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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