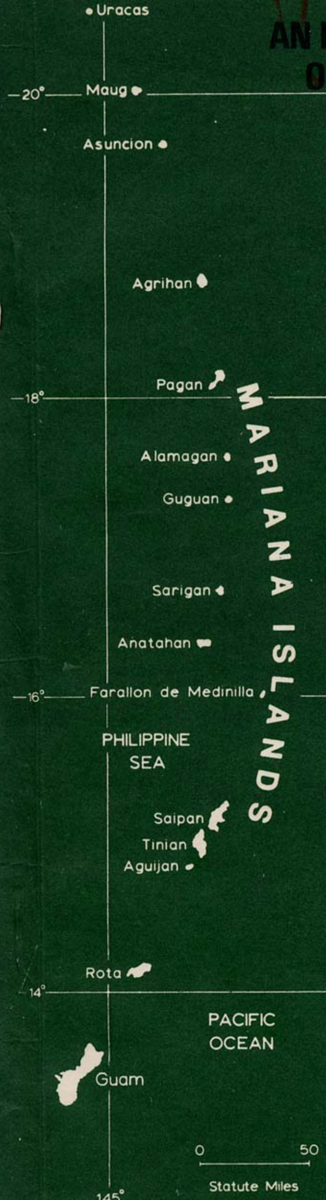

AN INVESTIGATION OF THE WATER QUALITY OF ROOFTOP RAINWATER CATCHMENT SYSTEMS IN MICRONESIA

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Water and Energy Research Institute of the Western Pacific

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Project Completion Report

for

AN INVESTIGATION OF THE QUALITY OF ROOFTOP RAINWATER CATCHMENT SYSTEMS IN MICRONESIA

Project No. A-029-Guam, Agreement No. 14-34-0001-2112

Principal Investigators: Theo A. Dillaha and Stephen J. Winter

Project Period: January 1, 1982 to September 30, 1983

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This research involved an investigation of rainwater catchment system (RWCS) characteristics and water quality in Micronesia. The objectives of the research were to determine the bacteriological state of existing RWCS waters by analyses of fecal and total coliform bacteria and to try and identify those catchment characteristics and maintainance practices which affect catchment water quality.

A total of 203 different RWCS were sampled in Kosrae, Ponape, Yap and Palau. Seventy-one percent of the RWCS sampled had no fecal coliforms per 100mℓ and 37 percent had no total coliforms per 100mℓ. Eighty-five and 70 percent had 5 or less fecal and total coliforms respectively per 100mℓ. Cleaning the catchment tank, roof and gutters were not found to affect RWCS water quality significantly. Total coliforms counts were significantly affected by screening the tank inlet and by the type of catchment tank.

In general, screens and tank coverings improved water quality. The newer ferrocement tanks had the best water quality while metal barrels had the poorest.

Catchment tanks were the largest and most popular source of water in Yap where water is less plentiful. Catchment tanks were also popular in areas with other sources of water. Even in areas with treated piped public water supplies, catchment systems appeared to be preferred for drinking purposes because of objections to chlorine taste and mistrust of the quality of public water.

LIST OF TABLES

INTRODUCTION

Historically, rainwater harvesting has been practiced for thousands of years. Systems in North Africa and the Middle East, such as the extensive hillside systems developed by the Nabateans in the Negev Desert of Israel were developed two thousand years ago. Today, rainwater catchment systems (RWCS) are found in almost every nation of the world.

In spite of their current and long historical use, RWCS receive little attention on a world wide basis as a significant water source. One indication of this lack of attention is the fact that little work has been conducted to quantitatively evaluate the water quality or potability of water from RWCS. Water resources planners and public health workers therefore have a difficult time evaluating the relative merits of RWCS surface and groundwater sources for which a bountiful supply of water quality information exists. The current research study was undertaken to obtain information concerning the water quality of RWCS. Specifically, this study attempts to evaluate the bacteriological water quality of RWCS against as a function of system design and management. In addition, the study provides general bacteriological water quality data about RWCS as a whole.

Significance of Safe Potable Water Supplies

In Micronesia, as in most other areas of the developing world, the lack of a safe, dependable and convenient potable water supply is a major obstacle hindering economic development. A safe and adequate water supply is essential to protect the public health and for the development of industries such as food processing, fish freezing and tourism. Safe water not only minimizes suffering caused by water borne diseases but it also results in accelerated economic growth due to increased worker health and productivity.

Epidemicological studies have repeatedly identified contaminated water as the principal transmitting agent of typhoid, cholera and bacillary dysentery. A lack of safe water for drinking and washing is also an important factor affecting the spread of other diarrheal diseases. According to WHO estimates (WHO, 1981), a child under five dies every two seconds in the Third World from diarrheal disease (the most common cause of death in infants in the developing world). Infant mortality due to diarrheal diseases is so prevalent in some areas of Micronesia that infants are not even named unless they survive their first year. Diarrheal diseases are also a leading cause of death for the elderly in Micronesia.

Because of the previous reasons given, the United Nations has declared that the 1980's be designated as "The International Drinking Water Supply and Sanitation Decade". The goal of the Decade is "Safe water for all" by 1990. Considering that up to 75 percent of the population of Third World countries lack safe and adequate water supplies, the problem is immense. It is hoped that this study will contribute in a small way towards the achievement of the goal of the Decade.

Rainwater Catchment Systems in Micronesia

Rainwater catchment systems are one of the primary sources of drinking water in Micronesia. On many of the low islands, rainwater catchments are the only significant source of freshwater because the islands have few if any springs or streams and because groundwater wells are often brackish or contaminated. On larger islands with adequate fresh groundwater and streamflow, RWCS are often still preferred because of the convenience of a source near the home or because of past bad health experiences with alternative sources. Many citizens (including environmental health and public works officials) in urban areas with piped public water supplies continue to use their RWCS for drinking and cooking because of taste and turbidity problems. Taste objections are usually due to chlorination while turbidity problems are generally caused by overloaded filtration plants and leaky distribution systems which allow infiltration of turbid groundwater into the system between water hour periods.

In Micronesia, RWCS generally consist of a collecting surface, a guttering system to concentrate and collect the flow and a storage tank. Figure 1 is an idealized schematic of a typical system. Typically, collecting surfaces are the rooftops of private homes or public buildings and the predominant roofing material is galvanized corrugated metal. Gutters and downsprouts are usually of prefabricated or homemade galvanized metal but plastic pipe and bamboo are also used.

Storage tanks are made from a variety of materials. Older tanks are generally of poured reinforced concrete or steel tanks obtained as war surplus material. Tanks of more recent construction are usually of poured concrete or ferrocement type construction. Ferrocement tanks are becoming increasingly popular because of their lower materials costs. Discarded 55 gallon drums are another common storage device. These are particularly common in remote areas. Typically, the tops are removed and they are left open but some are covered with cloth, screen or tin. Water is usually withdrawn using a dipper (a potential source of bacteriological contamination). Figures 2 through 5 are typical Micronesians RWCS storage tanks.

Also shown in Figure 1 are two devices for removing contaminants from rainwater before the water enters the storage tank. These devices, a foul flush device and a filter device, are not normally found in Micronesian RWCS.

Foul flush devices seek to improve catchment water quality by diverting the early runoff of dirty water from a roof at the beginning of a storm from the storage tank. This water typically contains a high concentration of dust, leaves and other debris which has collected on the roof since the last runoff event.

Filtering devices are used to remove solid matter from the roof runoff by passing the runoff through a sand or fiber filter. There are several operational difficulties with filters such as flow retardance and required maintenance which may preclude their use. Filtering devices may be used with or without foul flush devices. Keller (1982) presents a good discussion of the foul flush and filter devices.

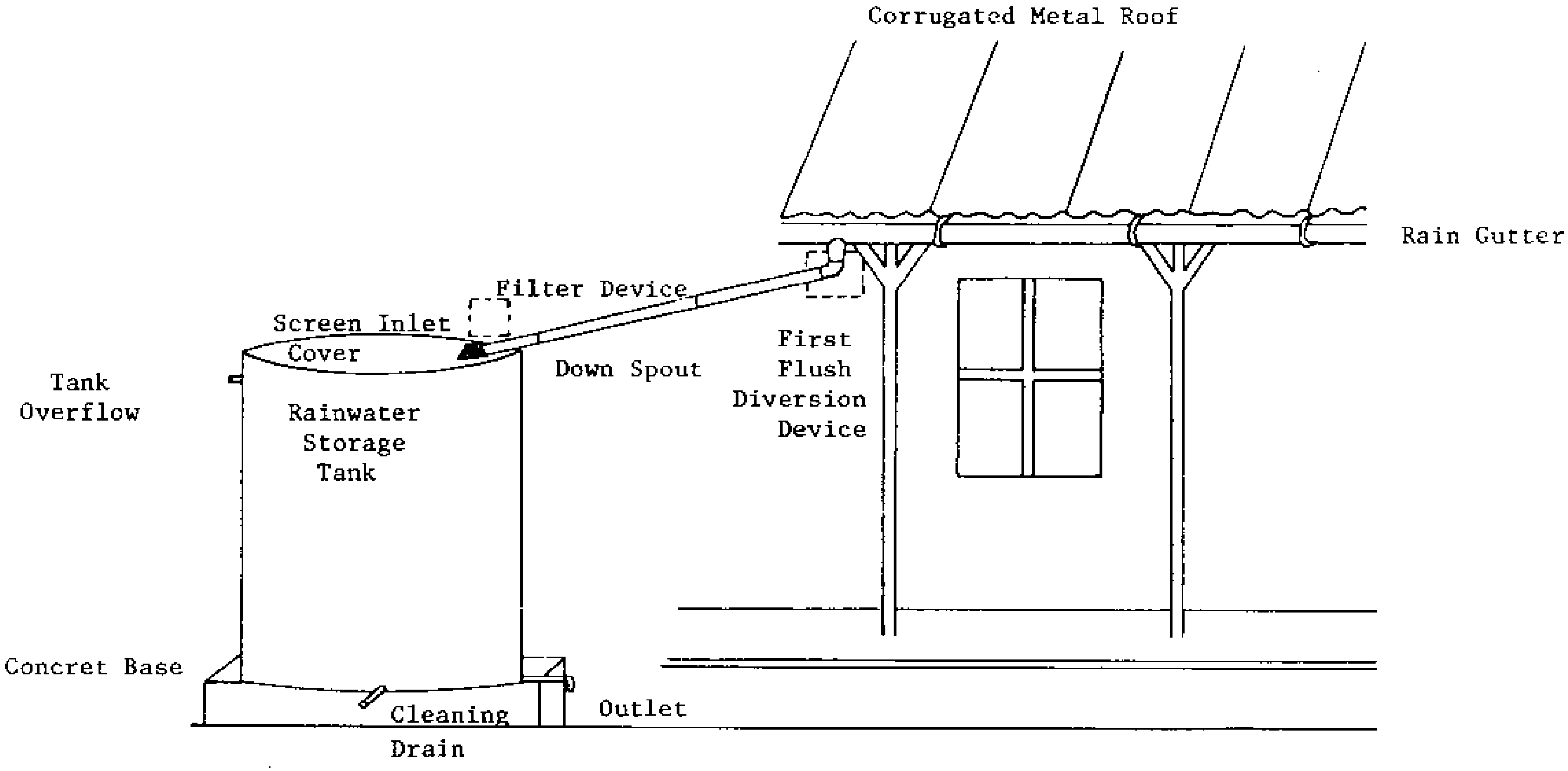

Figure 1. Rainwater catchment system.

Figure 4. Ferrocement catchment tank with cover (note bent tin gutter).

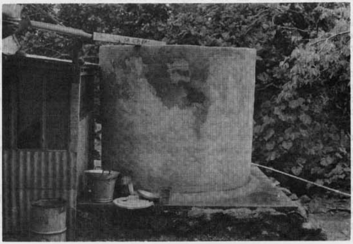

Figure 5. Ferrocement catchment tank without cover.

In Micronesia, the inlets to storage tanks are usually screened to prevent gross particles from entering the storage tanks. Normally, window screen type wire mesh is used but cloth is used in some locales. If the tank is covered, as it is in most cases, the screened inlet (and overflow outlet) also keeps insects, animals, leaves, etc from entering the tanks. Screen is particularly valuable in excluding mosquitoes which may otherwise breed in the tank.

All RWCS must be maintained properly if they are to provide safe water. Maintenance procedures include periodic cleaning of roofs, gutters, screens and the insides of the catchment tanks. Roofs and gutters are cleaned to minimize foul flush problems. Screens are cleaned to keep the inlet open and to prevent biological growth on them. Tanks are cleaned to remove objectionable materials which have entered and accumulated in the tank. Tanks are also normally disinfected with a chlorine wash during the cleaning process.

Another common maintenance procedure is the periodic addition of a disinfectant such as chlorine to the tank to kill any bacteria that are present. This practice is not common in Micronesia.

Literature Review

Though rainwater collection systems have been ignored as a research topic, recently, increased interest has focused on their potential for supplying drinking water. The International Conference on Rainwater Cistern Systems, co-sponsored and held at the University of Hawaii in 1982, was a product of this increased interest (University of Hawaii, 1982). Several studies were presented at the conference that dealt specifically with rainwater catchment systems in the tropical third world.

In Micronesia, Stephenson et al. (1982) investigated the use of water on Majuro atoll of the Marshalls Islands. Their sample of 41 households contained a clear majority, 61%, of homes using permanent to semipermanent structures to collect rainwater for a domestic water supply. The other households either utilized makeshift apparatus (e.g. plastic buckets) to collect direct runoff from the roofs of their homes or borrowed water from neighbors who had constructed a collection system. Socioeconomic factors (i.e. cost of materials), were determined to be the main characteristic in RWCS design and utilization. Romeo (1982) conducted a survey of 15 catchments in Koror, Palau, Western Caroline Islands, for total and fecal coliform bacteria, specific conductance and turbidity. His findings showed that catchment bacteriological water quality was good. Only 3 of 15 catchments sampled had fecal coliform present. O'Meara (1982) conducted an investigation into the social aspects of freshwater use, including rainwater, in selected villages in Palau. Of 30 households visited, 29 had devices for collection of rainwater and, despite the existance of a public system, rainwater was still mentioned as the primary source of drinking water.

In contrast to Micronesia, the islands of Bermuda have been in close, continous contact with western civilization since they were settled the 16th century. Having no surface water sources and only brackish water in groundwater aquifers, the people of Bermuda have developed residential rainwater catchments systems to an elaborate degree even to the point of legislating cistern size and maintenance requirements for residential roof areas (Waller, 1982). Bacteriological quality of Bermuda cisterns is quite high with typical cisterns having less than 3 total coliform colonies and no fecal coliform colonies per 100 mℓ. This shows the potential of RWCS to deliver safe water when they are adequately constructed and maintained. In contrast, an investigation of RWCS in St. Thomas, U.S. Virgin Islands, showed that a lack of proper design and maintenance of RWCS can result in contaminated water supplies that require tremendous amounts of chlorine addition (to overcome chlorine demand from organic debris) or boiling for cistern waters to be rendered safe for drinking purposes (Lee and Jones, 1982). Unfortunately, for many of the above studies, no detailed coliform analyses accompanied the investigations nor did they specifically investigate reasons for success or failure of systems to provide bacteriologically clean water. Numerous publications were found relating to design and construction methods (Hogge, 1983; Keller, 1982; Stern, 1982; Wagner and Lanoix, 1959; Wright, 1977; Feachem et al., 1978) but they addressed water quality aspects in only the most general terms. Almost all recommended boiling or chemically disinfecting and cleaning the catchment tanks, roofs and gutters regularly but that was the extent of information in the area of water quality.

The lack of information concerning the bacteriological water quality of RWCS in the literature was disturbing and justifies the intent of this research. Undoubtedly, many RWCS have been sampled in the past during routine water quality surveys but this study appears to be one of the first to intensively investigate RWCS bacterial water quality.

METHODOLOGY

The main objectives of this project were to investigate different types of RWCS in Micronesia to determine which types of systems produce the best quality water and to identify those catchment design and maintenance factors which have a significant affect on water quality. The catchment parameters thought to have the main influence on RWCS bacteriological water quality are shown in Table 1. The questionnaire was designed to obtain this information from each household sampled.

Rainwater catchment systems in four of the main island groups of Micronesia were selected for study. The islands were visited during 1982. RWCS were evaluated by collecting water samples from private and public rainwater cisterns. Observations were also recorded concerning RWCS characteristics and the catchment owner or person responsible for its maintenance was interviewed concerning his attitude about water quality, catchment use and maintenance practices. The water samples were subsequently analyzed for total and fecal coliform bacteria as an indication of their bacteriological water quality. Owners were notified during the course of the study if their catchments were found to be contaminated and remedial actions were recommended.

Table 1. Catchment parameters thought to affect RWCS bacteriological water quality.

Parameter
1. Island
2. Type of tank
3. Tank volume
4. Cover on tank
5. Screen on tank inlet
6. Tank cleaning frequency
7. Cleaning frequency of roof and gutters
8. Roof type

At the conclusion of the project, the water quality and interview results were analyzed statistically to identify predominate RWCS characteristics and practices. Inter-island differences were also investigated along with RWCS bacteriological water quality in general and as affected by RWCS characteristics.

Questionnaire

Rainwater catchment system owners or operators were interviewed in the island groups of Kosrae, Ponape, Yap and Palau using the questionnaire shown in Appendix A. Interviews were conducted by project personnel or by local environmental health officers if the interviewees did not speak English. Some errors were undoubtaly introduced by different interviewing styles and translation difficulties and their affect on the data base is acknowledged.

Responses to specific questions were catagorized and coded according to the coding scheme presented in Appendix B. If a response did not fit one of the specified catagories it was classified as a missing value.

Questions 4 and 5 of the questionnaire caused problems during the initial surveys. Question 4 was found to not be specific enough in some areas as many people responded yes but only when making coffee and tea. After this problem was discovered, it was made clear that the question pertained to boiling the water to purify it. An interesting note is that many people on Kosrae said they boiled the water for infants and children but not for adults. This response was coded as "sometimes".

Question 5 also led to a lot of misunderstanding. Originally, the question was "How often to members of your family get diarrhea?" Some people were offended by the question or gave obviously erroneous reponses so the question was changed to its present form "Does the water ever make people sick?"

Catchment, roof and gutter descriptions presented are estimates by project personnel. Size dimensions were approximated as measuring devices were not used. The additional accuracy obtained by actual measuring was deemed unnecessary for the purposes of this project and if carried out would have significantly reduced the total number of catchments and water samples included in the study.

Bacteriological Water Quality

Bacteriological water quality was determined through analyses of fecal and total bacteria present in the rainwater catchment waters. The analyses were performed using the membrame filter technique according to the procedures given in Standard Methods (1980).

Samples were collected in sterilized polyethylene bottles or Whirl-Pak sample bags. Samples from catchments with faucets were collected after the faucets had been running for 5 to 10 seconds. Catchments from which water was dipped (metal drums) were sampled using the catchment dipper or by dipping the sampling container into the catchment. Hands were kept out of the water during the dipping process to minimize sample and catchment contamination. Samples were stored in an ice chest with ice (if available) during transport to the laboratory. Samples were normally processed within 3-5 hours after collection. Samples collected from the remote islands of Kayangel and Ulithi were stored on ice or refrigerated until they could be processed in the laboratory 12-24 hours later.

Dilution of RWCS water samples to obtain low bacterial plate densities was not preformed in this study. Catchment water aliquots of 1 to 100 mℓ were filtered in all cases because coliform populations (fecal and total) were expected to be low (<100) in most cases. This expectation was found to be correct. Dilutions were also not performed because the study was trying to determine relative degrees of bacterial contamination and the greater accuracy achieved through dilutions was not deemed worthwhile in view of the added laboratory work required. It should be kept mind that laboratory work conducted in Micronesia, as in other rural third would locales, must take into account unreliable power and water supplies and in some cases insufficient laboratory equipment and supplies. All supplies for this study including, in some cases, distilled water, were shipped into each study area by the Water and Energy Research Institute Laboratory on Guam.

All positive plates were counted as accurately as possible unless the coliform count was greater than 200/100 mℓ. Counts in excess of 200/100 mℓ were recorded as TNTC (to numerous to count). However, samples classified as TNTC were arbitrarily given a plate count of 200/100 mℓ in subsequent statistical analyses: so, average coliform counts will be conservative.

Plates which were grossly overcrowded with bacteria colonies so that coliform growth was inhibited or confluent were treated as missing data. The total coliform test results for Ponape were rejected because it was felt that the data were a product of bad media or too high a density of bacteria for proper total coliform sheen development.

Statistical Methods

The coded reponses to the questionnaires were analyzed for statistical significance using Statistical Package for the Social Sciences (SPSS for VM/CMS, Version M, Release 8.1, Aug. 15, 1980) programs available on the Virginia Polytechnic Institute and State University computer sytem.

The rainwater catchment survey questionnaires (Appendix A) were coded according to the data coding scheme given in Appendix B. The final code responses for all the questionnaires are presented in Appendix C. This is the data file which was used in all the SPSS analyses.

Two SPSS programs were used in statistical analyses. An analysis of variance program, ONEWAY, was used for significance testing of dependent/ independent variable relationships where the independent variable was a metric parameter (i.e., coliform counts, tank volume, roof area, etc). Only one-way analysis of variance was attempted in this study. Higher order analyses may be possible but a larger data base would have been better for the more advanced analyses required. For comparisons with nonmetric independent variables (category type responses), the Chi-square test for statistical significance provided by the SPSS program, CROSSTABS, was used.

Two types of information were sought from the questionnaires. One type was a summary of the questionnaire responses as a whole and for each island. This summary was designed to both tabulate and to evaluate inter-island similarities and differences. The second type of information sought was the identification of parameters which had a significant impact on water quality throughout the islands.

A quick glance at the rainwater catchment survey sheet (Appendix A) shows that there are many possible combinations of parameters which could be investigated for possible statistical correlation. (378 for one-way correlations alone). The intent of this research, however, was to investigate only those catchment characteristics and management practices which were thought to have the highest probability of affecting bacteriological water quality. As indicated before, the total and fecal coliform tests were used as the standards from which to gage water quality. Table 1 is a summary of the catchment parameters and management practices which were thought to be factors significantly influencing catchment water quality. The data of Appendix C are available for those who which to test other postulated relationships.

RESULTS

Before proceeding with a discussion of the RWCS survey results, it is important to be aware of some of the limitations of the survey procedure. First, none of the islands were surveyed extensively except for Kosrae (where an investigator was trapped for several weeks due to an aviation fuel shortage). The islands of Truk, the Northern Marianas and the Marshall Islands were not visited at all due to time and budget limitations. Catchment systems in Ponape were sampled in only two municipalities. One had piped public water while the other had no piped public water. Sampling in Yap State included the capital, one municipality on the main island and the islands of Ulithi atoll. In the Republic of Palau a significant portion of the population with catchments was sampled but only those who requested sampling after public radio announcements of the project. Sampling was not therefore truly representative of the population. Sampling was also conducted on the islands of Peleliu and Kayangel but the water quality analyses were lost due to a data collection problem.

It is also important to note that the present study does not address the effects of seasonality on bacteriological water quality. One would intuitively expect water quality to be better during the wet season when roofs and gutters are cleaner due to more frequent precipitation and less dust and debris in the air. These effects were not addressed due to the short duration of the project and because individual RWCS were generally sampled only once.

The reader should therefore be cautious in interpreting the data contained herein. This study is the most comprehensive RWCS survey ever undertaken in Micronesia but it still has its limitations.

Inter-Island Variations

Table 2 is a summary of information obtained from the survey questionnaires by island and for all the islands as a whole. The table presents the response distribution in the form of percentages for all categorical type responses. The mean value of the responses is given. The total number of valid responses for each question is enclosed within parenthesis. Also indicated in the table is the significance level for inter-island question response variation. Significance levels greater than .05 are not considered to be statistically significant and are so indicated with a N.S. designation.

Only a few of the significant results of Table 2 will be discussed here. Detailed analysis of the other parameters is left the reader.

Question 1.

The mean number of users per catchment sampled varies from 9 in Palau to 59 in Yap and 33 for all the islands. The inter-island variation in the number of users was also found to be statistically significant ($P<.00$) indicating that there are probably sociological or economic differences relating to water use between the islands. This is a valid hypothesis

Table 2. Questionnaire response summary by island.

Question and Parameter	Level of Significance	Response Summary (no. of valid responses)*				
		Kosrae	Ponape	Yap	Palau	All
1. Average Number of Users/catchment	.00	49(55)*	43(16)	59(29)	9(78)	33(178)
2. Users opinion of water, Percent	.04	(60)	(17)	(34)	(38)	(149)
Bad		15	12	6	8	11
Good		78	59	88	87	80
Don't Know		7	29	6	5	9
3. What is Catchment water used for?, Percent	.00	(63)	(17)	(34)	(57)	(171)
Drinking		6	12	27	28	18
Washing		0	6	0	0	1
Drinking and Cooking		89	77	32	42	61
Washing and Bathing		0	6	6	0	1
Cooking, Washing and Bathing		0	0	0	2	1
Everything		5	0	35	28	18
4. Is the water boiled for drinking? Percent	.00	(61)	(16)	(33)	(39)	(149)
No		48	81	15	56	46
Yes		39	0	67	26	38
Sometimes		13	19	18	18	16
5. Does the water make people sick? Percent	.04	(59)	(14)	(33)	(39)	(145)
No		69	86	97	79	80
Yes		7	0	0	13	6
Sometimes		19	14	3	8	12
Don't know		5	0	0	0	2
6. Average times per year catchment tank cleaned	N.S.	3.7(59)	4.1(15)	3.5(25)	2.4(50)	3.3(149)

Table 2. Continued.

Question and Parameter	Level of Significance	Response Summary (no. of valid responses)* Kosrae	Ponape	Yap	Palau	All
7. Average times per year roof and gutters cleaned	N.S.	2.3(51)	1.3(15)	3.2(25)	1.1(49)	1.9(140
8. Do you ever run out of water? Percent	N.S.	(61)	(13)	(31)	(57)	(162)
No		56	69	61	77	65
Yes		44	31	39	23	35
9. Do you use other sources of water? Percent	.00	(62)	(16)	(32)	(60)	(170)
No		0	0	19	5	5
Yes		100	100	81	95	95
10. What other sources of water are used? Percent	.00	(62)	(16)	(26)	(56)	(160)
Public		100	44	0	57	63
Streams		0	25	15	0	5
Springs		0	31	15	4	7
Wells		0	0	42	39	21
Other catchments		0	0	27	0	4
11. What is the other source used for? Percent	.00	(57)	(16)	(26)	(53)	(152)
Drinking		0	0	4	0	1
Washing		2	0	46	2	9
Drinking and Cooking		0	0	4	0	1
Washing and Bathing		95	56	15	60	65
Cooking, Washing and Bathing		3	19	0	23	11
Everything		0	25	31	15	13
12. Catchment type, Percent	.00	(63)	(17)	(36)	(84)	(200)
Poured Concrete		92	6	47	36	53
Ferrocement		2	47	0	6	7
Steel tanks		5	41	8	36	22
Metal drums		1	6	36	19	15
Other		0	0	9	3	3

Table 2. Continued.

Question and Parameter	Level of Significance	Response Summary (no. of valid responses)* Kosrae	Ponape	Yap	Palau	All
13. Average catchment volume, m^3	.00	13.2(57)	5.5(16)	23.0(33)	6.3(72)	11.5(178)
14. Internal cleanliness of catchment Percent	N.S.	(40)	(2)	(24)	(27)	(93)
Good		40	0	46	63	47
Fair		40	100	21	22	31
Poor		20	0	33	15	22
15. Is catchment covered? Percent	N.S.	(62)	(16)	(36)	(81)	(195)
No		16	37	28	19	21
Yes		84	63	72	81	79
16. Cover type? Percent	.00	(50)	(10)	(26)	(31)	(117)
Tin		28	100	31	67	45
Concrete		72	0	57	16	48
Screen		0	0	8	7	3
Cloth		0	0	0	7	2
Wood		0	0	4	3	2
17. Is catchment inlet screened? Percent	.00	(50)	(16)	(32)	(76)	(174)
No		30	69	69	29	40
Yes		70	31	31	71	60
18. Roof type? Percent	N.S.	(63)	(16)	(34)	(84)	(197)
Tin		100	100	91	98	97
Concrete		0	0	9	2	3
19. Roof condition? Percent	.01	(58)	(14)	(33)	(80)	(185)
Good		40	50	49	69	55
Fair		46	43	27	22	32
Poor		14	7	24	9	13

Table 2. Continued.

Question and Parameter	Level of Significance	Response Summary (no. of valid responses)* Kosrae	Ponape	Yap	Palau	All
20. Gutter Type? Percent	N.S.	(61)	(14)	(34)	(83)	(192)
Plastic or prefabricated		42	71	41	32	40
Bent tin		54	29	41	57	51
Bamboo		2	0	6	1	2
None		2	0	12	10	7
21. Gutter condition? Percent	N.S.	(56)	(13)	(26)	(72)	(167)
Good		57	61	54	60	58
Fair		20	31	19	32	26
Poor		23	8	27	8	16
22. Roof area, m^2	N.S.	85(50)	130(16)	75(33)	90(83)	90(182)
23. Percent of roof area used for water collection?	.00	45(61)	34(15)	79(33)	42(77)	49(186)
24. Fecal coliforms/100 m	N.S.	14(63)	15(17)	40(36)	18(60)	21(176)
25 Total coliforms/100m	.00	6(63)	-(0)	63(37)	38(55)	31(155)

*where ( ) contains the number of valid responses to this question.
N.S. indicates that the inter-island differences are not significient at the 95 percent confidence level.

since much of Palau is served by public systems and water is much more available while the areas sampled in Yap had no public supplies.

Question 3.

Rainwater catchment water use was fairly consistent between islands. Seventy-nine percent of those interviewed indicated that they used their RWCS water exclusively for drinking and/or cooking purposes (79%). This indicates that Micronesians understand that their catchments' capacities are limited and they conserve water by restricting its use.

Question 4.

When asked if RWCS water was boiled prior to drinking, only 38 percent responded yes in spite of the fact that all Environmental Health officers have been trying to encourage disinfection prior to consumption. This response is supported as 80 percent of those interviewed reported that their catchment water was good and didn't make people sick. Yap was radically different with respect to the boiling question; 67 percent reported they boiled their water.

Questions 6 and 7.

The number of times that catchments, roofs and gutters were cleaned per year was not found to differ statistically between islands. The people of Yap appeared to be the most frequent cleaners while those on Palau were the least frequent. On the whole, catchment tanks and roofs and gutters were cleaned 3.3 and 1.9 times per year respectively. Obviously, not as much importance is given to roof and gutter cleaning.

Questions 9 and 10.

Ninty-five percent indicated that RWCS were not their only source of water. Only on Yap did a significant number of people indicate that RWCS water was their only source (19%). These individuals were from the Ulithi atoll. Atolls, because of their low elevation, generally have brackish ground water and no surface water resources. One hundred percent of the people on Kosrae indicated that their secondary source was a public system (untreated piped stream water) but none said they used the water for drinking or cooking. In Ponape, public, stream and spring-water was available but it was avoided as a potable source. In Yap all water sources available were used and the sources were used for drinking water supply. Public water and wells were the primary alternative sources in Palau but they were used for purposes other than drinking. Overall, the secondary sources were used for drinking only 14 percent of the time. Statistically significant inter-island effects existed for all these questions.

Question 12.

Poured concrete and steel catchment tanks were the predominant tank types observed with 53 and 22 percent respectively. Metal drums with 15 percent were the third most common storage vessel. Although not reflected in this survey, most new tanks appear to be being built using ferrocement construction techniques due to a special low cost, self help, Micronesia-wide Environmental Health RWCS project. These economical tanks are constructed by plastering perforated flat tin shells with cement (see Figures 4 and 5).

Question 13.

Average catchment volume was found to vary significantly from island to island. Catchment tanks were largest on Yap (23 m^3) and Kosrae (13 m^3) where alternative supplies are untreated and smallest on Ponape ($5\frac{1}{2}$ m^3) and Palau ($6\ ^1/_3 m^3$) where some treated public supplies are available. Average storage volume was $11\frac{1}{2}$ m^3. Combined with Question 1., the average number of users, the picture changes as the average water storage/user now becomes 700, 390, 270 and 130 liters/user for Palau, Yap, Kosrae and Ponape respectively. Kosrae and Ponape now appear to have low storage volumes but this is offset by their high annual rainfalls and lack of distinct wet and dry seasons. Palau and Yap which have distinct seasons have the larger storage volumes.

Question 17.

Screens were found on 60 percent of the catchment inlets overall but only 31 percent had screens in Palau and Yap, islands which also had lower numbers of catchments with covers. Screens should be incorporated into all RWCS because they remove some debris from inlet water and prevent animal access to the tank if it is covered properly.

Question 18 and 20.

Roofs were almost exclusively made from corrugated galvanized sheet metal (97%) with the remaining roofs being concrete. Gutters were predominantly home made using bent sheet metal (51%) or prefabricated from metal or plastic (40%). A few used bamboo guttering and 7 percent had no gutters; the rainfall just fell from the roof into the open cat tank.

Questions 22 and 23.

One important factor affecting RWCS use is the roof area available for rainfall collection and the percent of available roof area actually used. On the average, roofs were found to be about 90 m^2 in area with about half that (49%) being used for rainwater collection. On Yap, the roofs were the smallest (75 m^2) but the percent used was the largest (79%); as a consequence, the Yapese had the largest average areas available for rainwater collection (59 m^2 versus 38, 44 and 38 for Kosrae, Ponape and Palau, respectively). Other areas should emulate Yap to improve their RWCS performance.

Questions 24 and 25.

Coliform counts are used to assess the possible presence of pathogenic organisms. They are not normally pathogenic themselves but they are almost always found when pathogens are present. They are also relatively easy and safe to culture. Therefore, they are used as an indicator of pathogenic contamination. The World Health Organization (1971) recommends that 90 percent of all water samples from a water source should have a total coliform count of less than 10 per 100 mℓ. If the counts are consistently greater than 20 per 100 mℓ, then consideration should be given to treating the source. Total coliform bacteria are not always of fecal origin. Some are normal soil bacteria. Fecal coliform bacteria counts should be lower than total coliforms counts since they are an indication of recent human or animal fecal contamination. The presence of pathogenic organisms is therefore probable when fecal coliform are found.

The average total and fecal coliform counts for the RWCS tested were high, 21 and 31/100mℓ for fecal and total coliform respectively. These counts, particularly for total coliform, would have been even higher if dilution techniques had been used to accurately measure coliform populations instead of using 200/100mℓ as the upper limit on coliform numbers. Coliform counts were the highest in Yap where catchments are the predominant potable water source (40 and 63/100mℓ for fecal and total, respectively) and lowest in Kosrae. These numbers are somewhat discouraging with respect to RWCS water quality as whole. However, there were plenty of catchments that provided water of good bacteriological quality. The problem appears to be in gaging the maintenance effort needed for RWCS when such a variety of designs, materials and usage patterns exist.

Table 3 is a more detailed summary of the coliform counts by island. These numbers are much more encouraging as 56 and 34 percent of all the RWCS tested were found to have no fecal and total coliforms, respectively. If a coliform standard of less than or equal to 5 is used, then 75 percent of the RWCS had acceptable fecal counts and 58 percent had acceptable total coliform counts. These numbers suggest that RWCS are doing an acceptable job of providing drinking water in the majority of cases but problems do exist.

Factors Affecting Bacteriological Water Quality

Table 4 is a summary of the RWCS characteristics and management practices which were tested to see if they affected catchment bacteriological water quality. As shown in the table, none of the catchment characteristics had a statistically significant effect on fecal coliform counts. However, total coliforms were found to be influenced significantly by the island, whether or not the tank was screened, and by the type of tanks. Other parameters such as catchment cover, cleaning frequencies, and tank volume did not appear to influence water quality at the 95 percent level of confidence. This does not influence water quality, it just means that no statistically significant correlation existed with the present data base. A more comprehensive study over a longer period with a larger data base would very likely find more significant cause and effect relationships. For example, 79 and 82 percent of the catchments which had no fecal or total coliform bacteria, respectively, had covers. This seems like a strong indication that covers improve bacteriological water quality but other uncertainties in the data preclude a definitive statement concerning cause and effect.

Table 3. Coliform bacteria results breakdown by precent according to island.

Fecal Coliform/100mℓ	Kosrae	Ponape	Yap	Palau	All
0	71	47	42	53	56
1-5	14	18	25	20	19
≤ 5	85	65	67	73	75
6-20	7	18	3	10	8
21-100	2	12	14	7	7
100+	6	5	16	10	10
Total Coliform/100mℓ					
0	37	-	27	36	34
1-5	33	-	16	18	24
≤ 5	70	-	43	54	58
6-20	24	-	14	16	19
21-100	6	-	16	15	12
100+	0	-	27	15	11

Table 4. Correlations of bacteriological water quality with catchment characteristics. N.S. signifies no statistically significant correlation at the 95 percent confidence level.

Catchment Characteristic	Level of Significance	
	Fecal Coliforms	Total Coliforms
Island	N.S.	.00
Is catchment tank covered?	N.S.	N.S.
Is tank inlet screened?	N.S.	.00
Type of catchment tank	N.S.	.00
Tank volume	N.S.	N.S.
Tank cleaning frequency	N.S.	N.S.
Roof and gutter cleaning frequency	N.S.	N.S.

Table 5 presents mean coliform counts as a function of the same parameters in Table 4. As shown in this table, screens and catchment covers appear to greatly improve water quality in all cases except with fecal coliform counts and covered catchments. The reason for exception is unknown. The relationship between tank, roof and gutter cleaning are much less certain and the results of Table 4 are reaffirmed. Catchment tank type also appears to affect water quality as both total and fecal coliforms follow the same trends with catchment tank. Steel barrels consistantly have the poorest quality followed by steel tanks which are mostly World War II vintage and the poured cement tanks which are generally older and in poorer conditions than the newer ferrocement tanks.

SUMMARY AND CONCLUSIONS

This study shows that in the majority of cases, RWCS provide a relatively high quality water for domestic purposes. Fifty-six percent of the RWCS tested had no fecal coliform bacteria and 37 percent had no total coliform present. Of course, it is desired that coliform organisms be totally absent from drinking water but this is not always economically or technically feasible in present RWCS, especially in developing areas. In such cases, a standard of less than or equal to five total coliforms per 100 m/ℓ might be more appropriate. In this case, RWCS preformed satisfactorly for fecal and total coliforms in 75 and 58 percent of the cases tested. The remaining instances of contamination give evidence that improved maintenance and design of RWCS is needed.

Because coliform organisms were found in many catchments, some at very high and potentially dangerous levels, it is recommended that catchment users boil water before using if for drinking and cooking purposes. Thirty-eight percent of those interviewed said they currently boil water for drinking. Increased public education and catchment system testing could help increase the percentage who boil their water.

Fecal coliform counts were found to vary greatly and no statistically significant relationships were found between fecal counts and catchment characteristics. Fecal counts did appear to be lower in screened tanks though. Catchment coverings and cleaning frequencies had no apparent affect on the presence and numbers of fecal coliforms.

Total coliform counts were more visibly influenced by catchment characteristics and practices. The presence of covers and screens appeared to greatly improve water quality. Screens improved water quality to a statistically significant extent. The island the RWCS was on and the catchment tank type also statistically affected total coliform count. Kosrae had the lowest total coliform counts and ferrocement tanks had the best water quality. Metal barrels had the poorest water bacteriologically.

While not conclusive, the results of this study suggest that screening and covering RWCS can greatly improve RWCS water quality. It is therefore recommended that all catchment that do not have screens and covers should have them installed. It is also important that the screens be cleaned regularly to prevent organic buildup on them.

Table 5. Mean coliform counts versus catchment characteristics.

Catchment Characteristic	Coliform count/100mℓ	
	Fecal	Total
Island		
Kosrae	14	6
Ponape	15	-
Yap	40	63
Palau	18	38
All	21	31
Covered catchment tank?		
No	19	45
Yes	20	24
Tank inlet screened?		
No	26	55
Yes	11	13
Catchment tank type?		
Poured cement	17	14
Ferro-cement	5	6
Steel tanks	21	37
Steel drums	40	73
Other	11	9
Tank cleanings/year		
0	16	24
1-3	28	41
4-6	13	15
6+	7	25
Roof and gutter cleanings/year		
0	9	23
1-3	35	50
4-6	20	17
7+	5	25

Cleaning the catchment tank, roof and gutters was found to have little positive effect on water quality. In spite of this, it is recommended that users continue to clean their catchments, roofs and gutters as dictated by common sense. Tanks should be cleaned and disinfected 3 to 4 times per year and roofs and gutters should be cleaned often monthly if possible.

To further understand RWCS dynamics it is recommended that the Environmental Health offices of each island start sampling a few (5 to 6) typical RWCS on a routine basis (monthly) to collect long term RWCS water quality data. The effect of first flush diverters should also be investigated and a few simple designs adopted for use in Micronesia since diverters may offer the greatest potential for improving RWCS bacteriological water quality at minimal cost.

The diversity of RWCS designs and materials presently utilized and the varying usage patterns from household to household makes it difficult to prescribe a set maintenance program for RWCS that is suitable for everyone. Nevertheless, the maintenance RWCS has to become a scheduled household activity. Public education programs can be initiated with the objective of encouraging uniform, effective designs and material in RWCS besides maintenance procedures. Perhaps in areas where dependence on RWCS is nearly total for drinking water (e.g. Ulithi) government subsidized materials and designs can be provided to the public.

Consideration should also be given to periodic private or public sponsored disinfection of catchment tanks using chemical disinfectants. A quarterly disinfection program with 1 ppm residual chlorine would probably greatly improve RWCS water quality and community health.

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APPENDICES

APPENDIX A

Household RWCS

RAINWATER CATCHMENT SURVEY

OWNER: DATE:
ADDRESS: TIME:
Sampled by:

1. How many people use this catchment?
2. Is the water good?
3. What is the water used for?
4. Do you boil the water?
5. Does the water ever make people sick?
6. How often do you clean the catchment?
7. How often do you clean the roof and gutters?
8. Do you ever run out of water?
9. Do you use other sources of water? (Specify)
10. What do you use this water for?

Catchment Description

Type:
Dimensions:
Condition:
Cover:
Screen:
Internal cleanliness:

Roof & Gutter Description

Roof type:
Dimensions:
Condition:
Gutter type:
Gutter condition:
% used for water collection:

Coliform Tests

Fecal Coliforms Bottle No._____ _____/100mℓ
Total Coliforms Bottle No._____ _____/100mℓ

Other Chemical Tests or Notes

APPENDIX B

QUESTIONNAIRE PARAMETER CODES

RAINWATER CATCHMENT PROJECT: QUESTIONNAIRE & PARAMETER CODES

Column(s)	Description & Codes	Parameter Code
1	Island (1 - 4) (1) Kosrae (2) Ponape (3) Yap (4) Palau	ISLAND
2	State, Municipality or Village (016) (0) Missing value	VILLAGE

Kosrae	Ponape	Yap	Palau
(1) Leu	(1) Oh	(1) Yap	(1) Koror Area
(2) Tafunsak	(2) Sokesh	(2) Ulithi	(2) Peleiu
(3) Toful	(3) Colonia		(3) Kayangel
(4) Malem			
(5) Utwe			
(6) Walung			

Column(s)	Description & Codes	Parameter Code
3 - 4	ID (1-99)	ID
5 - 10	Date (Day, Month, Year)	DATE
11 - 13	How many people use the catchment? (0-999) (0) Missing value	USERS
14	Is the water good? (0-3) (0) Missing value (1) no (2) yes (3) don't know	QUALITY
15	What is the water used for ? (0-8) (0) Missing value (1) drinking (2) cooking (3) washing (4) bathing (5) drinking & cooking (6) washing & bathing (7) cooking, washing, & bathing (8) everything	USE[1]

17 Do you boil the water? (0-3) BOIL

(0) Missing value
(1) no
(2) yes
(3) sometimes

18 Does the water ever make people sick? (0-4) SICK

(0) Missing value
(1) no
(2) yes
(3) sometimes
(4) don't know

19-20 How often do you clean the catchment? CLEAN C

(0) never
(1-98) times/year
(99) missing value

21-22 How often do you clean the roof and gutter? (0-99) CLEAN R

(0) never
(1-98) times/year
(99) missing value

23 Do you ever run out of water? (0-3) RUNOUT

(0) Missing value
(1) no
(2) yes

24 Do you use other sources of water? SOURCE 2

(0) Missing value
(1) no
(2) yes

25 What other sources of water do you use? (0-9) SOURCES

(0) Missing value
(1) public, P
(2) stream, ST
(3) spring, SP
(4) well, W
(5) ST & SP
(6) ST & W
(7) SP & W
(8) ST & SP & W
(9) other catchments

CATCHMENT DESCRIPTION

28	Type? (0-9) (0) Missing value (1) poured concret (2) perforated tin/concrete (3) ferrocement (4) stainless steel (5) corrugated metal (6) miscellaneous steel (7) fiberglass/plastic (8) metal barrels (9) other	CTYPE
29-32	Volume, ft^3 (0-9999) (0) Missing value (9999) $\geq$ 9999 cu. ft.	VOLUME
33	Internal cleanliness? (0-3) (0) Missing value (1) good (2) fair (3) poor	CCOND
34	Cover? (0-20) (0) Missing value (1) no (20 yes	COVER
35	Cover type? (0-4) (0) Missing value (1) tin (2) concrete (3) screen (4) cloth	CVTYPE
36	Screen? (0-2) (0) Missing value (1) no (2) yes	SCREEN

ROOF AND GUTTER DESCRIPTION

37	Roof type (predominant) (0-5) (0) Missing value (1) tin (2) concrete	RTYPE

	(3) thatch (4) wood (5) other	
38-41	Roof area, ft^2 (0-9999)	RAREA
	(0) Missing value (9999) $\geq$ 9999 sq. ft.	
42	Roof condition (0-30	RCOND
	(0) Missing value (1) good (2) fair (3) poor	
43	Gutter type (predominate) (0-5)	GTYPE
	(0) Missing value (1) prefab (2) bent tin (3) bamboo (4) none (5) other	
44	Gutter condition (0-3)	GCOND
	(0) Missing value (1) good (2) fair (3) poor	
45-46	Percent of roof used for catchment (0-99) (0) Missing value (99) 100%	PERCENT
47-49	Fecal Coliforms (counts/100 mℓ)	FECALC
	(0-200) Bacteria/100 mℓ (998) too numberous to count, TNTC (999) missing value	
50-52	Total coliforms (counts/100 mℓ)	TOTALC
	(0-200) bacteria/100 mℓ (998) TNTC (999) missing value	

APPENDIX C

CODED QUESTIONNAIRE DATA

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