Figure 1). Details of associated activity depending on

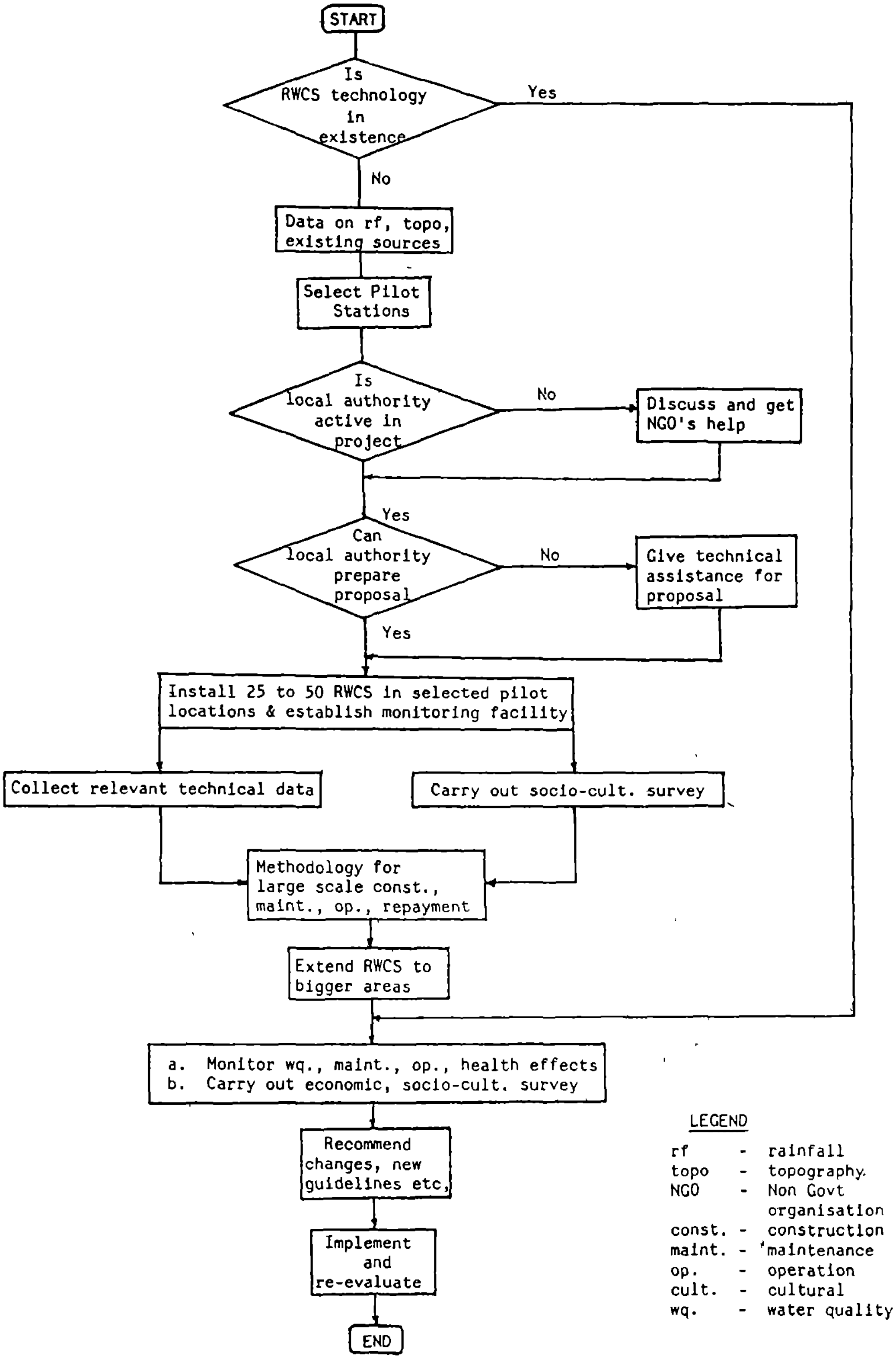

FIGURE 1 : FLOW CHART FOR A TOTAL APPROACH

the two main categories are as follows:

(a) Countries with no RWCS technology

In such locations, there is the need to do some preliminary survey on rainfall statistics, topography and water supply sources, if any. Using this information, an initial field visit to the location may be made and discussions held with the relevant authorities who, preferably, should be policy makers capable of implementing such systems on a large scale. Using this information, pilot locations can be established in strategic areas. The main aims of a network of pilot locations have been defined as follows (Appan, 1983):

(i) Identification of areas in the region that are ideally located and would be representative.

(ii) Establishment of a network of RWCS and gathering of actual field data in terms of rainfall, pattern of demand in relation to roof area, water quality etc.,

(iii) Utilistation of accrued data for arriving at near-ideal relationships between volume of cistern, roof area, demand etc.,

(iv) Use of different types of material including indigenous types for construction of storage tanks and assessment of efficacy in terms of cost, quality of water etc.,

(v) Studying the effect of environmental factors on RWCS and emphasising on a system that, as far as possible, will ensure a totally safe and palatable water supply.

(vi) Utilisation of accrued data to arrive at the most appropriate system/systems for each of the locations based on an economic appraisal.

In each of these identified areas, say 25 to 50 RWCS can be built in the pilot locations. The technology used for building should, be most appropriate to the region and the proposal should come from the authority who has plans to extend the RWCS after the system has been put through a trial period. This period should be used for testing the workability of RWCS, sensing its social acceptability and observing the types of problems that have potential to be magnified. This period can also be utilised by the implementing authority to work out the details for an appropriate financial model that will ensure that the extension of such systems is a workable proposition. This aspect of the approach is very crucial for application in developing countries.

The information obtained from the RWCS in the pilot locations will go a long way towards attaining a better understanding of the stochastic rainfall pattern, the relationship between draft and storage, and water quality. Also, the operation and maintenance of RWCS in the pilot locations will help largely towards establishing norms when the system is to be extended. Besides, if a proper survey is simultaneously carried out on the socio-cultural acceptability and financial repayment system, it can be deemed that the fundamental objectives of the RWCS in pilot locations have been achieved.

The extension of the RWCS to wider areas and the degree of success achieved will largely depend on the conclusions drawn from the analyses of data obtained.

(b) Countries where there is some form of RWCS

In countries, where RWCS of any form are already existent, there is the need to monitor the state of the systems, to understand the operation problems, survey the social acceptability and appraise the existing method of financing such systems. One of the best ways to get this data is to carry out relevant studies that are geared towards gathering of the following information:

(a) water quality in its different stages and associated problems,
(b) existing operation and maintenance methods and relevant issues,
(c) finance for constructing, maintaining and extending such systems and a model for reclaiming capital investment,

(d) socio-cultural acceptance,

(e) the effect on health and

(f) overall impact of RWCS with respect to improved quality of life.

In all these locations where RWCS are to be introduced, the above listed issues are bound to follow. It is thus an integral part of the total approach and its need will be dictated by the state of development of RWCS in a location.

CASE STUDIES

Based on the concept of the total approach outlined, pilot locations have been identified in Sri Lanka and the Philippines, countries where RWCS technology has not been established (Appan 1985). But in Thailand and Indonesia where RWCS are already in existence for some time, the studies that are being undertaken are of a different nature. Some details of the action being taken in the Philippines and Indonesia are presented.

The Philippines

RWCS in their present form are not found throughout the Philippines. The area identified for the establishment of pilot stations is the Province of Capiz in Panay Island. The island enjoys an average annual rainfall of 1710 mm and has a population of 490,000 of which 86.5% lives in rural areas.

Coastal municipalities faced difficulties as only brackish water was available or the sources were inadequate. Likewise, those living in upland areas experienced water scarcity and, very often villagers had to walk considerable distances to obtain water of a dubious quality from streams and open wells.

Based on the rainfall data in relation to basic drinking water requirements, a simple model was used (Appan, 1982) to arrive at appropriate cistern sizes of 5,000 litres for individual households and 10,000 and 16,000 litres for communal use.

A research program has been subsequently initiated (Paro Jr. and Villareal Jr. 1984) with the following objectives:

(a) to build install and maintain in three selected villages (pilot locations) a total of 30 cisterns as part of an RWCS program,

(b) to use ferrocement as the building material,

(c) to develop and conduct a non-formal course on the construction, installation and maintenance of ferrocement cisterns for recipients of tanks,

(d) to establish a monitoring station in each of the 3 pilot locations to record rainfall, water use patterns and water quality,

(e) to develop and test several self-supporting repayment schemes and

(f) to monitor the villagers perception, acceptance and maintenance of the RWCS.

The three sites selected had varied topography and are located in lowland and upland areas and coastal plains. Initially, two researchers of the RWCS project team are to be sent to Thailand and Indonesia to expose them to on-going projects and to train them in various construction techniques.

In the meanwhile, the villagers from the selected three pilot locations will also be informed of the project to obtain their support and solicit their active participation. A survey will be conducted on the household/demographic characteristics, household income, distances to existing water sources, daily water consumption etc., so as to identify the appropriate households to participate in the project. One essential criteria to be selected as a receipient is the willingness of the participant to undergo training on construction of RWCS and to carry out the construction himself.

Several strategies are being considered for repaying the cost of the RWCS constructed by each householder. These vary from training to be given to tank recipients on different skills to the possibility of selling the surplus rainwater and depositing the returns in a core fund to be managed by an association of RWCS owners.

A training program for all potential RWCS owners will also be conducted and it will include all aspects of simplified construction methods. Besides there will be instructions on simple maintenance procedures, on proper use of water and rationing methods during dry periods.

The project has been planned to extend for a period of 36 months. Analyses of all relevant data accrued in the design, construction, maintenance and operation of RWCS in relation to the socio-economic and cultural aspects are to be carried out and an end-of-the-project seminar is planned during the last 5 months of the project.

Indonesia

In Indonesia where RWCS are found far and widespread, construction materials used for cisterns have varied from reinforced concrete to ferro-cement, bamboo reinforcement, bricks, etc. (Doelhomid 1982, Kerkvoorden 1982, Aji 1983). Though these systems have been in existence since 1978 (Aristanti 1983), there have been no studies conducted on the impact of the implementation of RWCS with regard to the social attitudes of the people, the durability of the different systems and the effect on the health of the people. Therefore, there is the need for some research and survey of the existing systems to ensure that there are no drastic side effects by the implementation of RWCS. Under no circumstances should the process of overcoming one problem (lack of drinking water) be the cause for another or even several other problems (socio-cultural, economic, health).

Based on this need, it has been proposed (YDD, 1984) that a study be carried out with the fundamental aim of making RWCS to be fully utilised by the people. The study is to be carried out in six villages over a period of one year. Some of the detailed objectives are:

(a) to study the effect of the use of RWCS with respect to solving the people's problem of water scarcity,
(b) to identify the problems that arise from the use of RWCS in terms of technical, socio-cultural, economic and health aspects,
(c) to study the behaviour of the use of ferrocement and bamboo-reinforcement in water cisterns,
(d) to study the quality of water in RWCS and its effect on the health of users,
(e) to train users on any newly identified aspects that are hindering the full utilisation of RWCS, and
(f) to develop and field test a new strategy for better implementation of RWCS.

It is proposed to carry out this study in three phases to identify problems, solve them if possible, and evaluate the solutions.

The identification of problems will include technical, health, socio-behavioral and economic aspects. Sampling will be carried out amongst the local people who own and do not own RWCS, the implementors who could be the government, non-government agencies or individuals and village leaders.

Problem-solving should be quite subjective and, based on an analysis of the feedback, could result in some informal training or re-training.

The final phase of the study will be a process evaluation of the new training given and corresponding changes that are evident or those that can be envisaged. A comparative study will also be undertaken wherever educational programs are implemented to assess whether there is a change in the users' attitudes after the completion of this program. This should lead to an identification as to whether such education should be passed on to RWCS users before or along with the implementation stage of such systems.

DISCUSSIONS AND CONCLUSIONS

1. The success of RWCS in the immediate past in developing countries has indicated that the propagation of such systems can affect considerably the life style of the people who benefit by its introduction. The impact can be felt in terms of the economic and socio-cultural aspects of life of the villagers. Since the introduction of this system can affect the overall quality of life, a methodology has been evolved to ensure that all relevant aspects of life that will be affected are taken into consideration. This is the 'total aproach' that is recommended.

2. The identification of pilot locations by preliminary surveys and meeting of relevant authorities involved or interested, is a crucial process. Particularly in countries where RWCS are not in operation, these pilot locations have to be selected carefully as they will be largely instrumental in introducing RWCS to the people. By observing the success of this system, the people should be spurred on to extend its application to larger areas. The recommended number of RWCS per location is 25 to 50 units.

3. Monitoring of selected units in pilot locations will give qualitative and quantitative data that will help in the analysis of the design parameters. The period during which the RWCS in the pilot locations are in operation should be used to gauge the response to the system in terms of socio-cultural aspects of the users.

4. Following the establishment of RWCS in pilot locations, utilisation of data from monitoring stations, field surveys of socio-cultural impact and testing of financial repayment systems, the information obtained should be utilised extensively so as to propogate RWCS in a much larger scale.

5. Financing of RWCS is a very important facet of the program as the economic status of people in developing countries is quite low. In the past, it has been observed that in a scheme which was totally financed by an external source, there was a progressive lack of interest resulting in poor operation and maintenance. This attitude has been found to change for the better when self-help methodologies involving community-participation have been evolved. The contributions by potential owners have given them an opportunity to learn a skill and be more economically independent as in the case of building houses in Sri Lanka (Ariyaratne 1982) and constructing RWCS in Indonesia (Aristanti 1983). Hence, there is the proposal to teach skills to RWCS participants in the Philippines.

6. The design of the different units in RWCS in pilot locations has to be very carefully done. In areas where an educational process on the construction and use of RWCS is to be undertaken, the demonstration of the new system should be effected with the minimum of adjustment and there should be no detracting factors. Bearing this in mind, the ferrocement tanks for use in the Philippines are recommended to be carefully designed and tested and a simple methodology worked out for field construction and installation (Appan, 1985). The significance of this approach can be understood when it is realised that the 30 pilot location RWCS will be testing ground for a potential 20,000 units in the Province of Capiz in the Philippines.

7. In countries where RWCS are in operation, there is the need to monitor the status in terms of materials used, water quality,

socio-cultural acceptance, health, maintenance, operation etc. As proposed, studies undertaken could be most beneficial if the problems identified can be solved by training or re-training users. *They will also help in postulating the point of time at* which education on the use of RWCS has to be imparted.

8. Finance for the investigation of pilot locations and establishment of a few RWCS with monitoring facilities, will have to be provided, preferably, by the government or some external agency. The finance provided should be used for purposes demonstrating RWCS. At the expiry of the period of the establishing and analysing the RWCS in pilot locations, the main aim should be to arrive at an appropriate working methodology including a financial model that will be fully operational in the immediate environment.

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INTEGRATION OF RAIN WATER CISTERN SYSTEMS WITH OTHER LIMITED SOURCES OF WATER IN THE CARIBBEAN ISLANDS

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ABSTRACT

Conjunctive use of water supply sources in the Caribbean islands, rain water, ground water and sea water desalination is necessary as demands increase and traditional usage of single sources of supply is being found to be unsatisfactory. A methodology is developed for systematic integration of water from these sources. The strategy attempts to maximize those attributes of each source to as high a degree as possible while keeping the lesser desirable aspects to an acceptable minimum. Models are developed not only to show the effects of various system configurations but also the consequences of cistern use practices on the overall water supply system.

INTRODUCTION

Throughout the Caribbean area where rainfall in general averages about 50 inches annually, rain harvesting is a principal source of water. In many islands cisterns are required by law for all residential buildings and for some commercial structures. A typical cistern in the U. S. Virgin Islands is shown in Figure 1. Legal requirements and traditional practices are not the only reasons why people in this area use cisterns. Cistern harvested water is preferable because of taste, cost and also because of the independence it affords. The cistern owner has greater knowledge and control of the quality of his water supply.

As personal water demands increase due principally to changes in standards of living, cistern supplies are being supplemented by water from other sources. Common, supplemental sources include ground water and desalination. Since these supplementary sources as well as cistern supplies each have unique characteristics, management strategies devised for their use should incorporate to the greatest extent possible, attributes peculiar to each source, and exclude the lesser desirable consequences. Models intended to facilitate this process are proposed herein.

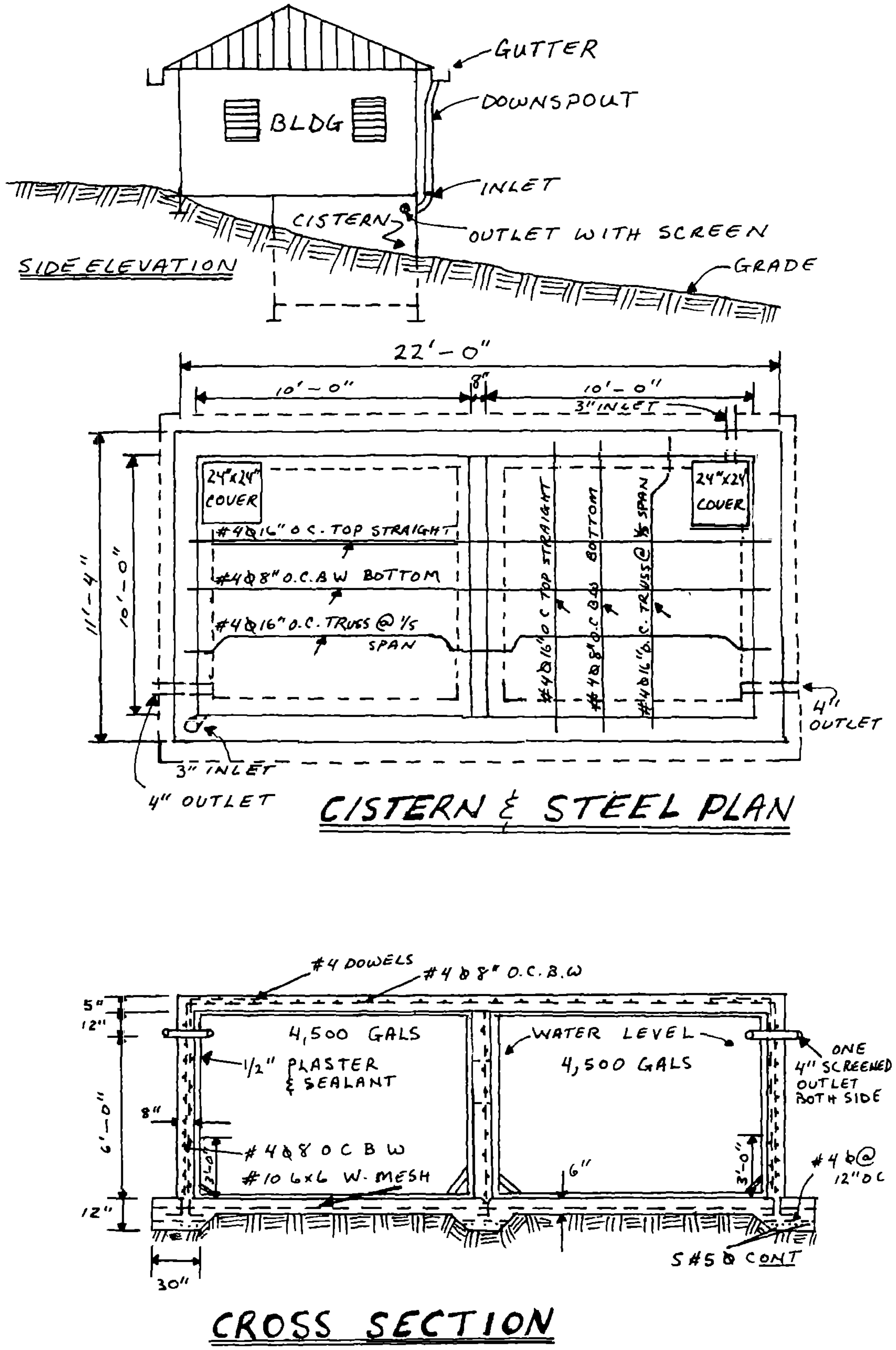

Figure 1 Typical Cistern in the U.S. Virgin Islands

PROBLEM STATEMENT

Costs of having desalination provide supplemental water to a demand principally served by cistern systems may be reduced if the desalination plant is used in a manner that it operates only during certain critical periods of the water supply year. During these critical periods, the plant may provide the peak load requirements and divert the excess to storage. Alternatively, before the critical period is reached, desalted water may be produced and added to storage in anticipation of need. Such a practice may result in a smaller plant requirement and also reduction in periods of shortage.

The study objective then is development of a procedure for determination of design capacities for cistern and desalination plants in conjunctive operation. The procedure would suggest guidelines for selection of cistern and desalting plant capacities as well as the operating rule for the desalting plant. The setting in which the procedure is expected to be most applicable is that in which rainfall, though plentiful, is seasonal and other natural sources of supply are negligible or nonexistent. Desalination, though expensive, may be used as the only other feasible supplemental source of water.

MODEL DEVELOPMENT

The Cistern Sizing Model

A simulation procedure is used in the model CISTERN RELIABILITY to determine the minimum storage that must be provided for each unit area of catchment surface in order to achieve a desired level of reliability. For each simulation time unit (week) the volume of rainfall which contacts the catchment surface is determined. Based on the catchment efficiency, a portion of the water is computed as available for use. The demand is subtracted from this amount. This procedure is similar to Jenkin's (1978) Yield Before Storage (YBS) model. Excess demand is supplied from storage. Alternatively, excess harvested rain is added to storage. Spills occur when demand has been satisfied and harvested water is in excess of available storage. If demand cannot be satisfied then a failure occurs. System reliability is calculated based on the number of failures and the total time units (trials) in the simulation period. The reliabilty of a system with a specified roof area, demand rate and cistern capacity is known at the end of the simulation period.

The Conjunctive Use Model

A conjunctive use model, CONJUNCTIVE USE, was developed to simulate the relevant interactions between the various components of the water supply system. Provision is made in this model for inclusion of a ground water component based on that of McWhorter and Sunada (1981) for a small island. The simulation starts with the determination, after considering the week's rainfall, of the availability of ground water for system satisfaction as well as the water available for harvesting.

Ground water is first used to satisfy demand and if not of sufficient quantity, then an attempt is made to satisfy demand using harvested rainfall. If the volume of water in storage is below a specified amount the desalting plant is brought on line. If it is above a maximum value, a check is made to see if the plant is on line. If it is, it is closed down and the duration of the running time determined. If the plant is on line but the volume of storage not above the shut off value, then the weekly capacity of the plant is added to storage.

For each period in the simulation the following is determined and recorded:

i. Volume of spills or shortages if any.
ii. Whether the plant is on or off.
iii. Volume of water in cistern and/or supplemental storage.

With this information it is possible examine the production record of the plant and the storage histories of the cisterns and other supplemental storage. With the running cycles of the plant known, an analysis may be made of the load that is exerted on the plant. Short running times may indicate too much storage in the system and/or a plant with a greater capacity than is necessary. Alternatively, extended running times are an indication of the plant being too heavily loaded and/or a need for greater storage capacity in the system or possibly need for a larger desalting plant The record of shortages permits an estimation to be made of additional storage needed in the system. The simulation may be repeated changing parameters as necessary until a desirable system is obtained.

The Plant Factor Model

The total cost of a desalination plant over its lifetime may be expressed as the sum of the capital, energy and operation costs. Strobel (1973) showed that the principal components of cost in a typical 10 million gallon per day desalting plant were capital (35%) and energy (52%). In 1984, Awerbuch (1984) determined that energy costs remained at 52% while capital costs increased to 46%. Operating costs will be neglected in this discussion.

Schwarz (1973) showed that as efficiency of a desalting plant increases, then capital cost increases. The equation

$$UC = FC / (PC * PF)$$

where UC is the unit cost, FC is the fixed cost, PC is the plant capacity and PF is the plant factor, may be used to demonstrate the influence of plant availability on unit cost of water. If FC and PC are held constant, it is readily seen that as PF is changed then UC changes oppositely. In short then, as the plant factor of the desalination unit is increased the relative annual cost of water increases. At the same the actual unit cost of the water decreases.

For situations then where a desalination plant is not expected to be in operation on a full time basis it is more economical to use a plant with a lower design plant factor. The higher unit cost of water will allow greater savings to be realized on a long term basis.

Though the program, PLANT FACTOR, takes the operation history of the desalting plant and determines the actual plant factor over the simulation period, this might not be the best plant factor on which to base the design. Instead the least costly design plant factor may be one that considers the distribution of the plant's operation time. This is discussed in detail by Smith (1985). Using the operation history and the distribution of plant cost for various load factors between capital and energy costs, PLANT FACTOR determines the plant most suited for the situation being simulated.

The Economic Model

A simple model to provide cost estimates was developed. Desalting unit costs were based on estimates provided by Spiegler (1980). Total desalination costs are calculated based on the plant's capacity, the distribution between the capital and energy components of the unit costs, and the operating history of the plant.

MODEL APPLICATION

The procedure developed was applied to the town of Charlotte Amalie, St. Thomas, Virgin Islands. Average annual rainfall in this area is 44 inches with a weekly distribution as illustrated in Figure 2. The daily demand used in the simulation was 778,800 gallons, and a total catchment area of 9,086,000 square feet with an estimated efficiency of 85%. All residences in the Virgin Islands are required to provide 10 gallons of cistern storage for each square foot of roof area while commercial establishments provide 4.5 gallons of storage for each square foot of roof area.

Using the model CISTERN RELIABILITY the cistern storage required to acheive various levels of reliability for the system described was determined. Results are summarized in Figure 3. The present storage requirement appears to provide a reliability of about 66%. A storage requirement of half this volume (5 gallons per square foot of roof area) would provide a reliability of 60%.

CONJUNCTIVE USE was used to determine the effect of storage provision on total shortage. Figure 4 shows the results obtained which supports the findings using CISTERN RELIABILITY. While with an increase in storage the total shortage declines, there is a very significant decrease in incremental reliability value. There is a point at which provision of additional storage does not increase system reliability for then rainfall becomes the limiting factor.

Above it was determined that a practical cistern storage requirement would provide a reliability of about 60%. In the system then it would be necessary to have an alternative source of water that would provide the balance of

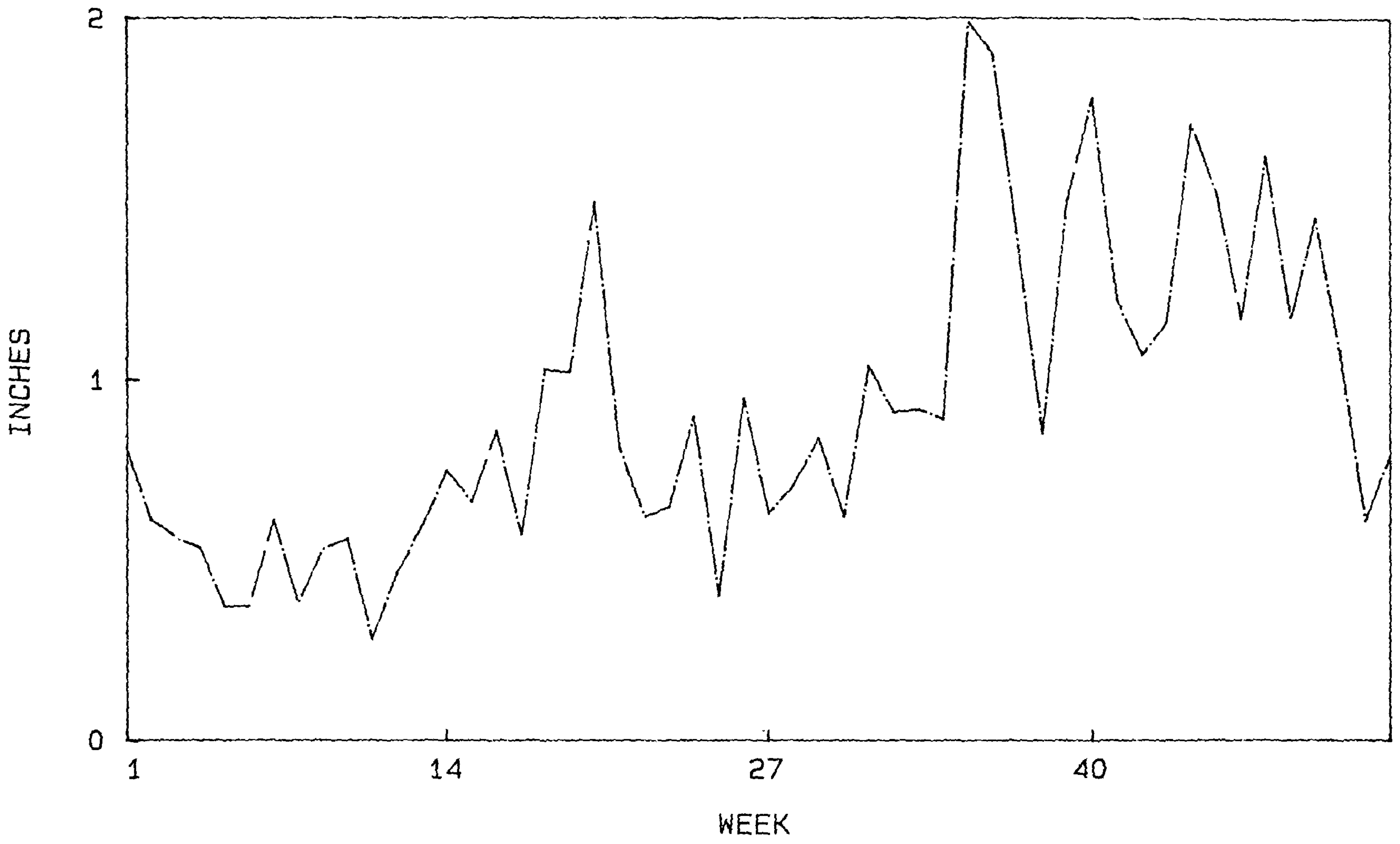

Figure 2 Average Weekly Rainfall Distribution in St. Thomas, Virgin Islands

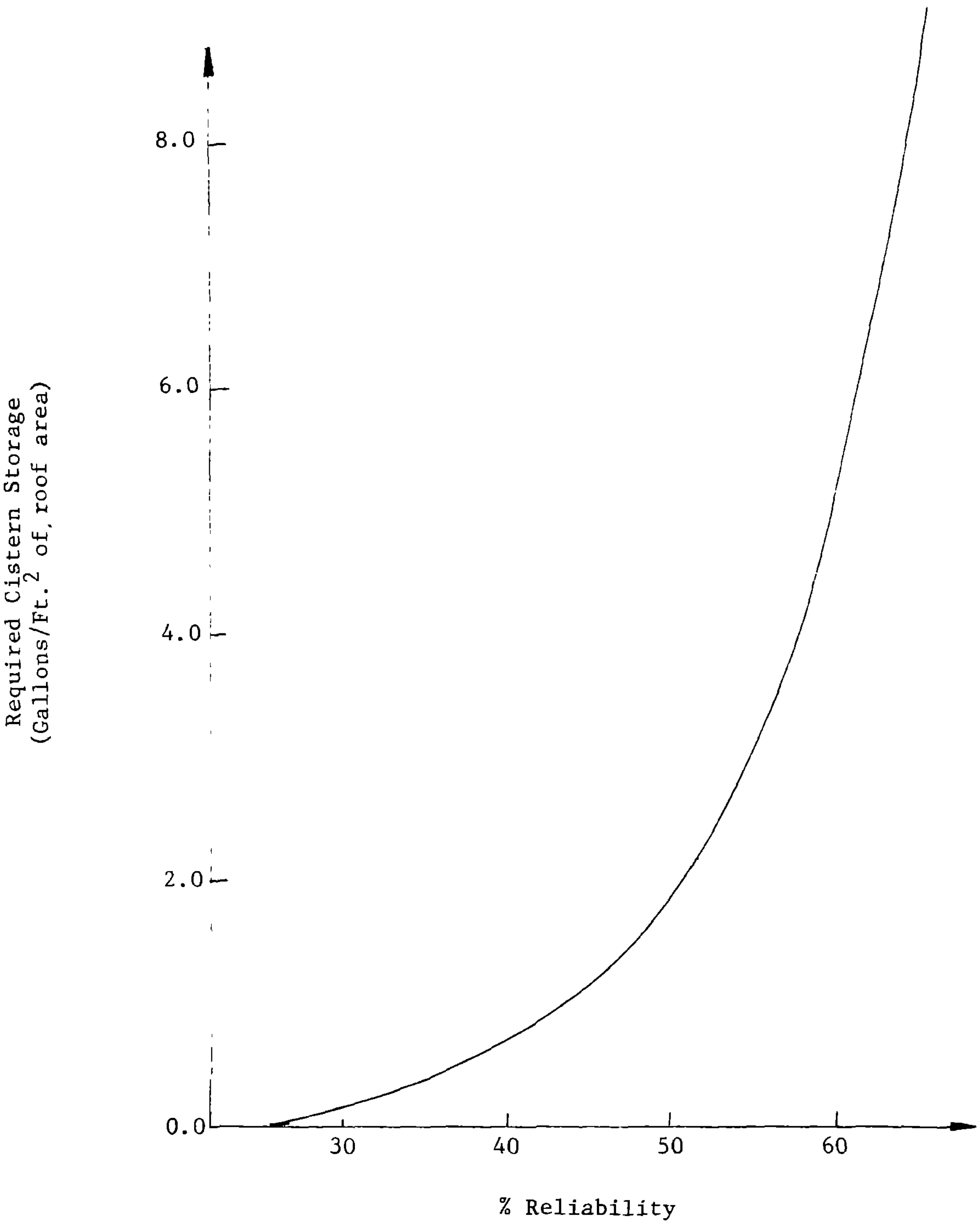

Figure 3 Required to Achieve Various Levels of Reliability for Roof Area of 9.1 Milion Square Feet and Daily Water Demand of 800,000 gallons

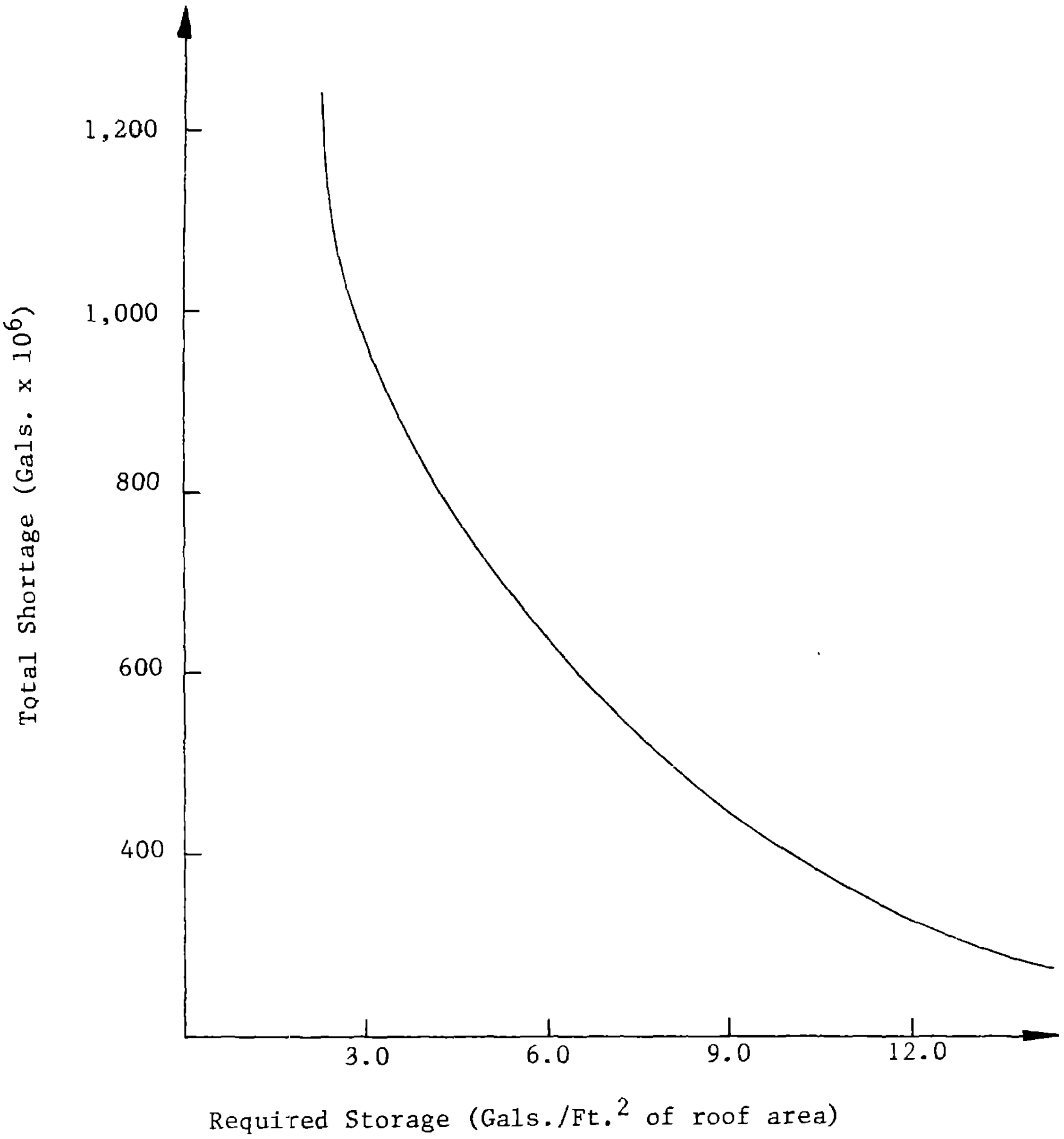

Figure 4 Effect of Storage Provision on Total System Shortages

about 40%. Thus a desalting plant with a weekly capacity of 2.5 million gallons was chosen for use in another simulation. The simulation was repeated for several system configurations varying required cistern and desalting plant capacity. Configurations summaries and results are presented in Table 1. Notice that the average plant factor was never the least costly plant factor.

The economic model was used to determine relative costs of these configurations. Results are summarized in Table 2.

CONCLUSION

A systematic method to plan and manage a conjunctive use strategy for integration of ground water, cistern and desalination systems using simulation was developed. A procedure was first developed to determine the cistern storage which must be provided in order to achieve various levels of reliability. A model simulates the system and determines for a chosen plant capacity and cistern storage requirement, the operating history of the plant and the supplemental storage which must be provided. Using the operating history of the plant, another model determines the design plant factor which results in the least relative desalination costs over the simulation period.

It was demonstrated that using systematic procedures, cistern, ground water and desalination water supply sources may be conjunctively operated in a manner more beneficial than if each source was utilized independently.

Table 1 Summary of Several System Configurations

Plant Capacity (Mgal./Week)	Required Cistern Capacity[a]	Cistern Reliability (%)	Supplemental Storage Needed (Mil. Gals.)	Average Plant Factor	Least Costly Plant Factor
1.75	2.5	55	b	b	b
	5.0	60	22.4	0.71	0.85
	7.5	64	6.3	0.56	0.80
	10.0	66	2.9	0.46	0.75
2.00	2.5	55	b	b	b
	5.0	60	18.1	0.66	0.85
	7.5	64	2.5	0.48	0.75
2.50	2.5	55	b	0.73	0.85
	5.0	60	5.6	0.53	0.80
	7.5	64	0	0.46	0.75
5.00	2.5	55	3.8	0.49	0.75
	5.0	60	0	0.45	0.75
	7.5	64	0	0.43	0.75

a. Gallons for each square foot of roof area.
b. Prohibitively large storage volumes required.

Table 2 Summary of Desalination Costs for Various System Configurations

Plant Capacity		Water Cost for 0.90 Plant Factor Plant ($/1000 Gal.)	Required Storage (Gallons/ Square Foot of Roof Area)				
mgw[a]	mgd[b]		2.5	5.0	7.5	10.0	
1.75	0.25	7.2	c	1,392,493 (7.56)	1,322,484 (8.28)	1,220,147 (8.86)	Annual Cost[d] (Cost/1000 Gal.)
2.00	0.29	6.8	c	1,434,915 (7.14)	1,365,810 (8.37)	c	Annual Cost[d] (Cost/1000 Gal.)
2.50	0.36	6.4	1,789,338 (6.72)	1,642,742 (7.36)	1,577,846 (7.88)	c	Annual Cost[d] (Cost/1000 Gal.)
5.00	0.71	5.2	2,627,658 (6.40)	2,525,806 (6.40)	2,471,062 (6.40)	c	Annual Cost[d] (Cost/1000 Gal.)

a. Million Gallons/Week
b. Million Gallons/Day

c. Large supplemental storage required makes this configuration unattractive.
d. At 10% interest over 20 years.

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THE STRATEGIC OBJECTIVES OF **RWCS** IN DRINKING WATER SUPPLY

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Abstract

The strategic objectives of rain water cistern system (RWCS) in drinking water supply for rural areas are presented and discussed in this paper. Strategic objectives have been classified to address the international drinking water supply and sanitation decade (IDWSSD), the finances of RWCS development, operation, and maintenance, as well as public health education, and social well-being of the future.

The importance of solving the problems of drinking water supply and the safe disposal of human waste simultaneously, are first addressed, the finance strategy for RWCS development, operation, and maintenance follows, and finally, the public health education and social well-being aspects are presented. The future of RWCS concludes the discussion.

Introduction

The use of rain water cistern system (RWCS) for drinking water supply has been recognized as an important alternative that has great applicability in rural areas of developing countries. Diamant (1982), stressed RWCS as the most appropriate technology for these countries to develop safe drinking water supply in their rural areas. As reported by the World Health Organization (WHO 1973) many surface water supply sources have been contaminated by human waste and made unfit for drinking. Since RWCS collects rain water, the danger from human waste contamination is much less, and since RWCS is developed in the rural area, it provides the conveniences similar to public stand-pipe water supply systems.

The development of RWCS should consider several strategic objectives from different concerns so that the developed system can serve its designed purposes. This paper addresses several practical strategies for the development of RWCS in rural areas.

RWCS Strategic Objectives

Drinking Water Supply and Sanitation

As stated in the proclamation of the International Drinking Water Supply and Sanitation Decade (1981-1990 IDWSSD), the objective is to provide water of safe quality and adequate quantity, with the basic sanitary facilities to all peoples by the year 1990. It is the most important strategic objective in the RWCS development. This proclamation gives a clear direction to provide better water supply to 1.32 billion people of the developing countries and at the same time to prevent unsanitary disposal of human waste that may contaminate their drinking water supply.

According to the IDWSSD Directory (1981), there are several points that require attention. First, there is the problem of imbalance in funding between the water supply and sanitation development. It is perhaps, because water supply development has the spotlight due to the human instinct for survival, while tradition places a taboo on talk about toilets. Second, the shortage of trained personnel for the planning and development has been identified in many developing countries. Instead of hiring foreign engineers, the strategy should be to train engineers locally, because the long-term benefit is evident. Third, the appropriate technology should be promoted internally within each country because self-sufficiency can only be attained by using locally available skilled and unskilled labor, methodology, and materials. However, in the course of promoting appropriate technology, provisions must be made for incorporation of modern technology. For example, the dual water supply residential system is a new trend for domestic water supply planning. Therefore, in the process of RWCS development, the dual water supply system should be included because it will be expensive to install dual water supply systems in already developed areas. In nature, RWCS is one part of the dual water supply system providing drinking water to the household, while the other part provides water for all other uses. Finally, strict water conservation measures must be promoted by means of institutional policy on financing of the water supply projects and community education. For example, in Indonesia, water conservation measures have been incorporated in the financial policy for water supply development: full support is offered to projects that have a limit of 60 liters/house/day to cover 60% population of a town, while only loans are offered to projects that have more than 125 liters/house/day. Community participation in water supply and sanitation planning, development, and maintenance are promoted in Indonesia, Philippines, and Thailand with the support of community education in water conservation and public health. Recent programs are reported in WASH (1986).

Levels of Economic Development

According to the United Nations IDWSSD estimation, the total cost would be as high as $300 billion. In order to support the decade's development, individual developing countries must find the appropriate water supply and sanitation systems that they can afford. The strategy is to match their own economic situations to their planning horizons and the availability of technology in their own localities. Climatic environment is also an element for consideration. Per capita cost for drinking water system is frequently used for comparison between adaptable drinking water supply systems.

In the different stages of economic development planners in the developing countries may consider the per capita cost of each drinking water supply system to establish the guidelines of affordability. A system analysis of drinking water supply systems can be made and the national policy for drinking water supply and sanitation can be developed with these multiobjective planning methodologies. Perhaps, in some countries, the RWCS in certain rural areas may be used for just a few years and subsequently may be modified or replaced with a centralized modern water supply system when the rural area grows into an urban city. Then the general economic development increases the affordability of the drinking water supply system into a higher level and at the same time, the city can afford to pay for sanitation disposal of waste and waste water.

In other words, the economic strategy for the adaptation of a certain drinking water supply system can be established by means of multiobjective system analysis. The result of the system analysis can help planners to project the cause-and-effect of the future. At the same time, they can avoid the mistakes that have been made by the developed countries. For example, dual water supply systems have not been adopted in the United States and as a result, the water supply has to be treated to maintain the drinking water standard, while most of the water is used to flush the toilets, wash the cars, and irrigate the lawns. The wasting of good quality drinking water is evident. Perhaps. in the future, the United States may join other developed countries in bottling the drinking water while providing tap water for domestic uses other than human consumption.

From the resources conservation viewpoint, dual domestic water supply system is the answer for drinking water supply planning, because it is cost effective when phased in at the earliest stages. Another alternative for the dual water system may be established by means of in-house water treatment system such as filtering attachments through the kitchen and bathroom faucets. This alternative of in-house water treatment in developed countries leads the consideration of the strategic objective analysis of management of the drinking water supply system. Clearly, on different levels of economic development, the concern of water supply and the subsequent reactions in public and private sectors are changing, subject to the availability of the water supply in quantity and in quality. This consideration is discussed in the following section.

RWCS Management and Operation

In general, most of the RWCS are privately owned. As indicated by Waller and Inman (1982), privately owned RWCS are seldom capable of supplying sufficient water to users, therefore, water conservation is a built-in management practice. The variability of rainfall, the catchment area, the storage capacity, and demand by users are the main factors that affect the management and operation of the RWCS. Fok et al. (1982), and Perrens (1982), have presented evaluations for RWCS operation and management.

If RWCS is designated to provide drinking water only and not for other domestic uses, then even a small storage tank with 500 liters storage capacity may be able to supply drinking water for a household for weeks. Perhaps this is the most reasonable RWCS management policy, because it maintains the dual water supply system policy and under this policy, safe drinking water from RWCS will not be contaminated with other sources of water supply. Furthermore, it will provide habit-forming opportunities for every user of the RWCS to protect and conserve water within the system.

Although there are different cultural traditions among developing countries, the practices to protect and conserve water are similar. Drinking water is often boiled before it is served, most of the time in the form of tea or coffee. In many countries, drinking water is kept in covered containers and placed in a protected corner of the kitchen or another room. In other words, the tradition of respect for drinking water can be promoted as the RWCS operation and management strategy objective.

The private ownership of the RWCS may face a hardship during times of prolonged drought. The safeguard of the water in the cistern is a problem that should be considered even before the construction of the RWCS in a given area. The areal drinking water management policy and its operation should be established for periods of water shortage. Emergency drinking water supply should be included in the RWCS development plan. Perhaps a water rationing plan can also be developed. The traditions of sharing drinking water should be researched for adaptation during water shortage periods.

Drinking water is a life supporting element, traditionally it is a resource in the environment that is shared among users. However, when rain water is collected and stored by means of RWCS or other systems, it may be the only remaining water source in a given area. Obviously, there is a need to establish areal drinking water management policy to guide RWCS operations during periods of water shortage.

Another RWCS management and operation problem is maintaining and sustaining water quality standards. There are many traditional methods to maintain water quality in the RWCS. However, they should be gathered and classified by interested researchers in order that their usefulness can be assessed for adaptation. Also, recent methodologies for RWCS water quality up-keep should be introduced and documented for references and application. The World Health Organization can perhaps undertake the task of providing such information and training and testing services.

Public Health, Community Education, and Social Well-being

The United Nations IDWSSD 1981-1990 aims to improve the world's public health by means of safe drinking water and adequate disposal of human waste to eliminate water-borne diseases. The use of appropriate technology to develop drinking water supply systems and sanitation facilities to improve the public health is the aim of the community educational efforts. The involvement of each community to participate in the selection of an appropriate drinking water supply system and sanitation facility, the development planning, construction, maintenance, and operation, all require some form of education so that teamwork can be effectively organized and executed. The focus of public health will not be limited to just water supply and sanitation. Once the community receives the benefits of water-related public health improvement and the know-how to participate in community cooperative efforts, all other aspects of public improvements such as roads, playgrounds and parks, schools and many other projects will follow. All of these community efforts to improve the quality of life will contribute to social well-being. These are the identifiable strategic benefits that can be realized from the Water Decade.

The Water Decade is the first worldwide unified efforts to upgrade quality of life for human beings. It provides the training for individuals to work together to improve the water supply and sanitation facilities, and to maintain and operate these facilities together. The teamwork experience is invaluable. RWCS is one of several drinking water supply systems that has great flexibilities for adaptation to various environments. Communities that adopt RWCS as their drinking water supply system can benefit from the strategic objectives as presented in this paper. Ultimately, they will enjoy enriched unified communities through their teamwork experiences.

Conclusions

Based upon the discussions of the RWCS strategic objectives presented in this paper, the following conclusions are drawn:

1. The strategic objective of the United Nations Water Decade is to provide, by 1990, all people with water of safe quality and adequate quantity together with sanitary facilities for human waste disposal. Appropriate technology adapted by the community is the main approach for development.

2. The level of economic development will provide the affordability measurement based upon the per capita cost of the drinking water development. Multiobjective system analysis can provide the time frame for the phase-in of different drinking water systems from now into the future. Dual water supply systems should be the model for drinking water supply planning. RWCS is one of the dual water supply systems which can be modified in the future.

3. The management and operation of RWCS should recognize the private ownership of the system. However, areal drinking water management policy should be established for water shortage periods, so that emergency water supply can be made available from pooled storage of RWCS. The management of RWCS water quality should receive information, training and testing services from WHO. Water quality research is needed.

4. The Water Decade provides communities opportunity to work together to improve their public health. The involvement of the communities to select, plan, and develop their own drinking water supply and sanitary human waste disposal is needed to perform community education. Once the participants have gained their teamwork experience, they will extend the community cooperative effort to other projects, to improve the quality of life by teamwork.

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TECHNOLOGY

BUSINESS-A WAY OF TRANSFERRING TECHNOLOGY

Steve Layton
Project Manager

During the second half of 1982 and the beginning of 1983 large areas of the North Solomons Province of Papua New Guinea were experiencing a prolonged period of drought and in the worst affected areas on the outer Atolls the Provincial Government was forced to ship water in old 44 gallon drums Although, the province had been promoting rural water supplies for sometime , this drought illustrated the massive shortfall in rural water storage capacity.

Village Industry Research and Training Unit (VIRTU) was requested to look into the possibilities of transferring ferro-cement tank making technology to the rural areas of the province After reveiwing a number of projects undertaken by various groups through-out Papua New Guinea, it was found that their approach was to give the technology to the people in the form of demonstrating the construction of one or two tanks at "appropriate technology workshops" or "village technology courses" with most of the effort being channelled towards encouraging the participants to construct one or two tanks on their return to their villages

The approach taken by VIRTU was very different It was very quickly realized that if a tank could be designed to be mass produced by rural based entreprenuers, not only would the use of the technology create much needed rural employment But more importantly if all the design criteria were met, rural people would for the first time in the province be able to purchase a relatively low-cost, long-life tank

After three years of rural entreprenuer training many lessons have been learnt, improvements have been made in the fibre-glass mould used to form the tank, construction techniques have been reviewed with the aim of making the production time shorter. But most importantly VIRTU and other development agencies have learnt the benefits of using business as a medium of transferring technology. And resulting from the success of this project other traditonally non-commercial development projects are being reviewed with the aim of exploring possible ways in which rural entreprenuers can actively promote these projects.

The use of ferro-cement technology to construct water storage tanks enables low-income rural villages to harvest large amounts of rain water. And in many area's of the South Pacific rain-water harvesting is preferable to alternative sources of water supply where surface water is scarce, costly and difficult to treat. Or where ground water is unsuitable for consumption or expensive to exploit. Ferro-cement water storage tanks also provide an additonal source of high quality water in well-watered areas and depending on conditions rainwater harvesting may satisfy total drinking water requirements.

Even if the water drawn from a ferro-cement tank were of poor quality, this form of supply achieves easy access to water. For villages who do not have access to water supplies all the year round and walk long distances to fetch water, the immediate and often felt need is accessibility rather than safety.

More rural areas in Papua New Guinea are frequently characterized by dispersed settlements. Unit costs for water supply systems involving distribution networks increase with decreasing population density. This means that individual catchment and tanks can be a very economic way of supplying water to many areas. The lower the density of a rural settlement, the more favourably roof catchments supplying ferro-cement tanks compares to other means of water supply in terms of cost per person. The capital cost is minimized since a roof catchment is a point of source with no distribution, no or limited treatment, and a gravity rather than a pumping scheme for water delivery. Also, failure of an individual system does not affect the rest of the population, and contamination risk is confine to a small number of users, so that the possibility of the transmission of infection is reduced.

Rainwater harvesting also encourages energy conservation, no high cost energy is consumed and no pumping should be required on well designed systems. Because of continuing energy shortages and growing difficulties in identifying adequate in terms of capacity and simple to operate hand pumping devices, it would seem that the promotion and more importantly the use of rainwater harvesting and in particular the use of ferro-cement techlonogy should be wide-spread through-out the South Pacific region.

It could be argued that ferro-cement technology is widely available in the South Pacific,through many of the appropriate technology and more general technical agencies operating in the region. However, in many cases outside of a limited number of village/rural training workshops aimed at transferring ferro-cement tank making technology, and a small number of aid programmes aimed at building large numbers of ferro-cement tanks often with outside expertise It would seem that only a limited amount of work has been carried out to develop the local capacity amongst the people of the region to fully utilize this most appropriate technology

This paper will focus on the work carried out to promote ferro-cement technology in the North Solomons Province of Papua New Guinea,and in particular the role of small-scale business development in relationship to the growing use of this technology

During the second half of 1982 and the begining of 1983, large area's of the North Solomons Province were experiencing a prolonged period of drought And by far the worst affected area's were the outer Atolls and Islands of the Province After a month or so into this drought the situation became so bad that the Provincial Government Authorities were compelled to ship water to the 5000 or so people living on these outer Atolls and Islands in old 44 gallon oil drums.

Although a number of programmes over the years aimed at promoting rural water supplies had been carried out The 1982 drought apart from illustrating the massive shortfalls in rural water supplies, also illustrated the ineffectiveness of many of the past programmes. During the period of the drought alot of interest was generated about the possible use of appropriate technology materials and products, with the view of building up the local capacity to develop water supplies. And it was at this time that the Community Works Section of the North Solomons Provincial Government requested VIRTU' to look into the possibilities of promoting ferro-cement water tank making technology.

The first step taken by VIRTU was a review of the projects established in Papua New Guinea,with the aim of training rural people to build ferro-cement water tanks. Drawing on the expertise of a number of experienced field workers it was found that in general the approach used to transfer the technology and skills involved in ferro-cement tank making in these projects had been very similar. In most cases the projects "gave" the technology and skills to the people in the form of demonstrating the construction of one or two tanks at "appropriate technology workshops" or "village technology courses". And in alot of these workshops/courses, given the limitations on time, most of the training effort was channelled into the construction of the demonstration tank and encouraging the rural participants to construct one or two tanks on their return to their villages.

With more in-depth discussions with some of the workshops organizers it became clear that the real cost of running such workshops was normally written off as a developmental expense. And very little work was carried out to try and calculate the cost effectiveness of these workshops.

Also given the nature of the skills, trainers were usually outsiders with very little insight into the local pattern of development and the key people involved in that development. More often than not the trainers would have very limited or in some cases no opportunities to revisit the area and provide on-going project support. It was quickly realized that if a VIRTU programme was going to try and introduce ferro-cement tank making technology on a scale that would have a positive and long term effect on the people of the North Solomons Province. VIRTU's approach would have to be very different from many of the past programmes.

The VIRTU approach was based on the fact that like most developing countries, Papua New Guinea has a large and growing pool of young rural based unskilled labour. And most of these young people have little or no opportunity of getting formal employment and given their age, limited opportunities to become involved in cash cropping other that as seasonal labour. Also with the higher levels of education enjoyed by many of these young people, the aspirations of this young unskilled workforce are for the most part unobtainable given that to meet their felt needs these young people would have to actively participate in a cash economy.

[1] VIRTU.(Village Industry Research and Training Unit) is a technical (appropriate techology development) section of the Division of Commerce in the North Solomons Province of Papua New Guinea. Virtu was initially funded by a National Government grant,but is now jointly funded by the Provincial Government, Development Funding Agents and funds generated by it own commercial activities.The aim of the Unit is to promote rural-based imcome generating activities primarily in the less developed areas of the province.At the time of writing,VIRTU has a staff of 12 full-time officers whose experiences cover a wide range of professional expertise and a number of full-time support staff. VIRTU is based in Kieta which is the second largest town in the province and its facilities include a large well-equiped covered workshop,a number of vehicles and an office equiped with a technical information library and computer.VIRTU is engaged in a number of projects ranging from the training of small-scale sawmill operators,investigation, trials and sales of a number of driers used in cash croping and the promotion of rural industries producing building materials.

It was felt therefore that if a programme could be designed to commercialise the production of ferro-cement tanks. And to utilize this pool of labour, it would be possible to produce tanks on a scale that would greatly increase the rural water storage capacity.

Given this commercial approach to what was traditionally a non-commercial development activity, it was necessary to clearly state the guidelines for the development of this programme.The following list of guidelines was drawn up in 1983.............................

1.... .Ferro-cement tanks promoted by the VIRTU programme should be able to compete with the commercially available tanks,(Table 1.) while at the same time offer a fair economic return for the labour input needed for their construction, (Table 2.).
2. .. The production process should utilize the local young rural unskilled workforce and encourage the establishment and development of small- scale rural industries.
3.. .....The size of a tank should meet the needs of an average rural family and be within that families financial reach.
4........Materials,equipment and production techniques should not only be understood, but sustained by the entrepreneurs who are going to use them. And where possible,raw materials should be obtained locally,and where it is necessary to purchase materials they should be type's which are commonly stocked by local sales outlets.

TABLE 1.

Commercial available water tanks and their costs to a rural purchaser (Kina)

SUPPLIER.	TYPE OF TANK	INITIAL PURCHASE	ALLOWANCE FOR TRANST	ON SITE COST	COST PER LITRE (OVER 10 YEARS)
J.Lysaght	9000 lts.corr,Iron	298.00	100.00	398.00	0.22t
	4500 lts.corr,iron	194.00	80.00	274.00	0.30t
Steamships	9000 lts.corr,iron	298.00	100.00	398.00	0.22t
	4500 lts.corr,iron	94.00	80.00	274.00	0.30t
	3600 lts glass-fibre	575.00	80.00	655.00	0.18t
	5400 lts. glass-fibre	745.00	80.00	834.00	0.15t
	9000 lts.glass-fibre	1349.00	100.00	1449.00	0.16t
CWS	9000 lts.corr,iron	310.00	40.00	350.00	0.19t
	4500 lts.corr,iron	210.00	40.00	250.00	0.28t
Kain Samling-Islap	9000 lts.corr,iron	310.00	40.00	350.00	0.19t
	4500 lts.corr,iron	210.00	40.00	250.00	0.28t
Barlow	9000 lts.corr,iron	295.00	100.00	395.00	0.22t
	4500 lts.corr,iron	195.00	80.00	275.00	0.31t
VIRTU (tanks)	4000 lts ferro-cement	200.00	0.00	200.00	0.05t

Note; The average usefull life time of a corrogated iron tank in most parts of the North Solomons Province is estimated to be 2 years.

Other factors taken into consideration were, if the programmme was to be a success a production process would have to be developed to allow for the tanks to not only be produced as quickly as possible (Appenpix 1) so as to offer a reasonable return on one's labour. But more importantly the process would have to fit into the normal rural working patterns,(eg subsistance agriculture) of the tank makers as it would be very unlikely that the income from a tank making business would completely meet all the financial needs of an individual entrepreneur Also for the programmme to be implemented on a large scale it would be necessary to develop a tank design which had a uniformly attractive and marketable appearance (Figure 1) Plus given it is unlikely that a potential entrepreneur would be willing to invest more than K1500 00 on equipment given the amount of

CASH FLOW (FIRST 6 MONTHS)

	MONTH.					
INCOME,	**1**	**2**	**3**	**4**	**5**	**6**
Share Capital	1456					
Tank sales	600	600	600	600	600	600
C/forward		423	508	545	678	715
BALANCE	2056	1023	1108	1145	1278	1315
EXPENSES,						
Tank mould	800					
Cement mixer	220					
Hand tools	50					
Wages	225	225	225	225	225	225
Transportation	30	30	30	30	30	30
Cement	137	137	137	137	137	137
Wire netting	96	48	96	48	96	48
Tie wire	48	48	48	0	48	48
Dep;Mould	15	15	15	15	15	15
Dep;Tools	12	12	12	12	12	12
BALANCE	1633	515	563	467	563	515

Profit & Loss Account (First 6 Months)

Gr Profit		2106
Wagus	1350	
Transportation	180	
Dep;Mould	90	
Dep:Tools	72	
Net Profit	414	
	2106	2106

Balance Sheet (First 6 Months)

Liabilities		**Assets**	
Share capital	1456		
Profit	414		
		Moulds	710
		Tools	198
		Cash in hand	962
		Assets	
	1870		1870

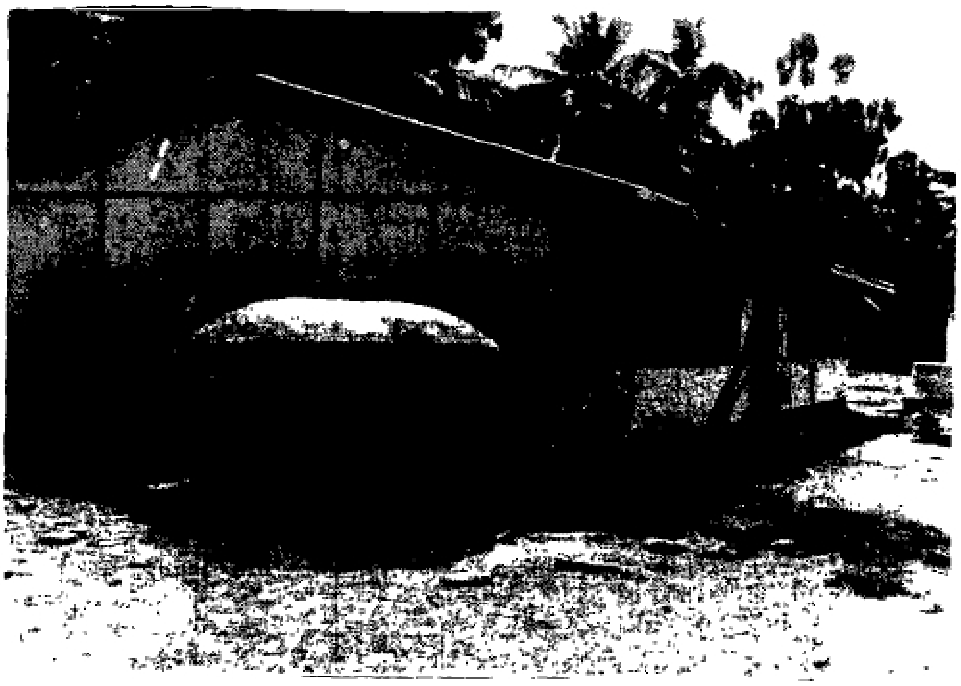
TABLE 2
Financial information relating to the first 6 months operation of a ferro-cement tank making business.

Note;This business would give a 28.4% return on the Share capital invested in the first 6 months.

possible returns from such a small business This amount was used an upper limit on the purchase price of equipment designed for this programme

FIGURE 1

Completed tank at Tasman Island Aid Post ready to be connected to roof

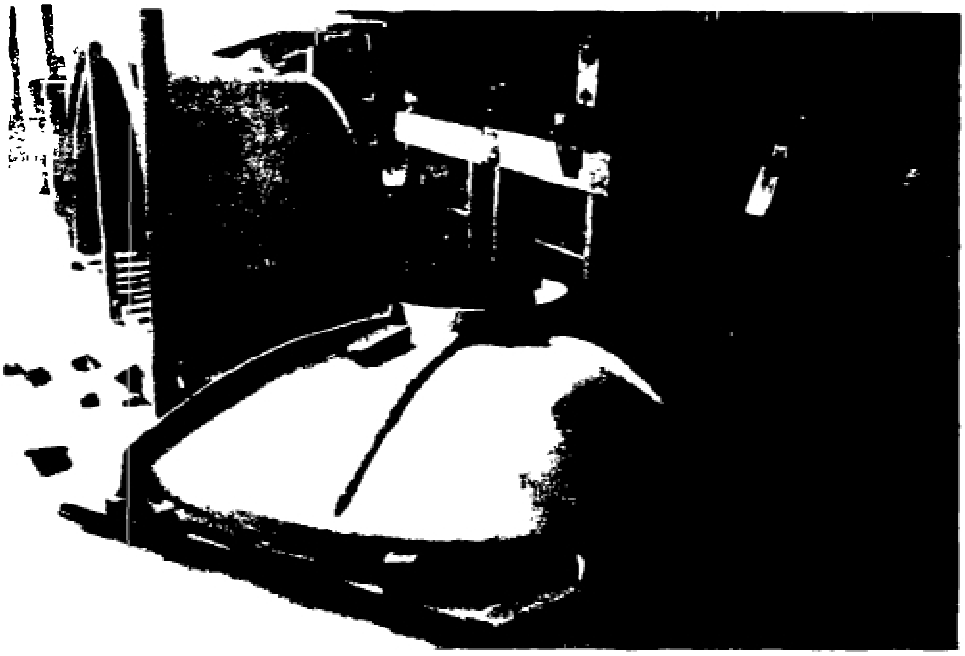


After several months of tests and trials, a tank was developed which for its construction required the use of a glass-fibre mould (Figure 2) This mould is manufactured for the VIRTU programme by a locally owned company, and is available at a retail cost of K800 00 This mould has been designed to

1 Support the re-inforcement wire and the wire netting during plastering and thus aviod the need for excessive re-inforcement purely to support the wire during construction
2 Support the cement mortar during construction,thus reducing the level of skills needed to construct a tank And speed up the plastering operation,which allows the mortar to dry uniformly
3 Assist the entrepreneurs to monitor the standard of their workmanship and the amount of materials used.
4 Be lightweight, robust and withstand repeated use
5 Ensure that all the tanks produced have a uniformly attractive appearance

FIGURE 2

The VIRTU designed tank moulds in the VIRTU workshop awaiting shipment to a project



From the design point of view using glass-fibre as a material to produce tank moulds has a number of advantages As a mould material glass-fibre has the ability to form contours (Figure 3)which would be very difficult to achieve using the materials commonly used to form moulds eg timber and steel Also given that all the tank moulds are cast from one master mould, any design improvements identified can be incorporated into the master mould and once this is done all other tank moulds will be produced with the up graded design

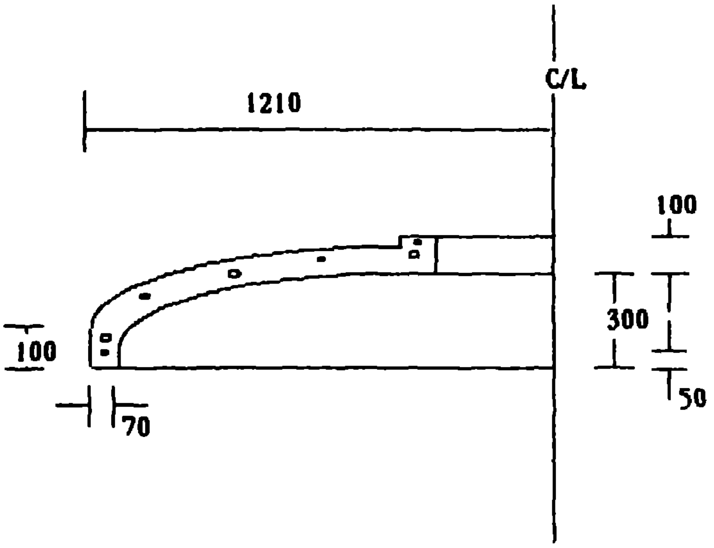
As importantly as the design considerations, the economic aspect of glass-fibre moulds also encouraged the use of this material Glass-fibre moulds are in general economic terms a very attractive option for small a business wishing to produce large numbers of cast-cement products over a long period of time Unlike timber glass-fibre is not affected by distortion cause by water And unlike steel, glass-fibre is light,robust. non-corrosion and with only basic training simple repairs on moulds can be carried out in a rural location without the aim of costly equipment or power tools

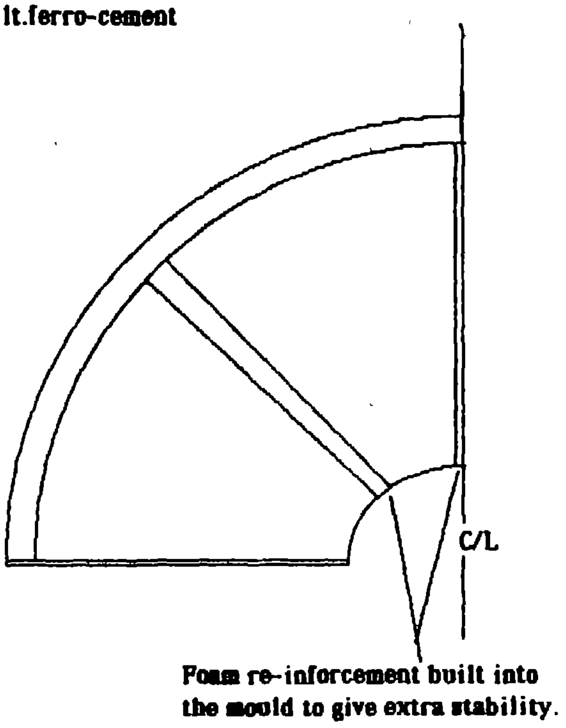
The VIRTU ferro cement tank making process and equipment **"package"** was developomed to a stage were it was clear that, it was possible to create viable small-scale business's around this technology The package was offered to would-be entrepreneurs on the basis that training in the skills needed to construct tanks would be provided by the VIRTU government supported programme But the cost of all the equipment and materials would have to be met by the interested entrepreneurs In many cases it was possible for these entrepreneurs to utilize government and

FIGURE 3.

Sectional drawings of the VIRTU designed glass-fibre mould, used to construct 900 lt.ferro-cement water tanks.

TOP MOULD

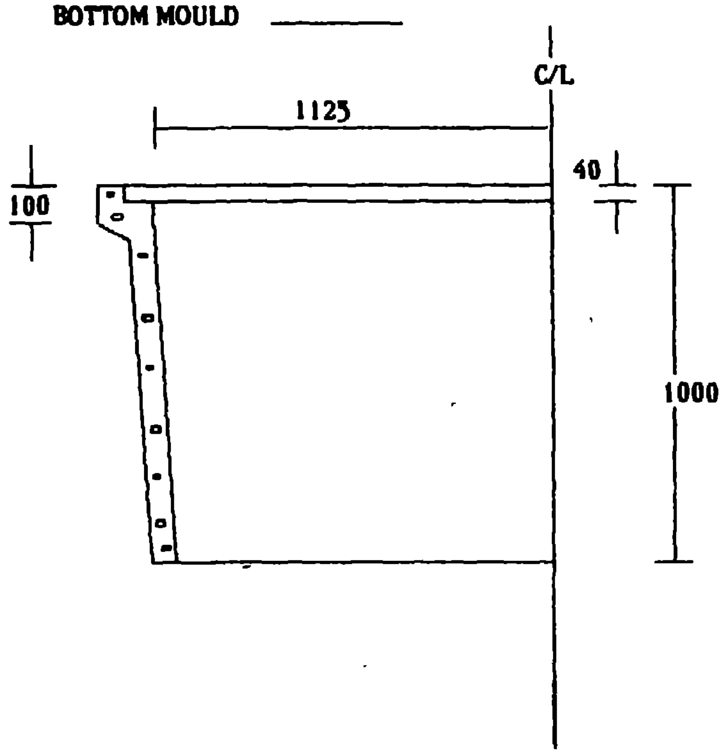


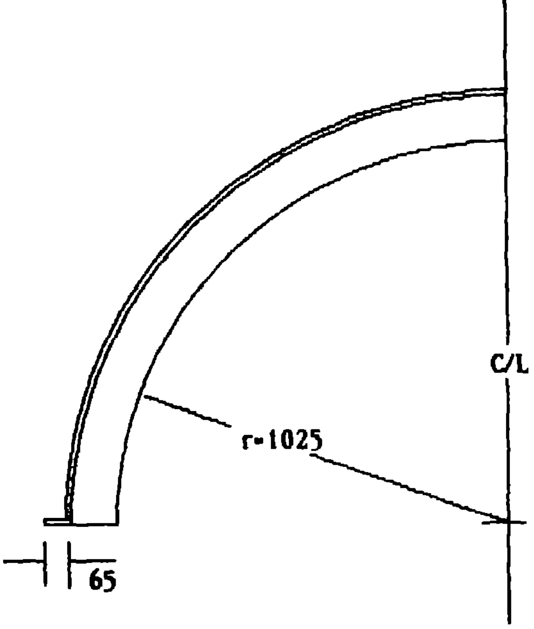


Foam re-inforcement built into the mould to give extra stability.

- ▫ -Pre-cast mould location lugs
- ▪ -6mm holes used to connect second half of mould

BOTTOM MOULD





All sizes in millimetre's
Drawing not to scale.

non-government rural development support schemes to assist in the share capital requirements needed to start such a business. But even in such cases around 50% of the share capital would be increased by the rural entrepreneurs

The form in which the individual business's developed differed greatly However, many business's were started or supported by a local community government authority,who saw the possibilities of contracting tank construction to local groups. This type of community government support not only allows an authority to purchase more tanks by removing expensive transportation costs,but also allows an authority to be seen as supporting the development of local rural industry This type of community government support proved an important factor in the success of many of the tank making business's

The out-put in terms of tanks produced also differs between individual business's. Out-put do'es not always reflect demand in terms of need or the availability of finance But in many cases the out-put reflects the amount of time that an entrepreneur is willing to put into the business, given other demands on his time. However, this type of informal production has not stopped the business's or the overal programme developing

In 1985 the production of the VIRTU designed ferro-cement tank in the North Solomons Province reached an estimated 180 units. Although this out-put is small given the need for this type of produce and the employment created by its production.The out-put of the VIRTU programme has to be viewed in relationship to the overallproduction of ferro-cement tanks in Papua New Guinea. No other programme is producing ferro-cement tanks on the same scale as the North Solomons programme And although at this time no annual figures are available on the total number of ferro- cement tanks constructed in Papua New Guinea, it is likely that the VIRTU programme accounts for 40/50% of the total of this type of tank produced. This figure is significant given that the North Solomons is only one of 20 provinces in Papua New Guinea.

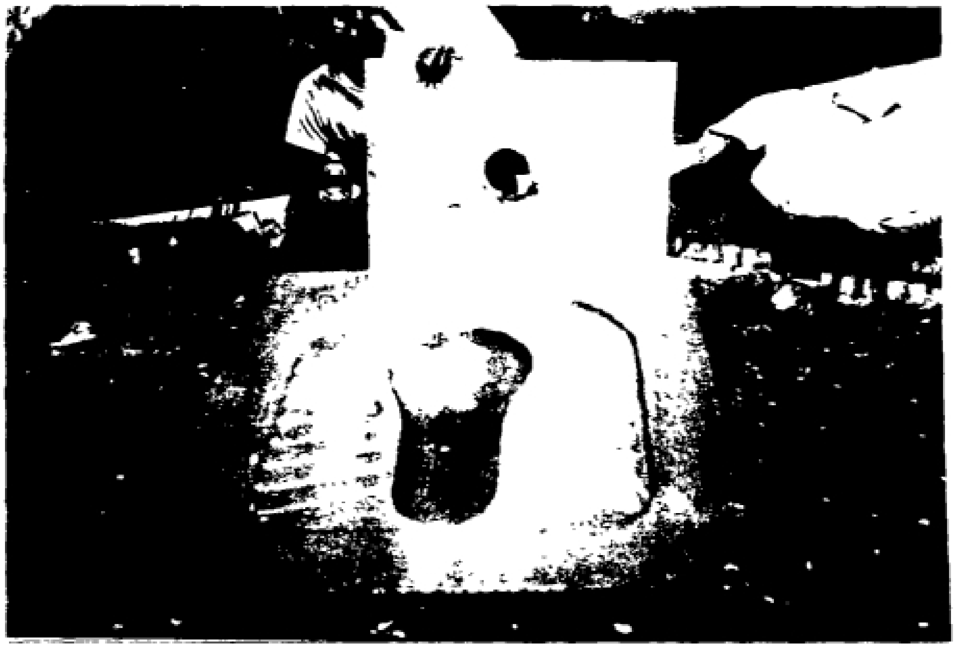
It success is measured in terms of production, then the VIRTU programme can be viewed as a success given its relatively high production of tanks measured against the overallproduction of ferro-cement water tank in Papua New Guinea. However, perhaps the success of the programme should not be viewed from the point of view of output, but its development of a technology suitable for use in small-scale rural industries.

If real and meaningful rural development is to take place, that development has not only to be identified by rural people, it also has to be implemented by them. Many so-called development programmes identify a rural problem and design a project to respond to that problem In many cases this respondance means additional work for rural families who already have a full workload.

The VIRTU programme has illustrated that by using rural based small-scale industries and well designed products it is possible to not only create employment But also contribute to the overalldevelopment process by supplying basic commodities to rural families. The success of the VIRTU programme has also meant that other products are now being reviewed with the aim of looking into the possibilities of their commercial production by small-scale rural industries,(Figure 4.)

FIGURE 4.

This picture show a newly developed glass-fibre mould designed to be used by small-scale rural industries to cast ferro-cement covers for pit latrine



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APPENDIX 1

Description of the process involved in the construction of a VIRTU designed ferro-cement tank

STAGE ONE

- Assembly of moulds, equipment and raw materials on the site where the tank is to be constructed.
- Cleaning of cement tank-stand or if the tank is to be constructed on the ground, the site should be levelled and cleaned

STAGE TWO (2-3 hours work)

- Assembly,location and light oiling of bottom mould
- Fitting of vertical tie wires.(All tie wire used in the tank making process is 1.6mm high tensile galvanized wire).
- Fitting of first layer of wire netting.(All wire netting used in the tank making process is 12mm x 1m wide galvanized chicken wire).
- Fitting of second layer of wire netting.
- Fitting of 6 horizontal tie wires by interlacing them with the wire netting

STAGE THREE (2 hours work)

- Assembly,location and light oiling of top mould.The top mould should be supported by a small of earth or sand.
- Fitting of wire netting.
- Fitting of 6 circular tie wires by interlacing them with the wire netting.
- Fitting of 9 horizontal tie wires,in sets of 3 equally spaced across the mould running parallel to the mould joint line.

STAGE FOUR (3-5 hours work)

- Using the hand operated cement mixer to produce a 1 4 mixture of cement and sand,apply a 20mm thick coating onto the base and sides of both moulds.
- Using the 3 sets of horizonal wire in the top mould form 3 ridges with an approximate radius of 50mm
- After the cementing is completed,the moulds should be covered with plastic sheeting

STAGE FIVE (1-2 hours work)

- 24-36 hours after cementing,it is possible to remove the moulds.When the moulds are removed they should be washed and stored ready for use again.

STAGE SIX (2-3 hours work)

- 72 hours after cementing the top half of the tank can be turned and placed onto the bottom half of the tank.Jointing the two halves is done by cementing the fillet joint created (inside and outside) when the top and bottom of the tank are put together.
- The final step in the construction of the tank is the mixing of a paint like slurry made of equal parts of cement and sand. This slurry is used to coat the inside and outside of the tank.

A LOW COST RAINWATER TANK

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ABSTRACT

A low cost cylindrical rainwater tank was developed for 6 and 12 cu.m. tanks. The height and diameter of 6 cu.m. tank are both 2.0 m. while those of 12 cu.m. tank are 2.5 m. The tank's wall is made by plastering mortar onto a mould coated with clay. The wall is reinforced with steel wire. The technique renders it possible to make a thin wall, i.e. 50 and 60 mm. thick for 6 and 12 cu.m. tanks respectively. The roof of the tank is made of steel reinforced concrete. Cost comparison revealed that the cost of material for this tank is the lowest. The material costs for 6 and 12 cu.m. tanks are approximately 1,500 and 2,800 baht (US$ 60-110). Performance tests indicated that this tank design is sufficiently strong and the construction technique is simple.

Several wire reinforced mortar tanks were built in Khon Kaen and Ubonratchatani and they are found to perform very well. This wire reinforced mortar tank is now being used for the rainwater tank program in Ubonratchatani and for the Rotary Club's Clean Water Project which will be inaugurated to pay homage and express loyalty to His Majesty the King in the celebration of his sixtieth birthday.

1. INTRODUCTION

The Northeast of Thailand, with a population of nearly 17 million and with an area of 17 million hectares (170,226 sq.km) constitutes nearly one-third of the Kingdom in terms of population as well as area. Almost all major indices used to reflect the quality of life in the Northeast have been consistently identified as poor, if not the poorest, in comparison with other regions as well as national averages.

One of the most severe problem for the Northeast is the lack of water. The problem of lack of water arises from a very long period of dry spell of about 7-8 months and the unfavorable soil condition. Surface water and ground water are the major sources of water in the region. Even though water from most of these sources is unsuitable for drinking, these people have to rely on these sources during the dry period. For many villagers even the surface and ground water are hard to find and they have to walk a considerable distance to get it.

Clean safe drinking water is a basic need. It is a prerequisite to improved health and standard of living. The rain in the Northeast which falls in the rainy season for a period of about 4 months is ample, hence scheme for building rainwater tanks and jars have been initiated to solve the drinking water problem. The capacity of the standard jar is 2 cu.m. and the cost of material for a mortar jar is around 400-450 baht (US$ 16-18) which is exceptionally low and very attractive. The capacity of rainwater tank ranges from 6-12 cu.m. with the 12 cu.m. tank being the common size. The price of the tank is variable depending on the type and the construction technique.

Most of them are cylindrical tanks and can be classified according to the building materials and construction technique as: steel reinforced concrete tank, bamboo reinforced concrete tank, ferrocement tank, brick tank and concrete ring tank. The cost of material for a 12 cu.m. concrete or mortar tank is approximately 4000-7000 baht (US$ 165-270) which is quite expensive. This makes the scheme for building rainwater tank very costly as compared to the jar building program. Several attempts have been made to lower the cost of the tank. One of the promising design is the interlocking mortar block tank (Vadhanavikkit et al, 1984). This tank design is now being tried on a large scale jointly by the Population and Community Development Association and Khon Kaen University.

The calculated minimum water required by an average household in the Northeast is around 6 cu.m.(Thai-Australia Village Water Supply Project, 1984). Therefore, three mortar jars are usually needed by an average household. However, many villagers prefer tank because putting three jars in the house takes up a lot of room and they also think of tank as a more permanent water containing structure and a status of well to do. Tanks are also a common feature for community centres such as monastery and school.

It is estimated that about 60-70% of the rural population will be served by jars and the remaining 30-40% and the community centres will be served by tanks. Moreover, once the minimum amount of clean water is met, the use of water will be increased. Hence, tanks will be more appropriate in the future and will slowly replace jars.

It is believed that many hundred thousand of tanks will be constructed all over the Kingdom of Thailand. The cost for building a tank has to be made lowest while the safety and ease of construction need to be maintained. It is therefore imperative that a study and development of low cost rainwater tank is undertaken.

2. DEVELOPMENT OF WIRE REINFORCED MORTAR TANK

The cost of tank per cubic meter of stored water is higher than that of jar (Thai-Australia Village Water Supply Project, 1984). The low cost of jar is due to several factors which can be identified as :

1. The shape of jar is close to a sphere which has the lowest surface/volume ratio. This leads to the smallest amount of material needed to cover the surface.
2. The strength of the jar relies on membrane action and hence the thickness of the jar's wall can be made quite thin.
3. The construction technique makes possible the construction of thin wall. The mould consisted of steel frame with bamboo coated with clay (the mould is removed after the construction and can be reused) allows the application of a thin and even coat of mortar. The mortar is strengthened with wire reinforcement (Thai-Australia Village Water Supply Project and Faculty of Engineering, KKU; 1984).

Although the close-to-sphere shape of the jar is the most efficient, its configuration and construction technique make the construction of a large jar of 6 cu.m. or larger impractical. For a cylindrical tank, the action of force in the cylindrical wall is membrane action. The cylindrical tank built with the jar construction technique can thus be expected to be the proper solution.

For a cylindrical tank, the smallest surface/volume ratio occurs when the diameter is equal to the height. A 6 cu.m. cylindrical tank with 2 m. in diameter and height and a 12 cu.m. tank with 2.5 m. in diameter and height should therefore be optimal sizes. The analysis based on the ultimate strength has shown that the wall thicknesses of 40 mm. and 50 mm. are sufficient for 6 cu.m. and 12 cu.m. tanks. However, to take care of the unevenness of the wall thickness and bad worksmanship of the villagers, wall thicknesses of 50 mm. and 60 mm. for 6 cu.m. and 12 cu.m. tanks are recommended.

Minimum wire reinforcement is required to strengthen the mortar and prevent the sudden failure of the tank. Wire No.14 (ø 2.1 mm.) and No.11 (ø 3.2 mm.) are used for the 6 and 12 cu.m. tanks respectively. The spacings of the horizontal wire reinforcement are 7, 10 and 15 cm. for the bottom, middle and top parts of the wall respectively. The spacing for vertical wire reinforcement is 15 cm. Fig.1 gives the details of the wire reinforced mortar tank.

Cost comparison between different types fo tank's wall revealed that the wire reinforced mortar tank is the cheapest (Chindaprasirt et al, 1986). The material costs of 6 and 12 cu.m. tank are approximately 1,500 and 2,800 baht (US$ 60 and 110).

3. TESTING OF WIRE REINFORCEMENT

Minimum wire reinforcement is put in to take care of the possible sudden failure of the tank when mortar fails to do so. This can happen when the tank is made of very bad quality mortar or the construction and curing of mortar is badly done. This test is to ascertain that the wire reinforcement is sufficiently effective.

Symbols	6 cu.m.	12 cu.m.
B = Base thickness	7.5 cm.	10 cm.
D = Diameter	2.0 m.	2.5 m.
H = Height	2.0 m.	2.5 m.
R = Roof thickness	5 cm.	6 cm.
S = Steel rod	6 cm.	9 cm.
t = Wall thickness	5 cm.	6 cm.

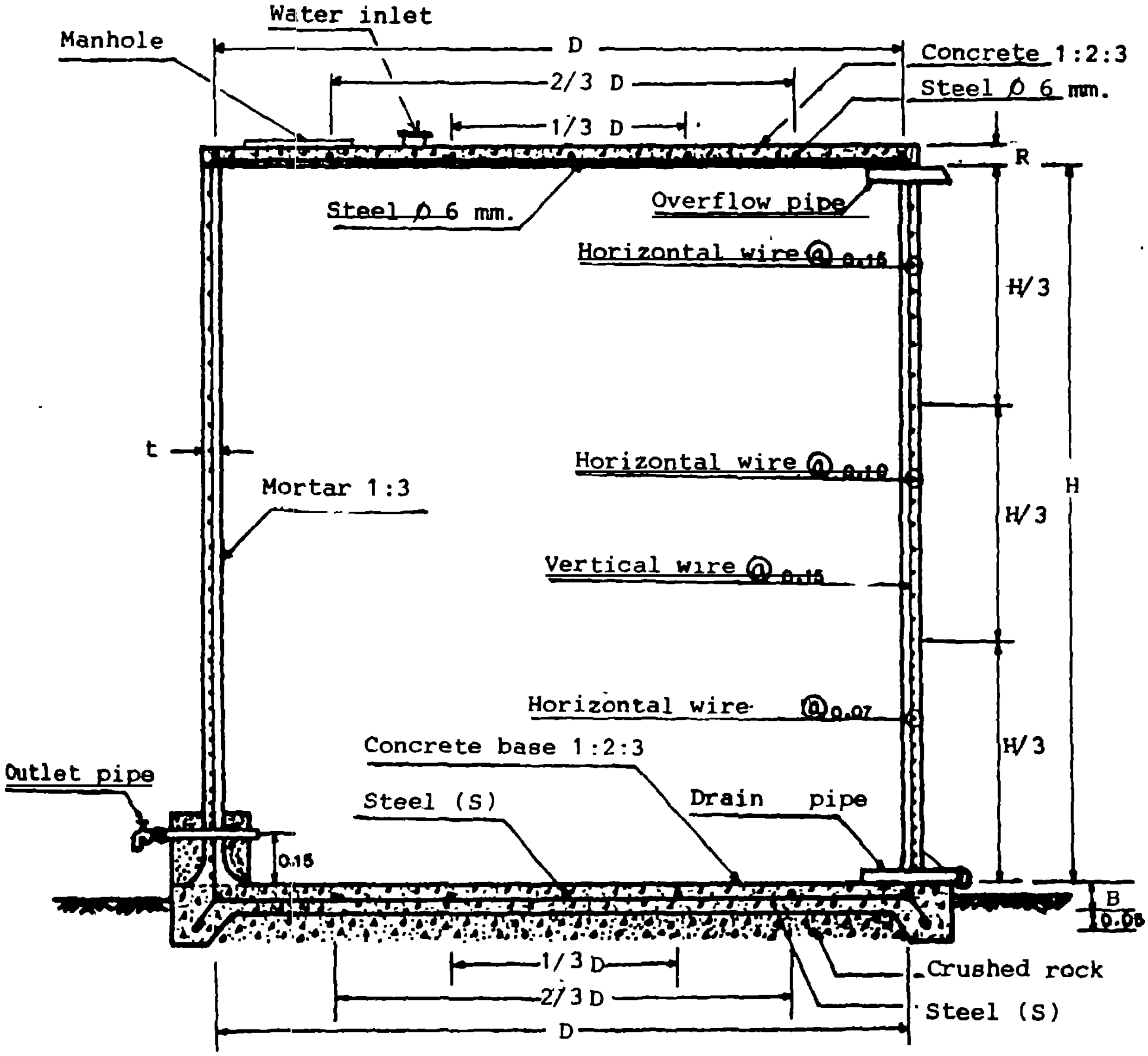

Fig. 1 Details of wire reinforced mortar tank

A 6 cu.m. wire reinforced mortar tank was used for this test. A local fine sand of bad quality was used for the making of mortar and the thickness of the wall of 35 mm. was employed instead of 50 mm. It was estimated that this tank would be less than half the strength of the tank normally constructed. All these were deleberately done to make sure that the tank is quite weak and would crack when the tank is filled with water at the early age of the tank.

The tank was tested at the age of 7 days. The tank was filled with water from the main pipe system. The level of water in the tank rose quite slowly. A vertical tension crack with a length about half the height of the tank developed at the middle part of the wall and extended towards the top and bottom ends of the wall when water was nearly three quater full. At this stage water was slowly seeping through the small crack.

The test was continued until the tank was full. The water in the tank was kept at the full level for another 10 minutes. The tank showed no other sign of damage. It was therefore concluded that the wire reinforcement provided in the wire reinforced mortar tank was effective in taking care of the water pressure when the mortar failed to do so. It was also thought that the sudden failure was very unlikely.

4. PRESSURE TEST

Two 6 cu.m. wire reinforced mortar tanks were built. The roofs of the tank were built with ferrocement technique. These roofs were built without an openning to ascertain of the pressure tightness. A small steel tube was put in the roof to provide an inlet for the compressed air.

After the construction, the tanks were covered with plastic sheet for curing. Demoulding of the wire reinforcement mortar tanks was done at the age of 2-3 days. Both tanks were filled with water to nearly full at the age of 14 days.

A few days before the pressure test, the roof of the tank was strenthened with metal strips as shown in Fig. 2. Before pressure testing, a transparent plastic hose was connected to the tank's outlet pipe. The other end of the plastic hose was raised into a vertical position by securing it to a vertical timber post. Water from the tank was allowed to flow into the hose by opening the outlet pipe. The level of water in the hose was used for measuring the pressure in the tank. This testing technique was used for pressure testing of mortar jar (Chindaprasirt and Wirojanagud, 1985). Fig. 2 shows the setup of the test.

The pressure test was performed at the age of 2 and 6 months. An air compressor was used to pump air into the tank through the steel tube at the roof. The pressure was applied to the tank slowly and steadily by controlling the rate of rise of water level in the transparent plastic hose.

The pressure was put into the tank until the pressure was equal to 1.5 m. of water as measured from the top of the tank. This 1.5 m. high pressure was maintained for another ten minutes and the pressure was then released. All the tests showed no sign of damage. The test indicated that the tanks are sufficiently strong.

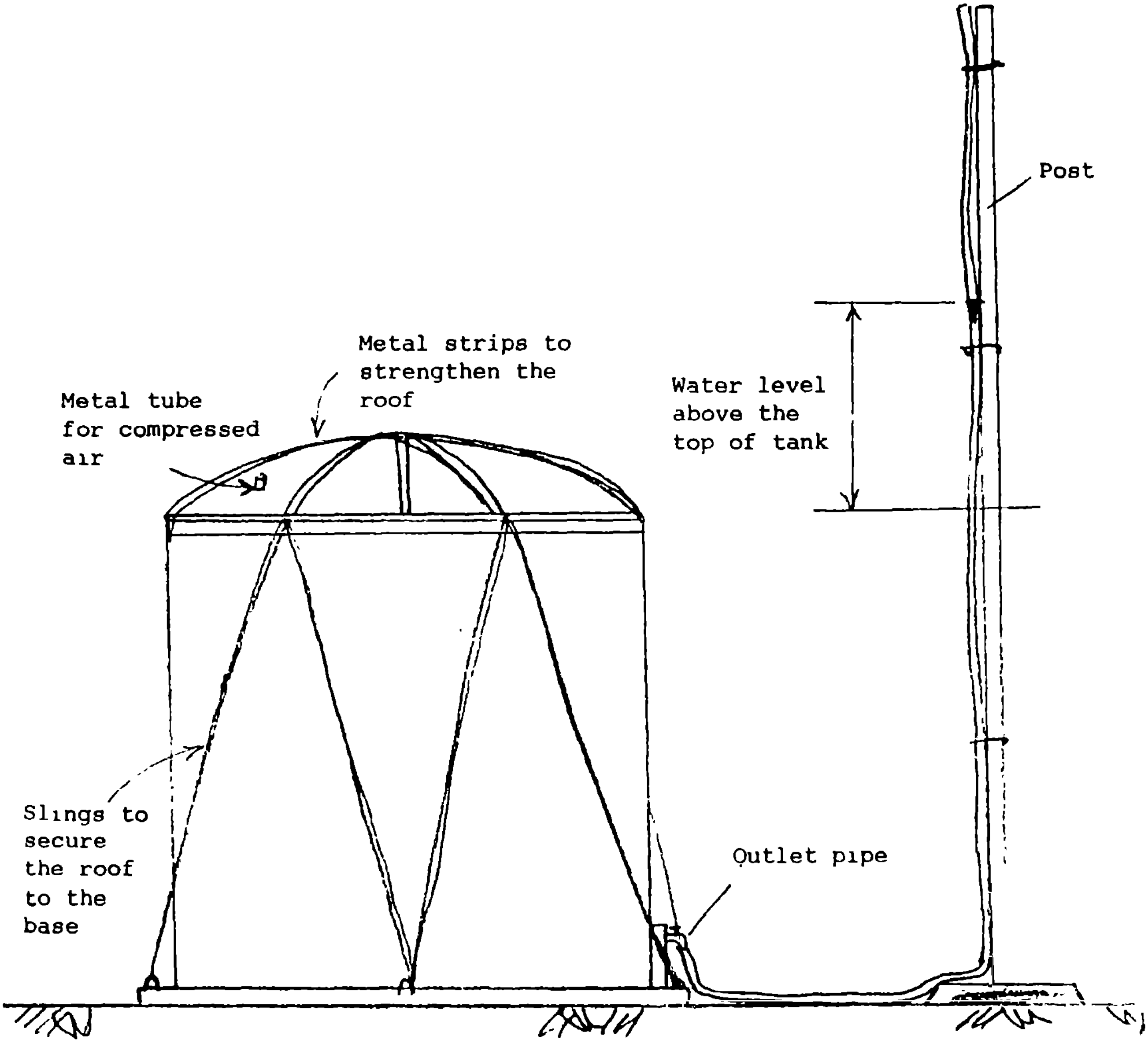

Fig.2 Test setup for pressure test of tank

5. STEP OF CONSTRUCTION

The details of the construction can be found in a wire reinforced mortar tank construction manual (Chindaprasirt et al, 1986). The short pictorial display of construction is given in the Appendix.

6. FIELD APPLICATIONS

The 6 cu.m. wire reinforced mortar tank was introduced to a few villages in Khon Kaen. A total of 8 tanks were constructed and this tank design was very well received by the villagers. The 12 cu.m. wire reinforced mortar tank was introduced to Ubonratchathani. A total of 20 tanks were constructed in primary schools. The Governor of Ubonratchatani, Mr. Danai Ketsiri was very receptive to this tank and has asked the Faculty of Engineering, Khon Kaen University for this tank design to be used as drinking water container in Ubonratchatani. As a result, this tank design is now being used as a household drinking water container for Ubonratchatani.

Coincidently, the Rotary Club of Thailand was going to launch a clean water program, which Deputy Prime Minister Bhichai Rattakul is the president. This program will be delivered and pay homage to His Majesty the King for his sixtieth birthday occasion in 1987. The secretary of the Clean Water Program has visited a primary school in Ubonratchatani and is very impressed with the wire reinforced mortar tank and recommends that the design be used for this royal program.

7. CONCLUSIONS

From the study it can be concluded that the rainwater tank built with wire reinforced mortar technique is suitable for the rainwater program for household and community centres such as school and monastry. The construction technique uses plastering of mortar onto a mould consisted of steel frame with bamboo coated with clay. The villagers are familiar with the technique and like this design because of its simplicity and low cost. The manual of this tank is now being sent to every province and agency involved in the tank construction. It is believed that this tank will help eradicate the drinking water problem and safe the government a lot of money.

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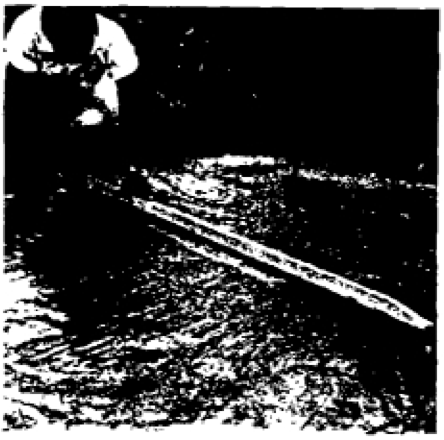
APPENDIX

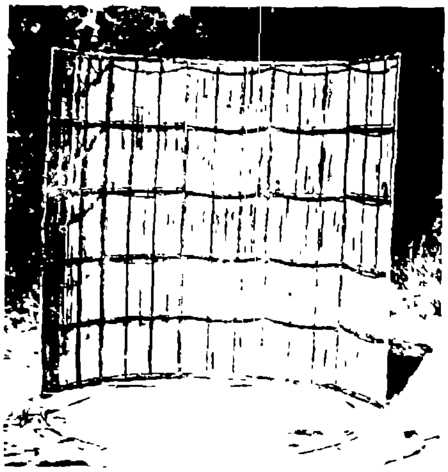
Construction Steps of Wire Reinforced Mortar Tank

Remove about 5 cm. thick of top soil of a circular area about 25 cm. bigger than the tank's diameter and fill with gravel and crushed stone. (If a higher base is needed, extra soil can be filled and compacted before the filling of gravel).

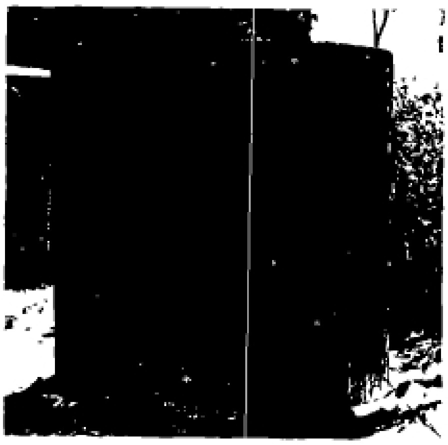
Pour the first layer of concrete about two third of the base thickness and lay the steel reinforcement with wire. Concrete with cement:sand:gravel = 1:2:3



Pour the top layer of concrete and the surface is smoothened.



The steel mould with bamboo is assembled on the base.



The mould is then secured with two steel rings, one at the base and the other at the top of the frame. This is to make the mould stable and does not move during the plastering of mortar.

The mould is then covered with a thin layer of soft clay.

After the application of clay the roughened concrete surface is cleaned by using a trowel to scrape out the clay.

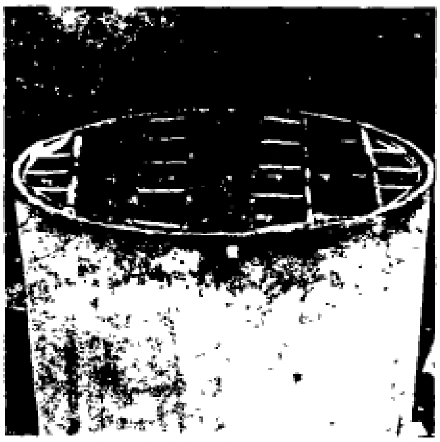
The first layer of mortar is then applied evenly to half the thickness of the wall. Mortar with cement:sand = 1:3. Wait until the first layer of mortar is quite firm and then start to put in wire reinforcement.

Apply the second layer of mortar to complete the wall.

The surface of the wall is smoothened. A plastic sheet is used to cover the surface of the wall for curing.

Demoulding is done after 2 days. The inner surface of the wall is then cleaned and painted with cement slurry.

The tap, over flow pipe and drain pipe are put in. The intersection between the wall and base is thickened with mortar to prevent leakage.



Bamboo rods are used to support the formwork.

Bamboo spread is used as a flat formwork for concreting.

Steel reinforcement is put in and the concrete roof is cast.

RURAL WATER SUPPLY IN THE SOUTH PACIFIC

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ABSTRACT

Water supply in the island states of the South Pacific is a particular problem. The islands are generally very small, with limited and often non-existent surface water resources. Only the larger volcanic islands have rivers or streams and reasonably consistent rainfall. The smallest coralline islands and atolls are forced to rely on even more limited supplies of groundwater, usually as a freshwater lens in the underlying porous substratum. More frequently, however, water supply is by rainwater catchment.

This paper will look at the various rainwater catchment practices in the South Pacific, and the increasing use of ferrocement water tanks. Particular reference will be made to different tanks and their design, construction, durability and possible repair. The discussion will consider economic as well as technological aspects of rainwater catchment systems and training-extension programmes. Several water supply projects in the region will be described and discussed. The paper will describe a ferrocement tank built without formwork that has been developed and propagated by the Institute of Rural Development.

INTRODUCTION

The South Pacific consists of nearly twenty island countries. Most are now independent following a process of colonial withdrawal from the region, starting in the 1960's. This paper will concentrate on the eleven independent small island states served by the University of the South Pacific - the Cook Islands, Fiji, Kiribati, Nauru, Niue, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Western Samoa.

These islands range in size from Tokelau, at 10 sq km, to the 27,500 sq km of the Solomon Islands. Populations range from 1,600, again for Tokelau, to over 600,000 for Fiji (see table of island statistics). Nearly all the countries are archipelagic (except Niue, which is a single rock), some consisting of hundreds of islands scattered over vast areas of ocean. The major characteristics of the region are therefore small size and great dispersion - while the total land area is less than 100,000 sq km, the ocean encompassed by the island's 200-mile Exclusive Economic Zone (EEZ) is over 11 million sq km. Another similarity is that most of the countries in the region are characterised by young and rapidly growing populations - over 3% in some cases.

Despite this overall similarity, and the Western media-myth of the South Pacific, the islands of the region are very diverse. Individual countries and islands within them range considerably in size and type - from low-lying atolls and coral plateaus to soaring volcanic peaks. Climates also vary, particularly rainfall, both regionally and seasonally. Social life is varied. Whilst most islanders live in extended family groups, land tenure, politics, language and customs are generally specific to each country, often to islands within them. Most islanders live a fairly traditional lifestyle, in villages of less than 200 people. Urbanisation is however increasing, particularly in some locations, where population densities are high. Household incomes vary in the region, from an annual average of $2000 to $4000.
Housing in rural areas is predominantly of local un- or semi-finished materials, with an increasing appearance of tin roofs and, more recently, concrete floors and walls. Life in the islands is generally benign, with few of the worst tropical diseases, although malaria is on the increase in the Solomon Islands and Vanuatu. Gastro-intestinal conditions are however not uncommon, particularly among children. As populations expand, however, the relatively healthy situation may change, because of the highly sensitive and fragile nature of most island ecosystems. There has already been an outbreak of cholera leading to a ban on pit latrines in urban Kiribati, and cases of typhoid elsewhere. Climatic catastrophes such earthquake and flooding also contribute to potential health problems. From another perspective, it can also be noted that irrigation is not a facet of island agriculture, and that interest in this area may need to be tempered with a concern for overall water management if water resources are not to be contaminated with agrichemicals.

Water, Water, Everywhere...

The provision of clean drinking water is the primary objective in promoting good public health. The adequate supply of potable water in the rural South Pacific is, however, frequently a major problem for villagers. Regular rainfall only occurs on the larger islands, where the only rivers and springs in the South Pacific exist. Many coralline islands and atolls are too small to ensure regular rainfall and too porous to hold any surface water. The only water supply is therefore from catchment or groundwater - existing on the larger coral islands as a freshwater lens floating on deeper saltwater intrusion. Smaller coral islands frequently have a brackish lens, or no lens at all.

The provision of reticulated water supply, with standpipes or household taps, is increasing but typically limited to larger villages in the South Pacific. Such supplies are usually pumped from a well or borehole by diesel, electric or wind pumps, none of which generally have a good record of durability. Hurricane damage is also a big problem with windpumps, and many of the windpumps that have been installed are no longer working. Repair, maintenence and service support to pumping equipment is essential at village level to remedy such operational problems, together with a choice of better, more appropriate technology. Other suggested technical solutions, or "fixes" to the problem of water supply have included solar stills and desalination plants. Drinking water is even back-shipped into Nauru on phosphate carriers. None of these solutions are however considered applicable for anything but special use in the South Pacific.

The main problems of water supply at village level are the frequent droughts on smaller islands. At such times lower quality water is often the inevitable consequence, either from more distant rivers (if they exist) or as more brackish groundwater. Whilst the problem of water supply may be insoluble in the long term, without the application of sophisticated technology of doubtful durability, or the drastic action of moving populations from drought-stricken islands that has been undertaken, less sweeping measures are often applicable. Quite often potable groundwater may exist only feet below the village, where the need is for simple manual boring equipment and basic, affordable handpumps. A preferred approach is the provision of roof catchment and tanks of sufficient size to maintain supply during droughts.

Rainwater catchment and storage

Most rural domestic water supply in the South Pacific remains a household responsibility. In general, the majority of villagers prefer roof catchment and the domestic storage of rainwater for drinking, and use rivers, groundwater or the sea for washing.

Rainwater catchment is as strong a reason for the popularity of tin roofs as environmental protection. In villages of Solomon Island "leaf-houses", for example, often the only tin roofs to be seen are for water collection. All around the South Pacific, water may be stored in oil drums, corrugated galvanised steel, fibreglass or, a more recent innovation, ferrocement tanks (or, more properly, thin-walled cement-mortar tanks). Oil drums are not an ideal way of storing water because of rust problems, and the increasing cost of good drums - which has risen from around $1 to over $10 in very few years. Several drums may also be needed due to ensure adequate water for household supply. An ideal basic size of cistern is around 6000 litre (1300 gal), suggesting either galvanised steel or ferrocement tanks. Galvanised steel tanks can start corroding in less than five years, which is a serious problem. Fibreglass tanks have been found to crack and are difficult to repair. Ferrocement water tanks are better suited to a salty humid tropical environment, should last at least 50 years and are of approximately the same overall cost. Tanks of sufficient size for household use are however not readily affordable, and some sort of programme support is usually necessary for the propagation of larger tanks.

Water supply projects in the South Pacific

Water supply projects exist in almost every country in the South Pacific, run by governments, non-governmental and international organisations. Government Ministries (e.g. Works, Health) or statutory authorities (e.g. Water Boards) are usually responsible for the installation and operation of reticulated supplies in urban areas and larger villages, usually from boreholes. The few reticulated supplies found elsewhere have also usually been installed by government agencies. Responsibility for operation and maintenance in these cases is often imprecise, frequently assumed to reside within the local community. This situation, along with a lack of local technical knowledge, often leads to high degrees of system unreliability. Another constraint is the shortage of boring equipment or appropriate techniques of well construction in the islands. Bores are also frequently incorrectly drilled into the lens, leading to seawater intrusion. Elsewhere in rural areas, water supply is from a variety of sources - surface water, where extant (rivers and springs), groundwater (mainly from wells through to the shallow water table in coastal areas, where most villagers live) and, predominantly, rainwater collection. Surface and groundwater is usually collected by hand in small receptacles - leading to potential contamination. Rainwater tanks as described above are another potential cause of contamination. It was against this background that an interest developed in ferrocement tanks, to provide clean storage of sufficient volume, as an alternative to the previous inefficient collection systems, corroding galvanised tanks, potentially problemmatic and costly reticulated supplies. Ferrocement tanks are now being constructed in most islands, usually as part of non-governmental projects.

Ferrocement tanks, as usually constructed, however, need some sort of formwork or mould against which to plaster. This requirement predisposes ferrocement tank construction toward series production, which favours an organised small business or project orientation. Such an orientation has indeed taken place in the South Pacific, as elsewhere, although in the islands it can be limiting due to the tiny populations involved, particularly on outer islands. Often the problems involved in transporting the necessary formwork, materials and skilled personnel taken together are quite sufficient to preclude activities on outer islands or considerable delays in tank construction programmes.

Considerations relating to the transportation of materials, equipment and skills also prompted interest in the construction of ferrocement tanks not requiring the usual fairly elaborate formwork and associated construction and assembly skills, of increased cost and complexity, along the lines of an earlier method (Watt 1978). This approach forms the basis of the ferrocement tank developed at the Institute of Rural Development of the University of the South Pacific.

DIFFERENT TANKS

The ferrocement tanks found in the South Pacific fall into two categories: those constructed as a vertical cylinder around formwork in a more-or-less "conventional" manner, and those assembled from sections cast in more elaborate mould(s). Most of the tanks built by small businesses are of the first type, together with about half of those built as part of water supply projects. The others of this category consist of different types of tanks built along modular lines.

The basic or "conventional" type of water tank is usually built in sizes ranging from 5000 to 15000litre. For formwork, galvanised metal sheet around a wooden or tubular metal framework is generally used, around which chicken-, pig-wire or woven mesh and straight wire is wrapped. The form is then plastered with a cement mortar, usually three coats in all - a core, the formwork removed and inside and outside finishing coats. A roof form is then installed and the roof reinforcement wired on and plastered before the tank is finished. This type of tank has been built for many years around the world, particularly in New Zealand, and has generally been found to be durable and economic. The only problems that have been experienced in the South Pacific have arisen with poor quality control and inadvised economising - such as the reduction of cost by the use of mortars that are too weak (in cement content), leading to unsound tanks that have subsequently cracked.

One modular type, propagated by the World Health Organisation in the South Pacific, is a cubic tank of 5000litre, assembled from square panels approximately 20mm thick and reinforced using a lattice of wire and 15mm steel pins. The tank is manufactured at a central location and then transported to site, where the edges are wired together and plastered. Another consists of two similar deep bowl-shaped modules which are transported or cast on-site and then mortared and abutted together around their rims.
The theory behind modular construction techniques is that they

enable sections to be manufactured at a convenient location, where equipment and skills may be centralised, thereby allowing more complex techniques to be used and a higher standard of quality to be maintained. The sections, by necessity lighter than a complete tank to facilitate transportation and occupy less space during transit, are then transported and assembled in the field, by trained personnel.

Practice, however, sometimes falls short of theory, and several complications may arise. Some of the "advantages" of modular construction may turn out to be illusory when the overall economics are considered, and the technology involved may be needlessly complex, leading to unnecessary problems with equipment and quality control. It is often better to transport the materials (thereby also gaining the advantages claimed for modular tanks) and build the tanks on site with a trained crew, possibly using available local unskilled labour, and a training element. This approach has been found to be successful in Kiribati, Tuvalu and Vanuatu, using a "conventional" tank.

Also, the basic tried-and-tested vertical cylinder tank is a good design because the imposed stresses are well contained by the walls of the tank - apart from the junction between the walls and the floor, which can simply be given adequate reinforcement. Cubic and some other modular tanks, on the other hand, have walls that do not always follow the stress lines, or joins at pressure points, and so the basic concepts may not incorporate good design principles. This does indeed appear the case with cubic tanks, because there is a considerable problem with cracking around the edges, due to imposed bending stresses set up in the walls and floor. Almost every tank of this design seen by the author in the South Pacific has shown signs of leakage, except those where adequate edge gussets have been mortared in place.

A_Ferrocement_Tank_Built_Without_Formwork

A "conventional" type of ferrocement water tank was chosen as the tank design most suited for construction and propagation in the South Pacific, as part of the Technology Programme of the Institute of Rural Development, for the reasons indicated elsewhere in this paper. Potential problems with the provision and/or transportation and use of the formwork with which such tanks are typically constructed prompted the examination of alternative ways of constructing a vertical cylinder ferrocement tank. Based on consideration of typical household sizes and drought conditions across the South Pacific, a tank volume of 6000litre was chosen, with approximate dimensions of 2m diameter and 2m wall height.

The method suggested by Watt (1978) seemed promising, despite the problems of plastering the tank and amount of cement required noted by Watt , which were thought to be surmountable by the use of certain innovations. The basic construction method was to lay the tank base in the conventional way, using weldmesh (from 2m x

4m sheets, 150mm mesh) and chicken wire, and then to use sheets of weldmesh reinforcement to form the sides of the tank, 2m high. This weldmesh cylinder was then wrapped in chicken wire - two layers, one inside and outside the weldmesh, prior to the initial coat of mortar being applied. Apart from the gain in local stiffening, the main use of the chicken wire was to provide a better surface onto which to key the mortar.

The first innovation was then used in plastering the tank. Rather than have the operators inside and outside the tank using trowels (floats) to apply the mortar, working opposite each other, a piece of flat but easily bendable galvanised sheet steel of around 600mm x 1000mm, with two handles affixed to one side, was used as movable formwork. Two operators stand inside the tank and hold the sheet, whilst two other operators stand outside, and plaster onto the mesh and wire, with the sheet behind. When one area is plastered, the sheet is gently slid around and up the tank walls for further plastering. This approach makes plastering easier - onto a larger area, and requires only the application of mortar from outside the tank. The problems noted by Watt are therefore overcome, using a movable equivalent of conventional formwork, but without the problems of construction, removal and cost. When this initial coat of plaster is dry, final coats are applied to the inside and outside of the tank, not quite reaching the top of the mesh/wire walls. The tap and overflow are installed as work proceeds.

The second innovation then concerns the structure of the roof of the tank. Rather than fixing the roof reinforcement - of weldmesh and chicken wire again - onto the roof, thereby necessitating the use of internal formwork to plaster, the roof is partly finished off the tank. The weldmesh is cut into a square of correct size. A radial cut is then made into the centre, and the mesh pulled over itself and wired together, thereby forming a cone, which is the shape of the roof. A hole is cut out for the tank filling port/inspection hatch and the whole covered inside and out with chicken wire, and trimmed into a circle of sufficient size to slightly overlap the tank.

A third innovation, consisting of a mound of sand or soil is then formed, the exact shape of the conical roof. This mound is covered with polythene sheet and the roof placed on it. Using this makeshift "formwork" the roof is then plastered with a single coat of mortar. When the mortar is dry the roof is removed and a finishing coat of mortar applied to the inside of the roof. When dry the roof is then affixed to the tank, trimmed, and the edge joins given three coats of plaster, as elsewhere. The roof hole is cleanly finished and the roof given a final coat of plaster. A hole cover is cast, consisting of a ring to overlap the roof hole, with central hole incorporating a plastic filter screen.

Economic Comparisons

The technical differences in tank designs and construction techniques have been noted and commented on above. Reference will be made here mainly to economic considerations. Chief among these are capital cost per unit volume of storage, and considerations relating to durability - the likely need and cost of any maintenance and repair and expected life of the tank. Three main tank types will be compared - a "conventional" vertical cylinder tank built by a small business, the WHO "cubic" tank, and the "conventional" tank not requiring formwork developed at the Institute of Rural Development. Note will be made to other tanks, although details of cost breakdowns are not available.

FIGURE 1 - Tank Data

Tank	Vol(l)	Mat.cost($)	Mat.cost/unit vol($/l)
"Conventional" tank	6800(nom.)	147	0.0216
WHO "cubic" tank	5000(act.)	117	0.0235
IRD/USP tank	6300(act.)	160	0.0254

Notes:

Material costs include overhead discounted equipment costs, but no aspact of labour costs. Labour costs in the above are similar - $67 for the small business "conventional" tank and $54 for the USP tank; it can be assumed that building costs for the "cubic" tank are similar. Volumes for the latter two tanks are actual, the volume of the first tank is nominal - as given by the manufacturer of the tank. Given volumes are frequently exaggerated, either deliberately, using unspecified gallons (US rather than Imperial) or relate to the external dimensions of the tank. Cost data supplied by makers. All costs 1986 US$ in Tonga.
The size and shape of the "conventional" ferrocement tanks noted here are broadly comparable - $147 and $160, as are their shared materials, labour and transportation costs. Formwork, some weldmesh sheet (for the floor and ceiling) and plain wire however is required for small business tank, and weldmesh, but no formwork or plain wire for the USP tank. The difference between discounted formwork and weldmesh costs therefore mainly account for overall cost differences. It is apparent that the extra costs of labour involved in constructing the small business tank using formwork bring the cost of the "conventional" to almost exactly the same production cost, of around $214 ($0.034/l; it is worth noting here that both tanks are actually almost equal in internal volume). Labour costs for the "cubic" tank are approximately $55, and must also include a cost of $30 for the assembly of the tank from the separate panels. The total cost of the "cubic" tank is therefore around $202 ($0.040/l). None of the figures given here includes any component of profit.

It can be seen therefore that the two "conventional" ferrocement tanks are alomost equal in overall cost and cost per unit volume, and that the smaller "cubic" tank is absolutely cheaper but higher in cost per unit volume (by 18%) than the "conventional" tanks. This is largely due to the more costly and higher technology involved. For further comparison, a 4500l (1000 gal) corrugated galvanised steel tank currently costs approximately $300 in Tonga ($0.067/l; retail cost - $350). Similar tanks produced in the South Pacific have similar costs, and some have been made cheaper through the use of weaker mortar mixes, although many of these have been found to crack or otherwise leak. These figures compare broadly with data given by Watt.

Maintenance_and_repair

The above comments regarding the durability of corrugated steel tanks derive from observation in the South Pacific. Maintenence - suitable painting - is frequently neglected, and such tanks rarely last more than 5 years before serious corrosion starts and some form of patching is required. Such repair is difficult, particularly in rural areas, where there is usually insufficient technical knowledge or equipment. Tanks also need to be drained for repairs. Corrugated steel tanks can however be repaired by converting them into ferrocement tanks - by covering the inside and outside with chicken wire and then plastering with a mortar as described above, the old tank acting as its own form.

Ferrocement tanks, on the other hand, should not require any maintenance or repair, provided they are properly constructed from the correct materials, with no corners being cut. Many larger ferrocement tanks found in the South Pacific date from the Pacific war and beyond, and look as durable today as ever before, despite the probably hasty construction in adverse conditions. Leaks, however, do occur as a result of earthquakes, old age and other reasons. Whilst these can be serious if the integrity of the internal structure is impaired, repairs can be facilitated.

More serious repairs require the tank to be drained and the area around the hole/crack to be chiselled out, the reinforcement to be replaced and the tank locally replastered. Smaller cracks can be repaired by a clever technique without draining the tank, provided the water inside the tank covers the location of the suspect leak. About two cup-fulls of powder cement are poured into a 2m length of plastic or tin downpipe that is held from the top of the tank to below the water level inside the tank. During this operation the downpipe is used to stir the water inside the tank, rather like adding sugar to a large cup of tea. When the cement is thoroughly admixed with the water no water must be removed (otherwise blockage of the tap might occur) and the tank left for a period of about one week. The cement will then find its way into the leak and, because of its hydraulic property, set into the leak pathway and so effect a seal. Intransigent leaks may require two such applications. The treatment has been found in Tonga to work wonders with leaking or porous tanks.

CONCLUDING REMARKS

It has been found that ferrocement water tanks are the best suited to the South Pacific. The tanks are environmentally durable, cost-effective, relatively easy to construct using basic hand tools and available materials, and require little if any maintenance. If repair does become necessary, it is usually fairly straightforward and readily accomplished. As with any technology, however, it is important to ensure are adequate quality control and the avoidance of cost- and corner-cutting.

The correct choice of particular ferrocement tank design and construction technique is also as important as the choice of this general approach, however. Of the different types of ferrocement tanks in the South Pacific, it is apparent that the basic vertical cylinder type of tank has been the best choice of technology. This type of tank is relatively easy to build, and to teach others to build. It may not win awards for technological innovation, but the design is sound, reliable and straightforward. The cubic tank illustrates the problems that can be associated with innovative designs and novel construction techniques, which may be found to be practically inappropriate. Innovative ideas may be better applied in an incremental fashion, such as in displacing the need for cumbersome formwork in the IRD-USP tank, especially where limited numbers of tanks in a particular location are required, as is the case in many of the small outer-island rural areas of the South Pacific.

Extension_work_and_rural_water_supply

The importance of good extension work cannot be underrated in any rural development activities, particularly in isolated, sea-locked areas such as the South Pacific. Good extension services are essential to identify areas of need, and then to organise and implement water supply and tank installation projects. Good extension work therefore includes the choice of best technology, given local conditions of isolation, transportation difficulties and limited local materials and skills. Frequently, however, these considerations are given inadequate attention, and this is a reason why water supply projects have encountered problems.

Training in the construction of ferrocement tanks is relatively straightforward, as has been shown by the training-of-trainers workshops held in Tonga, where over fifty women rural development workers from the South Pacific have been trained in tank making. The underlying rationale in these training programmes has been the placing of skills and techniques in the hands of end-users, or the trainers of end-users, as it has been found that technology training can be of limited use in the wrong hands. The end-users of most water in island villages are women and women are mainly responsible for water collection. Women are also generally the extension workers to or trainers of other women.

TABLE 1 - Island Statistics

Country	Population 1980 (est)	Land area sqkm	Sea area 1000sqkm	Pop.dens per/sqkm	Growth rate
Cook Is.	17,900	240	1,830	75	1.8
Fiji	634,100	18,272	1,290	35	2.4
Kiribati	58,600	690	3,550	85	2.1
Nauru	7,300	21	320	348	1.7
Niue	3,400	259	390	13	1.9
Solomon Is.	225,200	27,556	1,340	8	3.3
Tokelau	1,600	10	290	160	1.7
Tonga	97,400	699	700	139	2.1
Tuvalu	7,500	26	900	288	0.9
Vanuatu	117,500	11,880	680	10	2.8
Western Samoa	156,400	2,935	120	53	2.9
Total (av)	1,319,600	62,567	11,090	(21)	(2.6)

Source: South Pacific Commission, 1982.

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TECHNOLOGIES FOR PREVENTING SEEPAGE AND MAINTAINING POTABILITY OF RAINWATER IN RURAL PONDS AND CISTERNS IN INDIA

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ABSTRACT

Several villages of India continue to face scarcity of drinking water due to variety of reasons. Women of these villages have to walk long distances to fetch water. Being extremely scarce, any water is consumed overlooking its quality or ill-effects on health. Since annual rainfall is the sole source of fresh water supply, which also varies from year to year, it is of utmost importance that this water is collected, conserved and consumed most appropriately and economically over a longer period of time. While the rural people followed traditional practices of rain-water harvesting in ponds or cisterns, they have always needed efficient, lasting and cost-effective technologies to minimise the seepage losses and maintain the potability of rain water thus collected. Low Density Polyethylene (plastic) film lining of ponds and ferrocement treatment of cisterns have been found socially acceptable and environmentally sound. Integrating these technologies with ongoing rural development schemes has been noted to be more effective in their advancement and application. The paper presents such experiences of Indian 'problem' villages.

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Views expressed in the paper are those of the author and not necessarily of CSIR

INTRODUCTION

Out of 575,939 villages in India, nearly 324,770 were declared as 'problem'* villages (April, 1980) as they do not have any dependable source of drinking water supply. The worst sufferers are the rural families who do not get even drinking water within easy reach and are compelled to drink whatever water is available. This situation has been greatly responsible to deteriorating state of health of rural people and their livestock. Since responsibility of collection of drinking water is that of womenfolk, they have to walk long distances to fetch water and accordingly spend long hours. In addition to walking, they have to physically lift and carry heavy load of water. The same is the condition in hill areas, where every day is a tiring track up the hill for a pail of drinking water. To provide the above minimum need of the people, the Government of India has decided to saturate all 'problem' villages (Fig.1) with some source of drinking water by the year 1990(1).

Sources of drinking water in the villages are mainly through shallow or deep wells, ponds, streams, rivers, springs, etc. In the arid/semi-arid regions, the drought prone areas and where other sources of water are far away or too costly, the rural people harvest rain-water in natural or impounded earthen ponds (small storage reservoir) and cisterns (rain-water trap) for human and livestock consumption. The stored water in these structures have, however, been prone to seepage, evaporation and external contamination and continue as an unending agony to the people of these areas. With the increase in population and a corresponding increase in water requirement, there was an urgent need to conserve the precious rain-water. It was also necessary to supplement the available quantity of water by making unsuitable water into potable water at rural level. All these, required interaction of modern science and technology (S&T), water management and education. This paper discusses the various techniques and technologies used or having scope of utilisation in conserving and preserving rain-water in rural areas of India. The paper also presents the need for interlinking these activities with the ongoing schemes of Integrated Rural Development Programme (IRDP).

RAINWATER HARVESTING SYSTEM

Rain-water harvesting methods followed in India are different in different ecological locations. While open ponds serve as the main lifeline and provide a useful source of water both in lean rainfall season and in low rainfall regions, the cisterns are constructed in semi-arid/arid regions and hill areas.

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* The number of 'problem' villages has since fallen down.

Criteria for declaration of 'problem' villages are:(1)Source of drinking water away from 1.6 km or more;(2)depth of groundwater more than 15 metres;(3)source of water in hill areas at an elevation difference of more than 100 metres from the habitation;(4)water sources having excessive salinity, iron, fluoride/other toxic elements hazardous to health; or (5) water exposed to the risk of water-borne diseases such as guinea worm.

RURAL DRINKING WATER SUPPLY IN INDIA

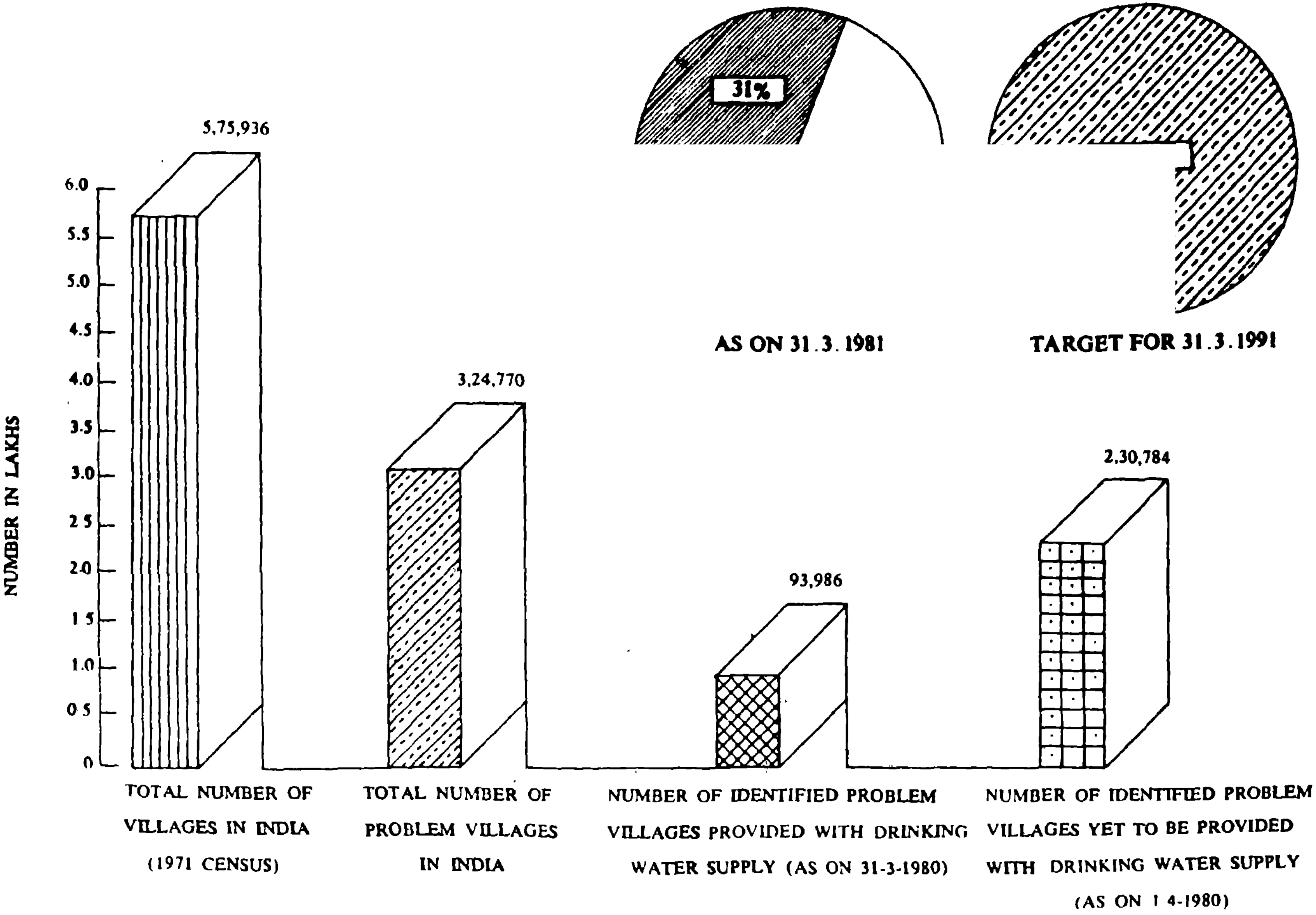

FIG. 1

OPEN EARTHERN PONDS

The existing ponds in rural areas generally possess an adhoc shape. These are either natural depressions caused due to runoff or man-made dams around such depressions. These are located in variety of soil types. A major portion of run-off collected in these ponds, however, is lost due to seepage and evaporation (Table 1). For example, a pond having 4 metre depth of water located in a heavy clay loam soil area gets totally exhausted within 40 days. In case, the pond is located in porus gravel soil, it would be empty in about 5-7 days. The seepage also creates problems like breaches in the catchment area and embankment and increased salinity in adjecent areas. In order to reduce the seepage losses, the villagers plaster the pond basin with especially prepared mud plaster.

TABLE 1

Seepage Losses in Different Kind of Soil (2/3)

Type of soil	Water loss through seepage (Cusecs/million sq.m of wetted area)	Drop in depth per day (cm)
Heavy clay loam	0.90-1.20	10.36
Medium clay loam	1.20-1.80	16.84
Silty clay loam	1.80-2.70	24.61
Sandy loam	3.60-5.20	44.03
Loose sandy soil	5.20-6.10	51.80
Porous gravelly soil	8.80-10.70	90.65

Seepage Control (Input Indicators)

The input indicators for the choice of lining of ponds for control of seepage are (i) impermeability; (ii) strength durability and reasonably long life; (iii) resist damage from rodants and weed growth; (iv) withstand weathering radiation, wind damage and subgrade movement; (v) flexible in use and easy of installation by local labour; (vi) easy of repair; (vi) economical; (vii) visible impact on seepage control; (viii) transportability with respect to the use of material at site; (ix) non-toxic, corrosion proof and no adverse impact on environment; (x) socially and culturally acceptable to the users of water; and (xi) readily available material within the easy reach of end users. Keeping these indicators in view, the following techniques were given field trial:

1) lining of the catchment area with tiles;

2) laying chicken mesh on the surface and spreading cement over it; and

3) lining with plastic film - Low Density Polyethylene (LDPE) films.

The comparative cost of these lining materials is given below(3):

Table 2

Comparative Cost of Various Lining Methods

Method of lining	Cost per sq. metre in Indian Rupee (IR) (1 US $ = IR 12.25 approximately)			
	Plastic film (LDPE)	Earth* work	Total IR	Total US $
1. Double tile lining	-	-	24.00	(1.95)
2. Single tile lining	-	-	10.00	(0.81)
3. LDPE with single tile cover				
a) 400 gauge (100 microns)	2.30	-	12.30	(1.00)
b) 1000 gauge (250 microns)	5.75	-	15.75	(1.28)
4. LDPE with 60 cm soil cover				
a) 400 gauge	2.30	2.40	4.70	(0.38)
b) 1000 gauge	5.75	2.40	8.15	(0.66)
5. LDPE with 90 cm soil cover				
a) 400 gauge	2.30	3.60	5.90	(0.48)
b) 1000 gauge	5.75	3.60	9.35	(0.76)

* Earth work at the rate of Rs 4.00 (US $ 0.32) cu. metre and LDPE film costs at the rate of IR 25.00 (US $ 2.04) per kg.

Low density Polyethylene (LDPE)

Lining the ponds with LDPE film of 400-600 gauge[+] was found to be an efficient and economical mode for control of seepage (Fig.2). This helped to save 35-40 per cent of water loss and also acted as antisalinity measure in saliine land (the total desolved solids and chlorides do not increase due to impermeable partition between water and saline earth). The product is manufactured in India by Indian Petrochemicals Corporation Limited (IPCL), a Government of India undertaking who also undertake consultancy in the LDPE (Agrifilm) lining[++].

[+] The existing ponds are shaped in a trapezoidal section with a slide slope of 3:1 and a bed gradient of about 1:1000 (See Fig.2).

[++] The LDPE films (ISI specification: IS 2508-1984) are laid directly over the finished sub-grade with a soil cover of 30 cm at the bed and 45 cm at sides. The films are jointed with heat sealing or use of self-adhesive tapes.

Cross-section of Lining of pond (Open earthen small water storage reservoir) with Low Density Polyethylene (plastic) film

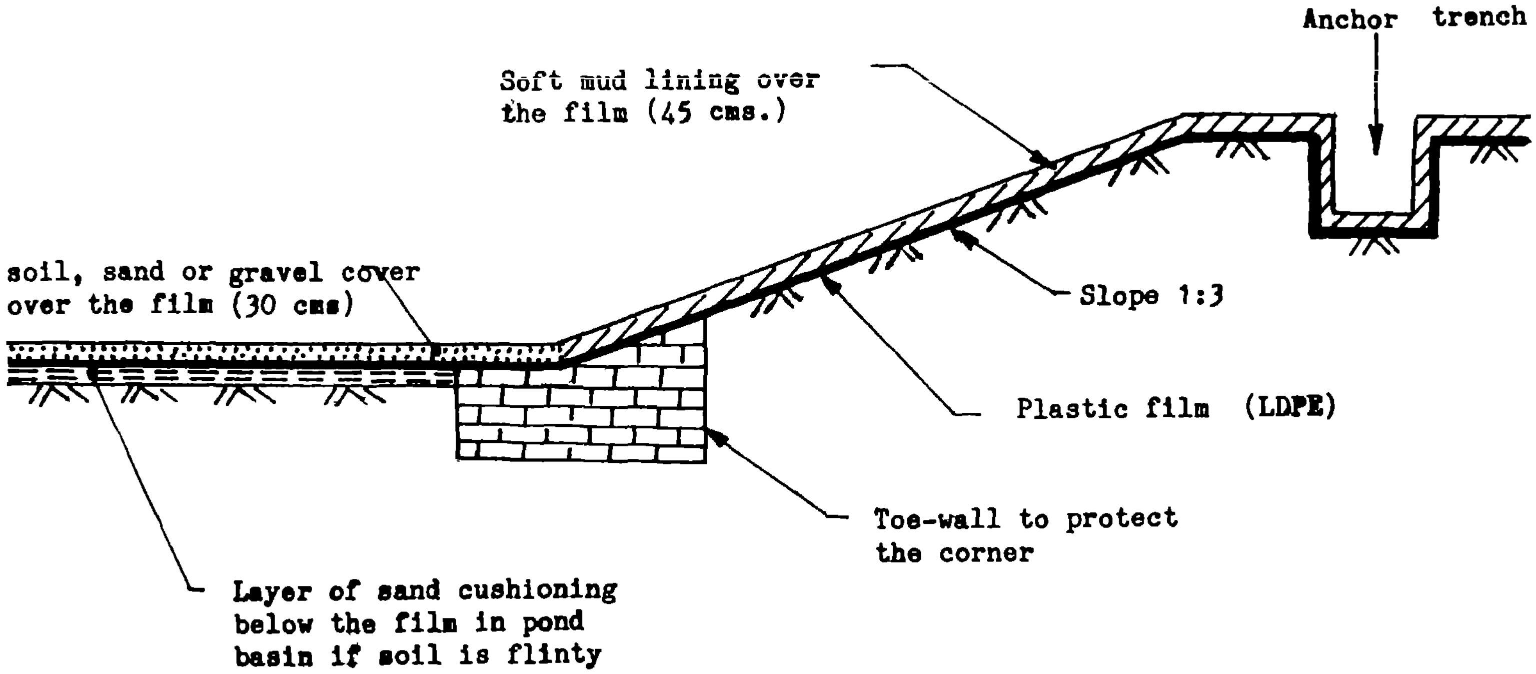

Fig. 2

(NOT TO SCALE)

Case Study, Gujarat

A case study on lining of a pond with LDPE film (400 gauge) and the output of technology in the village Dholera (name of pond Rahtalav) near Ahmedabad in the State of Gujarat, undertaken by IPCL in collaboration with a social voluntary agency (MAHITI) is appended (Appendix I). The total work involved a cost of about IR 1.90 lakhs (US $ 15510) in 1984-85. This also provides information about social benefits accrued.

Evaporation control

There is considerable evaporation loss in open ponds which varies from month to month as it is governed by temperature, radiation, humidity and wind velocity. In arid/semi-arid and drought prone areas, normal evaporation ranges between 20-30 per cent (350 cm to less than 150 cm and for a given quantity of impounded water, the percentage loss would be higher if stored in a shallow pond). One of the methods tried to minimise the evaporation is through energy plantation. The fuel trees are planted on the embankment or around the pond in such a way that the leaves do not fall directly in the water. Pond structure also plays an important role in the control of evaporation. Here, the water storage capacity is maximised and exposed surface area is minimised. This subject, however, requires R&D. CSIR (NCL, Pune) has developed an evaporation retardent by the preparation of mono condensates of long chain fatty alcohols with ethylene oxide. The product (Trade name Tinoxyl CS40) is marketed by M/s. HICO Products Limited. The use of the product saves about 25 per cent of evaporation loss.

Arid/Semi-arid Regions

In arid and semi-arid regions with as little as 50-80 mm average annual rainfall, following methods of rainwater harvestin are followed:

(1) Village pond

The peculiarity of this method is that 2-3 wells are dug in the pond basin (peoples' own innovation). The water is first consumed from the pond and when it dries up, it is drawn from the wells.

(2) Step-wells

Where sub-surface water is upto 10 metre deep and there is a regular recharge, step-wells locally called 'Bavri" are made. Stone-slabs are laid in the walls to reach water surface. These wells have, however, been found heavily infected with guinea worm.

(3) Dug-wells

People dig wells in river basin and draw water when the river dries up.

CISTERNS

The cistern method of harvesting rainwater is mostly found in arid and semi-arid region especially in the State of Rajasthan and forms an integral part of the life of rural people. Here, the rainfall is as low as 50-80 mm. In order to harvest rainwater various types of catchment surfaces based cisterns are made. The estimate of runoff of some of these is given in the following table (+). In 'problem' villages, even the life style of the people is reflected by the scarcity of water.

Table 3

$$\text{run-off coefficient} = \frac{\text{harvestable rainfall}}{\text{total rainfall}}$$

Type of catchment	Runoff coefficient
Uncovered catchment surface	
flat	0.3
sloping 0- 5 per cent	0.4
sloping 5-10 per cent	0.5
sloping more than 10 per cent	> 0.5
Covered catchment surface	
Roof tiles	0.8 - 0.9
Corrugated sheets	0.7 - 0.9
Concrete bitumal	0.7 - 0.8
Plastic sheet	0.7 - 0.8
Brick pavement	0.5 - 0.6
Compacted soil	0.4 - 0.5

Well Type Cisterns

In this system, a catchment well of about 3-4 metres deep with 1 to 2 metre diameter is dug. This well is lined with brick and mortar. Around this well, the land (upto 100 sq. metres) in circular form is scarped in such a manner (gentle slope of 15° - 20° ending to the trap well) that it forms a catchment area. Some rural communities dig furrows ending to the well. A suitable site is selected for construction of these cisterns keeping in view distance from village, altitude, natural depression, etc. During rainly season (May-July), water is collected in these cisterns and is covered with branches of tree and dry bushes and surrounded with thorns for protection from stray cattle. When all other sources of drinking water exhaust, people consume water fom this cistern. The water is drawn in buckets with rope. One such cistern meets the drinking water need of 5-6 families.

+ Source: Hofkes, EH (1981), Rainwater Harvesting for drinking water supply, IRD, The Hague, The Netherlands.

Ferrocement lining of cistern

Such cisterns could be lined with ferrocement*. This technique eliminates the use of moulds (casting); controls seepage; and helps in maintaining the quality of water. The lining can easily be done by local mason.

Pot Type Cisterns

Well to do families make their houses in such a way that the courtyard could be converted into a catchment. Sometime, two families having common courtyard also make such a cistern. The water from inclined roofs falls in the courtyard having slope ending to the cistern. The floor of such catchment is made of stabilized soil or cement. The underground cistern is made of baked clay giant size pot (made by local potters) with a mouth which is covered by wooden or metal lid.

Cisterns in Hill Areas

In hill areas, the slopy roof-tops are used as catchment for collecting rainwater. These are attached with a metal water channel (sloping towards end corner of the house). It has two outlets one to drain out dirty water of first shower and another directed into the water storage tank (water-jar) placed on the ground (Fig.4). These tanks are generally the used bitumen drums (discarded after road construction) or the tanks made of galvanised iron sheet. The drum is covered either by metal, wood or bamboo lid (4).

Ferrocement water tank (5)

The technology for fabricating ferrocment water storage tanks (giant water jar) having inlet, outlet and overflow arrangements, has been developed by CSIR (SERC, Roorkee) of capacities varying from 250 to 2500 litres. These have been found quite suitable for rain-water collection in hill areas. Such tanks are hygienic, require little maintenance and can be fabricated as a manufacturing unit to generate new employment opportunity. The tanks, cylindrical in shape are cast by a simple semi-mechanised process utilising only rural level skills. Such tanks could also be fabricated into prefabricated components and assembled at site (Fig.3).

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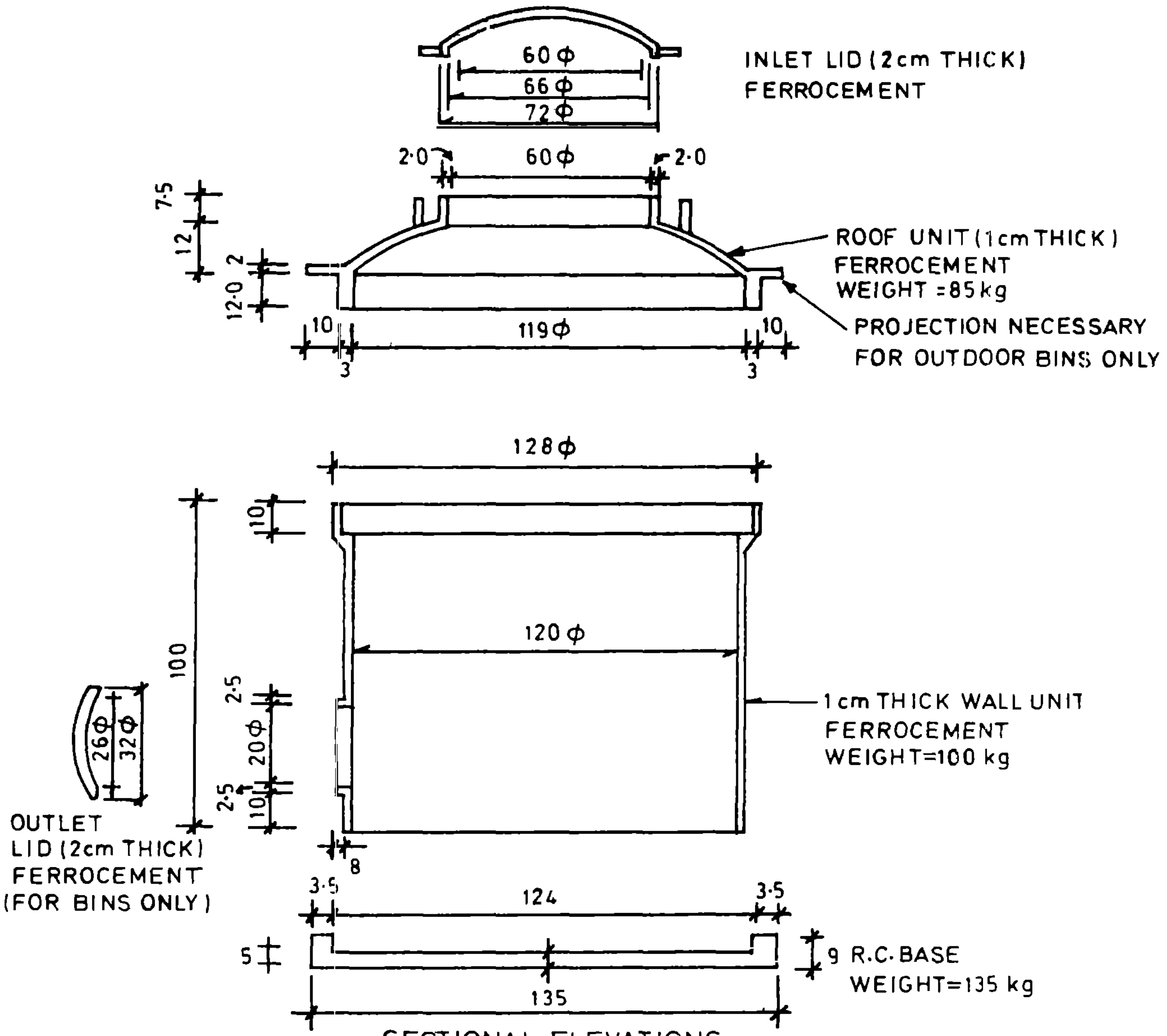
* Ferrocement is a highly versatile form of reinforced mortar consisting of closely spaced layer of wiremesh reinforcement impregnated with a rich cement-sand mortar. This possesses high resistance to cracking. After excavating the well, it is first plastered over the earthen wall (6-8 mm thick) with cement (1:4). After about 30 minutes, nails are driven partly in plaster and partly in earth at 50 cm internal grid. Hexagonal wire mesh (26 gauge) is laid over these nails and plastered (6 mm thick) with cement (1:3). It is finally finished with cement mortar (8 mm thick). The bottom of the well is plastered (25 mm thick) with cement, sand and concrete (1: 2 : 4). The roof and lid over it could be casted with the help of an earthen mould. The cost of construction of such cisterns has been estimated at IR 0.60 (US$ 0.05) per litre capacity in India (Roorkee,1986).



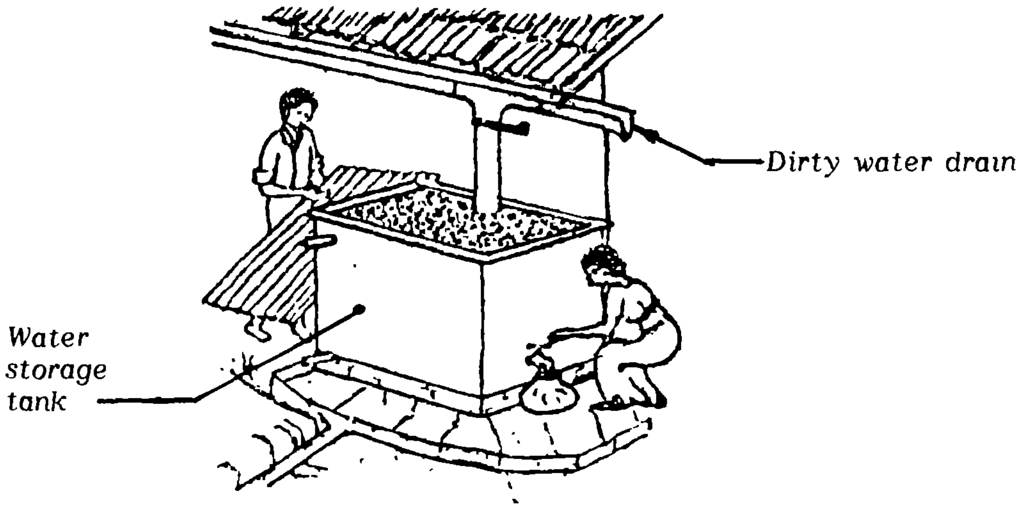
SECTIONAL ELEVATIONS

ALL DIMENSIONS IN CMS
NOT TO SCALE

PREFAB UNIT FOR GRAIN STORAGE BIN SAME TECHNOLOGY IS USED FOR STORAGE OF WATER OVER THE GROUND

Fig.3

Household Roof Rainwater catchment



Cross-section of Ferrocement Water Jar

(Capacity 800-1000 litres)

Fig. 4

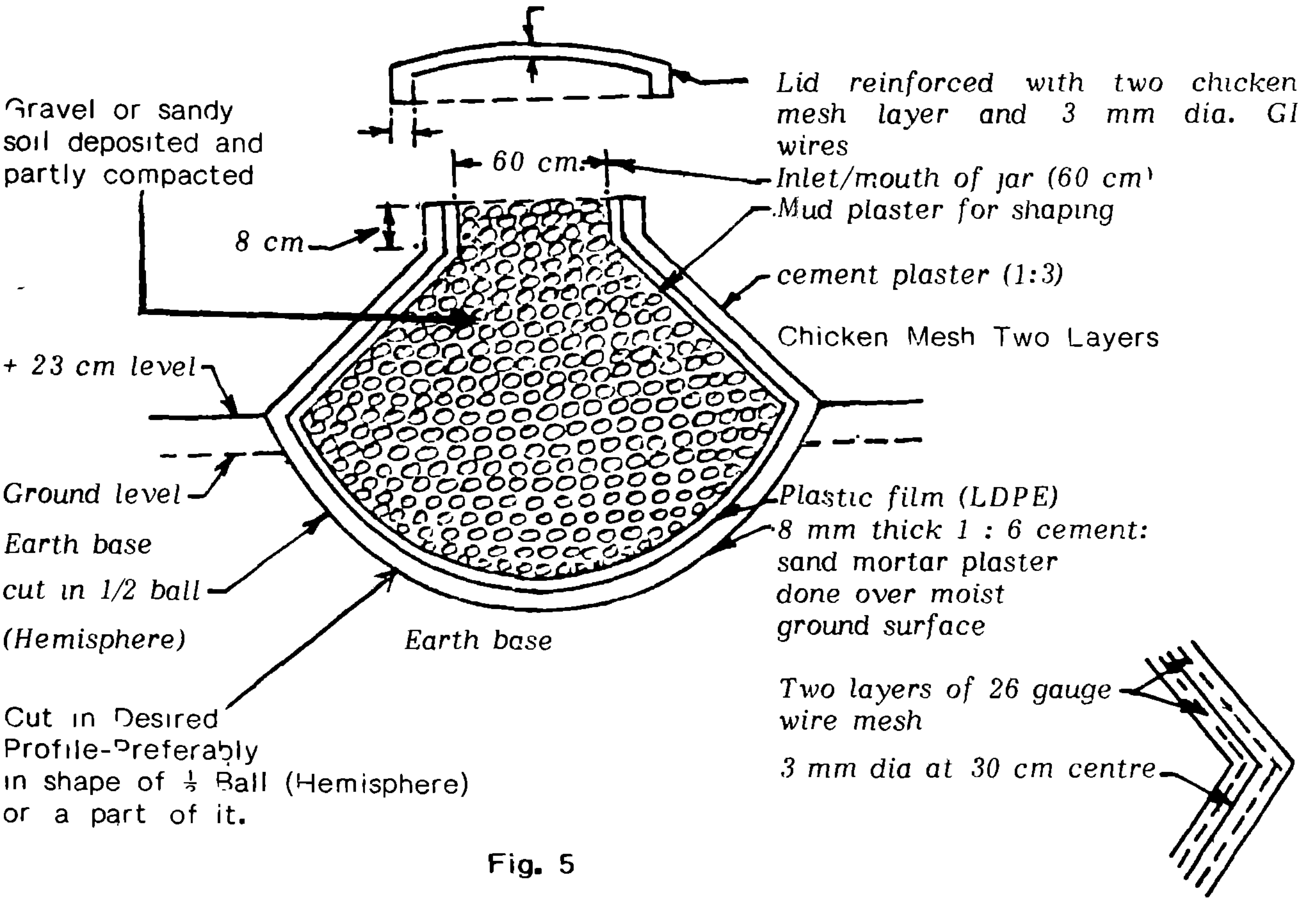


Fig. 5

NOT TO SCALE

Ferrocement rainwater jar

For meeting drinking water needs of individual household, ferrocement jar could be fabricated at site. Such jars are partly built below the ground and partly above the ground. The technique eliminates*the use of moulds or casting and the ferrocment jar is built at site*. This is cheaper thar metal/ferrocment water tanks (op. cit.) while serving the same purpose. A ferrocement jar of 1000 litre capacity made in 1985 costed IR 1000 (US$ 82) including unskilled labour cost(Fig.5).

Ferrocement rain-water jar (based on hesian cloth sack mould)

Ferrocement water storage jars (capacities 0.5-$2m^2$) suitable for collection of rainwater through roof catchment system can be produced on self-help basis at the village level. The technique is very simple and can be adopted with a little training. This involves use of hesian cloth, chicken mesh, G.I. wix and cement. The hesian cloth pieces (cut according to the diameter of the jar) are stitched together to make a sack-mould and filled with sawdust or ricehusk to make the shape of jar (see fig.6). It is on this sack-mould that chicken mesh cage is made and casted with ferrocement mortar. After curing the sack-mould, fillers are removed. Such jars are placed on ground level. It has an in-built inlet to collect water and outlet for drawing water and cleaning the jar. Cost of making such jars has been estimated to IR 0.60 (US$ 0.05) per litre of capacity (Roorkee, India,1986).

Water Quality Protection

In all these rain-water harvesting methods, water sanitation should be given top priority and the stored water should be regularly tested and treated before drinking. In the cisterns, contamination of water generally takes place due to dirt of thatch roof, catchment surface and drawing method of water. To preserve the drinking water, people clean the catchment area before the rains. They also skip over first** rain flash (10 minutes) from roof as thatch roof cannot be cleaned.

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* The technique involves digging a semi-circular pit in the ground. Its base is thoroughly levelled. A 8 mm thick layer of 1:6 cement sand mortar plaster is applied over the cut surface. The plastic film is laid on plastered surface. Two chicken-mesh layers are spread over this surface and plastered with cement mortar (1:3). This bowl shaped pit is filled with gravel, sand or loamy soil and raised above the ground in a conical form (see Fig5). The gravel heap is properly surfaced with mud and plastered with cement (1:3). This is followed by laying of chicken mesh and another cement plaster (1:3). The top is left out for the mouth of the jar to receive rainwater. When this structure is cure, the inside fillers are carefully removed and cleaned. The inside surface is finished with cement and painted with drinking water paint. A cover or lid according to the mouth size could also be moulded at site.

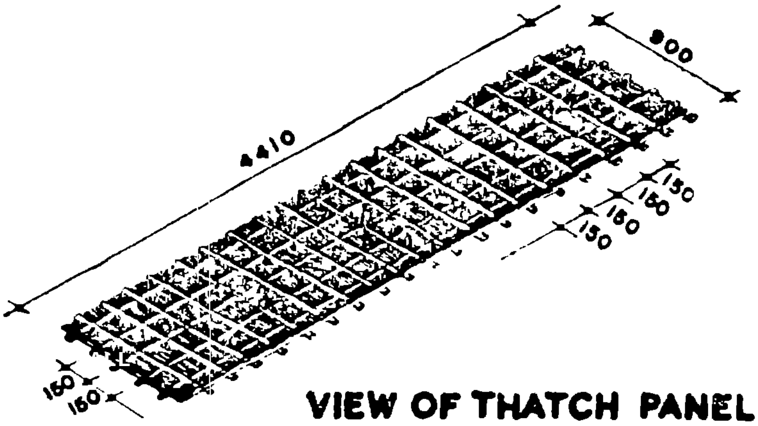
** CSIR, India (CBRI, Roorkee) has developed (6) a technique of treating thatch roof with bitumenised mud plaster (Fig.7). This treatment helps to make the top surface smooth which can be cleaned easily. This treatment also makes the roof-top resistant to rain and fire-retardant (Appendix II).

FERROCEMENT
RAINWATER
STORAGE JAR
(Hesian based)

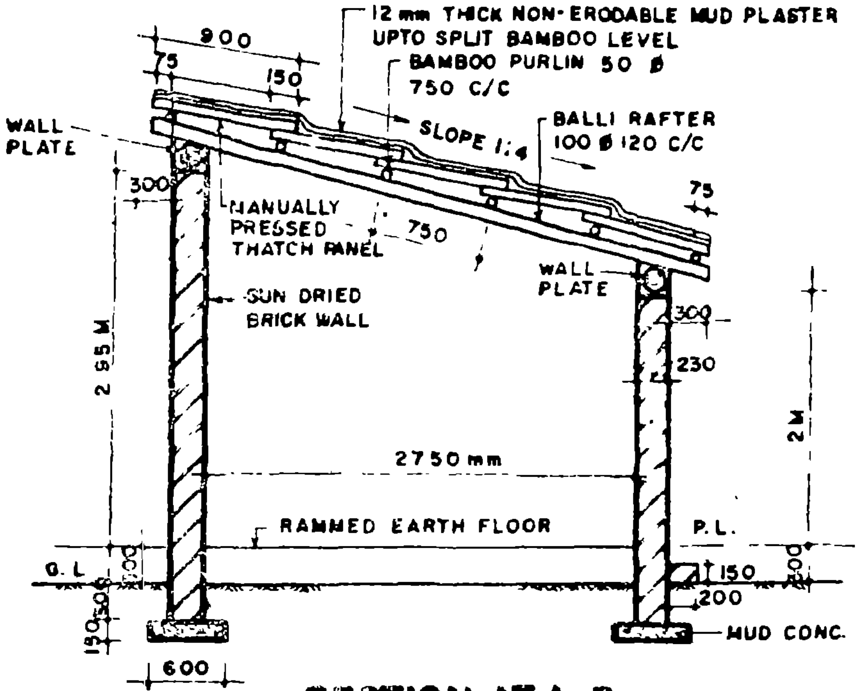
Forming of sack-mould of the jar - sawdust/rice husk filled and compacted well with hand.

Hesian surface is moist and ferrocement casted over wire mesh. The ring is the top opening.

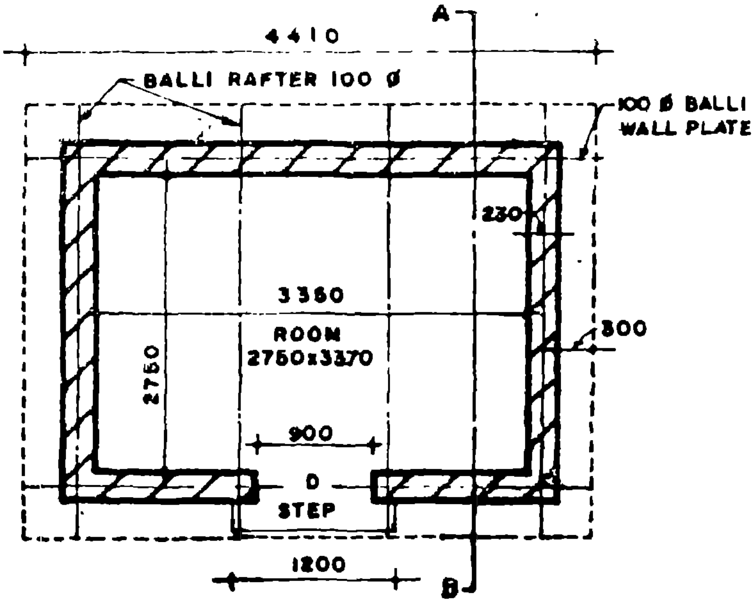
Fig. 6



VIEW OF THATCH PANEL



SECTION AT A-B



PLAN

IMPROVED METHOD OF MAKING THATCH ROOF

Fig. 7

In order to maintain the potability of water in storage, people add a little lime (Calcium hydrate). Use of Chlorine tablets/ampoules, a technology developed by CSIR, (NEERI, Nagpur) as a substitute to lime has, however, been found more effective and handy in use. Similarly, to avoid contamination in drawing water from cistern through bucket and rope and to minimise losses in the distribution of water, use of shallow-well handpump a design developed by CSIR, (CMERI, Durgapur) is quite useful and hygienic.

The thatched roofs may be covered with thin plastic sheets to prevent water contamination.

THE OUTPUT *

The output indicators for application of 'appropriate' technologies could be the following :

1) solace to the sufferings of people with the availability of additional quantity of water within their easy reach;

2) availability of safe drinking water at a nominal cost;

3) reduction of hardship and drudgery of womentfolk; and

4) release of time for womenfolk to take-up some income augmenting activities.

Output in terms of food, water and fodder

From the case studies (Gujarat, Rajasthan, and UP Hills), it has been noted that in these areas efforts are made to collect the rain-water channelled into the cisterns and used for drinking purposes. The village people keep their grazing stock out of the reach of such catchments. This area in some places has thus sprung up with green cover, an essential output to improved environment and green fodder. In case of LDPE film lined ponds, it has been noted that prior to the use of this technology, villagers were able to raise only one uncertain crop. With the application of lining technology, they are now able to take two assured crops. The production has also increased.

Output in terms of mutuality of efforts

The mutuality of interest to collect and conserve the precious water, made villagers to become mutually reinforcing.

Output in terms of ~~development~~ of ~~womenfolk~~

Because of easy availability of drinking water, near the village, women now have more time for caring for children and milch cattle, undertaking kitchen garden, colleting 'munj/bhabbar' grass for making ropes and other income generating activities. The women Extension Officer organised 'Mahila Mandal' (women's club), the key to success of the project. She introduced fuel efficient cook-stove and biogas

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* Also refer socio-economic benefit - case study Gujarat, Appendix I.

plant for meeting rural energy needs. Their huts have become more hygienic and safe (Appendix II). They have become demanding and also developed strength to check activities which may threaten the well-being of the village community.

TECHNOLOGY INTEGRATION WITH RURAL DEVELOPMENT SCHEMES

Drinking water supply in rural areas forms one of the important components of the Rural Development programme of India. It aims at covering 100 percent "problem" villages under drinking water supply by the year 1990 and preventing the water scarcity conditions in other villages. The ongoing Rural Development Schemes covering various aspects of drinking water supply in India include the following :

1)Minimum Needs Programme (MNP);
2)Accelerated Rural Water Supply Programme (ARP);
3)Desert Area Development Programme (DADP);
4)Drought Prone Area Programme (DPAP);
5)Rural Landless Employment Guarantee Programme (RLEGP);
6)Development of Women and Children in Rural Areas (DWCRA); and
7)Training of Rural Youth for Self-Employment (TRYCEM).

The schemes cover resource generation, employment/work opportunity and earning potential, supply of inputs, technology transfer, training for operation and maintenance, water testing and water/health eduction. All these activities broadly form the part of an integrated rural development approach. The input of different government departments viz. Health, Education, Science & Technology, Engineering, Ground Water Board, Tribal Development and Rural Development, etc., converge at district level (an administrative area in India). All schemes are, therefore, implemented by only one agency i.e. the District Rural Development Agency (DRDA). This also involves training of local youth (TRYCEM) to work on retainers basis for advancement and servicing of technology and for providing feedback to the managers of rural development and to the generators of technology. Keeping in view the importance of above linkages, guidelines for integrated planning, implementation and coordination of all these programmes with rain-water harvesting for drinking purposes have been drawn. These guidelines also include institutional, financial and management support required and the scope of involvement of voluntary agencies. The integration of rainwater harvesting programme with rural development is also essential particularly to low income group (rural poor). To this end, efforts are made first to generate resources and increase the income level of the beneficiaries so as to help them to use this income to install/adopt one of the available drinking water technologies.

CONCLUSION

Water means life. It has no substitute. There is, therefore, need to harness all possible resources especially for those staying in drought prone areas, hill tops and arid and semi-arid regions. Harvesting rain-water for drinking purposes is one such avenue, practised in some of the "problem" villages in India. This, however, required application of improved techniques and new technologies for prevention of seepage losses and maintenance of quality of water stored in village ponds and cisterns. The lining of pond-basin with Low Density Polyethelene film and the cistern with ferrocement and use of ferrocment water tanks or jars have been found technically feasible, economically viable, socially acceptable and environmentally sound. Such applications also generated employment opportunities locally. Use of chlorine tablets/ampoules for disinfection and installation of hand pumps for drawing water to avoid external contamination to the stored water supplemented the efforts to water sanitation. Waterproofing of thatch-roofs and energy plantation are some other complimentary technologies. While these inputs bridged the structural and water treatment inadequacies, these require extensive demonstration and education to the beneficiaries especially the womenfolk. The exhortation and participation do not work especially if these are aimed at people who live on the margin of subsistence. They need to be helped to come up the poverty line and be capable of adopting new techniques. This is one of the main objectives of rural development. These activities should, therefore, be integrated with the ongoing Rural Development schemes which will not only lead to meeting the expected output and a better living, but may also smoothen the process of inculcating a 'faith in successfulness' in life among the rural people struggling for survival.

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i) Indian Petrochemicals Corporation Limited, Baroda (Gujarat)

ii) Mr. P.C. Sharma, Scientist, Structural Engineering Research Centre (SERC), Roorkee (U.P.)

iii) Dr. Ram Gopal, Scientist, Defence Research Laboratory, Jodhpur Rajasthan.

iv) Dr. Narendra Verma, Scientist, Central Building Research Institute (CBRI), Roorkee (U.P.)

v) Dr.K.K. Bokil, Scientist, Central Salt & Marine Chemicals Research Institute, Bhavnagar, Gujarat.

vi) Dr. K.N. Shelat, Chairman, District Rural Development Agency (DRDA), Rajkot (Gujarat)

vii) Dr. B.D. Tilak, Director, Centre for Application of S&T for Rural Development, Poona, Maharashtra

APPENDIX I

CASE STUDY GUJARAT

In water scarcity areas in Gujarat, the villages are named after the rain-water ponds. One such village called Dhorela in the district of Ahmedabad has a population of 1000 persons and about 500 cattle (livestock rearing being the traditional profession). The annual rain fall is 20-25 cm. Drinking water supplies are also met by the government through water brought from distant places in tankers. The villagers, therefore decided to dig a pond locally named as 'TALAV' under the Government's Rural Development Programme viz. MNP. (op. cit.). Other programmes viz. DPA and RLEGP enabled provision of funding and other inputs like technical services of a civil engineer to supervise the civil work and the technicians for lining of the pond with plastic film (in this particular case technology input was provided by the Indian Petrochemicals Corporation Limited, (IPCL) Baroda). The entire earth work and lining was done by local village men and women. The motivation and enlistment of cooperation of local beneficiaries was done in collaboration with a social voluntary agency 'MAHITI' of Ahmedabad.

Civil-Work

The pond-area was worked out on the basis of water requirement at the rate of 10 litres and 5 litres per capita per day for human and livestock respectively. The pond having a water storage capacity of about 10,000 cubic meters (85 m x 45m x 2.5 m) with a surface area of 4475 sq.m was dug. The basin surface was first lined with soil cover of 30 cm and 45 cm on sides. Sand cushioning (12 mm) was provided over this sub-grade. The wall slope of 3 horizontal to 1 vertical was made (see Fig.2)

LDPE FILM LINING

LDPE film (Agri film 22 FA 002 manufactured by IPCL) of 400 gauge (100 microns) was laid on the pond surface area (with sand cover) with the provision of overlaping. The joints were sealed with a specialy made adhesive tape. Plastic film was also used for anchoring. To save the plastic film from direct exposure to sun another sand cover of 45 cm was laid over the film. The cost of lining as worked out is given in the following table.

COST OF LINING RAHTALAV (POND) IN VILLAGE DHOLERA (INDIA)
(COST WORKED OUT IN IR)

	Item	Quantity	Rate	Amount
1.	LDPE FILM*	1 Sq. metre	2.80 sq. metre	2.80
2.	Sand (12 mm thick cushion over sub-grade)	0.012 cu.metre	60.00 per metre	0.50
3.	Sundaries (labour, etc.)			0.30
	Total cost of material		Rs	3.60
4.	Labour Cost			
	Laying the film			0.25
	Sand cushioning in 12 mm layer			0.25
	Laying sand cover of 45 cm over LDPE film			0.25
	Labour cost per sq. metre		Rs	0.75
	Civil/Technical supervision at the rate of 15 per cent		Rs	0.65
	Total cost of LDPE film lining per sq. metre		Rs.	5.00**
				(US $ 0.40 approximately)

Socio-economic Benefit (Output)

The following output were recorded:

1)there is a visible impact that more water is available for a longer period of time (about 40 per cent of seepage was controlled due to LDPE film lining);

2)use of LDPE film eliminated seepage and ensured potability of drinking water in an intensive saline area;

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* 1 Kg of 100 micron film provides a coverage of 10 sq.metres.

** The cost of LDPE film was worked out to be Rs.14,000 (US $ 1142) handling charges and transport Rs.1,000 (US $81) and lining on already excavated pond of above size Rs. 25,000 (US $ 2040). Thus total cost of lining plastic film per cubic metre of water storage and preservation from seepage came to Rs.2.50 (US $ 0.20) for all time to come (1984-85).

3)the pond reduced the cost of transportation of water through tankers, camel or bullock-cart;

4)cost towards pumping underground water, making of overhead storage tank and laying distribution pipes and their maintenance cost were eliminated;

5)drinking water is now available at the door-steps of village and accordingly the drudgery of women was reduced (a women had to walk 6 km each way spending 8-10 hours time a day)

6)the time thus saved from above is now utilized in the care of livestock (calf and heifers) and children and in undertaking crafts work under DWCRA;

7)the local people jointly guard their stored water more than their valuables;

8)water-borne diseases and resultant hardship and absentism from work were reduced (this is, however, being watched);

9)the earth work and other labour input generated an income of Rs 80,000 (US $ 6530 approximately) to the local people (at the rate of Rs 13.30 a day for 8 hours per head) under RLEGP.

Other Output

1)Every family opted to plant a fuel-tree around the pond; the women have been given responsibility to nurse it. When these plants will be matured, this will ease the drudgery of fuel search and collection. The falling leaves would be collected for cattle-feed.

2)There appears to be visible change in people's attitude towards application of improved techniques and new technologies under rural development schemes.

3)The project has generated a faith in successfulness (also being watched).

4)The project generated a faith in the application of S&T among the rural development workers and the voluntary agency involved in the project.

5)The plastic film tubes are used for making bags for plant nurseries and packaging, etc. If the demand increases these may need to be supplied through local depots in a decentralized manner. It may perhaps open new income/employment avenue.

Replication (multiphier effect)

The project is a glowing example to nearby villages who have approached the District Rural Development Agency (DRDA) for necessary assistance in replicating the said technique in improving their existing ponds or constructing a new one. The income generated through the Rural Development Project (Output 9 above) could perhaps be one of the reasons.

APPENDIX II

Technology for Thatch Roof - Material & Labour Requirements

Requirements for 10 m^2 Roof Area

FOR PRESSED THATCH PANELS

Material	Unit	Quantity
Soil	m^3	0.3
Paddy or wheat straw	kg	18
Bitumen	kg	10
Kerosene	Litre	2
Cowdung	kg	7.5
Fire wood	kg	10

Labour	Mandays
Mason	1
Helper	2

EXTRA FOR CONVENTIONAL THATCH

Addtional requirements for ceiling

Material	Unit	Quantity
Soil	m^3	0.14
Paddy or wheat straw	kg	9
Bitumen	kg	7.5
Kerosene	Litre	1.5
Fire wood	kg	4

Labour	Mandays
Mason	1
Helper	1

For Pressed Thatch Panels

COST*/m^2 with self help - Rs 6.00 (US $ 0.50 approx.)

COST*/m^2 with hired labour - Rs 10.00 (US $ 0.80 approx.)

For Conventional Thatch Roof

COST*/m^2 with self help - Rs 9.75 (US $ 0.80 approx.)

COST*/m^2 with hired labour - Rs 16.75 (US $ 1.36 approx.)

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* As per rates prevailing around Roorkee, India in November, 1984

WATER QUALITY

WATER QUALITY ASPECTS OF A RAIN WATER CISTERN SYSTEM IN NOVA SCOTIA, CANADA

Richard S. Scott [1] *and D.H. Waller* [2]

ABSTRACT

The physical, chemical and bacteriological water quality characteristics of a newly installed rain water cistern system in Nova Scotia, Canada, were monitored monthly for a two year period at points within the system. Calcium concentrations, alkalinity and pH in precipitation were increased by leaching from cistern walls. Seasonal growth patterns of surrounding vegetation cover were reflected by variations in concentrations of potassium and phosphorus. Sludge accumulations in the cistern represent potential water quality problems. First flush concentrations of some chemical and heavy metal constituents were elevated, but diversion of first flush runoff is not considered necessary to maintain cistern water quality.

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INTRODUCTION

In rural Nova Scotia, increased attention has been directed to the use of rain water cistern systems (RWCS) as a potable water supply for single family dwellings. This attention has been stimulated by complaints of either inadequate ground water supplies or various levels of mineral contamination and nutrient contamination of wells principally attributable to iron, manganese, arsenic, uranium, nitrate and salt water.

Water quality aspects of RWCS in Nova Scotia have been considered by Waller and Inman, 1982 , and by Waller et al.,1984, but several questions were not addressed in previous work:

(1) Temperatures of precipitation and cistern water vary considerably on a seasonal basis. The effects of this variation on cistern quality was unknown.

(2) Cistern sludge is considered a potential contaminant and is periodically removed from cisterns at intervals that vary from annual (Lee and Jones, 1982), to at least once every six years (Waller, 1982). Little information is available about composition of the sludge or impact on cistern water quality.

(3) Asphalt shingles are the usual roofing material in Nova Scotia, but other materials are used. The relative effects of these materials on cistern quality was of interest.

(4) RWCS in Nova Scotia do not include provision for diversion of the "first flush" from each storm event, although inclusion of a device for this purpose is recommended by many authors (King and Bedient, 1982; Michaelides and Young, 1984; and N. S. Department of Health, 1982). Nova Scotia precipitation events are frequent and are distributed throughout the year, and the need for first flush diversion in this situation was uncertain.

The foregoing questions were addressed by systematic study of a RWCS serving a single family dwelling, supplemented by data from other dwellings and by consideration of data obtained from small roof simulators.

SITE AND SYSTEM DESCRIPTION

The single family dwelling chosen for the study is located in Fall River, approximately 25 km from the City of Halifax. The home is situated in an area of deciduous-coniferous forest.

The area of the asphalt shingle roof that serves as the catchment for this system is 209.9 m^2. The cistern is a 3.658 m square x 2.235 m deep untreated concrete tank, yielding a storage capacity of 29.90 m^3. Precipitation is routed to the cistern via enamelled aluminum eavestroughing and PVC collection pipes. Plastic 7.5 mm mesh screening placed over the eavestroughing is intended to eliminate large debris particles from entering the cistern.

Stored water is pumped into the home by means of a submersible pump located at the center of the tank in a 1 m deep pit to achieve maximum available storage. The copper pipe distribution system is equipped with a charcoal filter and an ultra-violet disinfection unit.

CISTERN AND TAP WATER QUALITY

Objective

The objective of this study was to examine, and attempt to explain, differences between precipitation, roof runoff, cistern, and tap water quality.

Methodology

Monthly water samples were collected from the approximate center of the stored water volume, and at a household tap, between October, 1983, and October, 1985. In situ measurements of dissolved oxygen, water temperature and specific conductance were recorded between August, 1984 and October, 1985.

Cistern samples were retrieved using a Nalgene hand-operated vacuum pump equipped with a 500 ml pyrex vacuum flask and 6 m of 4.8 mm ID tygon transmission tubing. Two 2.5 m x 1.27 cm acrylic rods were used to position the tubing in the tank for sample extraction.

The tubing and vacuum flask were rinsed three times with approximately 150 mls of cistern sample water prior to actual sample collection. Tap water was allowed to run for 3 to 5 minutes prior to sample collection.

All samples for chemical analysis were placed in 1L Decon (BDH Chemicals) washed, distilled water rinsed polyethylene bottles and stored at 4^{o}C. Bacteriological samples were collected in sterilized 8 oz. glass bottles. Chemical analyses were completed in the Centre for Water Resources Studies Laboratory at the Technical University of Nova Scotia within one week of collection. Bacterological testing was performed at the Victoria General Hospital, Department of Microbiology within 24 hours of collection.

Of the 19 parameters analyzed on monthly samples, only pH, alkalinity, calcium, potassium, and phosphorous appeared to display effects of system materials and meteorological influences. Techniques and equipment used for these five parameters are as follows: pH and alkalinity were measured using a Radiometer ETS 822 end-point titration system; potassium and calcium were measured by flame atomic absorption spectrophotometery using Varian-Techtron AA-5 and Instrumentation Laboratory 751 instruments, respectively; total phosphorus was measured by the molybdenum blue method (Murphy and Riley, 1962) on samples previously mineralized by potassium persulfate digestion (Menzel and Corwin, 1965) utilizing an LKB Ultrospec 4051 equipped with 100 mm cells. Dissolved oxygen and temperature were measured using a portable YSI Model 57 oxygen meter while specific conductance was performed using a portable YSI Model 33 S-C-T Meter.

Results and Discussion

Figures 1 to 3 illustrate variations in cistern level and water quality during the study period. Table I shows mean concentrations of water at stages in the RWCS. Roof runoff concentrations are means of samples collected from asphalt roofs at the Fall River Site, the principal author's house, and from the asphalt roof simulator. Precipitation quality data in Table I are weighted mean concentrations for Nova Scotia precipitation from Underwood, 1984.

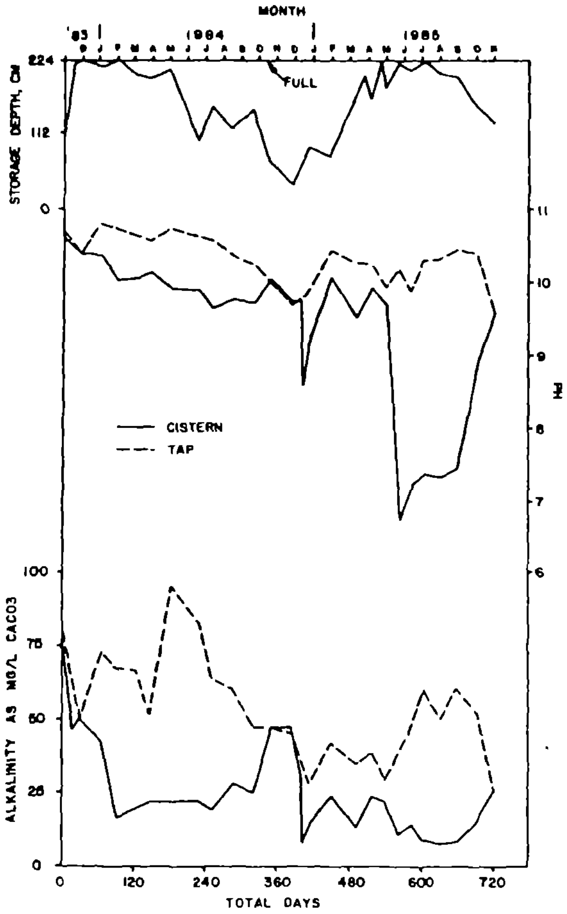

Figure 1. Variations in cistern storage depth and cistern and tap water pH and alkalinity for the period Oct 1983 to Oct. 1985

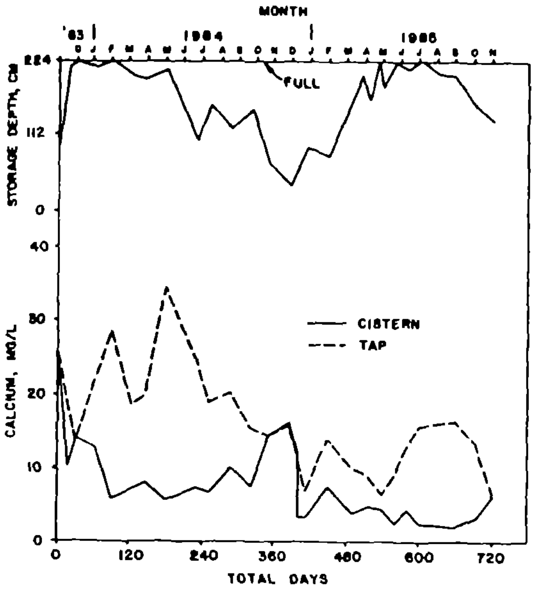

Figure 2 Variations in cistern storage depth and cistern and tap water calcium concentrations for the period Oct 1983 to Oct. 1985.

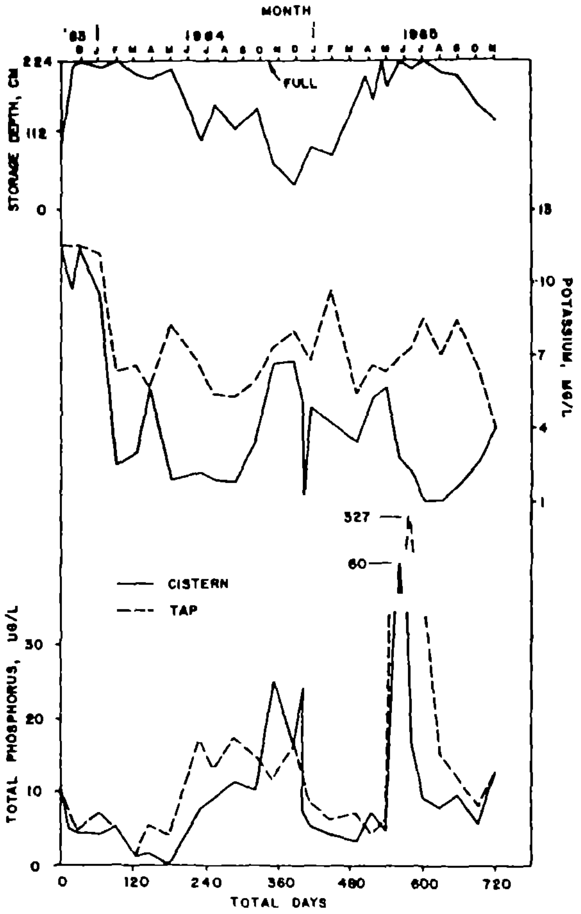

Figure 3 Variations in cistern storage depth and cistern and tap water potassium and total phosphorus concentrations for the period Oct 1983 to Oct. 1985

Table I

Mean Composition of Water Passing Through The Cistern System

Parameter	Precipitation [a]	Roof	Tank	Tap
pH	4.61	5.02	9.37	10.32
Alkalinity as mg/L$CaCO_3$	0.0	0.1	24.4	53.1
Calcium mg/l	.21	1.41	7.7	16.5
Potassium mg/l	.11	.29	6.0	8.8
Total Phosphorus mg/l	.012	.011	.013	.028

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[a] From Underwood 1984

Table I indicates that water quality is altered significantly as it passes through the system. Figures 1 to 3 indicate that these differences are most pronounced in the Winter, and are minimal in the Fall.

Table II is an example of a profile of cistern water quality with depth. A total of 33 samples were withdrawn from 11 representative columns at 15 cm, 102 cm and 190 cm depths. A single tap sample was also collected. Dissolved oxygen and temperature readings were taken *in situ* at four depths for one of the columns. Specific conductance was recorded for seven depths at the same site.

Results obtained from chemical analyses for the 34 individual samples were used to estimate values for alkalinity, calcium and potassium, given the specific conductance for 127 cm, 152 cm, 165 cm and 178 cm depths. Regression equations used to estimate these values are:

1. Specific conductance/alkalinity
   $Y = (.342)\ X + 1.423 \quad r = .999$
2. Specific conductance/calcium
   $Y = (.096)\ X - .403 \quad r = 998$
3. Specific conductance/potassium
   $Y = (.032)\ X + 2.732 \quad r = .964$

Table II
Cistern Profile Taken August 12, 1985.[a]

Depth cm	Dissolved Oxygen mg/l	Temp ^{o}C	pH	Alkalinity as mg/l $CaCO_3$	Calcium mg/l	Potassium mg/l	Specific Conductance umho/cm
15	9.1	18.5	7.38	10.2	1.9	4.1	25.5
102	9.1	15.1	7.46	9.5	1.9	2.9	23.7
127				13.5	3.0	3.9	35.0
152	9.1	13.8		18.8	4.5	4.4	51.0
165				24.2	6.0	4.9	67.0
178				28.8	7.3	5.3	80.0
190	8.7	12.8	10.18	37.5	10.0	6.3	105.3
TAP	7.4		10.54	66.0	17.2	8.6	188.0

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[a] Storage depth at time of sampling was 205 cm.

As Table II indicates, tap water quality reflects water quality at the bottom of the tank, from which water is pumped into the household system. The cistern samples were taken from mid-depth. Temperature profiles indicate that for most of the year the cistern is thermally stratified, that complete mixing in October-November coincides with the period when cistern and tap water quality are similar, and that these effects are apparent in both a dry year (1984) and a wet year (1985). Table II illustrates thermal stratification, and associated chemical variations, in mid-August.

Chemical and thermal mixing of water contained in the cistern resembled that of lakes and reservoirs in northern temperate climates: warmer surface water maintains stability in the summer; Fall mixing is due to cooling of surface waters; winter stability is maintained when surface waters are cooled below $4^{o}C$; and increased surface temperatures in the Spring result in instability that may permit mixing if an energy source is available. An important difference between the cistern and an open reservoir is the absence of wind effects, which mix reservoirs in the Spring when thermal stratification is minimal.

Waller, 1984 , attributed high values of pH, alkalinity, and associated elements to leaching from concrete cisterns. The study reported here commenced immediately following construction of the concrete cistern, when these effects might be expected to be most apparent. Concentrations of pH, alkalinity, and calcium, are consistent with this expectation. The sharply reduced pH in mid-1985 is the result of high rates of precipitation, associated with low antecedent storage volumes.

Potassium concentrations peaks follow those in pH, alkalinity, and calcium, except that a Spring peak is also evident in each year. There is no obvious explanation for these Spring peaks.

Phosphorous concentrations in tap water are somewhat higher than those in the cistern, reflecting release of phosphorous from bottom sediments. Orthophosphorous released from sludge by aqueous extraction (Table III)--0.49 mg/gm--is consistent with measurements by Hart et al., 1986, of 0.37 and 0.60 mg/gm of O-PO4 leached from leaves on the ground and in gutter accumulations.

Seasonally high concentrations of phosphorous, if they occur in regions, such as the Caribbean, where open cisterns are common (Haebler, 1986), may cause cisterns to exhibit another property associated with lakes and reservoirs: growths of nuisance algae that are capable of producing objectionable tastes, colour, odour, and turbidity, and may interfere with treatment processes by clogging strainers and filters.

Coliform counts in the cistern and tap water were consistently negative throughout the study period. This may be due to inhibiting effects of the high pH levels that existed for most of the study period. Martin et al., (1982) demonstrated that increasing the pH range from 6.8 - 7.2 to 8.5 - 9.0 in the distribution system for the City of Halifax eliminated multiplication of coliform bacteria. The only positive coliform counts recorded coincided with low pH tank conditions in July and August of 1985.

CISTERN SLUDGE

Objective

The objective of this study was to examine the composition of cistern sludge and its relationship to cistern and tank water quality.

Methodology

Composite samples were vacuum extracted from the thin 1-2 cm layer of sludge at the cistern bottom on August 12 and November 18, 1985. The supernatant of the August sample was analyzed for BOD, while a more complete examination of the chemical and biological composition of the sludge collected in November was made.

All chemical testing was performed by the Victoria General Hospital, Environmental Chemistry Laboratory following Standard Methods (1980) procedures. Results are expressed as ug/gm of freeze-dried sludge for two extraction methods - aqueous and acid.

The aqueous extraction technique used for sample preparation placed a known weight of freeze-dried sludge in a known volume of distilled water. The mixture was allowed to stand for 24 hours and then filtered (Whatman 934 AH glass microfiber filters). The BOD test used a weight/volume approach, using the freeze-dried sludge, following Standard Methods procedures.

The acid extraction procedure (nitric-hydrochloric-perchloric) reports metal concentrations as 'total recoverable'.

Biological examination of sludge material retained by a 420 micron screen was performed by the Nova Scotia Museum. The Victoria General Hopsital, Department of Microbiology identified algal groups and analyzed for Standard Plate Count.

Results and Discussion

The results of chemical and bacteriological testing for the November 18 sample are presented in Table III. Biologically, the sludge contained debris from deciduous and coniferous trees: seeds, spruce needles, pollen and maple flowers; dead and often fragmented animal forms: non-aquatic mites, aphids, flies and beetles; and numerous algae: Anabaena, Chlorococcum, Spirogyra, Chrysococcus and Tabellaria.

Wind blown litterfall from a relatively dense stand of hardwood and softwood tree species in close proximity to the home is the probable source of most of this material.

The total solids concentration for the sample described in Table III was 181,200 mg/l. Corresponding concentrations of alkalinity and calcium aqueously extracted from the sample are 35,510 and 1,486 mg/l respectively, values that are consistent with higher concentrations of these chemicals in cistern bottom water.

Table III

Composition of Cistern Sludge

METHOD OF EXTRACTION

AQUEOUS ug/gram		ACID ug/gram	
Calcium	8,200	Calcium	51,800
Magnesium	243	Magnesium	4,900
Sodium	40	Aluminum	12,500
Potassium	190	Boron	63
Sulfate	809	Barium	165
Chloride	<100	Beryllium	< 1
Floride	21	Cadmium	15
Silica	1,400	Cobalt	< 1
Phosphate, Ortho	490	Chromium	68
Nitrate + Nitrite	< 5	Copper	30
Ammonia	< 5	Iron	17,200
Alkalinity	196,000	Manganese	806
Humic Acid	14,300	Nickel	65
B.O.D.	23,200	Lead	1,750
		Vanadium	99
		Zinc	1,200

Volatile Solids	592,800 ug/gram	(59.3%)
Standard Plate Count	20,000/ml	
Oil and Grease	35,940 ug/gm	(3.6%)

The BOD of the sludge supernatant and the sludge itself was 2,120 and 4,203 mg/l, respectively. These high values of oxygen demand are consistent with bottom water dissolved oxygen levels, which range from 8 to 12 mg/l, except from mid-May to the end of September: they are rapidly depleted to <1.0 mg/l for the entire month of June, followed by a gradual increase to 8 mg/l by the end of September.

Numerous sources exist from which metals found in the sludge may originate. Of these, airborne soil dusts, auto and industrial emissions, forest litterfall and system materials (asphalt shingles, aluminum gutters, concrete) are most prominant. The degree to which each of these and other sources contribute to the metal load is unknown. Although concentrations of metals in both cistern and tap water were well within Canadian Drinking Guidelines (1978) during the study period, the high concentrations in the sludge are a cause for concern: resuspension of bottom silt -- which might be caused by combinations of low cistern levels, thermal mixing, or turbulance due to rain water inflow -- could significantly increase concentrations of metals in the household system.

The nutrient rich environment of the cistern sludge may provide a habitat for the survival and multiplication of microorganisms which may contaminate tap water if the sludge is disturbed. Waller, 1977, cites reports of multiplication of fecal coliforms in nutrient-rich environments.

The potentially detrimental effects of sludge accumulations on cistern water quality emphasize the importance of methods to prevent or eliminate such accumulations. For the system considered here, sludge removal at intervals two years or less would not be inappropriate. The plastic gutter screens employed on the study system were clearly inefficient in preventing entrance of material contributing to sludge composition. An alternative approach under consideration at the Technical University of Nova Scotia is a pre-filter using a geotextile fabric. A successful pre-filter system could reduce the time and labour required to remove the sludge, possible system down-time, and risk of contamination of cistern water during the cleaning operation.

ROOF WATER

Objective

The objective of this work was to examine affects of roof material and first flush runoff on water quality.

Methodology

Four roof simulators were constructed, using fiberglass panelling, galvanized metal, asphalt and untreated cedar shingles as catchment surfaces. Each simulator consisted of a sloping surface with an area of approximately 1 m^2. Runoff was routed to covered 20 L polyethylene buckets via plastic eavestrough and downspout.

Four precipitation events were evaluated between February and November, 1985. The complete runoff in each storm event from each surface was collected, in two or three portions, at intervals that depended on opportunity. Each portion was sampled for chemical and bacteriological analyses and total volumes were recorded. The 20 L storage container was rinsed with alcohol and distilled water between sampling intervals during each event to prevent any bacteriological-chemical carry over. Metals and bacteriological analyses were performed at the Victoria General Hospital, while pH, acidity, colour, phosphorous, sodium, and total nitrogen were determined at the CWRS laboratory.

Results and Discussion

Sample results, in Table IV, are presented as (i) catch-weighted means of all samples and (ii) catch-weighted means of all except the initial 'first flush' samples. The two sets of results are described in Table IV as 'total catch volume' and 'net catch volume' samples, respectively.

All parameters measured for both total and net catch volumes are below Canadian Drinking Water Guideline (1978) accepted levels, with one exception: zinc concentrations measured in samples from the metal roof simulator for both total and net catch volumes, at 8.9 and 6.0 mg/l respectively, exceed the maximum acceptable concentration of 5.0 mg/l. For most parameters total storm concentrations are somewhat higher than net values, indicating the impact of higher first flush concentrations. pH values are somewhat lower.

Net volume results in Table IV (without 'first flush' samples) are not sufficiently below the total volume results to support an argument for diversion of the 'first flush' as a method of water quality improvement. Volumes of 'first flush' samples from the 1m^2 catchments ranged from 1.1 to 10.1 L. These values are all larger than that recommended by the Nova Scotia Guidelines: 0.5 L/m^2, i.e. if the volumes recommended by the Nova Scotia Guidelines were diverted, the differences between total and net results would be even less than those shown in Table IV.

Bacteriological concentrations in net volumes are higher than in total samples. This is consistent with results from the Fall River site, where the only coliform count recorded in a series of sequential grab samples collected in a storm event occurred during a period of high runoff 9½ hours after the start of the event.

Table IV indicates the relative contributions of metal, asphalt, and cedar roof surfaces to cistern water quality. Differences in concentrations between precipitation and runoff from the plastic surface are indicative of the contribution of materials accumulated and washed from roof surfaces. The only chemicals contributed from any of the roofs that might be considered significant were acidity, colour, phosphorous, sodium, and zinc; other metals were not added by roofing materials. Concentrations of acidity, pH, and zinc were noticeably higher in samples from the galvanized metal roof. The cedar roof yielded higher concentrations of colour and sodium, and somewhat elevated phosphorous. The asphalt roof influenced only phosphorus concentrations. All roofs produced similarly slight increases in coliforms, and increased plate counts.

Differences between the composition of precipitation and runoff from the plastic roof are indicative of contributions of dry fallout to roof water quality in the area of downtown Halifax, Nova Scotia, where they were located. Changes in all parameters except nitrogen and colour are apparent in Table IV. Increases in aluminum and iron are particularly noticeable.

TABLE IV

Chemical and Bacteriological Results for Selected Parameters for Four Different Roofing Material Simulators. Total Volume-Weighted Mean (1) and Net Values (2) are Given. Net Values Characterize the Final 70 Percent of the Total Catch Volume.

	pH		ACIDITY as Mg/l $CaCO_3$		COLOUR HAZEN UNITS		PO_4-P ug/l	
	1	2	1	2	1	2	1	2
Precipitation	4.10	4.15	5.5	5.5	2	2	3.8	3.0
Plastic Simulator	4.19	4.21	5.0	4.6	3	3	12.7	6.5
Metal "	6.27	6.42	11.9	8.2	3	3	14.8	8.0
Asphalt "	4.49	4.58	3.6	3.1	3	3	18.0	11.7
Cedar	4.13	4.23	9.4	7.6	49	43	13.5	11.5

	TN mg/l		Na mg/l		Fe mg/l		Pb mg/l		Zn mg/l	
	1	2	1	2	1	2	1	2	1	2
Precipitation	.25	.25	.9	.8	.020	.020	.003	.003	.01	.01
Plastic Simulator	.25	.25	2.3	1.9	.121	.050	.008	.005	.04	.02
Metal "	.26	.32	2.4	2.0	.136	.055	.005	.003	8.87	5.97
Asphalt "	.31	.26	2.7	2.2	.115	.082	.005	.004	.03	.02
Cedar "	.20	.18	4.8	4.2	.064	.036	.006	.005	.06	.04

	Al mg/l		Total Coliforms/100ml		Total Plate Count/ml	
	1	2	1	2	1	2
Precipitation	.05	.05	0	0	0	0
Plastic Simulator	.17	.06	1	1	18	6
Metal "	.10	.06	2	2	850	1260
Asphalt "	.13	.10	3	4	195	190
Cedar "	.07	.05	7	8	370	400

NOTE: Copper and Cadmium results were less than detection, < .01 and < .002 respcctively, for Precipitation and Each of Four Simulators.

ACKNOWLEDGEMENTS

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WATER QUALITY OF RAIN WATER COLLECTION SYSTEMS IN THE EASTERN CARRIBEAN

R.H. Haebler and D.H. Waller

ABSTRACT

Bacteriological, chemical and physical water quality of rain water collection systems in the Eastern Caribbean were monitored over a four month period. Bacteriological levels exceeded Canadian Drinking Water Guidelines on a few occasions, but most were below acceptable levels. Chemical ion concentrations fluctuated throughout the sampling period, with iron and lead the only parameters exceeding Canadian Guidelines. The impact of industrial emissions on cistern water quality was found to be negligible, based on the heavy metal analysis. Roof and cistern materials, and maintenance practices, influence cistern water quality.

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INTRODUCTION

Sixty-three water quality samples were analyzed from 11 rain water collection systems (RWCS) on the islands of Trinidad, Tobago and Carriacou in the eastern Caribbean between July and October 1985. This period coincided with the rainy season in the region. The regional climate of the area is tropical, with average annual rainfall varying between 1,200 mm and 3,300. Samples were routinely taken and analyzed for pH, colour, turbidity, conductivity, calcium, magnesium, sodium, zinc, iron, sulphate, chloride, bicarbonate, plate count, total and fecal coliform. A heavy metal analysis was conducted on 24 of the 63 samples.

The primary objective was to obtain basic water quality data on RWCS in the eastern Caribbean. The Caribbean is one area of the world where limited research on RWCS has been done, despite a long history of rain water collection. A secondary objective was to address a concern that had been expressed about potential impacts of industrial and automotive pollutants on RWCS water quality.

Eight of the 11 sites monitored were private residences, which used the rain water for all drinking and cooking requirements. In some cases rain water was supplemented by domestic piped water, which was used for washing, cleaning and flushing. These houses used their galvanized metal roofs as a catchment surface and stored the water in metal or concrete tanks. Roof area varied between 60 m^2 and 400 m^2, with the average at 170 m^2. The first rains, which fall in June after a six month dry period, were discarded so that the dry fallout which had been deposited on the roof would be washed away. No further diversion of rain water was practiced. Tank volume varied, depending on the number of people served by the system, and ranged betweeen 1,300 L/person and 27,000 L/person.

The three remaining sites were public RWCS that utilized a concrete ground catchment and storage tank to supply small villages with water. This water was used for drinking, cooking, washing and flushing. Tank volumes varied between 140,000 L and 380,000 L.

RESULTS OF WATER QUALITY ANALYSIS

Tables 1 and 2 summarize physical and chemical data for Trinidad, Tobago and Carriacou. Metals not included in these

TABLE I

MEANS, STANDARD DEVIATIONS, MINIMA AND MAXIMA TRINIDAD AND TOBAGO DATA*

VARIABLE	N	MEAN	STD DEV	MINIMUM	MAXIMUM	STANDARD**
pH	55	7.52	0.80	6.70	9.70	6.5-8.5
Color	55	8.09	6.49	0.00	30.00	15 TCU
Turbidity	51	1.42	1.28	0.36	8.00	5 NTU
Conductivity	55	38.71	22.31	15.00	99.00	umhos/cm
Alkalinity	55	15.36	10.38	3.38	58.00	-
Calcium	55	3.53	3.15	0.00	11.00	-
Magnesium	54	1.43	1.25	0.24	8.20	-
Sodium	54	2.41	2.42	0.25	11.30	-
Zinc	49	1.08	0.80	0.12	2.77	5.0
Iron	49	0.12	0.14	0.01	0.75	0.3
Sulfate	55	1.17	1.81	0.00	13.00	500
Chloride	55	8.29	4.47	0.23	20.00	250
Bicarbonate	55	18.04	13.15	4.73	71.00	-
Arsenic	24	0.007	0.004	0.005	0.020	0.005
Manganese	24	0.015	0.020	0.010	0.100	0.05
Lead	24	0.012	0.025	0.002	0.090	0.05
Copper	24	0.010	0.002	0.010	0.020	1.0
Aluminum	24	0.054	0.011	0.050	0.100	-
Boron	24	0.020	0.0	-	-	-
Barium	24	0.051	0.058	0.005	0.210	1.0
Cadmium	24	0.002	0.0	-	0	0.005

*Unless otherwise noted concentrations are expressed in mg/l

**Canadian Drinking Water Standards 1977

TABLE II

MEANS, STANDARD DEVIATIONS, MINIMA AND MAXIMA CARRIACOU DATA*

VARIABLE	N	MEAN	STD DEV	MINIMUM	MAXIMUM	STANDARD**
pH	8	7.90	0.01	7.73	8.00	6.5-8.5
Color	8	2.50	2.67	0.00	5.00	15 TCU
Turbidity	8	1.08	0.21	0.80	1.40	5 NTU
Conductivity	8	86.88	15.80	60.00	100.00	umhos/cm
Alkalinity	8	37.82	7.91	25.00	50.00	-
Calcium	4	11.20	2.85	8.80	14.40	-
Magnesium	4	1.34	0.61	0.49	1.94	-
Sodium	4	6.24	3.84	3.80	11.95	-
Sulfate	4	2.00	0.0	-	-	500
Chloride	4	15.63	1.98	13.47	17.32	250
Bicarbonate	4	41.23	7.15	30.70	46.60	-
Arsenic	8	0.005	0.0	-	-	0.005
Iron	8	0.038	0.035	0.020	0.120	0.3
Manganese	8	0.010	0.0	-	-	0.05
Lead	8	0.005	0.006	0.002	0.020	0.05
Zinc	8	0.228	0.443	0.010	1.300	5.0
Aluminum	8	0.066	0.018	0.050	0.090	-
Boron	8	0.020	0.0	-	-	5.0
Barium	8	0.018	0.020	0.005	0.050	1.0
Cadmium	8	0.002	0.0	-	-	0.005

*Unless otherwise noted values are expressed in mg/l

**Canadian Drinking Water Quality Standards 1977 tables, because their concentrations were below the detection limit of the Plasma Emission Spectrophotometer, are: berrylium, chromium, cobalt, nickel, antimony, selenium, tin and vanadium.

Table 3 summarizes bacteriological data for Trinidad, Tobago and Carriacou.

DISCUSSION OF RESULTS

Overall, the results of the chemical analysis compare favourably with the guidelines set by Canadian and international health authorities. High iron and lead levels are probably due to corrosion of the storage tank and catchment surface, lead being an impurity in the galvanized coatings used on the corrugated roofs of many houses (Gumbs, 1985). The water in RWCS is weakly mineralized; this poses some cause for concern as weakly mineralized waters tend to leach minerals present in food and increase urinary excretion (Neri, 1984).

There were instances where high bacteria counts were evident in RWCS water samples. Positive total coliform counts occurred on 26 of 57 tests. Thirteen of 26 results were above the recommended limit of 10 coliforms per 100 ml of sample. Positive fecal coliform counts were evident for 20 out of 57 samples. The main sources of bacteriological contamination in RWCS are believed to be the excrement of birds or animals deposited on the catchment surface, or insects, such as mosquitos, that make their way into the storage tanks to lay their eggs.

The high plate counts exhibited at some sites can be attributed to dust, soil in the air, and leaves which land on the catchment surface. There is a large amount of dust in the Trinidadian atmosphere and the high plate counts are not extraordinary when one considers the many ways bacteria can enter the system.

Fluctuation of Water Quality with Time

Figures 1, 2 and 3 are graphs of mean values of pH, colour, turbidity, sodium, chloride, zinc and iron for all sites in Trinidad and Tobago. Turbidity and pH remained fairly constant throughout the sampling period, which corresponded to the rainy season. The slight decrease in turbidity could be due to increased flushing of

TABLE III

BACTERIOLOGICAL DATA

	Total Coliform		Fecal Coliform		Plate Count	
	Mean	**Positive**[1]	**Mean**	**Positive**[1]	**Max**	**Min**
TRINIDAD						
House 1	39	2/7	0.1	1/7	6500+	4
House 2	3	2/8	8	1/8	6500+	21
House 3	6	6/8	0.5	2/8	6500+	12
House 4	2	1/8	2	2/8	6500+	13
House 5	5	4/8	2	5/8	6500+	88
House 6	15	3/8	5	3/8	6500+	11
House 7	0	0/2	42	1/2	6500+	70
CARRIACOU						
House 1	8	2/2	5	2/2	1950	432
Public Tank 1	29	2/2	25	1/2	6500+	6340
Public Tank 2	19	1/2	13	1/2	6500+	264
School Tank	29	1/2	6	1/2	6500+	1170

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[1] Fraction of Samples with a Positive Count.

the storage tanks as the rainy season progressed. Color fluctuated throughout the sampling period. Sodium and chloride exhibited a gradual decrease in concentration with time. Iron and zinc remained in the same concentration range.

Effect of Storage Tank and Catchment Surfaces

To determine the effect of storage tank and catchment surfaces on water quality, the data has been separated with respect to these items. Table 4 lists means and standard deviations of the data for the three types of storage tank encountered in this study.

Concrete tanks displayed the highest mineral content. Mean concentrations of sulphate, calcium and conductivity were highest in concrete tanks. Calcium values were five times greater in concrete tanks as compared to metal and fiberglass tanks. Zinc was highest in metal tanks, which is expected since most tanks were galvanized. Fiberglass tanks had the lowest mean values and standard deviations, and approximated values found in bulk rain. This suggests that fiberglass tanks do not significantly interfere with the mineral chemistry of rain water.

The data in Table 4 suggest that concrete tanks leach minerals into water held in storage to a greater degree than do metal or fiberglass tanks. Sharpe and Young (1982) found that acidic rain water was neutralized by lime present in concrete tanks. The introduction of minerals during storage can be a positive effect since rain water is characteristically low in minerals. People in the Caribbean prefer concrete tanks as they seem to keep the water the coolest. This is believed not only to inhibit bacterial growth, but also to increase taste.

Waller (1984) cites examples where low pH waters have demonstrated pick-up of lead and copper from copper plumbing systems, but this should not be a problem in the eastern Caribbean as most plumbing is done with polyethylene pipe.

All catchment surfaces on Trinidad and Tobago were corrugated metal roofs, painted or unpainted. The four Carriacou systems included three ground-level catchments (one of which was supplemented from a roof surface) and one roof. Chemical analyses for the Carriacou systems should therefore be largely influenced by

TABLE IV

MEANS AND STANDARD DEVIATIONS FOR WATER QUALITY DATA FROM CONCRETE, METAL AND FIBERGLASS TANKS*

PARAMETER	CONCRETE n=31		METAL n=16		FIBERGLASS n=8	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
pH	7.89	0.87	7.18	0.18	6.75	0.08
Color (TCU)	7.10	4.79	10.31	9.21	7.50	5.35
Turbidity (NTU)	1.23	0.53	2.05	2.16	0.90	0.21
Conductivity (umhos/cm)	44.84	25.14	31.19	18.07	30.00	7.07
Alkalinity	19.46	12.25	10.23	5.38	9.74	5.38
Calcium	5.40	2.99	1.02	0.99	1.34	0.88
Magnesium	1.49	1.64	1.48	0.46	1.12	0.40
Sodium	2.63	2.53	2.38	2.80	1.60	0.60
Zinc	0.51	0.39	2.10	0.37	1.54	0.34
Iron	0.12	0.14	0.17	0.17	0.04	0.03
Sulphate	1.44	2.30	0.89	0.83	0.71	0.59
Chloride	8.22	4.45	9.16	5.09	6.79	3.08

*All values in mg/l unless otherwise indicated the ground catchments.

The Carriacou samples (Table 2) have higher concentrations of most major ions, and lower color, lead, and barium, than samples from the roof systems in Table 1. Bacteriological results (Table 3) for roof systems are generally better than those from ground-level catchments.

Effect of Industrial Emissions on Water Quality

To determine the effect of industrial/automotive emissions on RWCS water quality, the sampling sites were selected such that some would be more heavily influenced by these emissions than others. Figure 4 shows locations of the sites, and Table 5 presents the pertinent data. Group A results are those most likely to be affected by air pollutants. Carriacou and Group B results are those least likely to be affected by air pollutants.

The results indicate that there are no observable effects on water quality from automobile, factory and oil refinery emissions in Trinidad, the most heavily populated and industrial island of those which were visited in the eastern Caribbean. Heavy metal levels were too low to indicate any significant contamination. Ironically, the sites which were located away from heavy traffic and major industrial areas displayed higher mean values of turbidity, conductivity, sulphate, magnesium, iron, manganese, lead and barium than those which were located in and around these areas.

Lead was the only parameter that exceeded Canadian standards for water quality, and then only on one occasion. However, it is thought that lead content in a RWCS is due more to corrosion effects than to industrial effects.

Effect of Maintenance on RWCS Water Quality

Table 6 separates the data into two groups, one representing well kept systems and the other representing poorly maintained systems. Distinctions were based on the senior author's personal experience with the sites. Systems defined as well maintained display lower iron, turbidity, colour and sulphate levels when compared to those receiving little or no maintenance. This may be due to less corrosion in well maintained systems. The more

TABLE V

MEAN VALUES FROM GROUP A, GROUP B, TRINIDAD AND CARRIACOU

PARAMETER	GROUP A	GROUP B	TRINIDAD	CARRIACOU
pH	7.47	7.44	7.52	7.89
Color (TCU)	5.00	10.42	8.09	2.50
Turbidity (NTU)	1.03	2.18	1.42	1.08
Conductivity (umhos/cm)	29.17	47.75	38.71	86.88
Calcium	2.45	5.30	3.53	11.20
Magnesium	1.15	2.18	1.43	1.34
Sodium	1.34	4.48	2.41	6.24
Sulphate	0.65	2.41	1.17	2.00
Chloride	6.35	11.53	8.29	15.63
Arsenic	0.008	0.005	0.007	0.005
Iron	0.035	0.194	0.115	0.038
Manganese	0.010	0.028	0.019	0.010
Lead	0.004	0.020	0.012	0.005
Copper	0.011	0.010	0.010	0.010
Zinc	1.150	0.832	0.991	0.228
Aluminum	0.051	0.057	0.054	0.060
Boron	0.020	0.020	0.020	0.020
Barium	0.046	0.057	0.051	0.018
Cadmium	0.002	0.002	0.002	0.002

Group A = Affected by air-borne pollutants

Group B = Not affected by air-borne pollutants

Unless otherwise noted all values in mg/l

TABLE VI

MEANS AND STANDARD DEVIATIONS FOR POORLY MAINTAINED AND WELL KEPT RWCS IN TRINIDAD AND TOBAGO*

PARAMETER	POORLY MAINTAINED (n=23)		WELL KEPT (n=24)	
	MEAN	S.D.	MEAN	S.D.
pH	7.39	0.40	7.71	1.12
Color (TCU)	11.52	7.75	5.21	4.29
Turbidity (NTU)	1.90	1.82	0.93	0.40
Conductivity (umhos/cm)	31.91	13.42	30.37	11.64
Alkalinity	10.87	6.12	13.29	6.30
Calcium	2.26	1.64	2.86	2.62
Magnesium	1.13	0.62	1.21	0.52
Sodium	2.62	2.12	0.95	0.65
Zinc	0.99	0.77	1.41	0.81
Iron	0.22	0.17	0.03	0.02
Sulphate	1.00	0.77	0.67	0.63
Chloride	8.60	4.15	6.83	4.22
Total Coliform	19.13	55.66	3.58	7.58
Fecal Coliform	2.65	6.71	4.25	7.96
Plate Count	2784	3115	1331	2410

*All values in mg/l unless otherwise noted important differences, however, are in bacteria counts: total coliforms are considerably more prevalent in poorly maintained systems, and plate counts much higher.

CONCLUSIONS

All conclusions refer to the study period, which paralled the rainy season. Water quality could differ during other seasons of the year, and from year to year.

Based on the chemical and physical analysis, the water quality of RWCS studied on Trinidad, Tobago and Carriacou are well within prescribed Canadian and international Drinking Water Standards. Iron and lead were the only chemicals which exceeded these standards, and then only on a few occasions. Excess iron concentrations are due to corrosion of storage tanks and roofs. Lead is introduced to RWCS from corrosion of storage tanks, but the concentrations in most cases were below detectable limits.

The bacteriological content of the cistern water was above limits established for drinking water. However, there was no recorded illness at any of the sampling sites.

The effect of industrial emissions on RWCS water quality was found to be negligible. Indicator parameters such as vanadium, cadmium, barium, sulphate, lead and aluminum were present in undetectable or extremely low concentrations.

Well maintained systems show definite improvements in water quality when compared to systems with little or no maintenance.

When one takes into consideration the alternatives for water supply in many parts of the Caribbean, such as the heavily chlorinated and relatively turbid domestic surface waters, rain water becomes a desirable choice. A RWCS is an inexpensive method of obtaining fresh water, and if properly maintained can provide safe and reliable supplies. Many people had a distinct preference for rain water over the domestic treated water whenever rain water was available.

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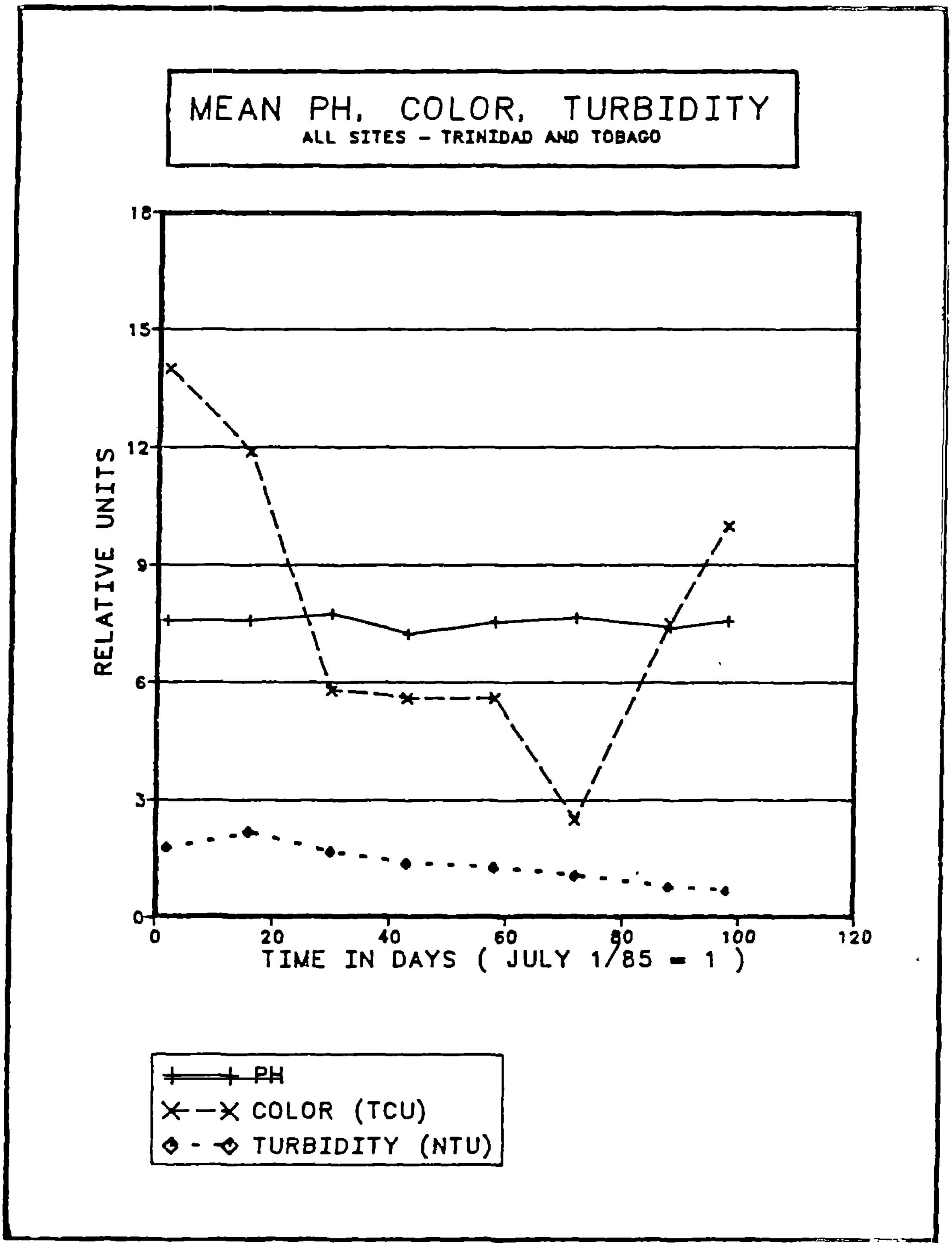

Figure 1. Mean values for all sites on Trinidad and Tobago for pH, color and turbidity.

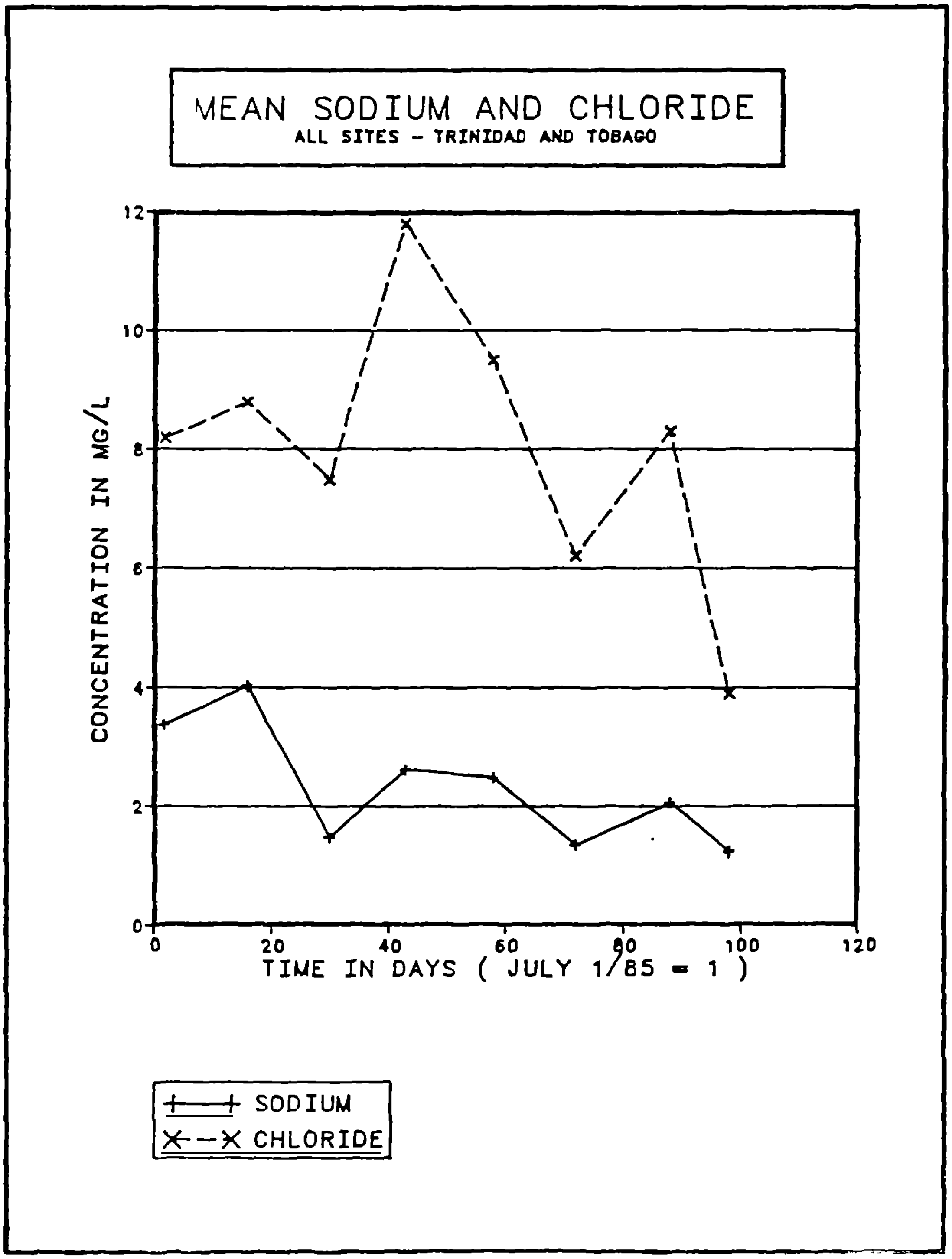

Figure 2. Mean values for all sites on Trinidad and Tobago for sodium and chloride.

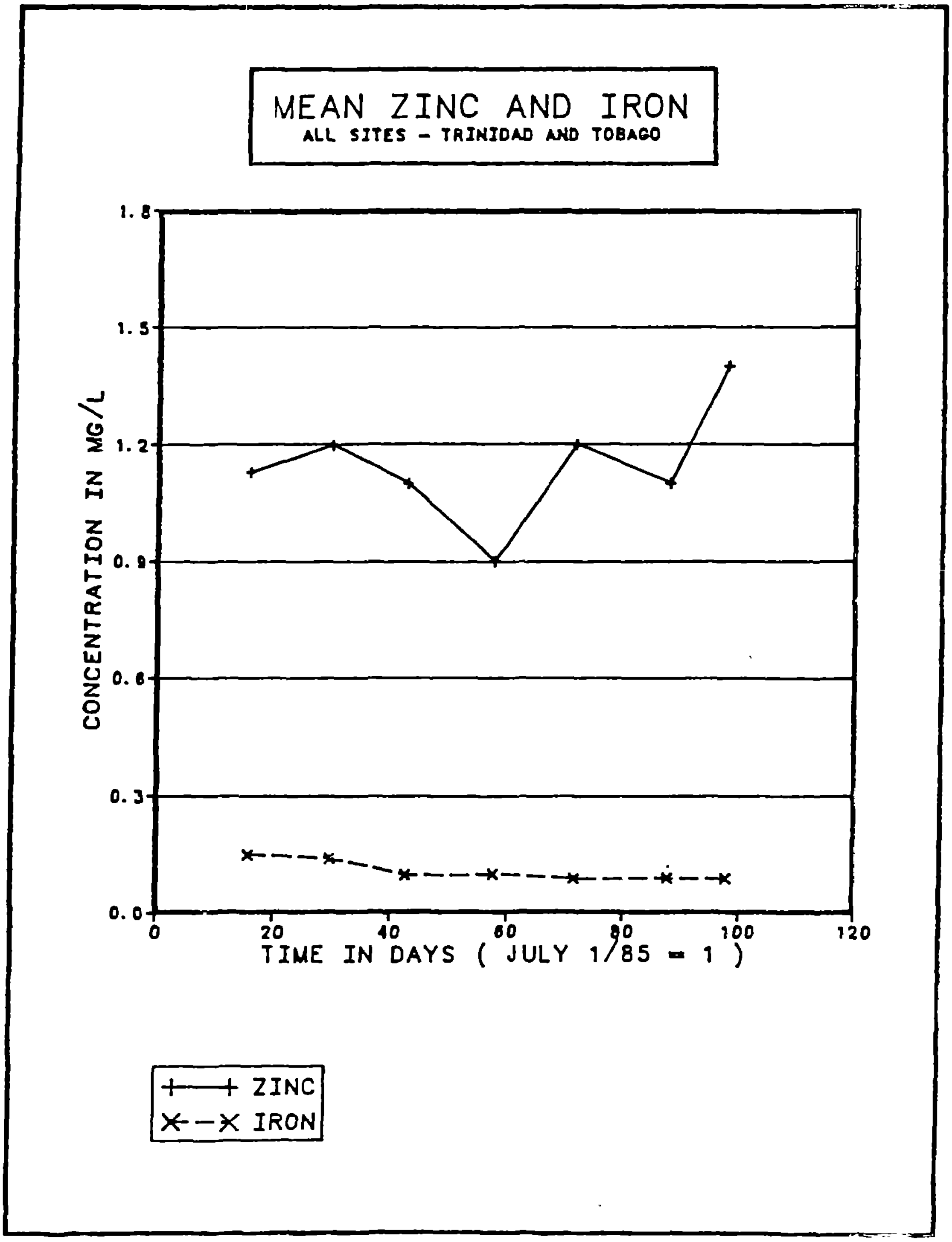

Figure 3. Mean values for all sites on Trinidad and Tobago for zinc and iron.

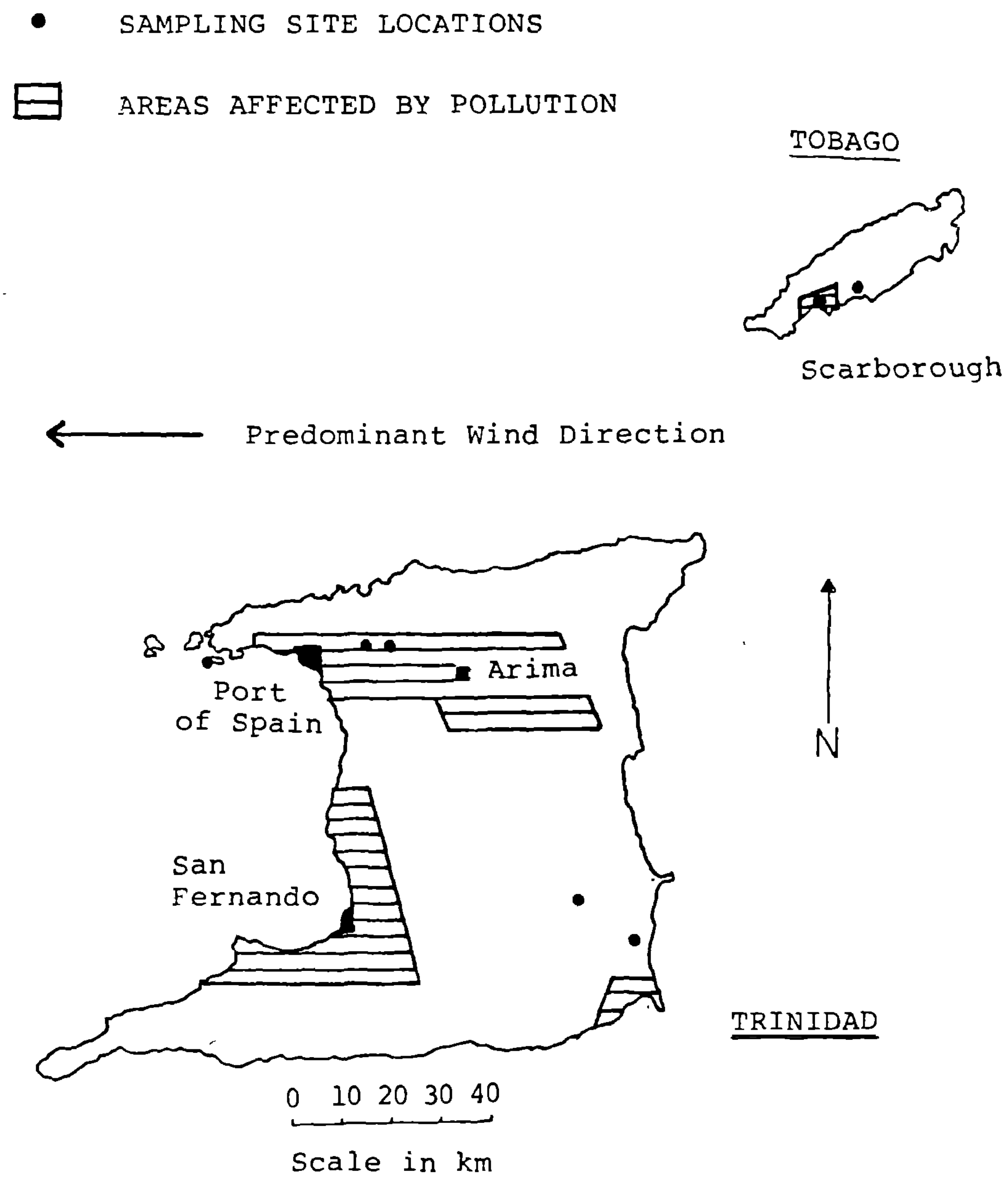

Figure 4. Sampling sites shown in conjunction with areas affected by pollution.

THE MICROBIOLOGICAL QUALITY OF CISTERN WATERS IN THE TANTALUS AREA OF HONOLULU, HAWAII

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ABSTRACT

The drinking water quality of cistern waters in the Tantalus area of Honolulu, Hawaii was evaluated by analyzing 18 cistern systems for concentrations of bacteria, conductivity, turbidity and total solids. The results indicate that concentrations of total salts, and total solids in these cistern waters were well within the current U.S. drinking water standards. Moreover, only 2 of 36 cistern water samples exceeded the maximum turbidity level of 5.0 NTU established for individual sources. However, high concentrations of one of the three fecal indicator bacteria (total coliform, fecal coliform, fecal streptococci) were often recovered from these waters indicating that most of the cistern waters would not be able to meet U.S. microbiological drinking water standards. Fecal streptococci was recovered much more frequently and at higher concentrations than coliforms indicating that the source of fecal contamination was birds rather than humans. These cistern waters were also determined to contain very high concentrations of total bacteria, almost always exceeding 500/mℓ, the minimum level at which interference with the recovery of total coliform bacteria have been reported. Since assays for fecal coliform and fecal streptococci are not interfered by the presence of high concentrations of total bacteria, we recommend that these alternative indicator bacteria be analyzed for to determine the extent of fecal contamination of cistern water supplies.

INTRODUCTION

The city of Honolulu in Hawaii is known for its excellent source of drinking water. This deep, groundwater source of water is naturally free of coliform bacteria and therefore the water is served to its consumers without chlorination. However, this municipal supply of water is not piped to the Round Top-Tantalus area of Honolulu because of the steep elevation and the limited number of homes in this area. As a result, the approximately 110 homes in this area must obtain their own source of water and primarily use individual rainwater cistern catchment systems. Most of these private cistern systems simply catch the rainwater from their roofs and store them in tanks for use. First foul flushing, filtering, or disinfection of these waters are generally not used. Since each of these cistern units are considered private, individual water sources, there are no regulations or agencies with responsibilities to ensure or to monitor the quality of these water sources. Most of the residents have not had the quality of their water tested. The purpose of this study was to select 18 representative cistern systems from this area and to assess the bacterial, turbidity, conductivity and total solid contents of these waters based on current U.S. drinking water quality regulations and guidelines.

STUDY SITE AND SAMPLING SITES

The Round Top-Tantalus area of Honolulu is part of a forest reserve area covering approximately 39 hectares at elevations ranging from 300 to 495 meters above sea level. It is a lush, semi-tropical forest area with an average of 300 cm of rain per year and most of the 110 homes are well scattered among the groves of koa, kukui and eucalyptus trees. A total of 18 cisterns were selected for this study based on two criteria: First, the composition of the inner surface of the cistern reservoir tank. Second, the composition of the household roof. Each of the 18 households were interviewed to obtain more information about their cistern system, their maintenance practices, and use of the waters. Table 1 summarizes the characteristics of each of the 18 cisterns.

TABLE I
Composition and Maintenance of Eighteen Cistern Systems at Round Top - Tantalus Area, Honolulu, Hawaii

Cistern Number	Household Roof Composition	------Reservoir Tank------- Inner Lining Material	Year Last Cleaned
1	Redwood	Fiberglass*	1
2	Aluminum	Tin	Never
3	Aluminum	Sheet Metal	?
4	Galvanized Steel	Redwood	1
5	Galvanized Steel	Redwood	Never
6	Galvanized Steel	Redwood	5
7	Galvanized Steel	Redwood	1
8	Aluminum	Redwood	Never
9	Aluminum	Redwood	7
10	Aluminum	Redwood	Never
11	Aluminum	Concrete	3
12	Asphalt	Redwood	Never
13	Asphalt	Redwood	Never
14	Asphalt	Concrete	2
15	Tarred Paper	Redwood	3
16	Tile	Concrete*	Never
17	Tile	Redwood	Never
18	Gravel	Concrete*	1

*Reservoir storage tank located below ground. All others above ground.

For each of the cisterns, two water samples were collected in clean, sterile, polyethylene bottles. The first sample was collected from the reservoir tank, approximately six inches below the surface of the water or at least six inches above the bottom of the tank. The second sample was obtained from a frequently used household faucet, such as from the kitchen. Water samples were analyzed for bacteria, turbidity, conductivity, and total solids within four to five hours after collection using methods as described in Standard Methods (1975). The membrane filtration method using selective media was used to recover total coliform (mEndo agar), fecal coliform (mFC agar), fecal streptococci (KF agar) bacteria. The spread plate method using standard plate count agar was used to recover total heterotrophic bacteria. Turbidity was measured in nephelometric turbidity units (NTU) using the HACH Turbidimeter (Model 2100A) while conductivity was measured in micromhos/cm using the YSI Electrical Conductivity Bridge (Model 31A). Total solids were measured as mg/ℓ by evaporation.

RESULTS AND DISCUSSION

Preliminary Analysis of Cistern Waters

Initially, water samples from the reservoir tank and from a household faucet from each of 18 cisterns were analyzed for conductivity, turbidity, total solids and for fecal indicator bacteria (total coliform, fecal coliform, fecal streptococci). The results, summarized in Table 2, show that the conductivity and total solids but not turbidity content for all the cistern water samples were well below the recommended maximum contaminating levels (MCL) established for drinking water in the U.S. (EPA, 1985). Conductivity, which is a measurement of salts in the water ranged from 25 to 91 µmhos/cm indicating that all cistern waters were well below the MCL of 250 mg/ℓ of chloride (490 µmhos/cm). Total solids of all cistern samples, which ranged from 1 to 118 mg/ℓ were also considerably below the MCL of 500 mg/ℓ of total dissolved solids. Although 17 of the 36 cistern water samples exceeded the recommended monthly MCL of 1.0 NTU turbidity for community supplies, only 2 water samples exceeded the 5.0 NTU turbidity limits established for non-community sources of water.

The intent of drinking water regulations is to provide consumers with drinking water free of fecal contamination. As a result, the MCL level for fecal indicator bacteria is essentially less than one total coliform bacteria per 100 mℓ of water. In this study, we analyzed waters for total coliform, fecal coliform and fecal streptococci bacteria. The latter is an alternative indicator of fecal contamination and is known to be found in lower concentrations than coliform bacteria in the feces of human but to be found in higher concentrations in the feces of animals such as birds (Geldreich, 1976). The results (Table 2), clearly show that the frequency and concentrations of recovering fecal streptococci in cistern waters were greater than that of recovering coliform bacteria, indicative that fecal contamination of cistern waters was due to fecal droppings of birds on the roofs of houses. Fecal streptococci bacteria was recovered in 34 of 36 water samples ranging in concentrations from 0 to 643 CFU/100 mℓ. Total coliform and fecal coliform were recovered in 23 of 36 cistern water samples. Unexpectedly, higher concentrations of fecal coliforms (range: 0 to 302 CFU/100 mℓ) than total coliform (range 0 to 200 CFU/100 mℓ) were recovered from cistern water samples. Concentrations of fecal coliforms were significantly higher than total coliform in six of the same cistern samples analyzed. This was unexpected because total coliform is known to be a more conservative indicator of fecal contamination than fecal coliform. Absence of all three indicator bacteria was observed in only two household water samples and only one reservoir tank samples. There was a tendency to recover less bacteria in household water samples than from the reservoir tanks indicating that die off or removal of some bacteria in transit from the storage tank to the faucet outlets within the household may be occurring. Finally, higher turbidities in water samples did not always correlate with higher concentrations of indicator bacteria.

Bacterial Quality of Cistern Water

The most significant observation in the preliminary analysis of the 18 cistern water systems was the recovery of variable but

TABLE II
Preliminary Analysis of All Cistern Systems for Selected Water Quality Parameters

Cistern System Number		Conductivity (µmhos/cm)	Turbidity (NTU)	Total Solids (mg/ℓ)	Total Coliform	Fecal Coliform	Fecal Streptococcus
					(CFU/100 mℓ)		
1	R	59.0	1.7	2	57	1	6
	H	64.0	4.3	ND	0	0	4
2	R	42.5	6.3	<1	0	0	0
	H	34.0	0.7	ND	8	10	254
3	R	28.5	3.1	108	1	2	49
	H	26.5	0.4	ND	5	0	7
4	R	34.0	0.6	1	26	0	16
	H	37.5	0.7	ND	0	0	0
5	R	50.5	3.4	118	90	302	305
	H	43.5	1.8	ND	1	0	50
6	R	43.0	3.3	112	28	52	25
	H	44.0	2.0	ND	0	1	15
7	R	76.0	0.5	ND	12	70	100
	H	50.5	1.3	8	0	1	0
8	R	37.5	9.3	22	25	5	64
	H	51.0	0.9	ND	4	0	5
9	R	25.0	1.0	12	20	28	300
	H	26.5	1.7	ND	16	15	100
10	R	23.0	0.4	12	3	4	126
	H	27.5	0.8	ND	0	0	0
11	R	37.5	0.4	ND	0	0	72
	H	57.0	4.4	16	0	0	1
12	R	41.0	2.0	ND	85	73	246
	H	34.0	4.5	2	0	1	1
13	R	24.5	0.8	3	1	60	368
	H	28.5	0.9	ND	0	1	9
14	R	46.0	0.8	3	50	139	215
	H	35.5	0.8	ND	6	18	125
15	R	51.0	2.2	6	74	24	643
	H	57.5	2.4	ND	134	23	449
16	R	90.0	0.7	2	200	100	132
	H	91.0	0.8	ND	36	36	71
17	R	30.0	0.8	<1	140	20	200
	H	43.0	0.9	ND	0	0	1
18	R	44.0	0.6	ND	0	0	24
	H	90.0	0.7	<1	0	0	95

NOTE: R = reservoir tank, H = household faucet, ND = not done.

often high concentrations of the three fecal indicator bacteria. Moreover, the recovery of higher concentrations of fecal coliform than total coliform and the observation of high background growth of non-coliform bacteria on the total coliform medium (mEndo agar) suggested that cistern waters contain high concentrations of total bacteria. In this regard, Geldreich et al. (1978) reported that when the total bacteria concentrations of water exceeds 500/mℓ, the recovery of total coliform bacteria on mEndo agar will be interfered with. To verify the high concentrations of fecal indicator bacteria in cistern waters and to determine the effect of total bacteria on the recovery of total coliform bacteria, eight (8) cistern water systems (reservoir tank and household faucet sources), were re-sampled and analyzed for total coliform, fecal coliform, fecal streptococci and total heterotrophic bacteria.

The results in Table 3 show again that high concentrations of at least one fecal indicator bacteria were recovered from most (14/16) of the cistern water samples. Only one reservoir tank sample (No. 14) and one household faucet sample (No. 7) were free of all three fecal indicator bacteria. Fecal streptococci bacteria were present in 16 of the 18 cistern samples while total coliform and fecal coliform were recovered in only 8 of the 16 cistern water samples. The predominance of fecal streptococci bacteria to coliform bacteria indicate again that the source of fecal contamination of cistern waters is probably birds and not of human origin (Geldrich, 1976). All cistern water samples contained very high concentrations of total bacteria ranging from 100 to 84,000 CFU/mℓ. Only three cistern samples contained ⩽500 CFU/mℓ, the minimum concentration at which recovery of total coliform bacteria can be interfered with (Geldrich, 1978). Thus, recovery of total coliform can be expected to be interfered with in 13 of the 16 cistern water samples. This was supported by the observation that fecal coliform was recovered in higher concentrations than total coliforms in five of the water samples with total bacterial concentrations ranging from 6,100 to 16,600 CFU/mℓ. Total bacteria will interfere with the recovery of total coliform but not fecal coliform bacteria because the incubation temperature for total

TABLE III

Concentrations of Bacteria in Eight Cistern Water Samples Obtained from Reservoir Tanks (R) and Household Faucets (H)

Cistern System Number		Total Coliform	Fecal Coliform	Fecal Streptococci	Total Bacteria (CFU/mℓ)
		---CFU/100 mℓ---			
2	R	2	0	10	500
	H	23	10	20	100
6	R	0	0	6	84,000
	H	0	0	4	74,400
7	R	260	340	750	16,600
	H	0	0	0	2,000
9	R	200	984	9,000	6,700
	H	1,400	50	180	67,900
13	R	520	1,750	800	14,000
	H	74	505	510	9,500
14	R	0	0	0	3,200
	H	80	1	60	21,600
16	R	0	70	149	6,100
	H	0	0	50	100
18	R	0	0	42	27,100
	H	0	0	23	67,900

coliform is 37°C, a temperature suitable for the growth of most environmental bacteria. On the other hand, the incubation temperature for fecal coliform is at 44.5°C which selectively inhibits the growth of most environmental bacteria. Concentrations of total bacteria usually do not interfere with the recovery of fecal streptococci because sodium azide, an inhibitor of gram negative bacteria, is added to the KF medium used to selectively recover fecal streptococci.

Disinfection of Cistern Water Using Sunlight

The frequency of recovering fecal indicator bacteria from cistern waters indicate that fecal contamination of cisterns is a common occurrence. The predominantly higher concentrations of fecal streptococci to fecal coliform bacteria indicate that the source of fecal contamination is non-human, most likely birds. The goal of all cistern water systems is to obtain water without or with minimal levels of fecal indicator bacteria. Two approaches can be taken to meet this challenge. First, to prevent the contamination of the reservoir tank with fecal bacteria. Engineering design and devices such as the installation of foul flushing mechanism and sand-type filters, can be used in this regard. Second, to disinfect the waters before it is consumed. Boiling of small volumes of water for direct consumption is one of the easiest means of disinfection. Automated, disinfection systems such as the use of chlorine or ultra-violet light to disinfect household water systems are available, but are expensive and require constant monitoring.

The use of natural sunlight to disinfect drinking water has not been evaluated. In this regard, we (Fujioka et al., 1981; Fujioka & Narikawa, 1982; Fujioka & Siwak, 1986), have completed a series of studies demonstrating that sunlight is an effective disinfectant of indicator bacteria such as fecal coliform, fecal streptococci as well as some pathogenic bacteria such as Salmonella sp. To determine whether sunlight can be used to effectively disinfect cistern waters of fecal indicator bacteria, a cistern water sample (No. 12) was obtained and added to rectangular, clear-glass bottles (500 mℓ). These bottles were then lain on their side in a shallow water bath to maintain the temperature of water in the bottle to less than 30°C. One rectangular face of the bottle was exposed to direct sunlight between 1000 to 1400 hours on a typically sunny day. Representative bottles were removed after various exposures to sunlight and assayed for residual concentrations of total coliform, fecal coliform, fecal streptococci, and total bacteria. For controls, one bottle exposed to sunlight was recovered with aluminum foil to reflect sunlight. Another set of bottles was maintained in the laboratory in the absence of sunlight. The results, summarized in Table 4, show that total coliform, fecal coliform, and fecal streptococci bacteria in cistern waters can be effectively disinfected when exposed to sunlight for periods of 1 to 4 hours. Total bacteria was also disinfected by sunlight but a substantial, residual concentration of total bacteria was still recovered even after 4 hour exposure to sunlight. In the absence of sunlight, these same bacteria were not

TABLE IV
Viability of Bacteria in Cistern Water Stored in Clear Glass Bottles in the Presence and Absence of Sunlight

Hours of Exposure	Total Coli-form	Fecal Coli-form	Fecal Strepto-cocci	Total Bacteria (CFU/mℓ)
	--------CFU/100 mℓ--------			
A. Presence of Sunlight (Roof Experiment)				
0 hr	500	650	210	1830
1 hr	0	96	10	270
2 hr	0	7	0	120
4 hr	0	0	0	240
4 hr*	360	386	130	3300
B. Absence of Sunlight (Laboratory Experiment)				
0 hr	500	650	210	1830
1 hr	600	510	173	1300
2 hr	540	620	140	1800
4 hr	500	470	200	1400

*Bottle covered with aluminum foil to shield from sunlight.

disinfected. These results indicate that fecal bacteria which contaminate cistern water supplies can be disinfected by collecting cistern water samples in clear glass bottles and exposing them to direct sunlight for 2 to 4 hours.

CONCLUSIONS

Cistern systems are vulnerable to contamination with fecal matter, especially feces of animals such as birds and rodents which spend some time on the roofs of houses. The results of this study indicate that most of the cistern waters in the Round Top-Tantalus area of Honolulu contained high concentrations of one of the three fecal indicator bacteria (total coliform, fecal coliform, fecal streptococci). Thus, most of the cistern water supplies in this area would not meet current U.S. microbiological drinking water standards. Fecal streptococci was recovered much more frequently and at higher concentrations than total coliform and fecal coliform bacteria, indicating that the source of fecal contamination was a non-human source, probably birds. Although the feces of birds can transmit some water-borne infectious agents such as <u>Salmonella</u> bacteria to humans, many of the human pathogens such as enteric viruses, protozoa, and some bacteria (<u>Shigella</u>) are not found in the feces of birds. Thus, the public health significance of indicator bacteria from birds which contaminate cistern drinking water supplies should not be viewed with the same alarm as the contamination of drinking water sources by human feces. These considerations should be evaluated in assessing the drinking water standards of cistern water supplies based on fecal indicator analysis.

The results of this study also indicated that the total heterotrophic bacteria content of cistern waters in Tantalus is very high, almost always exceeding 500/mℓ, the minimum level at which interference with the recovery of total bacteria has been reported. Evidence was obtained indicating that total bacteria concentration was interfering with the recovery of total coliform bacteria from the cistern water samples. High concentrations of total bacteria in cistern waters were also reported by Waller et al., (1984). Since assays for fecal coliform and fecal streptococci are not interfered by the presence of high concentrations of total bacteria, we recommend that these alternative indicator bacteria be analyzed for to determine the extent of fecal contamination of cistern water supplies.

Previous reports by Romeo (1982), O'Meara (1982), Dillaha and Zolan (1983), and Waller et al., (1984) indicate that cistern water supplies often contain substantial levels of fecal indicator bacteria. Since consumers should be drinking water which contain none or minimal levels of indicator bacteria, cistern waters must often be disinfected before they are consumed. The results of this study show that exposing cistern waters collected in clear glass bottles to sunlight for periods of 1 to 4 hours will effectively disinfect the fecal indicator bacteria present in the water source.

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A CASE HISTORY OF DISINFECTION OF WATER IN RURAL AREAS OF MEXICO

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ABSTRACT

Effective use rainwater as a source of water supply in rural and urban areas of the world, requires storage and containment in surface reservoirs, cisterns or tanks. While the purity of rainwater can be high when initially collected, especially in rural areas away from industrial air pollution, storage of water for long periods of time can subject this valuable resource to contamination from disease vectors, blowing dust and dirt, bacterial contamination from collection surfaces and direct contamination.

The purpose of this paper is to provide a case history of an alternative disinfection method whereby water storage vessels may be rendered virtually free of pathogenic and nuisance miroorganisms for long periods of time, thus providing a reliable disinfected water

supply.

A silver based colloidal suspension of silver in a protein carrier has been used successfully throughout Mexico to disinfect rural, urban and institutional water tanks for up to one year by coating the inside surfaces. When dry the coating becomes hard, but slowly redissolves and disinfects the water over a long period of time. Recent laboratory research confirms the efficacy of this disinfection method.

INTRODUCTION

This documents a case history of a protein based colloidal silver compound used as a disinfectant for municipal water supplies over a thirty year period, and recent laboratory efficacy tests demonstrate the principal advantages and limitations of this disinfection method.

The silver disinfectant, sold under the trade name of Microdyn, is a colloidal suspension of ionic and molecular silver in soluble and insoluble fractions, finely dispersed in a protein carrier. This material has unique properties that make it ideally suited for disinfecting water for domestic, municipal, institutional and industrial use where more conventional disinfection techniques are difficult, impractical or overly expensive.

Historical Background

Microdyn was developed in 1957 in Mexico City based upon work carried out in Czechoslovakia, Rensselear Polytechnic Institute, New York and Princeton University in the late 1930's. Since introduction as a commercial water disinfectant in 1957, the product has been used extensively throughout Mexico and is presently sold and distributed throughout thirty Mexican States.

For industrial use a concentrated form of 3.2 percent by weight of silver is available, while 0.32 percent solution is utilized for personal or domestic use. The commercial grade is utilized for disinfecting reservoirs, cisterns and water storage tanks for municipalities, hospitals, clinics, stores, cities and industrial concerns.

Method Of Application

Apart from the fact that it is tasteless and odorless, one of the principal reasons for the appeal and wide use of Microdyn in Mexico is in its method of application. For disinfecting large reservoirs Microdyn is applied to the walls of the tanks, a process known as "activation". The 3.2 percent Microdyn is applied at rate of about 50 to 60 cc per square meter or alternatively 1 liter per 20 square meters of surface. The applied material is allowed to dry into a hard shellac like appearance. Over a period of one year or more the Microdyn slowly dissolves into the water, thus not only is the water disinfected, but microbiological growth on the walls of the container is prevented for an entire year. This precludes the growth of algae, slimes, molds and other material that may be detrimental to the purity of the drinking water. Because of the constituents in Microdyn, some of the material dissolves into solution, while the remaining part forms an insoluble suspension. Because of the finely divided nature of the ionic and molecular silver atom, and further, because of the strong affinity of silver atoms for sulphur groups, Microdyn is effective in interrupting enzymatic functions and in destroying protein materials in microorganisms.

In rural areas, more particularly in undeveloped regions, storage of rainwater is essential, since treatment and distribution of potable water is rarely available. Moreover, continuous disinfection with alternative disinfectants is not always suitable because of the need for constant attention and the acquisition, use, and maintenance of metering equipment.

Contamination of stored rainwater supplies originates from rainwater collection surfaces, atmospheric pollution, dirt, dust and sediment and other disease vectors. The overall simplicity of applying Microdyn once annually to the walls, floor and ceiling of a water cistern or pot is simple, direct and finds favor with regulatory agencies since the cistern must be cleaned of dirt and debris annually before activation.

Laboratory Efficacy Tests

Laboratory tests have been conducted by the University of Arizona Microbiology Department to demonstrate the bactericidal efficacy of Microdyn. Bacteria selected for study included Salmonella, Shigella, Klebsiella, Legionella and Pseudomonas; viruses studied included Poliovirus, Rotavirus, and Herpes viruses - IBR and PRV. Other tests, carried out by Pemex in Mexico on cooling towers also indicate that algae, Tribonema and Spirogyra are inhibited by Microdyn.

Overnight cultures of *Salmonella typhosa*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa* were prepared on tryptic soy agar slants (TSA) (Gibco Laboratories, Madison, WI) and rinsed with sterile distilled water and filtered through #2 Whatman filter paper (Whatman Limited, England). Bacterial cultures were obtained from the American Type Culture Collection (ATCC) (Rockville, MD).

Suspensions of bacteria or poliovirus (type 1, LSC, also obtained from the ATCC) were added to sterilized (autoclaved) Tucson tapwater (Table 1 shows water composition) and incubated at room temperature on stir plates (Bell-Stir, Bellco Glass, Inc., Vineland, NJ).

TABLE 1

Composition Of Tucson Tapwater

Chemical Parameter	mg/l
Calcium	48.0
Magnesium	5.2
Sodium	42.0
Bicarbonate	150.0
Chloride	30.0
Nitrate	8.0
Sulfate	48.0
Total Dissolved Solids	298.0
Total Hardness	141.0
Organic Carbon	< 1.0
pH (after autoclaving)	7.2

A working solution of Microdyn, a colloidal silver solution, 3200 µg/l was prepared daily by diluting in sterile distilled water to yield a final concentration of 32 µg/l.

A neutralizer solution (100x) which neutralizes the effect of the Microdyn solution was prepared daily by dissolving ten grams thioglycolic acid (Sigma Chemical Company, St. Louis, MO) with 14.6 gm sodium thiosulfate (Fisher Scientific, Fair Lawn, NJ) in 100 ml distilled water and filtering through a 0.2 micron filter (Nalgene, sterilization filter unit, Type S, Nalge Corp., Rochester, NY).

Studies using different concentrations of Microdyn were conducted by adding different quantities of the Microdyn working solution to sterile Tucson tapwater and sampling at predetermined time points. Neutralizer solution (100x) was added to each sample (at one-hundredth the sample volume) at time of collection.

Bacterial assays were performed by membrane filtration as described in the Compendium of Methods for the Microbiological Examination of foods (1984) (Gelman 3-47 mm filter holder, using GN-6 membrane filters, Gelman Instrument Comp., Ann Arbor, Mich.). Filter housings were disinfected between samples by rinsing with 0.5% bleach (Georgia-Pacific, Los Angeles, CA) followed by rinsing with 5% sodium thiosulfate and exposed to ultraviolet light (BioGARD Hood, The Baker Comp., Inc., Sanford, MA) until use. Bacterial samples were plated on TSA plates and incubated at 37 degrees centigrade overnight. Poliovirus samples were assayed on Buffalo Green Monkey cells as described by Melnick (1979).

Survival Curves:

Table 2 shows test parameters for average and worst case water quality conditions as a measure of disinfectant efficacy. Worst case water quality conditions are designed to stimulate situations which would adversly effect the performance of most commonly used disinfections such as halogens, and the worst likely water quality to be used for drinking water.

TABLE 2

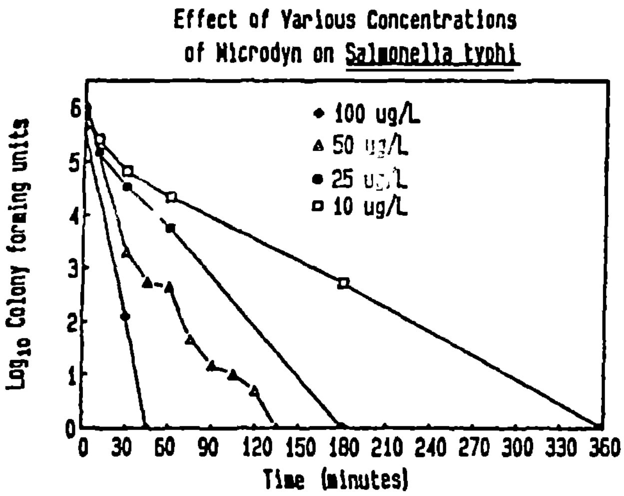
Water Quality And Test Conditions

Parameter	Average Water Quality Conditions	Worst Case Water Quality Conditions
pH	7.2	9.0
Organic Carbon (mg/l)	< 1.0	10.0
Temperature (degrees C.)	25	4
Turbidity (NTU)	< 0.1	32
TDS	298	1300

Average water quality conditions Microdyn and neutralizer solutions were prepared and used as described above. Assays were performed by spread plate technique as described in the Compendium of Methods for the Microbiological Examination of Foods (1984) (Fig. 1).

Worst case water quality conditions In order to test Microdyn under adverse conditions, sterilized Tucson tapwater was treated with 10 mg/l humic acid (Aldrich Chem. Comp., Inc., Milwaukee, WI), 150 mg/l AC Spark plug, air cleaner test dust (General Motors, Flint, MI) to yield a turbidity of 32 nephelometric turbidity units (model 2100A turbidimeter, Hach, Ames, Iowa), adjusted to pH 9 using 5N NaOH (MCB Manuf. Chem., Inc., Cincinnati, Ohio, using Beckman model 70 pH meter, Beckman, Irvine, CA) and incubated at four degrees Centigrade. Microdyn and neutralizer solutions were prepared and used as described above. Spread plate assays were conducted as described above.

Figure 1 presents die-off curves of Salmonella under average



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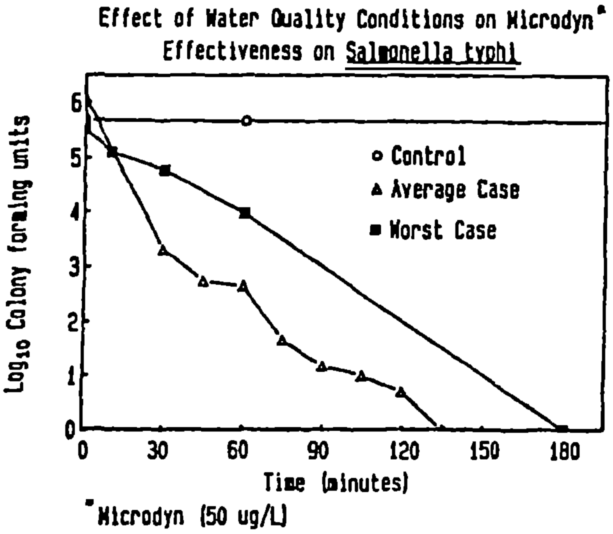
SALMONELLA, AVERAGE CONDITIONS



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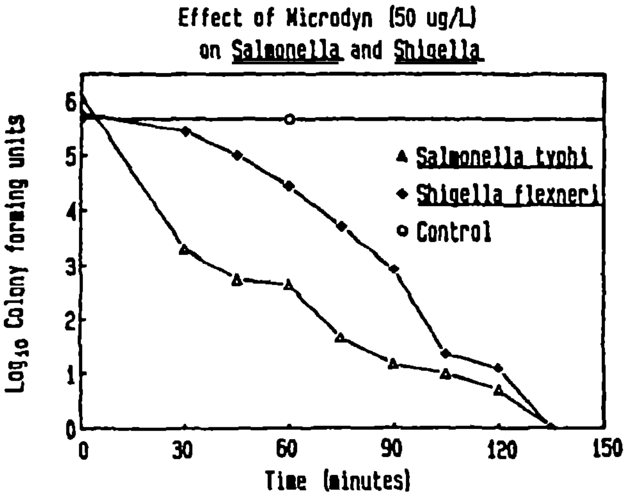
SALMONELLA, WORST CASE COMPARISON



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AVERAGE CONDITIONS, SALMONELLA AND SHIGELLA

FIGURE 1
DIE OFF CURVES

and worst case conditions with concentrations of silver from 10 to 100 micrograms per liter. With concentrations of 50 micrograms per liter to 200 micrograms per liter the disinfection capability increases dramatically. Tests with concentrations of 200 micrograms per liter provided a six log kill within 20 minutes. Assuming that a detention of more than 6 hours is maintained in a cistern, six log kill may be obtained with Microdyn silver concentrations below 10 micrograms per liter. The results in Figure 1(b) demonstrates that adverse water quality conditions (i.e. high turbidity, organic matter, and dissolved solids) do not have any significant effect on the performance of Microdyn against Salmonella typhi. Figure 1(c) demonstrates that Microdyn is effective against both Salmonella and Shigella at concentrations of 50 micrograms per liter. Other efficacy tests, not yet complete, indicate that Microdyn is effective against 1) Pseudomonas and Legionella at 200 micrograms per liter, 2) algae and fungi, 3) Trophozoites parasitic forms, 4) lipid viruses such as the Herpes viruses IBR and PRV. Microdyn is not effective against non-lipid viruses at concentrations less than 200 micrograms per liter. However, these are not expected to be present in stored rainwater cisterns. Because of the low silver concentrations required to disinfect water supplies the slow dissolution of Microdyn from the walls of the cistern is adequate to provide sufficient disinfection for up to 12 months.

Cistern Water Quality

Most rainwater from roofs and cisterns that we have examined contains coliform and fecal coliform bacterial numbers above that recommended for drinking water (Table 3). The origin of these organisims may result from animal droppings in the collection areas (e.e. rooftops, runoff from the land surface, dust, soil and seepage).

TABLE 3

Microbial Water Quality Of Cistern Water In Tucson, Arizona*

Standard Plate Count(/ml)	$10^{6.4}$
Coliforms(/100 ml)	$10^{4.4}$
Fecal Colifroms(/100 ml)	$10^{3.9}$
Turbidity (NTU)	8.1

* Average of eight samples from cistern water in Tucson, Arizona.

Another application of Microdyn is for domestic use in which Microdyn is applied directly to the water by droplet form from small 30 ml bottles of 0.32 percent solution. In this application one drop per liter is sufficient to disinfect water in 20 to 30 minutes by providing a concentration of approximately 100 migrograms per liter of silver.

Toxicology

Under Environmental Protection Agency guidelines for hazard evaluation for humans and domestic animals, the following toxicology was carried out for Microdyn: acute oral LD50, acute dermal LD50, primary eye irritation and primary skin irritation studies. These tests were carried out by an independent testing laboratory in New Jersey.

In the test for LD50, adult albino rats were dosed with full strength 3.2 percent Microdyn solution by the oral route. None of the ten animals died over the 14 day test period and all gained an average of over 50 percent in weight. Autopsies performed after the test showed that liver, spleen, kidney, lung, stomach and small intestine all appeared normal. The LD50 was calculated at greater than 5 grams per kilogram of body weight.

For allergic contact dermatitis (McGuire Test) guinea pigs were utilized in which the full strength 3.2 percent Microdyn solution was applied to a previously sensitized area of skin at time period 0, 2, 4 and 7 days. No allergic contact dermatitis was observed.

During acute dermal LD50 in rabbits, Microdyn 3.2 percent formulation was applied topically at a rate of 1.67 mils per kilogram of body weight. All animals survived the 14 day test period gaining in weight; the LD50 dose was computed at greater than 2 grams per kilogram of body weight, and therefore not toxic to adult rabbits when applied topically.

The acute toxicity by eye irritation included injecting 0.1 mils of 3.2 percent into the eye of an albino adult rabbit with and without rinsing; observations extending over a period of 21 days. All irritation in both groups disappeared by day 4 with the conclusion that Microdyn had no affect on the cornea of animals.

In the 1962 U.S. Public Health Service Primary Drinking Water Standards, silver concentration was limited to 50 micrograms per liter to minimize any adverse cosmetic effects. In recent years studies have shown that this in fact cannot be substantiated. Further, the case history of the use of Microdyn and that shown by the laboratory experiments for toxicology indicate that no cosmetic or ill health effects have been observed. In acknowledgment of the absence of adverse health effects and recognition of the beneficial uses of silver, the United States Environmental Protection Agency early in 1986 proposed removal of silver from the primary drinking water standards.

Case Histories

The follow case histories illustrate specific applications within Mexico where entire communities or institutions receive water disinfected entirely by Microdyn.

The City of Cruz Azul, Lagunas, Oaxaca

This City approximately 800 kilometers southeast from Mexico City centers around a cement works owned and operated by the Cruz Azul Cooperative. This cooperative also operates a second major cement plant in the state of Hildalgo. These cooperative towns have a total population of approximately 10,000 people. Prior to 1977 the water supply was in such poor condition that approximately 20 percent of the entire population died. The water is pumped from an adjacent river to a filtration plant and distributed to reservoirs throughout the city. Contamination from dead animals in the river contributed to the high pollution and presence of pathogenic bacteria.

In 1977 Microdyn treatment was implemented by activation of the open raw water reservoir (upstream from the filters); distribution reservoirs on hills throughout the city; and, private water cisterns in domestic residences. Since initial activation in 1977 the number of cases of gastroenteritis have been substantially reduced.

Ministry of Health applications

Microdyn is widely used by the Mexican government and administered by the Secretary of Health through the Ministry of Health for Federal Republic. Recently the Ministry of Health purchased large quantities of Microdyn for disinfection of water following the disatrous September 1985 earthquake in Mexico City. The government utilized Microdyn for disinfecting water in schools and hospitals primarily to prevent the outbreak of disease in areas where water supply mains had been broken.

Mexican oil company, Pemex

Pemex, operates oil wells, refineries, distribution and marketing outlets of petroleum products. Microdyn is used at the Tampico refinery near Vera Cruz for disinfection of cooling towers; on drilling rig platforms for disinfection of potable water and on ships distributing fresh water to the platforms.

In the cooling towers, Microdyn is painted directly onto timber splashboards at a rate of 50 cc per square meter. The cooling towers are approximately 8.5 meters high and carry a circulating water flow rate of 3,500 liters per minute. The water temperature entering is approximately 50 degrees Centigrade and 34 degrees Centigrade leaving. Prior to application with Microdyn the cooling towers were heavily fouled with bacterial, algal and fungal growth. Disinfection with other disinfecting agents had proven unsatisfactory and uneconomic. In August of 1985 the towers were cleaned and the timber baffles were painted with Microdyn. Observations were made daily and tests carried out every 45 days to ascertain water quality characteristics and the extent of microorganism fouling on the cooling tower itself. Although this series of tests is presently ongoing, results indicate that none of the surfaces coated with Microdyn have any microbiological growth attached to them including the more prolific and tenacious algal forms of Tribonema and Spirogyra. The conclusion of this test is anticipated in July of 1986.

Pemex also utilizes Microdyn for disinfection of potable water tanks in ships distributing water to oil platforms throughout the Gulf of Mexico. In this application Microdyn is coated on the insides of the epoxy lined steel tanks.

Summary

Throughout the 30 years of use in Mexico Microdyn has been employed by the armed forces, large industrial concerns, hotels, hospitals and institutions and it is estimated that approximately 1 million people are continuously served with water disinfected with Microdyn. Cistern water usually contains enteric bacteria which should be controlled by proper disinfection. Based on laboratory and field studies Microdyn has been shown effective in control of these organisms and enteric pathogens. Because of the very small amounts required for disinfection of water supplies this material has an important place in improving the sanitation and in protecting water supplies in rural areas or other centers of habitation where water distribution is not available. Microdyn effectively disinfects against pathogenic bacteria, lipid containing viruses and prevents the growth of fungus, algae and virtually sterilizes contact surfaces in which rainwater can be stored. This simple method of disinfection will help to raise public health standards in developing areas.

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RAINWATER CONTAMINATION

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ABSTRACT

Rainwater seems to be the most viable solution to provide acceptable quality drinking water in rural area. However, rainwater from roof catchment might be subjected to contamination brought about by dirt on the roof, decayed leaves, and animal excreta such as bird,reptiles, etc. The quality of water stored in a container might be contaminated by either from a collecting systems or by an unclean storage container. The bacteriological quality of rainwater samples collected from various sampling points, i.e., atmosphere, roof and gutter, storage containers (tank and jar), in-house container, were evaluated. It was found that the quality of most rainwater samples were below the drinking water quality standards recommended by WHO (1971). Some species of pathogens, Salmonella gr.E and gr.C, V.parahaemolyticus, Aromonas, were also found in some rainwater samples collected from storage tanks and in-house containers. The findings from this study indicate the possibility of bacteriological contamination of the stored rainwater.

INTRODUCTION

One of the most important factor determining health condition of the villagers, particularly the Northeasterners in Thailand, is the lack of acceptable quality drinking water. The villagers have to rely on rainwater in the rainy season and groundwater, from deep or shallow wells in the dry season. Water from deepwells in the Northeast usually contains high mineral contents which is unacceptable to the taste of villagers. The quality of water from shallow wells is unacceptable to the health because it is easily contaminated by microorganisms. Rainwater seems to be the most viable option for drinking water as indicated in the study of water quality in Northeast Thailand conducted by Thai Australia Village Water Supply Project (1985), and Department of Health (1984). Following the recommendation of the Jar Program proposed jointly by the Faculty of Engineering Khon Kaen University and Thai Australia Village Water Supply Project (1984), the Thai government has embarked upon a program to proliferate jar construction through the village revolving fund principle, with the ultimate goal of providing 2 big jars (each of 2 cubic meters) for each of 3 million rural households of Thailand by the end of 1990.

Considering the cost and labor put into the provision of adequate rainwater storage, and subsequent widespread use of rainwater for drinking, every effort should be made to minimize the health risks associated with consumption of stored rainwater. To do this requires the assessment of the bacteriological and physical/chemical quality of rainwater.

The transmission route for most of the waterborne diseases caused by pathogens, especially diarrhea, is fecal-oral. This occurs by any route in which excreta from an infected individual is transmitted to the mouth of another. Stored rainwater can serve as transmission route if [illegible] is contaminated with fecal material, particularly from birds. In order to assess the role of rainwater in disease transmission, it is necessary to evaluate the rainwater quality in terms of fecal contamination which, in turn, indicates the possibility of pathogen contamination.

Stored rainwater is possibly contaminated, with some heavy metals. A possible source for heavy metals is corrosion of the roofing materials or some other metal fixtures in the collection system. Most heavy metals such as, lead, chromium, cadmium , are detrimental to health at low concentration.

This study proposes to investigate the health risks associated with the consumption of rainwater and to determine the extent to which type of collection and storage systems contribute to these risks.

Therefore, the specific objectives of this work are:

1) to evaluate the rainwater contamination both bacteriological in terms of pathogen, and chemicals, in terms of heavy metal,
2) to determine the natural route of contamination of rainwater from the point collection, storage, and final consumption in the household,
3) to investigate the effect of types of collection and storage systems on the contamination of rainwater, and,
4) to develop recommendations to reduce the levels

of contamination in order to improve the quality of rainwater for drinking.

METHODOLOGY

1 Sampling station

Khon Kaen province is composed of 1600 villages. Based on the physical environment, most of the villages could be generally considered as rural villages. The physical environment include housing, toilet, water source and sanitation. On the basis of statistical analysis in terms of data replication, three villages which are in similar conditions were chosen for study target.

For each village about 6-7 households were selected as sampling stations. The selection of households was based on the following criteria:

a) each household must have storages which contain sufficient water to last one year,

b) each household must have storage tanks and collection facilities for investigating the effects of type of rainwater storages to the stored rainwater quality,

c) the owner must be willing to cooperate.

The three selected villages for the study are Ban-Kok-Phan-Pong, Ban-Dang-Noi, and Ban-Non-Tun (see location map in Figure 1).

2. Sample collection

As the objective of the project is to evaluate rainwater contamination in terms of pathogens and heavy metals, all possible points of contamination from the roof to the storage containers were investigated. Also, such points should represent the natural route of

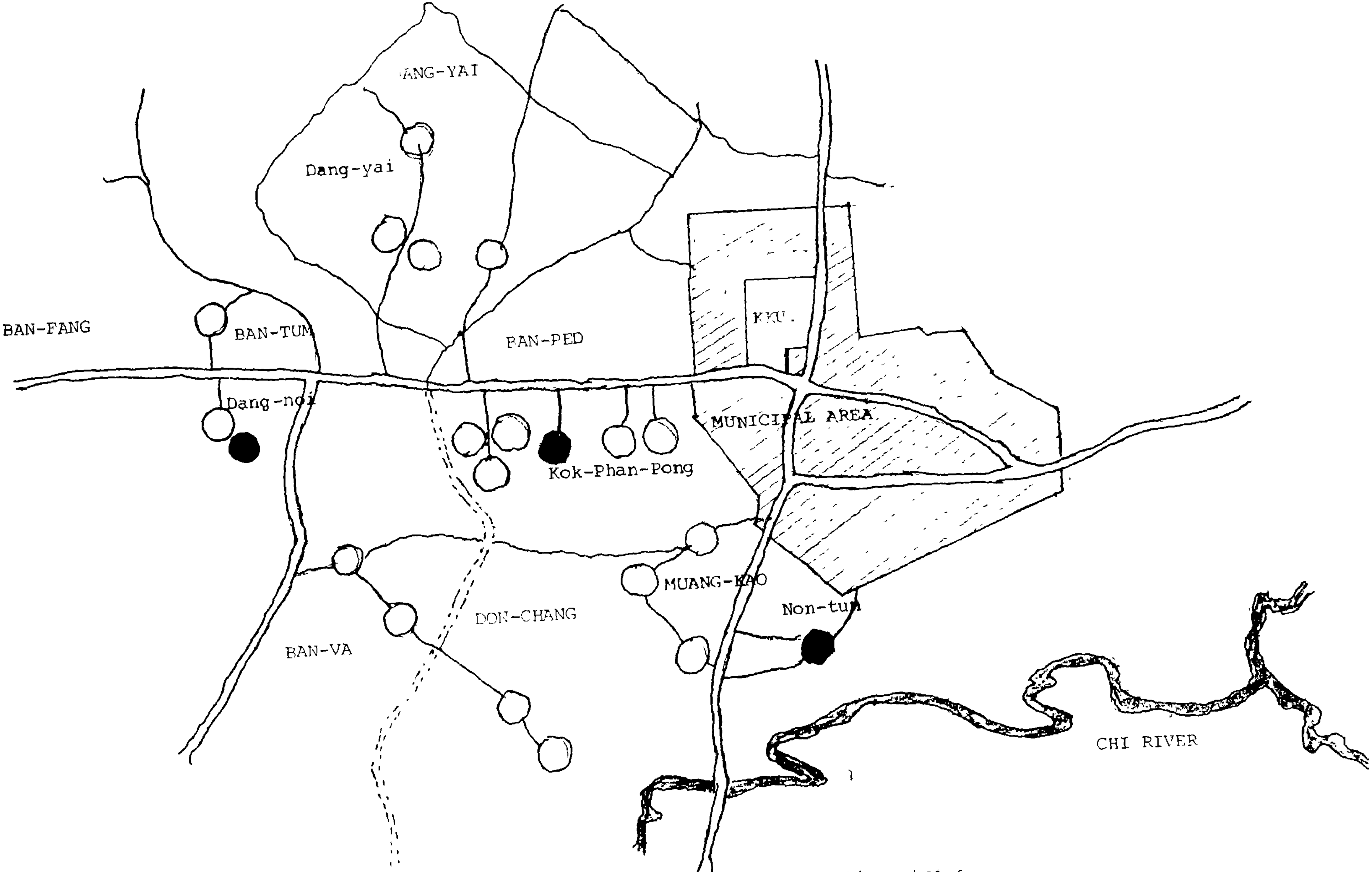


Figure 1 Location of the villages selected as sampling statio

contamination of rainwater. The sampling design is shown in Figures 2 and 3.

1. Atmosphere

Rainwater from the atmosphere was collected to provide baseline quality of rainwater. Two samples were collected from each selected village. The sampler for atmospheric samples was specifically designed as illustrated in Figure 4.

2. Roof and gutter

Materials used for roof include asbestos cement and galvanized iron but only galvanizad iron is used for gutters. However, asbestos cement roof is rarely found in any villages because of its cost. Therefore, samples from galvanized iron roofs with gutters were collected using composite automatic samplers. Three composite samples were taken from each household.

The composite automatic sampler was specifically designed with the capability of collecting rainwater samples from roof and gutter at variable time interval. The sampler composes of 3 cylindrical containers connected in vertical series (Figure 5). An automatic water sampler is connected to the bypass of the storage container. When it rains, rainwater from the roof and gutter will be collected in the bottom, middle, and top containers, respectively.

3. Rainwater containers

Rainwater containers are divided into two types : tank and jar.

3.1 Tanks: There are two kinds of tanks: cement and galvanized iron. Presently, galvanized iron tank is no longer used. Only cement tanks of capacity 10-12 cubic meters were used in this study.

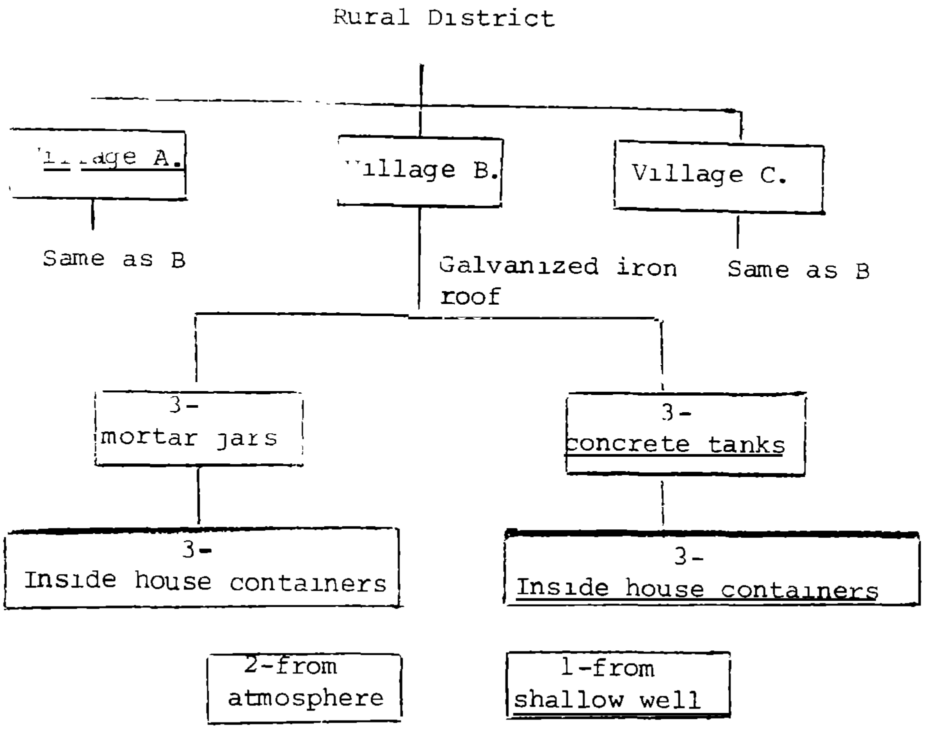
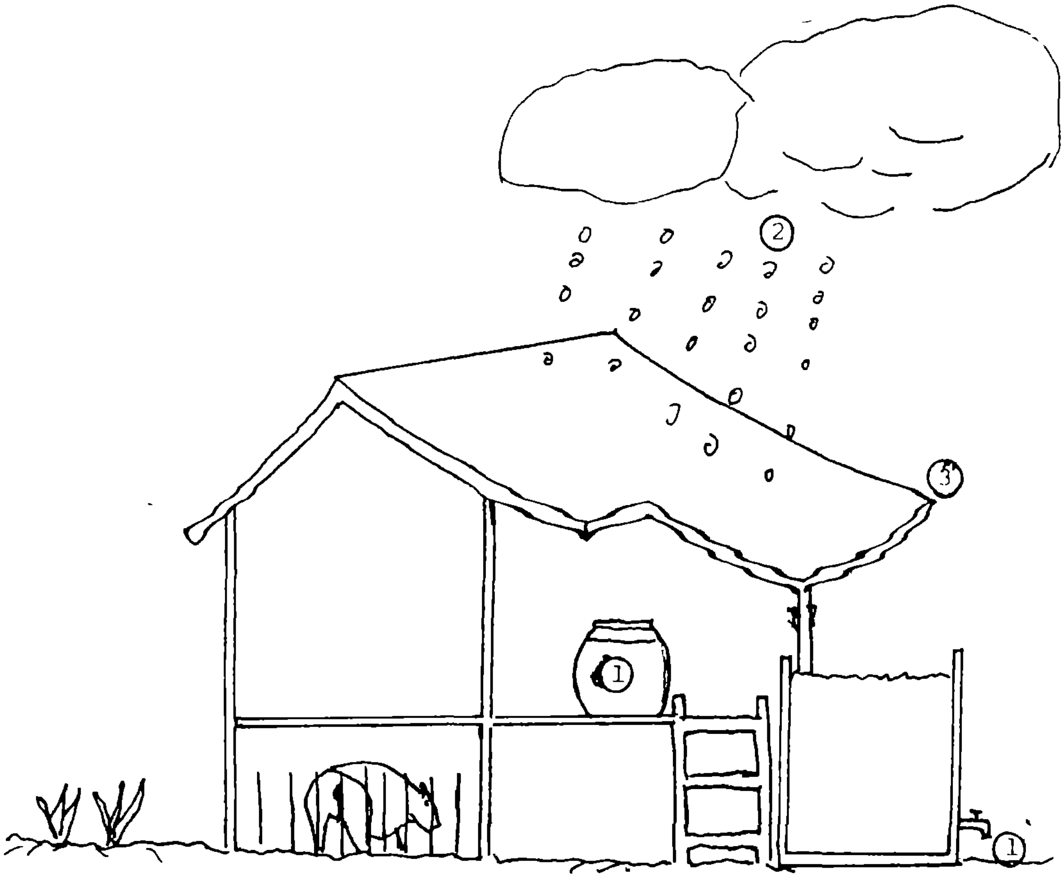


Figure 2 Research design for field water sample collection



○ point of sampling

number inside ○ indicate no. of samples to be taken

Figure 3 Points of sample collection

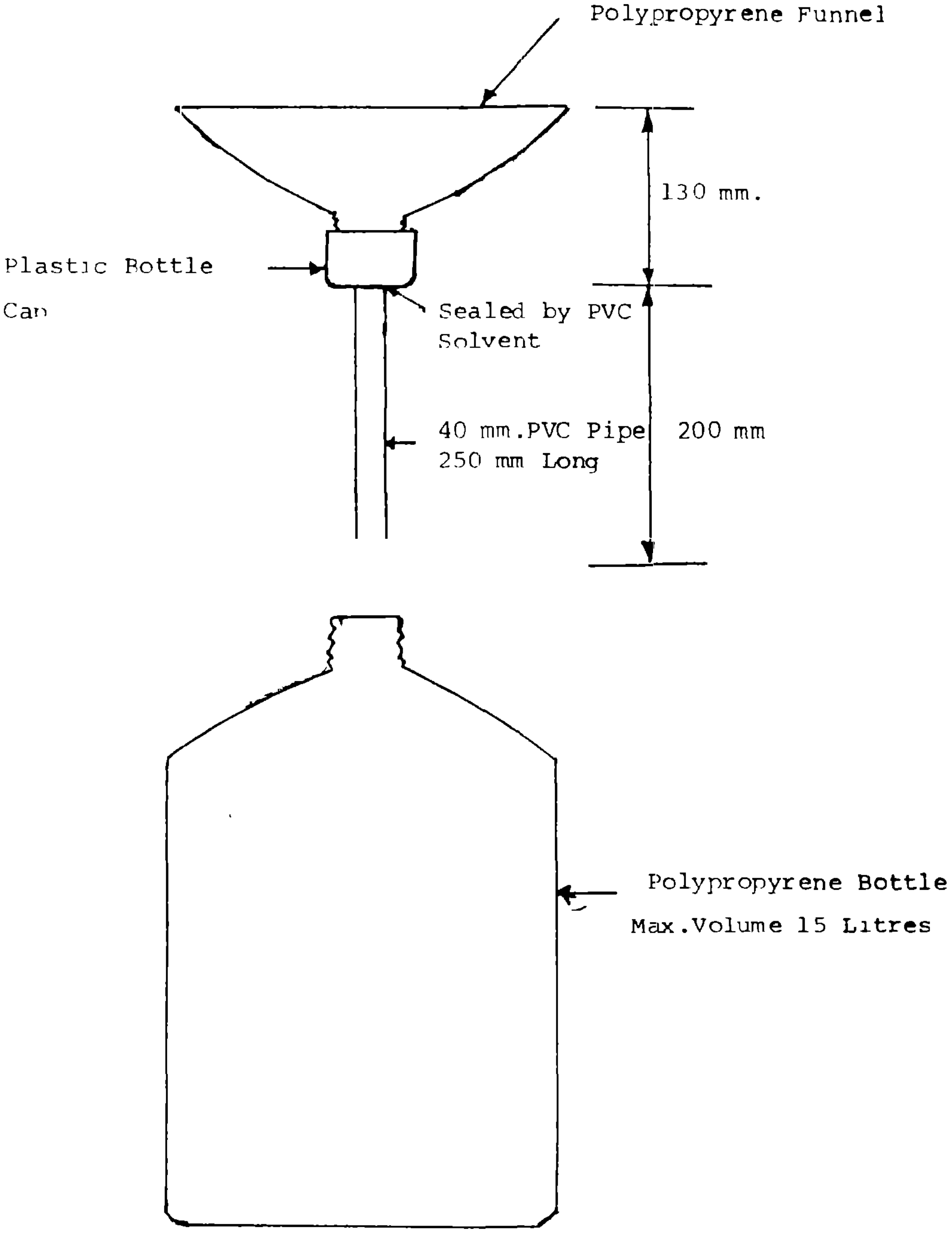
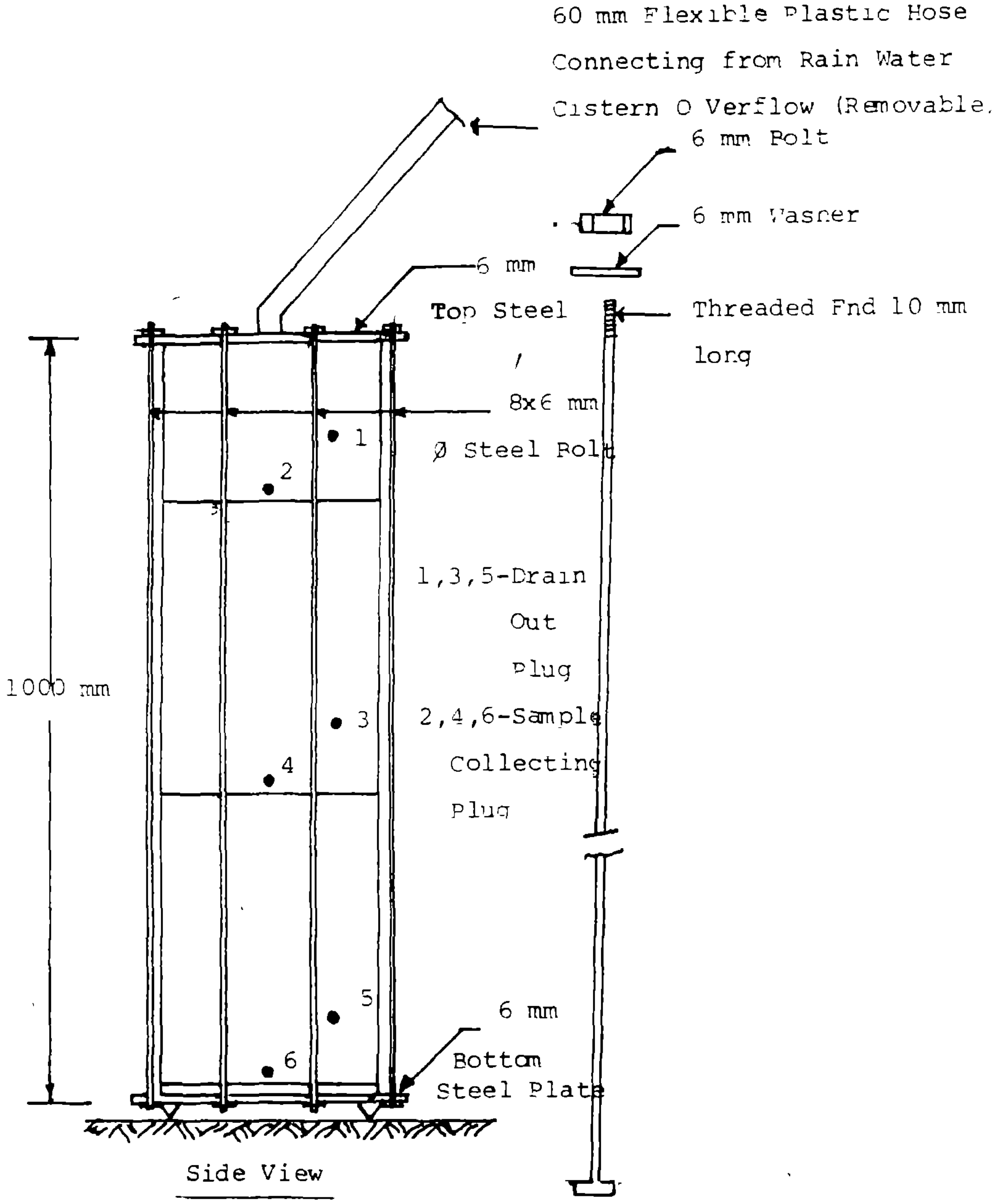


Figure 4 Atmospheric Rainwater Sampler (Scale 1:5)



Side View

(Scale 1:100)

Steel Bolt Detail

(No Scale)

Figure 5 Composite Automatic Rainwater Sampler

3.2 Jars: A mortar jar of capacity about 2 cubic meters was used in this study. Rainwater quality was evaluated for various storage and withdrawal practices. Thus, samples were taken from different types of jars, i.e. jar with tap or without tap, jar with cover or without cover.

Only two-year-old containers were used in this study, thus the effect of age of container can be neglected.

From these points of sampling, i.e. from the atmosphere, the gutter, and container, the natural route of contamination might be identified.

4. The point of consumption

Samples were taken from jars or other containers used for temporary storage inside the house. Most of the in house containers are small pots made of clay. Secondary contamination might be identified from this sampling point.

5. Shallow wells

Samples taken from shallow wells, which are available for drinking source, were analysed for comparison with the quality of rainwater.

The detail of sampling points and number of collected samples is summarized in Table 1.

Due to late preparation only three samplings from the atmosphere and roofs with gutters were carried out. Four samplings from containers and in-house containers were performed. As for shallow wells, three samplings were made.

3. Laboratory analysis

Two samples were taken from each sampling point. One bottle of about 500 ml was used for heavy metal

TABLE 1

Sampling points and Number of Samples

Sampling Points	Village 1	Village 2	Village 3
	Kok-Phan-Pong	Dang-Noi	Non-Tun
Atmosphere	2	2	2
Roof and Gutter *			
Top	7	6	6
Middle	7	6	6
Bottom	7	6	6
In-House Container	3	6	1
Tank	3	3	3
Jar	4	3	3
Shallow Well	1	1	1

* Rainwater samples from roof and gutter were collected in 3-vertical-connected-containers of the automatic sampler. Top, middle, and bottom, represent the position of the 3 containers, respectively, and are presented in all tables of this paper.

analysis, the other bottle of about 500 ml was used for bacteriological analysis. The bottles used for bacteriological contamination have to be sterilized before collecting the samples. All bottles of sample were preserved at 4°C by storing them in an ice-box. Samples, especially for bacteriological determination, were analysed as soon as they are arrived at the lab.

Since the atomic absorption spectrophotometer (used for heavy metal analysis) is not available at the time of sample collection the result of heavy metal analysis could not be presented at this time. Only bacteriological analysis was performed and the result of bacteriological study of rainwater is presented herein.

For the bacteriological study, the following indicator organisms and pathogens were determined :

Indicator organisms : total plate count
total coliform
fecal coliform
Eschericia coliform *(E.coli)*
fecal streptococci

Pathogens : Salmonella
Shigella
Aromonas

Indicator organisms and pathogens were analysed following the Manual for the Laboratory Diagnosis of Bacterial Food Poisoning (1978) or the Microbiological Methods for Monitoring the Environment, Water and Wastes (1978).

RESULTS AND DISCUSSIONS

The data presented herein is not completed as scheduled program. However, the present studied results indicate the possibility of rainwater contamination caused by waterborne organisms as the following discussion.

1. <u>Bacteriological quality of rainwater drinking vs. water quality standards</u>

Bacteriological quality of rainwater collected from various sampling points were compared to the standards of drinking water quality recommended by WHO (1971), and are summarized in Table 2. The standard bacteriological parameters include : (a) total bacterial count not to be higher than 500 cells/ml, (b) MPN coliform not to be higher than 2.2 cells/100 ml, and (c) <u>E.coli</u> to be absolutely absent.

To investigate the route of bacteriological contamination, the quality of rainwater from the atmosphere to the storage containers is sequentially presented.

Bacteriological quality of the rainwater samples collected from the atmosphere was very questionable. Naturally, the atmospheric rainwater samples should be free from any indicator organisms. However, indicator arganisms were found in the samples. One possible explanation is that the samples were contaminated during collection and handling.

Regarding rainwater from the gutter, the data in Table 2 state the bacteriological quality of all the samples did not meet the standard of bacterial count, 58-73 % of the samples did not meet the standard of MPN coliform, and 17-35 % did not meet the standard of <u>E.coli</u>. This means the bacteriological contamination of the stored rainwater could possibly be caused by unclean

TABLE 2 Results for the Analysis of Bacteriological Quality of Rainwater

Sampling Points	Number of Samples	Results as % of Samples					
		Total Bacterials Counts		MPN Coliform		E.coli	
–		Good Quality	Do not Meet Standard	Good Quality	Do Not Meet Standard	Good Quality	Do Not Meet Standard
Atmosphere	15	6.67	93.33	6.67	93.33	66.67	33.33
Roof and Gutter							
Top	43	2.33	97.67	41.86	58.14	65.12	34.88
Middle	57	0.00	100.00	26.32	73.68	82.46	17.54
Bottom	56	0.00	100.00	33.93	66.07	67.86	32.14
Storage Container							
Tank	33	39.39	60.61	27.27	72.73	69.70	30.30
Jar	28	28.57	71.43	42.86	57.14	75.00	25.00
In-House Container	32	15.62	84.38	31.25	68.75	62.50	37.50
Shallow Well	9	0.00	100.00	0.00	100.00	33.33	67.67

roof and gutter.

Results of the bacteriological quality of the stored rainwater in any containers, tanks, jars, about 60-70 % 57-72 % , 25-30 % of samples did not meet the standards based on total bacterial counts, MPN coliform, and E.coli ; respectively. These results also indicate the bacteriological contamination of the stored rainwater could be caused by both unclean collection system as well as unclean storage container.

For the quality of samples taken from the in-house containers, the percentage of samples which did not meet the standard was also high ; 84 % , 60 % , and 37 % based on total bacterial count, MPN coliform, and E.coli, respectively. The results obtained from this sampling point indicate the possibility of secondary contamination.

For shallow wells, 100 % of samples were below the standard of drinking water quality. The bacteriological quality of shallow well should be improved by disinfection before using as drinking source.

2. Fecal coliform vs. fecal streptococci

Fecal streptococci is also used for an indicator organism. The ratio of fecal colifrom to fecal streptococci (FC : FS) indicates the original source of fecal contamination whether from human and/or animal. A ratio of FC to FS of greater than 2 to greater than 4 indicates that fecal contamination source originated from human rather than animal, while a ratio of less than 1 indicates vice versa. If the ratio is in the range of 1-2 the fecal contamination source is originated from either human or animal.

The ratio of FC : FS of the samples are summarized in

Table 3. For the stored rainwater in tanks and jars, approximately 43-52 % of samples have FC : FS ratio less than 1, indicating the source of contamination was from animal rather than human. While the in-house container about 53 % of the samples have FC:FS ratio greater than 4, indicating the source of contamination was from human rather than animal.

Approximately 79 % of the rainwater samples collected directly from the atmosphere have FC : FS ratio greater than 4, indicating that the contamination source is from human rather than animal. Therefore, it can be concluded that contamination occurred during collection and handling of the samples.

For water from shallow wells, about 80 % of samples have FC : FS ratio greater than 4, meaning the source of contamination was originated from human rather than animal.

3. Contamination of pathogens

In this study, the bacteriological quality of rainwater was evaluated in terms of both indicator organisms and pathogens. Theoretically, pathogens in water is rarely found because of its short life. However, the pathogen contamination was analysed and was found in some samples as shown in Table 4. Salmonella gr. E and gr. C , V. parahaemolyticus, and Aromonas were found in the samples taken from the storage tanks and the in-house container. Four species of pathogens found in this study can cause diarrhea. For the standard of health, drinking water have to be free from any pathogens. The stored rainwater, therefore, could possibly be a route of waterborne disease transmission. However, more data is required to confirm this finding.

TABLE 3 Ratio of Fecal Coliform to Fecal Streptococci (FC : FS)

Sampling Points	Number of Samples	Results as % of Samples FC:FS >4	>2	1-2	<1
Atmosphere	14	78.57	7.14	7.14	7.14
Roof and Gutter					
Top	43	18.60	6.98	23.26	51.16
Middle	57	28.07	7.02	19.30	45.61
Bottom	56	23.21	3.57	26.79	46.43
Storage Container					
Tank	33	18.18	3.03	27.27	51.52
Jar	28	21.43	7.14	28.57	42.86
In-House Container	32	53.13	12.50	21.87	12.50
Shallow Well	10	80.00	10.00	0.00	10.00

TABLE 4 Contamination of Pathogens

Sampling Points	Number of Samples	No.of Sample contaminated with pathogens	Name of pathogen
-			-
Atmosphere	15	0	-
Roof and Gutter			
Top	43	0	-
Middle	57	0	-
Bottom	56	1	Salmonella group E
Storage Container			
Tank	33	2	Salmonella group C Aromonas
Jar	28	0	-
In-House Container	32	1	*V.parahaemolyticus*

CONCLUSIONS

The bacteriological quality of rainwater did not meet standard of drinking water recommended by WHO. The possible route of contamination is from both unclean collecting system (roof and gutter) and unclean storage container. The source of contamination was originated from both human and animals as evaluated in terms of fecal coliform : fecal streptococci ratio. Some species of pathogens, Salmonella gr. E and gr. C, Aromonas, and V.parahaemolyticus, were found in the stored rainwater. It means that rainwater could possibly be a route of waterborne disease, particularly diarrhea. It should be remarked that this is not the final conclusion since the study has not been completed. However, the finding from this preliminary study represents a step toward evaluating the route of contamination of rainwater and investigating the health risks associated with consumption of stored rainwater.

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RELATED TOPICS

RAINWATER HARVESTING WORKSHOPS IN TOGO AND BOLIVIA:

THE WASH EXPERIENCE

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This paper describes the recent workshop experience in Togo and Bolivia using the USAID-funded Water and Sanitation for Health (WASH) Project's "Training Guide for Rainwater Roof Catchment Systems." The Togo project, entitled "cistern campaign," is an activity of the USAID funded Rural Water Supply Project. The campaign developed as a result of the failure of drilling to produce water, and the lack of alternative water sources. The goal of the campaign was to construct 1500 individual cisterns (cement stave modelled after a grain storage silo) and 125 village roof catchment surfaces (hangars) over two years starting in late 1985.

In Bolivia, the Ministry of Health requested a WASH consultant to assist in the training of rural technicians to construct rainwater harvesting systems in eastern Bolivia. The workshop was implemented to train and stimulate the interest of rural technicians in this technology through the use of the WASH Training Guide and to possibly develop a project in the future.

A description of the development of the WASH Training Guide is followed by a discussion of its application in rural water project workshops in Bolivia and Togo. A comparison of the similiarities and differences in these two workshops is presented, followed by some lessons learned and conclusions for applying the WASH Training Guide and conducting workshops on rainwater harvesting.

TERMS

Hangar	The French word used to describe an open-air multi-purpose village building consisting of a metal roof and supporting concrete pillars.
Cistern Campaign	A subproject within the Togo Rural Water Supply Project to build 1,500 rainwater harvesting cisterns and 125 hangers in 27 villages.
Cement Stave	A prefabricated slab of cement 1'x2'x2", used in grain storage silos in Benin and adapted for use in the construction of cisterns in Togo.
ARD	Associates in Rural Development, Inc.
CDM	Camp Dresser & McKee International Inc.
CRAP	San Julian Regional Drinking Water Committee
DSA	Environmental Sanitation Directorate
FDSF	San Julian Peasants Federation
FIDES	The Comprehensive Development Foundation
ISTI	International Science and Technology Institute, Inc.
RTI	Research Triangle Institute
TRG	Training Resources Group
UNC	University of North Carolina at Chapel Hill

INTRODUCTION

The WASH Project* has been involved in rainwater harvesting promotion, information collection, and training since 1982. In 1985, three training workshops were conducted, two in Togo and one in Bolivia, which provided excellent opportunities to compare and learn how to stimulate, organize, and implement rainwater harvesting projects in other countries. This paper describes and compares those workshops and highlights the use of a Training Guide developed by WASH.

The WASH experience with rainwater harvesting began with a literature survey (Keller, 1982) which led to the conclusion that a practical workshop design for training community level workers was needed. A draft of such a design was prepared and field tests were carried out in Togo (Jennings, 1983) and Zaire (Yohalem, 1984). In late 1984, "A Workshop Design for Rainwater Roof Catchment Systems: A Training Guide", which incorporated the experiences from the two pilot tests was completed, reproduced, distributed and translated into French and Spanish (Edwards, Keller, Yohalem, 1984). A paper describing the workshop design and how it could be used was presented at the Second International Conference on Rainwater Cistern Systems (Hafner, 1984) in the Virgin Islands. During this time, WASH established and began operating a rainwater harvesting network and information center (Campbell, 1986) with 120 members and over 180 rainwater books, articles and reports.

Since its completion, over 1,000 copies of the Training Guide have been distributed to agencies, including UNICEF, Peace Corps, the World Bank, numerous private voluntary organizations, and many

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*The WASH Project is funded through 1989 by USAID, with staff from CDM and Associates -- UNC, TRG, ARD, ISTI, and RTI. The project provides short term technical assistance and information on water and sanitation to developing countries.

other individuals and local projects in the developing world. The Guide has been adapted, modified, sub-divided and used as a model for the development of locally produced training manuals. The workshops have been used to introduce the technology of rainwater cisterns and roof collection to innovators who have been willing to try a different approach to obtain water for domestic use.

Following the distribution of the Guide, the WASH Project has provided consultants to help plan and implement rainwater harvesting workshops in Togo and Bolivia. Those assignments are described below.

TOGO

In 1981, USAID funded the Togo Rural Water Supply Project to provide drilled wells, handpumps, health education and sanitation to communities in various regions of the country. Failure to produce water from wells in some regions prompted the search for alternative approaches to providing water. As a result, rainwater harvesting was suggested and introduced in a workshop (Jennings, 1983) for social development agents and village and project masons. During the next two years the idea of rainwater harvesting technology gradually developed. Local adaptations included a cement stave* cistern which was designed from a modification of a Benin grain storage silo, and a hangar* or open-air multi-purpose village building. Finally in 1985 it was decided to establish a sub-project, entitled Cistern Campaign within the Togo Rural Water Project. This was to promote and construct 1,500 cisterns systems and 125 roof (hangar) catchment surfaces in 27 villages in the Plateau and Savane regions which had dry wells.

The first step in the campaign was the training of staff to carry out the project promotion, implementation and field construction activities. A consultant from the WASH Project was requested and

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* See Terms

provided assistance in the development of a Togolese workshop training design, in implementing two workshops and in preparing project construction manuals. The design and planning began in October 1985 in Atakpame and the training workshops took place in Togo's northern Savane Region at Dapaong from November 4 to 15 and in the south-central Plateau region at Atakpame from November 25 to December 6, 1985. A total of 65 trainees participated in the two sessions including 31 field agents and 34 masons. Eight Togolese rural water project regional officers, four in each workshop, and the WASH consultant served as trainers. The WASH Training Guide was used as a model in the initial workshop planning.

The specific training objectives developed by the training staff for both workshops were divided into two sections -- for field agents and for masons. The objectives were as follows:

Field Agents

a. To study and practice the community organization exercises to prepare for and support the cistern campaign.
b. To practice the planning exercises necessary for cistern and hangar construction, material needs calculation and requisition, and programming and managing laborers and construction materials use.
c. To practice each step of cistern and hangar construction.

Masons

a. To practice and complete each step of construction for the cistern and hangar.
b. To teach village laborers the various skills needed in their role as construction aides.
c. To practice record-keeping in the masons' notebook to record their work schedules and materials used.

An additional objective in both workshops was to complete the construction of at least two cement stave cisterns and one hangar. All of these objectives were met. One trainee commented in the evaluation, "we won't know how well we learned here until we apply it in the villages". Because the Togo cistern sub-project was already clearly defined, the WASH Training Guide was used selectively and as a model and resource document rather than as the specific workshop design.

BOLIVIA

In October 1984 the USAID mission in Bolivia requested the assistance of a WASH consultant to investigate various water supply alternatives in the San Julian area of Bolivia. The consultant's report (Larrea, 1985) suggested that rainwater harvesting was a viable option to consider. Following the review of the report, the Comprehensive Development Foundation (FIDES), a local private voluntary organization, made the decision to promote projects and develop a training workshop in rainwater harvesting. At the same time, the Environmental Sanitation Directorate (DSA) of the Ministry of Health and Social Security expressed interest in training some of its rural technicians (sanitary inspectors) in the construction of rainwater harvesting systems.

USAID/Bolivia requested WASH assistance in organizing and conducting a joint workshop for FIDES promoters and DSA technicians in the Eastern Region of Bolivia. In September 1985, a WASH consultant made a visit to meet with the staff of the two organizations and plan the workshop (Larrea, 1986). The specific objectives in the WASH Training Guide were reviewed and accepted as appropriate by the trainers. The overall workshop purpose was defined as follows:

a. Train a group of ten FIDES promoters who are working in villages in the region of San Julian, Dept. of Santa Cruz.

b. Train ten sanitary technicians from the Regional Environmental Sanitation Directorate of Santa Cruz and La Paz who work in groundwater deficient regions.

The workshop was held in San Julian on November 4-16, 1985 and included ten community promoters from FIDES and ten engineers from DSA. The WASH consultant worked with two Bolivian trainers from FIDES and DSA in implementing the workshop. The fifteen specific objectives in the WASH Training Guide were all satisfactorily achieved and the participants' performance was rated as highly satisfactory by the trainers. Throughout the planning of the workshop the WASH Training Guide checklist was used and the overall design and specific sessions were followed closely. The WASH consultant's report states that "the participants were able to acquire the basic theoretical know-how, apply this in construction tasks...and collaborate with the communities to install and operate the systems, and instruct the people in how to maintain them".

COMPARISONS

It is interesting to note how these two rainwater harvesting workshops, which occurred at approximately the same time but in two very different countries, compare to each other. There are a number of similarities as well as differences.

A. Similarities

The similarities can be divided into WASH involvement, participants, setting and schedule, community involvement, and construction. It is clear that the WASH Project had significant involvement in the early formulation and introduction of the training workshops. Togo had been the setting for the first pilot field test of the WASH Training Guide in 1983. The WASH consultant in Bolivia suggested rainwater harvesting technology and the idea of the workshop in his initial assessment visit in 1984. The local organizations or project staff in both Togo and Bolivia used the planning checklist in the Guide in their preparation. WASH provided facilitators to work with a group of local trainers in planning, implementing and evaluating the workshops.

The second similarity in the two assignments is the participants and their performance. The numbers of participants in the two Togo workshops and the Bolivia workshop were between 20 and 30 each. There was also an equal number of field extension agents and technicians or masons in all of the workshops. The participants in the workshops tended to have problems in performing the mathematical calculations that were necessary in some of the sessions. In addition, the building construction sessions were all moved to the morning because participants in both Togo and Bolivia complained that it was too hot to work outside in the afternoon.

Other similarities in these assignments included the two week duration and the rural village setting. The WASH Training Guide, designed for village level workers, has proven to be most effective if carried out in a setting that most closely parallels the actual setting the participants will be working in. By having the workshop in a rural community it is much easier to practice the underlying principal of the Guide to have the community involved in every step of a project. This proved to be the case in both Togo and Bolivia.

Finally, both assignments stressed the actual construction of community cisterns during the workshops. Every effort was made to adapt the cistern design to the local materials available, which minimized costs and considered the preference of the local people. In addition, at the completion of each of the workshops a fully functioning rainwater harvesting system was left in the community.

B. Differences

The differences between the two assignments can be divided into four categories: past experience with rainwater collection, the type of project, the way the WASH Training Guide was used and technical variations.

In Togo there appears to be little evidence that rainwater harvesting has been practiced and used by people in rural communities. In eastern Bolivia on the other hand, there has been a tradition of using rainwater collection systems in many parts of the region. With no past rainwater tradition, the activity in Togo was more of an introduction of an innovation, whereas in Bolivia the assignment was not introducing a new technology.

A second difference is that in Togo the activity had the financial and technical support of an ongoing project of the government of Togo. There had been a commitment and decision to carry out a rainwater harvesting subproject called "cistern campaign" and to build a prescribed number of systems. In Bolivia there was no such project for the DSA participants, but an interest in the Government's Ministry of Health. For the local private voluntary organization there was support for the construction of rainwater cisterns. It is assumed that following this training, the idea and need for a broad scale "project" may be recognized in Bolivia.

The "type of project" difference in the assignments had a significant impact on how the WASH Training Guide was used. In Bolivia, nearly every session and step in the Guide was followed with relatively little variation or modification. In Togo, however, the guide was used as a model from which to develop a Togolese training guide that was designed specifically for a project which had a particular system design and a plan to build 1500 systems in two regions of the country. The French version of the guide was used in Togo, and in Bolivia the Spanish version was used.

The last type of difference between the two assignments was in the technical design and construction activities. In Togo, circular cement stave cisterns and hangars were built. In Bolivia a rectangular brick masonry cistern was built next to an existing building where guttering was added. In Bolivia participants made cement storage jars, built a guttering system for a thatched roof and made a simple filtering system out of local materials. None of these activities were done in Togo.

LESSONS

From these two assignments and the consultants reports, a number of lessons can be drawn which are worth noting. They are as follows:

1. The WASH Training Guide for Rainwater Roof Catchment System can be used effectively as a model to be adapted and modified for local use (the Togo case) and as an off the shelf design or "use it as it is" with few changes (the Bolivia case).

2. The WASH Training Guide can be used to train project staff at the beginning of a project or it can be used as a stimulus to develop a rainwater project.

3. The integration of field extension agents and technical construction masons in a training program of this type is not difficult and in fact is highly advantageous in promoting better collaboration and team work in a project staff.

4. Detailed planning and well managed logistical support are essential to the successful implementation of these workshops. (Lindblad, 1986 and Larrea, 1986)

5. The hangars or open-air multi-purpose village buildings are a potentially useful innovation in rainwater harvesting projects. (Lindblad, 1986)

6. Rainwater collection systems from thatch roofs are a viable alternative if proper filters are used. (Larrea, 1986)

CONCLUSION

In the four and a half years the WASH Project has been involved in rainwater harvesting information collection, training materials development and promotion of workshops and projects, we have seen a significant increase in the level of interest and number of projects. Private voluntary organizations and government ministries in Kenya, Zaire, Ghana and Belize have expressed interest in and/or have rainwater projects. The need for effective transfer of skills to plan, develop and construct rainwater harvesting projects is critical. The WASH Training Guide has proven to be an important vehicle to assist in promoting rainwater projects and in transferring skills.

ACKNOWLEDGEMENTS

I wish to express my gratitude to the two WASH consultants, Carl Lindblad and Oscar Larrea, who carried out the assignments in Togo and Bolivia respectively. In addition, the earlier work on the literature survey, pilot tests and training guide by Kent Keller, Dan Edwards, David Yohalem and Lee Jennings were valuable contributions to the overall effort. This paper could not have been produced without their outstanding field work and their insightful reports.

Photo . Trainees beginning to apply the exterior layer of mortar to the cistern.

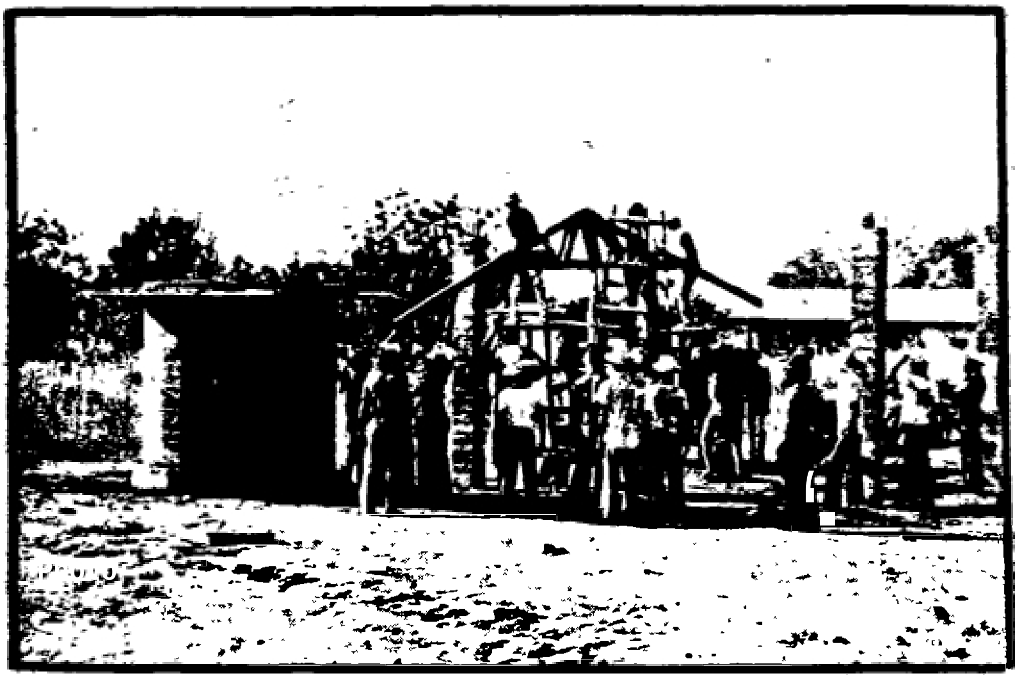

Photo Trainees hoist the roof beam atop reinforced pillars to build the catchments hangar.

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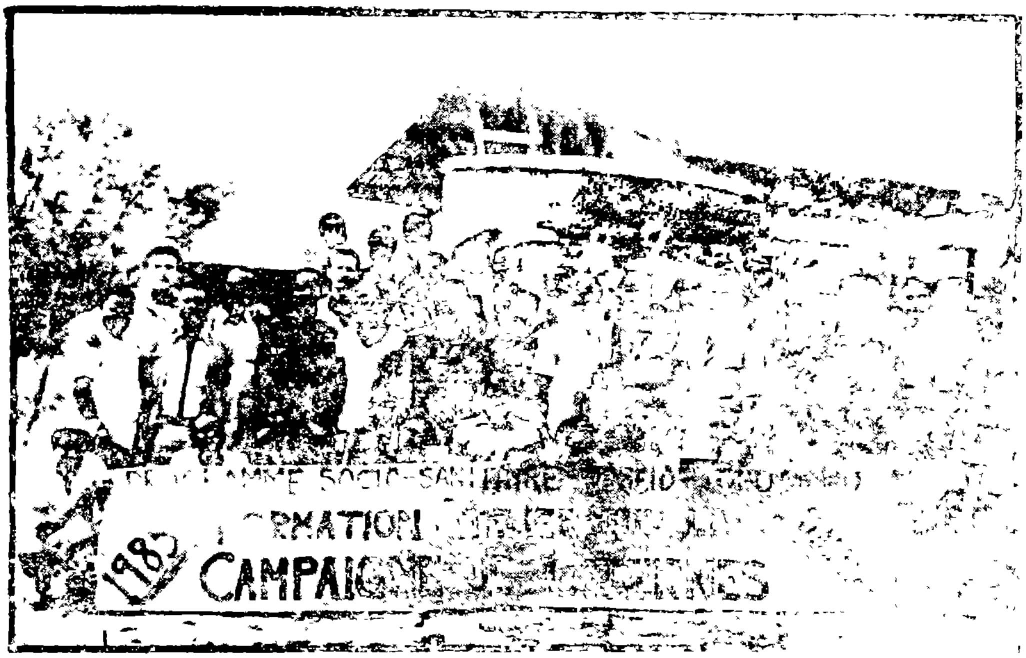

Photo . Trainees and trainers of the Atakpamé, [illegible] Citerne Workshop (Plateau Region).

Togo Rainwater Workshop

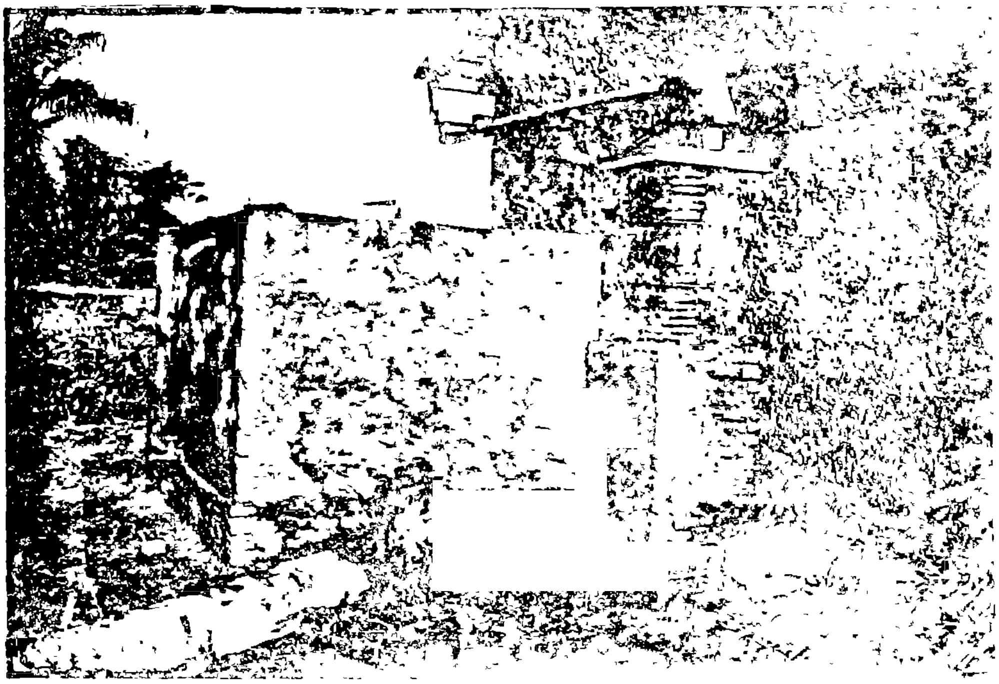

Foto . Pequeño tanque comunal (sin [illegible]). [illegible] metálicos y lavatechos automático para [illegible]

Photo . Small communal tank (unfinished), metal [illegible] and an automatic roofwasher for a thatch roof.

Bolivia Rainwater Workshop

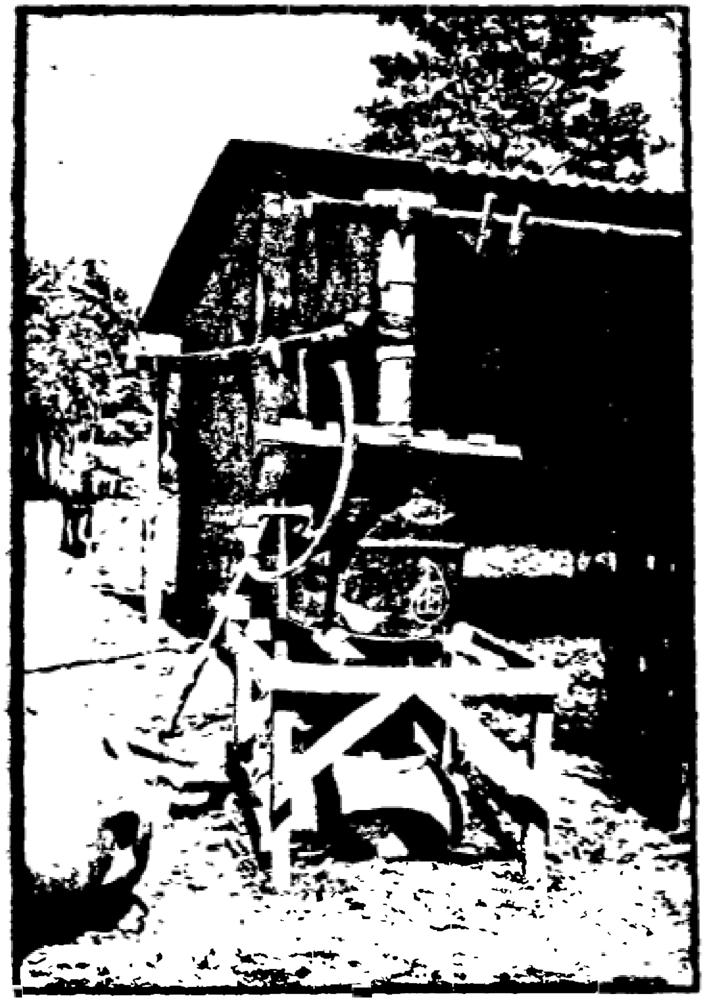

Foto . Lavatechos automático y tinaja semienterrada.

Photo . Automatic roofwasher and a semi-buried jar.

Foto . Curado exterior de la tinaja de cemento-arena.
Photo . External curing of the sand/cement jar.

RAIN WATER USE IN RURAL AREAS
FOR DOMESTIC PURPOSES AND AGRICULTURAL PURPOSES IN SRI LANKA

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ABSTRACT

The introduction gives a brief description of the island's population, land area, present land utilisation pattern, climatic conditions and rainfall. The background of the tank irrigation systems, soil conditions and ground water problams are also briefly discussed here.

Under the sub-heading 'Rainwater for domestic purposes', the rain water collecting systems and its drawbacks are discussed.

The introduction of the rainwater collecting systems into the Major Colonization Schemes of the island is described under the sub-heading 'Rain water for agricultural purposes'.

The advantages and disadvantages of the scheme is discussed next, followed by the conclusions and recommendations.

INTRODUCTION

Sri Lanka is a tropical island in the Indian Ocean. It's population is 16 million and it has land area of 16.2 million acres. Out of the total acreage, about 5 million acres are under permanent agriculture and 9 million acres under forest cover. About 70% of the permanent agricultural lands are in the Wet Zone and about 50% of the forest cover can be utilised as agricultural lands. Due to non-availability of proper irrigation facilities, some of the forest cover lands are utilized for shifting cultivation (Chena Cultivation) by using rain water.

The island's climate is characterized by temperature and rainfall. The island consists of two zones. The Wet Zone has an average annual rainfall of over 1900 mm and the Dry Zone which covers 2/3 of the land area has an average rainfall of 890 mm to 1900 mm. Average temperature of the island is 85°F and the humidity of the area is 60% - 85%. Major part of the rainfall comes in periodically between October to January and April to June. (See Annex 1 Table 1). The first season is called "Maha" and the second season is called "Yala". On the prevailing pattern of rainfall, Sri Lankans used to conserve rain water by making tanks to store it.

When we go through the 25 centuries of history of Sri Lanka, it is evident that its settlements were always linked with irrigation facilities. Therefore, its settlements gave birth to a hydraulic civilization. Sri Lankan was concerned about rain water as an important resource. At the very beginning, as far back as 5th Century B.C., they built small tanks to store water and through their experience mastered the art of building larger tanks. Though the tank irrigation systems were neglected by the Sri Lankans, due to invasion by foreigners and introduction of commercial crops, action was taken first by the British and subsequently by the successive governments of independent Sri Lanka to renovate and re-build the ancient tanks to make use of abandoned arable lands.

Annex I

Table I

MONTHLY RAINFALL IN SIYAMBALANDUWA, SRI LANKA IN INCHES 1945 - 1966

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1945										4.91	5.85	0.52
1946	3.20	4.40	4.75	11.05	5.75	1.05	0.20	1.66	3.75	8.77	6.80	8.90
1947	9.31	0.15	2.07	3.15	0.62	0.55	0.70	3.25	0.60	0.27	2.95	0.82
1948	1.00	0.00	0.70	6.47	0.60	0.00	0.30	0.40	0.32	2.09	5.33	10.08
1949	6.11	2.33	0.62	2.20	0.49	0.15	2.84	4.91	3.42	4.69	7.51	10.76
1950	5.82	4.44	0.65	2.07	1.21	0.00	3.74	4.07	3.57	4.07	4.85	2.34
1951	13.87	4.02	2.44	2.94	0.70	0.55	1.47	0.30	3.00	0.30	6.21	7.05
1952	7.59	1.75	0.21	2.67	2.57	2.35	3.31	1.77	1.30	2.05	10.60	1.64
1953	3.82	8.75	5.16	8.19	0.07	0.00	2.14	0.16	0.37	12.20	9.87	4.70
1954	9.89	4.67	3.28	7.60	2.50	0.00	3.62	2.44	6.62	6.33	10.89	9.89
1955	25.25	10.74	6.95	9.96	0.93	1.64	0.69	5.54	7.44	5.09	11.03	3.71
1956	6.80	0.82	2.00	2.33	0.75	3.12	2.75	8.40	2.77	6.23	11.76	7.20
1957	9.04	11.14	0.43	1.72	1.80	0.15	3.55	2.46	0.78	8.15	21.74	30.53
1958	7.65	4.65	4.73	5.90	2.88	0.00	3.34	8.27	6.46	0.26	6.59	9.97
1959	10.19	8.21	0.50	6.80	5.38	0.83	0.73	0.00	0.00	3.46	9.88	10.79
1960	14.08	24.57	3.16	3.45	5.57	0.00	8.76	2.71	1.97	2.82	14.97	4.84
1961	5.41	9.35	5.60	3.54	2.19	0.55	1.26	0.70	1.69	6.94	16.58	15.18
1962	9.35	4.13	1.15	6.96	4.35	0.00	0.27	2.00	5.32	3.14	10.77	19.94
1963	15.53	9.55	6.33	1.96	0.90	0.39	1.30	3.85	2.44	8.15	13.81	23.29
1964	14.15	13.50	6.13	5.40	1.24	0.00	6.69	1.96	5.70	7.22	9.48	4.34
1965	0.90	0.25	0.25	4.59	6.18	0.00	0.00	1.03	0.75	13.79	14.78	2.12
1966	7.10	2.96	5.97	7.54	1.16	1.40	1.24	2.09	6.03			

(Source - Final Report on Planning and Design Study - 1977, Sri Lanka Australia Dry Zone Development Project)

Although some areas of the dry zone get ample rain water, it limits the agricultural activities due to soil condition. Soil characteristics of the dry zone vary from reddish brown to sandy lome. On the other hand, ground water limits agricultural activities. Water quality problems vary both in kind and degree and it is modified by soil, climate and crop as well as by the skill and knowledge of water users. Therefore, selection of crops and human activities would be dependent on the availability of rain water and the quality of ground water. There are lime stones strata in the soil of some places which restrict habitation. The ground water of this area contains minerals and it has more tolerance to salinity or toxicity. Therefore, with the increasing demand for housing and other activities, the need to use rain water for human consumption and agriculture in these areas is greatly felt.

RAINWATER FOR DOMESTIC PURPOSES

Easy access to water is a main consideration in selecting a site for one's dwelling but in some cases, even the environment or the landscape attracts the would be dwellers. Even in the Wet Zone, in certain places, its ground water table would be deep and to ensure a regular supply of water for domestic purposes, it would be necessary to lift water to a higher elevation. In those places, more economically viable and most suitable method of water supply is collecting of rain water. Hence, people make use of the available resources and construct tanks to collect rain water. This system is very effective because adequate annual rain fall would ensure continuous supply of water.

Most of the settlers in settlement schemes in the dry zone use streams or well water for their day to day requirements. But in some places, settlers are compelled to spend much precious time and energy which could otherwise have been more lucratively used for their agricultural activities, to fetch water. Recent surveys revealed that some residents have to walk more than two miles to get water for drinking and bathing purposes. This is due to the non-suitability of ground water for drinking purpose, the quality of water being poor or its mineral content being high. This would contribute to the increasing incidence of bowel diseases. The implementing agencies who undertake settlement activities are, therefore, saddled with the additional burden of providing drinking water to the settlers. This service cannot be provided forever as the cost involvement is high.

In these circumstances, collecting rain water was introduced in government buildings and quarters on an experimental basis. Government assistance was provided and the knowledge of the officers in this operation had been satisfactory. Quarters and permanent buildings were designed to collect rain water by gutters and pipes channelled to a ground pit with a sufficient capacity of water to last for about two or three months. This water was supplementary to the water supplied by bowsers to the residents in the dry season. This model was extended to the settlers who had a permanent house. But they modified the storage tanks and constructed small scale tanks on the ground surface instead of underground tanks. They designed the roof of these houses in such a way that the slopes of its two sides(i.e. main house and the kitchen) meet at the centre thereby enabling the rain water to get collected in a wide gutter at the centre between the roofs. At the end of the gutter, a small tank is devised to collect water which is sufficient for a family for a few days.

Storage of water in these tanks was more tolerant to contamination or breading mosquitoes. Therefore, the design of the tank was modified to protect the water from pollution and more hygienic method was introduced. Tanks designed as a barrel which has inlet connected to the gutters and pipes and outlet for outflow of water. This model is very useful to store the rain water for longer periods without pollution. (See Annex 2 diagram 1).

RAINWATER FOR AGRICULTURAL PURPOSES

Normal practice of the farmers in dry zone area is to prepare the lands by clearing and burning the forest before the heavy rain comes. It was realised that this system is a cause for wastage of forest cover and soil. On the other hand, irrigation cannot be provided for all cultivable land which is not economically viable. Therefore, it was realised that it was useful to maintain permanent dryland farming in the dry zone with the help of rain water. Implementing this concept, into a workable programme, it was decided to set up a permanent dry farm project to stabilise the shifting farming system under Muthukandiya Dry Farm Project.

This scheme was introduced in 1980 and envisaged to construct 600 farm ponds. Total acreage of alienation is 3400 acres under this programme. Each farmer has been given 5.75 acres farm allotments and a pond is constructed within his farm. Ponds are designed for 25 years of life span and the capacity of each pond is 750 to 1000 cubic yards. The storage capacity of these tanks would be sufficient to supplement the rain water for his farm. Collected rainwater can be used in the dry season for cash crops or vegetable farming. (See Annex 3-photograph).

Taking into consideration the contours in the farm allotment, waterways and ponds have been constructed. To protect the waterways and ponds from soil erosion, it is covered with grass and it would help the farmers to feed his cattle in the farm. This grass cover is helpful to maintain the humidity of the farm vicinity.

ADVANTAGES AND DISADVANTAGES

Rain water collecting through the roofs of permanent houses is very effective because it is less costly and easy to maintain. The quality of water is far better than ground water of the area. This would help to ameliorate the hygienic condition of the water users. But there are difficulties in the successful implementation of this system.

The main constraint of this programme is little availability of permanent houses or houses with permanent roofs. Other constraint is the lack of money for capital investment on tank construction. Another reason is the less dependency of the residents on using rain water.

Advantages of collecting rain water for agricultural purposes are very remarkable. This system would help to stabilize the shifting cultivation and help to increase the soil stability by controlling runoff water. It would help to increase the infiltration of water into the soil. Contour systems and the ponds were designed to prevent soil erosion and it would help to improve the soil structure.

The farmer can use his labour more efficiently as the pond is situated within his own allotment. The ground water content also increases and the quality of ground water may improve. The farm family can maintain the farm pond and waterways.

This system also has its constraints because the capital investment for the system cannot be afforded by an individual. Therefore the need for some assisting agency to provide financial and technical assistance will arise. Another constraint is that the pond would help to breed mosquitoes and it will be a health hazard to the residents. This scheme is also new to the users and a programme for educating its users is being drawn.

CONCLUSIONS AND RECOMMENDATIONS

It has been revealed that there is a greater possibility of improving rain water use for domestic and agricultural purposes. Though there are few constraints like funds and technical know-how, it is economically viable to expand this system in every possible area. There would be some scheme of assistance for construction of rain water collection systems, ponds and waterways. It is necessary to improve the knowledge of the users by educating them. Storage of water in the ponds can be utilised more scientifically by use of water pumps and lift irrigation methods which would in turn help efficient land use.

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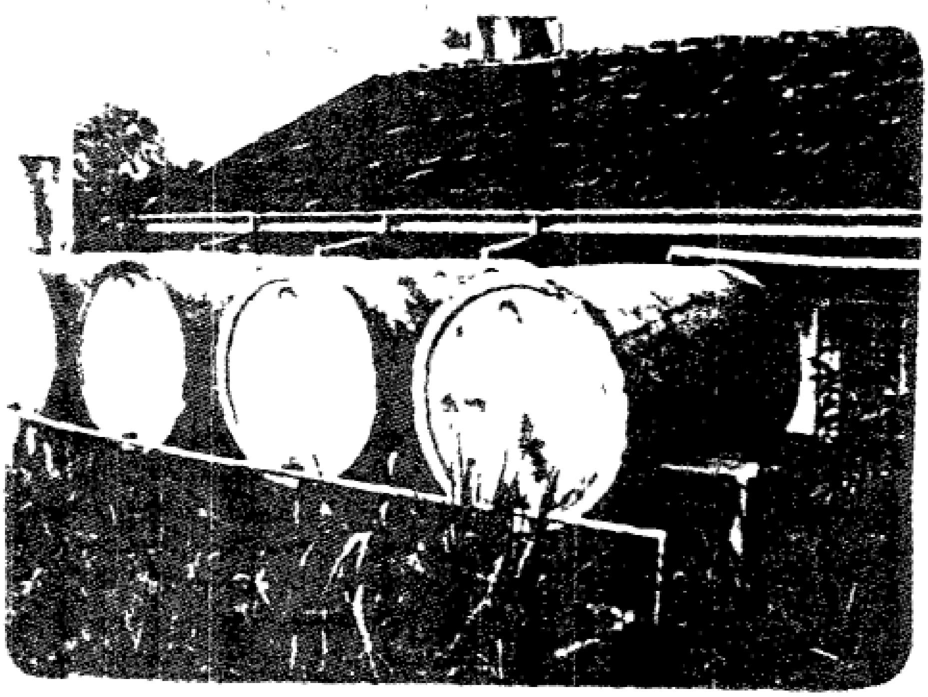
Report	Water Quality for Agriculture - F.A.O. Irrigation and Drainage paper - 1985 - 29 Rev. 1.

DIAGRAM 1



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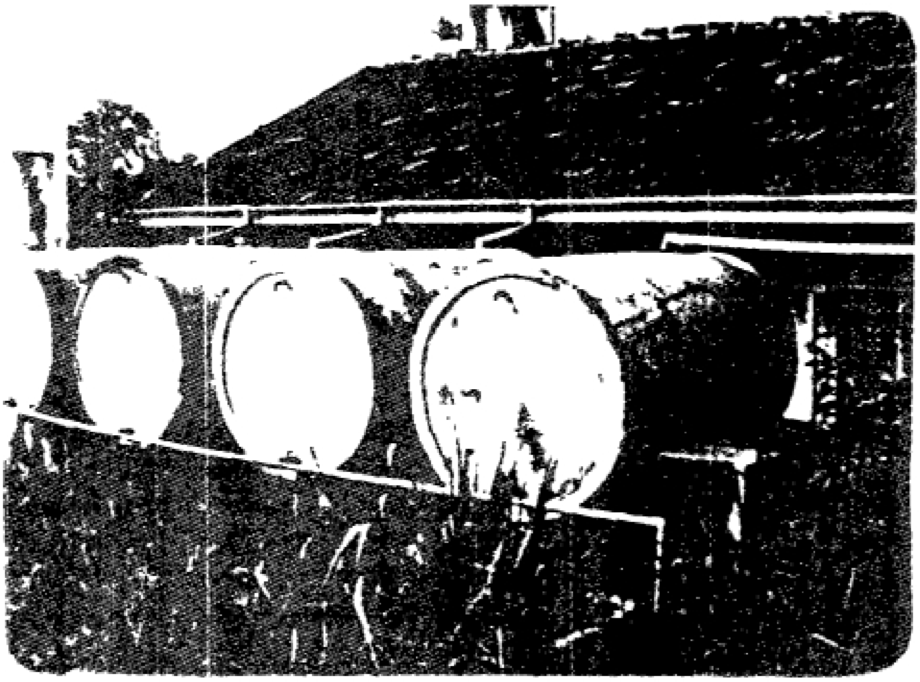
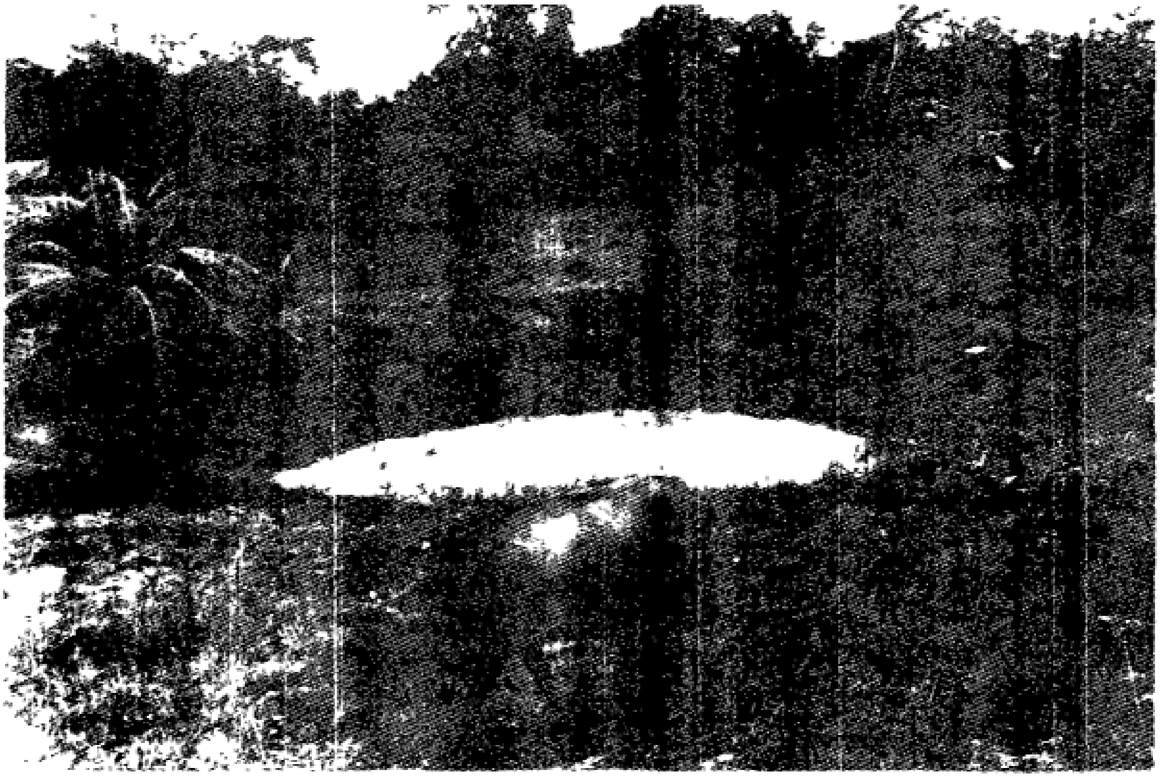
ANNEX 2

DIAGRAM 1



ANNEX 3



VILLAGE LEVEL WATER STORAGE AND UTILIZATION PRACTICES IN NORTHEAST THAILAND:

A SURVEY AND PROJECT EVALUATION

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ABSTRACT

This study was undertaken in three Provinces in Northeast Thailand in 1985. It was found that villagers normally utilized jars with varying capacity from 40-2,000 liters to store water. For nontank owners, an average storage capacity of drinking water per head was 175 liters. Those participating in the Rainwater Tank Project provided by the Population and Community Development Association, had an additional vessel with 11,300 liters capacity. The amount of water consumed by villagers varied with age groups and sexes. Regarding the impact of the Rainwater Tank Project on villagers' life styles, it was evident that the main benefit to the villagers was a private, safe water source for drinking and for other necessities. They utilized a larger amount of water for hygienic activities and practiced them more often than ever before --- a trend toward a better quality of life.

INTRODUCTION

Lack of clean drinking water has long been a major problem for rural villagers in the Northeast. In 1966, with the cooperation of various organizations, such as the office of Accelerated Rural Development, Sanitation Division, Department of Health, and the Department of Mineral Resources, the Thai government initiated the Drinking Water Supply Project for people in the rural areas (Sethaputra, 1984). Later other organizations, both governmental and private helped develop water resources such as the Thai-Australia Village Water Supply Project, the Population and Community Development Association, and the Jaques Pariso Foundation.

Despite all efforts made, the problem of the seasonal shortage of safe drinking water still exists in rural villages in the Northeast. Usually, villagers depend on water from natural water sources such as shallow water wells, deep wells, ponds, and natural lakes. Dams and reservoirs are found in only a few villages. As regards domestic utilization of water, it is known that during the rainy season, villagers have enough for domestic use and consumption. For them, rainwater is preferrable for it tastes better.

During the dry season, which extends from November to May, however, villagers face a problem due to shortages of drinking water (Nopmongkol and Patamatamkul, 1984). Various points relating to the drinking water problem include : drinking water containers ; the quality of the drinking water ; and a seasonal shortage of drinking water sources. As for drinking water containers, the Northeast rural villagers had only small types of containers such as pottery jars and ceramic jars (Bruns, 1984). These hold only a small amount of water. Therefore villagers do not have adequate storage capacity to keep enough rainwater to use throughout the year. Thus, they have to depend on natural water sources.

Regarding the quality of water from ponds and shallow wells, experts have some doubts about potability for it is easily contaminated. From a survey conducted by the Thai-Australia Village Water Supply Project (1984), it was found that in the provinces of Mahasarakham and Khon Kaen, there are still many sources of drinking water with unsatisfactory levels of faecal coliforms when judged against the WHO standard of zero MPN/100 ml.

As for the seasonal shortage of drinking water sources, this appears to be due to the lack of water from natural water sources, since they become dry in the dry season. In some places, villagers may have to look for drinking water in locations more than five kilometers outside their villages (PDA, 1984). Sometimes they have to wait in long queues and also have to wait for the water to accumulate in the shallow wells. This wastes both time and energy.

The study of White et al. (cited in TAVWSP, 1984) conducted in East Africa indicated that women in the rural areas used 9 per cent of their daily calories in carrying water. If these people did not have to spend this amount of energy, they could have used it for useful production, caring for children, and other essential activities. Similarly, in the Northeast region, if villagers have clean drinking water sources within their compounds, the water carriers can spend their energy for other activities beneficial for the economy of the family.

The aim of this study was twofold : first, to conduct survey research in order to provide information for researchers and personnel working on safe drinking water supply programs ; and second, to evaluate the Rainwater Tank Project which has been implemented by the Population and Community Development Association in the Northeast region from the year 1981 up to the present time.

In conducting the survey research, the investigation focused on current practices of rural villagers concerning water storage and utilizations, the pattern of water collection and storage methods, the association between villagers' water storage behavior and social variables, domestic water utilizations especially in the comparative sense between tank owners and nontank owners, per capita water consumption of villagers in different age groups and sexes, and seasonal variations in the quantity of water required by an average village family.

With regard to the PDA Rainwater Tank Project, it was initiated in 1981 with the purpose of providing a source of sanitary drinking water for rural villagers in the Northeastern part of the country and developing a community-based system for the delivery of provided services. This project has been carried out in four provinces : Burirum, Khon Kaen, Mahasarakham and Nakorn Ratchasima. In implementing the project, the PDA has encouraged members of the project or villagers to participate from the beginning through to the end of the operating system as much as possible. That is, those who applied for membership in the project have been required to form groups, each of which consists of approximately 15 members, under the condition that every member must contribute his/her labor to construct rainwater tanks on a rotational basis for each family in that group --- a system of cooperative work.

Regarding the revolving fund mechanism developed by the association, villagers provided all necessary labor while the association provided necessary tools and equipment, construction materials, and technicians to direct construction. During the construction stage, the PDA acted as an advisor and supervisor for tank recipients who worked together in groups. The leader of each group would be selected in order to take charge of the activities such as collecting installment repayments for the revolving fund and working as coordinators between PDA officials and tank recipients. Construction of a rainwater tank can be completed within about one day. The construction workers who were adept and motivated were selected to be trained as village volunteer technicians in order to help other tank owners to properly maintain and clean their tanks, and also help supervise the monthly repayment to the revolving loan fund. On the completion of each tank, the recipient signs a contract stipulating monthly repayments of 200 baht with no interest charges. A down payment of 500 baht is made at the time the contract is signed. The repayment period is 18 months.

Under the Rainwater Tank Project, PDA has constructed over 7,000 tanks over the period 1981 to the present time. The association estimates that 13,600 concrete tanks will be constructed in the four provinces of Northeast Thailand. Therefore, the present study was required to evaluate the impact and the implementation process of the project in order to assist all parties concerned in making appropriate future adjustments for the project's operations. The evaluation was undertaken with the following objectives : to ascertain the benefits derived from being project members, to identify the impact of the provided water sources on the owners' life styles, especially activities concerning water storage and utilization practices, and to identify the strengths and weaknesses of the internal dynamics of the project operations and search for explanations of the effectiveness, failures, and changes at various stages.

METHOD

Sample

The sampling procedure was based on the multistage stratified technique. The well defined factors related to the PDA Rainwater Tank Project such as implementational areas, number of tanks constructed in each village, and the tank's age, were taken into consideration in stratifications. From the beginning of the project through 1985, the activities were implemented in 20 districts of Burirum, Khon Kaen, Mahasarakham, and Nakorn Ratchasima provinces in the Northeast region. In this study, only the first three provinces were selected ; Nakorn Ratchasima was excluded due to its initial stage of implementation and also because the authors wanted to study those tank owners who constructed tanks and used them in catching rainwater for at least one rainy season. The PDA provided lists of tank owners and the number of tanks constructed in each district which were used as guidelines in stratifications. Districts in which the project has been implemented were randomly selected in the first stage of the sampling procedure. And within each district, the implemented villages were randomly chosen for the second stage of this multistage sampling. Finally, in the last stage, within each village, random selection of households was made, proportionate to the number of tank owner families of the village. As for the nontank owner groups, they were from both the villages of the existing rainwater tank project and those adjacent villages where the project is not operating. These groups were designed to be a comparison group to measure against the tank owner group.

This study was conducted in 26 villages ; 21 of which are villages of the existing PDA project while the rest are those outside the PDA's target areas. In collecting data, the group of researchers worked together in evaluation of the PDA project ; but for the survey research the group was divided into two teams : the social scientists and the engineering team. The number of households selected for the evaluation study and for the survey under the responsibility of the social scientists was 717 : 504 of which were tank owner families ; 213 were nontank owner families. The engineering team selected 168 tank owner families with 393 respondents and 161 nontank owner families with 435 respondents to estimate the per capita requirement of water for consumption and utilization by villagers.

Collection of Data and Information

Collection of data and information was accomplished by different techniques. The questionnaires constructed under the supervision of the social psychologist and the social scientist were used as guidelines in oral interviews with the target group. Observations on water storage patterns and utilization practices were concurently conducted during the interview with villagers in each household. As regards the respondents, there were two main respondent groups in each household, namely, the male household head or housewife, and water carriers. However, other family members were also invited to participate in the interview and group discussions. Simulations were also carried out by the engineering team in order to estimate per capita water consumption.

Apart from the aforementioned techniques, the research team also conducted indepth interviews with personnel involved in the PDA Rainwater Tank Project, and participated in activities and meetings organized by these people.

The responsibility of the social scientist team in collecting research data involved villagers' perceptions and practices concerning water storage and utilizations, cultural elements of water acquisition, socio-economic conditions of villagers, and villagers' attitude towards drinking water. The major concern of the engineering team was focused on estimating the per capita requirement of water for consumption and utilization by tank and nontank owners in each season.

With respect to evaluation of the project, dimensions of evaluation included both product and process evaluations. For the product evaluation, the approach was based on system analysis (Patton, 1980). The important input variables for the project such as the set target of number of tanks to be constructed and the baseline performance levels of tank owners before having tanks were identified. The ouput measures included placement rates of PDA tanks as compared to the set target, tank owners' skills in utilizing the rainwater tank as their own water sources, and benefits derived from being the project members. As concerns the process evaluation, the research team focused on the following issues : the strengths and weaknesses of the internal dynamics of the project operations, the perception of the PDA staff and the participants on the project, and the nature of staff-client interactions.

Analysis of Data

The research data were analyzed in terms of both descriptive and inferential statistical analyses. Regarding the descriptive statistical analyses, frequencies of data from classificatory samples, percentages, and the arithmetic means were presented to describe the existing characteristics of the target group. As for the inferential statistical analysis, the chi-square test for independence was utilized to determine the association between the social variables such as family size, economic status, etc. and water storage practices.

RESULTS AND DISCUSSION

It was evident from the survey that perceptions and practices of rural villagers concerning water storage and utilizations were substantially different from those living in urban areas. This might possibly be due to the fact that those villagers had to rely on primitive natural water sources for their water supply. Water storage patterns of the Northeast villagers at the household level are of interest : they distinguished between water for domestic utilization and that for consumption and therefore stored these two types of water seperately. Water for domestic utilization, was from several sources : ponds; rivers; shallow and artesian wells; and rainwater if it was in the rainy season. Drinking water was limited to rainwater, shallow well water, and water from ponds. Jars were the typical vessels used for storing water. Their capacity varied from 40-2,000 liters. Pottery and ceramic jars were generally favored for storing drinking water because of their advantage in protecting the flavor of the water especially rainwater. Those who joined the PDA Rainwater Tank Project, had in addition, concrete tanks to store rainwater, with 11,300 liters capacity.

Regarding the average drinking water storage capacity per head, even when the rainwater tank was excluded, it was still found that drinking water storage capacity of the tank owners is 259 liters which is much greater than 175 liters of the nontank owners (See details in Table I). To construct a water tank, one must improve the roof and gutter, thus creating more water-catching capacity. Some tank owners suggested that they regretted the loss of water from the gutter and the overflow pipe and that they wanted to store it, so they bought more vessels.

Results from the nonparametric statistical analyses, the chi-square tests, show that the groups of the nontank owner families from different income levels (chi-square = 28.73 ; df = 35), and family sizes (chi-square = 17.98 ; df = 15) did not significantly differ in their water storage capacities. This implies that those social variables do not notably affect the storage behavior of the nontank owner samples. We can see that the Northeast villagers' water storage behavior is interesting and worth further investigating for those working on water resources development projects.

As regards water utilizations, it was found that tank owners use more water than nontank owners in all household activities (See details in Table II) and with approximately 20 per cent more for the total household activity water. This may be the result of the convenience factor and/or the sense of security of having a large volume of water stored in the tanks. The amounts of drinking water consumed by tank and nontank owners during the same seasonal period were approximately the same. This shows that the convenience factor of having rainwater tanks did not increase the amount of drinking water consumption and also it reflects the consumption capacity of these ordinary people having a limited use of water with or without tanks. The amounts of drinking water consumed during the rainy and hot periods were 20-30 per cent and 60-70 per cent respectively greater than that consumed during the cold period. The amount of drinking water also varied with age groups and sexes. It increased with age, peaked between the age of 30-50, and started to decrease with older age. Males drank approximately 10-30 per cent more water than females of the same age group (See details in Table III). The per capita drinking water during the dry period was 4 liters/day. However, it was found that, villagers also used rainwater for cooking as long as it was still available. Hence, for the purpose of rainwater storage capacity estimation, the per capita water for internal consumption of 5 liters/day which is equivalent to 1 cu.m./dry period, should be used.

As for the evaluated project, this project as a whole is evaluated as highly successful. More tanks had been contructed than expected in the target districts, and also the target areas are extending with every year of implementation. Regarding the impact of water tanks on the owners' water storage and utilization practices, it was evident that having a rainwater tank has made the villagers see the usefulness of water storage

Table I

Average Storage Capacity of Drinking and Usage Water in Tank Owner and Nontank Owner Families

Average of Storage Capacity	Drinking Water			Usage Water	
	TO		NTO	TO	NTO
	Including Tank Capacity	Excluding Tank Capacity			
Per Family	12,750	1,450	891	720	69
Per Head	2,277	259	175	129	14

Table II

Average Amount of Water per Person per Day Used by Villagers for Each Household Activity

Activities	Average amount of Water per Capita per Day Used by Villagers (liters)	
	Tank Owners	Nontank Owners
Rice Steaming	3.33 (1.0-8.0;1.22)	2.84 (1.0-8.0;1.39)
Cooking	0.92 (0.16-3.0;0.47)	0.88 (0.28-2.50;0.42)
Vegetable Cleaning	1.87 (0.14-6.42;1.26)	1.63 (0.11-12.0;1.45)
Vegetable Gardening	4.99 (0.0-53.3;8.27)	3.91 (0.0-50.0;7.24)
Cloth Washing	7.51 (1.28-30.0;5.14)	6.13 (1.33-25.0;4.44)
Dish Washing	4.49 (1.11-15.0;2.54)	4.15 (0.75-22.50;2.96)
House Cleaning	1.25 (0.0-10.0;1.59)	0.90 (0.0-10.0;1.56)
Total	24.36	20.44

Note : 1. Figures in brackets mean (lowest Value-highest value; standard deviation).

2. The average amount of water use/person/day is calculated for each activity which may be done several times a day or one in several days.

Table III

Variation of the Amount of Drinking Water with Sexes and Age Groups

Age ranges	No of persons	Male Average amount of drinking water (liters)			No.of persons	Female Average amount of drinking water (liters)		
		rainy period	cold period	hot period		rainy period	cold period	hot period
0-10	22	2.07	1.64	2.74	25	1.83	1.47	2.48
		(0.92)	(0.75)	(1.22)		(0.91)	(0.79)	(0.95)
11-20	87	2.75	2.18	3.77	138	2.38	1.89	3.18
		(1.04)	(0.82)	(1.40)		(1.05)	(0.85)	(1.25)
21-30	54	3.22	2.64	4.23	99	2.67	2.08	3.58
		(0.97)	(0.87)	(1.33)		(0.99)	(0.86)	(1.17)
31-40	46	3.51	2.66	4.68	97	2.97	2.29	3.95
		(1.20)	(1.09)	(1.33)		(0.95)	(0.93)	(1.12)
41-50	44	3.69	2.83	4.97	74	2.79	2.28	3.70
		(1.24)	(1.02)	(1.40)		(1.03)	(0.95)	(1.06)
51-60	43	3.22	2.51	4.55	53	2.27	1.91	3.11
		(1.20)	(0.97)	(1.40)		(0.87)	(0.78)	(1.02)
61-70	17	2.65	2.09	3.79	21	1.72	1.38	2.57
		(1.11)	(0.91)	(0.99)		(0.48)	(0.55)	(0.55)
71-more	3	1.17	0.83	2.1	5	2.0	2.0	2.8
		(0.29)	(0.29)	(0.29)		(0.61)	(0.71)	(0.76)
	316				512			

Note : Figures in brackets are standard deviations.

and has encouraged them to provide more vessels so as to increase water storage capacity, the results of which give them the use of a larger amount of water for various activities especially the hygienic activities such as washing clothes, taking a bath, washing hands before meals, and cleaning the house. However, the disadvantages of the rainwater tanks according to the villagers' viewpoints, appeared to be the high cost of investment and the unfavorable flavor of water stored in a newly-built tank. With respect to the process evaluation, it appeared that the strength of the implementing project lies basically in the training of village volunteer technicians to act as communicators between PDA and villagers; these technicians helped disseminate the project activities and hold responsibilities in maintenance work. The other factors contributing to the success of the implementation process are, the utilization of the cooperative work, the provision of appropriate technology which the villagers could accept and adopt, the PDA work system, the qualifications of PDA staff, and the good relationship between staff and the villagers who joined the project. For the revolving fund mechanism, it was discovered that the main factor obstructing the PDA from receiving the first installment payment arose from the money collectors rather than from the economic difficulties of the tank recipients. If the money collectors understood their roles, and were attentive in collecting the installments from the tank recepients, and were honest ; the rate of repayments would be high.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study suggest that, having been exposed to the drinking water source development project the villagers recognized the benefits gained from their private water sources. The villagers' acceptance of the rainwater tank was evident through their willingness to acquire more storage containers. Accordingly, this helped them to overcome the problem of a seasonal shortage of safe drinking water. In addition, those who have access to safe water sources practiced hygienic activities more often.

Even though the generalizability of the results of this study is somewhat limited due to the samples selected for the investigation, the authors still hope that the present study could help alleviate lack of understandings on the Northeast villagers' practices on water storage and utilizations. In addition, lessons learned from the PDA Rainwater Tank Project may help prevent repeated mistakes in further operations of the implementation and other related projects as well.

At present, there are many campaign projects for clean water in the Northeast. These results encourage the villagers to own storage vessels with more storage capacity, thus decreasing water carriers' burden. The authors would like to recommend interested researchers to conduct a study on water carriers' behavior with no carrying burden. On what activities do these people spend their free time? Do these activities affect their families' economy? How much do these changes affect the people's going out to work outside their villages?

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