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[12] ABSTRACT (PURPOSE, METHOD, RESULTS, CONCLUSIONS)

Shallow wells and individual rainwater catchment systems meet the water requirements of many Micronesians. The quality of this water is a matter of public health interest because this region suffers from a high incidence of gastrointestinal disorders and water-related diseases. Poor sanitary conditions and particularly inappropriate excreta disposal practices pose a significant threat to shallow groundwater quality. Groundwater is usually used for nondrinking purposes; however, when alternative water sources are unavailable groundwater may be consumed. Rainwater catchment systems are the preferred source of drinking water. Catchment systems are often poorly maintained and storage capacity inadequate to last through even brief dry periods. The relationship between ambient sanitary conditions and shallow groundwater quality was examined on the island of Moen, Truk, Federated States of Micronesia. The relationship between construction and maintenance of rainwater catchment systems and the quality of water contained in the storage tanks was also examined. At 13 sites, samples of groundwater were obtained either from specially constructed test-holes or from selected wells that met certain construction criteria. Sanitary conditions in the areas surrounding each site were evaluated. Special attention was paid to the proximity of latrines and to the presence of animals and standing water. Samples taken from these test holes and wells were analyzed for fecal coliform. Thirty-two rainwater catchment systems were examined for parameters of construction and maintenance. Samples from each tank were analyzed for total and fecal coliform bacteria. All determinations were made according to the membrane filtration method as described in the *Standard Methods for the Examination of Water and Wastewater*, 16th ed. Generally, sanitary conditions were observed to be extremely poor. Groundwater in all of the test holes and wells was contaminated with fecal coliform (range = 16 to 360,000 colony forming units/100 ml). No correlation between any of the examined parameters of sanitation and the degree of contamination was established. Rainwater-catchment tank water was of superior quality compared to the groundwater (average total coliform = 110, average fecal coliform = 14 colony forming units/100 ml). The most important determinant of tank water quality was whether or not water from the island's central distribution system was put into the tank.

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BACTERIAL CONTAMINATION OF WATER RESOURCES ON MOEN, TRUK ISLANDS, FEDERATED STATES OF MICRONESIA

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ABSTRACT

Shallow wells and individual rainwater catchment systems meet the water requirements of many Micronesians. The quality of this water is a matter of public health interest because this region suffers from a high incidence of gastrointestinal disorders and water-related diseases. Poor sanitary conditions and particularly inappropriate excreta disposal practices pose a significant threat to shallow groundwater quality. Groundwater is usually used for nondrinking purposes; however, when alternative water sources are unavailable groundwater may be consumed. Rainwater catchment systems are the preferred source of drinking water. Catchment systems are often poorly maintained and storage capacity inadequate to last through even brief dry periods.

The relationship between ambient sanitary conditions and shallow groundwater quality was examined on the island of Moen, Truk, Federated States of Micronesia. The relationship between construction and maintenance of rainwater catchment systems and the quality of water contained in the storage tanks was also examined.

At 13 sites, samples of groundwater were obtained either from specially constructed test-holes or from selected wells that met certain construction criteria. Sanitary conditions in the areas surrounding each site were evaluated. Special attention was paid to the proximity of latrines and to the presence of animals and standing water. Samples taken from these test holes and wells were analyzed for fecal coliform.

Thirty-two rainwater catchment systems were examined for parameters of construction and maintenance. Samples from each tank were analyzed for total and fecal coliform bacteria. All determinations were made according to the membrane filtration method as described in the *Standard Methods for the Examination of Water and Wastewater*, 16th ed.

Generally, sanitary conditions were observed to be extremely poor. Groundwater in all of the test holes and wells was contaminated with fecal coliform (range = 16 to 360,000 colony forming units/100 ml). No correlation between any of the examined parameters of sanitation and the degree of contamination was established. Rainwater-catchment tank water was of superior quality compared to the groundwater (average total coliform = 110, average fecal coliform = 14 colony forming units/100 ml). The most important determinant of tank water quality was whether or not water from the island's central distribution system was put into the tank.

EXECUTIVE SUMMARY

This project is a continuation of an investigation, conducted in 1988, into the potential for contamination of two commonly used sources of water in Micronesia. This project builds on the findings of last year's investigation to further determine the degree to which shallow groundwater and water in rain catchment systems is contaminated with coliform bacteria on the island of Moen in the State of Truk, Federated States of Micronesia. As in last year's investigation a survey of sanitary conditions in areas around sampling points was conducted in an attempt to identify those environmental parameters which may be associated with the contamination of a water source.

Shallow sampling wells were constructed in order to obtain groundwater samples free from possible well effects which were believed to have affected last year's findings. Samples from these wells were analyzed for indicator bacteria of the coliform group to determine the degree of contamination of the groundwater. Membrane filtration methods were used to assay the bacterial indicator organisms in all water samples taken.

In the 1988 study it was found that the presence of sullage adjacent to the wells was associated with higher coliform counts in wells. It was further found that capped WERI (Water and Energy Research Institute of the University of Guam) solar powered wells had fewer coliform bacteria compared to most other well designs. It is believed that samples from these wells provided a more accurate picture of the coliform content of the groundwater than unprotected, hand bailed wells. Therefore the sampling wells constructed in the course of the present investigation followed the WERI design quite closely. The design, construction, and use of rainwater catchment systems was also examined, and water samples were tested for total and fecal coliforms. Although the microbial water quality was found to vary, the overall impression was that the rainwater in catchment tanks on Moen was good, and far superior to groundwater.

Problems and Research Objectives

Many Micronesian islands experience shortfalls in their water needs, during even brief drought periods. Water supply is a matter of concern both on small, remote atolls where the hydrogeology often limits the exploitation of groundwater, and in rapidly expanding major centers where the burgeoning populations require increasing amounts of water. Many Micronesians are heavily dependent on household rainwater catchment systems to meet their water needs. Groundwater from shallow, usually unconfined, aquifers supplements rainwater in most households. Generally this shallow groundwater is used for cleaning purposes;

however, during a drought this water may be consumed. This practice is believed to have been a factor in the 1982 outbreak of cholera in Truk, which coincided with a protracted drought period. Although there are ongoing attempts to provide the infrastructure for central water supply systems, the traditional sources—rainwater and shallow groundwater—will continue to meet the water needs of many Micronesians for the foreseeable future.

In areas outside the major population centers disposal of excreta generally consists of water-seal or dry-pit latrines, the seashore and mangrove swamps. Concern over the public health ramifications of traditional disposal practices has led to widespread adoption of dry-pit and water-seal latrines. This change to inland disposal of excreta poses concern for the potential contamination of water in shallow wells. Added to the fear of contamination of groundwater by excreta are concerns of contamination from improperly disposed of garbage, animal wastes, and gray water, prominent features in many Micronesian communities. Gastrointestinal disorders and waterborne illnesses are very prevalent in most of Micronesia and contaminated groundwater may be an important contributing factor.

Little is known about the capacity of Micronesian soils to prevent the passage of contaminants from either the surface or latrine pits (many pits penetrate the water table) to the groundwater supply. The research objectives of this project, therefore, were to examine waste-disposal practices and sanitary conditions in select communities on the island of Moen and to assess the impact that these practices and conditions have on the quality of shallow groundwater in these areas. A further objective was to examine rainwater catchment practices and to assess the bacteriological quality of water in rain storage tanks. This water represents the principal source of drinking water for many, if not most Micronesians, therefore, it is important to determine the effect of collection and storage practices under the unique environmental and social conditions extant in Micronesia.

Methodology

The sanitary conditions of selected communities were assessed. Parameters examined included amount of litter, presence of animals, and number of people using latrines. Groundwater samples were obtained and analyzed for fecal coliform bacteria (indicators of fecal contamination) according to the methodology described in the *Standard Methods for the Examination of Water and Wastewater*, 16th edition. To obtain groundwater samples representative of the water in the aquifer, dedicated sampling wells were dug by hand, with an auger, or with a small backhoe. These holes were cased and screened. Time series of samples were taken from the holes for bacteriological analysis. Samples were also taken from existing wells that met the requirements of proper construction necessary to preclude the possibility of contaminants entering by some route other than with water entering from the aquifer. It was felt that samples taken later in any time series would better reflect the quality of the water in the aquifer, as well effects (changes in the water which occur after it enters a well from an aquifer) such as bacterial die-off, would be minimized in these samples.

Sampling was conducted employing small submersible pumps powered either by solar photovoltaic panels or by a 12-volt battery. Samples were collected in sterile 250 or 500 ml Nalgene bottles, which were transported to the Truk State Health Department laboratory for analysis. A single sample of rainwater was taken from each of the catchment systems examined, and system construction and maintenance parameters were noted.

Principal Findings and Significance

In most of the areas evaluated, sanitary conditions were poor. Litter was very common and semidomesticated animals were observed roaming around most survey sites. Generally, drainage was very poor. Groundwater was found to be contaminated in all wells tested. The degree of contamination varied widely. The levels of contamination, however, could not be correlated to proximity of latrines. Large numbers of persons often shared a single latrine, and standing water—the effluent from bath, laundry, and kitchen drains—was commonly seen around houses. The sampled wells were protected from outside sources of contamination; and hence, the results indicate that the groundwater and not merely the well water in many areas is indeed being contaminated by the waste disposal practices of the inhabitants. The implication of this finding is that the use of shallow groundwater for drinking purposes poses a health risk in most areas, a fact that should be borne in mind when developing the resource to increase drinking water supplies.

The quality of water in rain catchment tanks was found to vary widely as did the quality of collection/storage systems. In areas served by the central water distribution system, the piped water was commonly stored in rain tanks during dry periods, a practice which introduced water contaminated with coliform bacteria into the tanks.

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INTRODUCTION

Description of Moen

Moen, one of the high volcanic islands which comprises the major land mass of the Truk archipelago, is located in the western Pacific, some 4,000 km southwest of the Hawaiian islands at around 8° north latitude, and about 152° east of Greenwich (Fig. 1).

Truk consists of nineteen high volcanic and at least sixty-five widely scattered low coral islands, with a total land area of about 127 square km. Only thirty-five of the islands are inhabited. The six main islands lie within a 2,000 km^2 lagoon, encircled by a barrier reef (Fig. 2). The lagoon islands are all within sight of one another and people frequently travel back and forth between them in open boats. There are smaller low islands scattered along the barrier reef and far out in the ocean. Some are hundreds of kilometers from the lagoon.

Geologically the Truk islands are located on the Pacific tectonic plate. This plate is gradually moving toward the Mariana Trench, a subduction zone in the far western Pacific. Hence, Truk is in the process of sinking into the ocean. The high volcanic islands of Truk are the erosive remnants of a submerging dormant shield volcano, and the low islands are the debris-covered tops of volcanic masses that have already gone under (Mink 1986).

The six main high islands found within Truk lagoon are Moen, Udot, Tol, Fefan, Dublon, and Uman. They are composed of volcanic rock (mostly basalts) surrounded by narrow coastal plains of alluvium and marine sediments.

Truk's population of approximately 47,000 is mainly concentrated on the lagoon high islands where there are the resources to support larger populations. Some 75% of the population lives within the lagoon. Moen, the most populous island and Truk's administrative center, has some 14,000 inhabitants. Moen's population increased fourfold between 1956 and 1976, with 70% of the increase attributable to immigration from other islands (Hawaii Architects and Engineers 1978). To a lesser degree this in-migration has occurred on the other lagoon islands and appears to be continuing. Development of services has not kept pace with the population increases on the high islands. Providing such services as water systems, electricity, and sewer lines to these burgeoning populations is an enormous economic burden on this island state.

The greater part of Moen's population lives on the coastal margins of the island, primarily on the north and west coasts. This margin is where the road, electrical transmission wires, and water lines run. There is also considerable habitation in the saddle between Tonachau hill and Mount Teroken (Fig. 3).

Water supply is a problem on Moen as it is in the rest of Truk. The areas immediately around the major settlements on Moen are served by a municipal water system that draws water from both surface and deep groundwater sources. The surface sources are completely

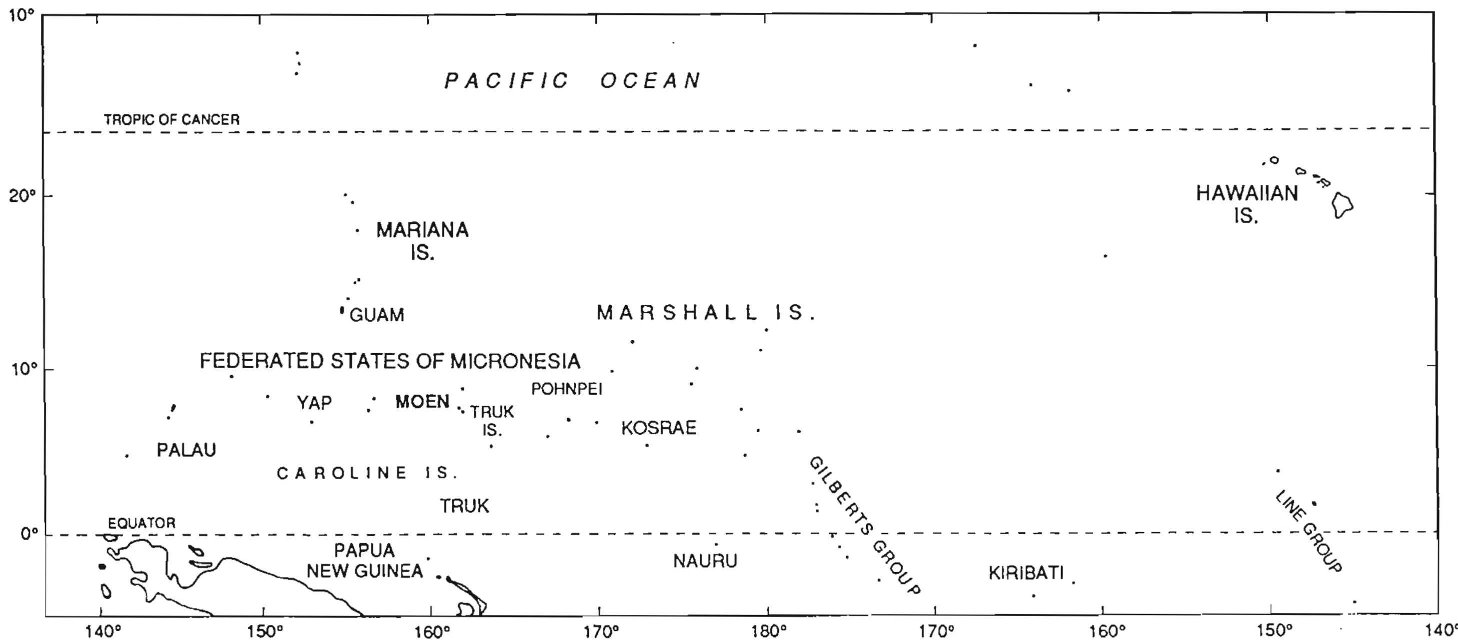


Figure 1. Map of the western Pacific

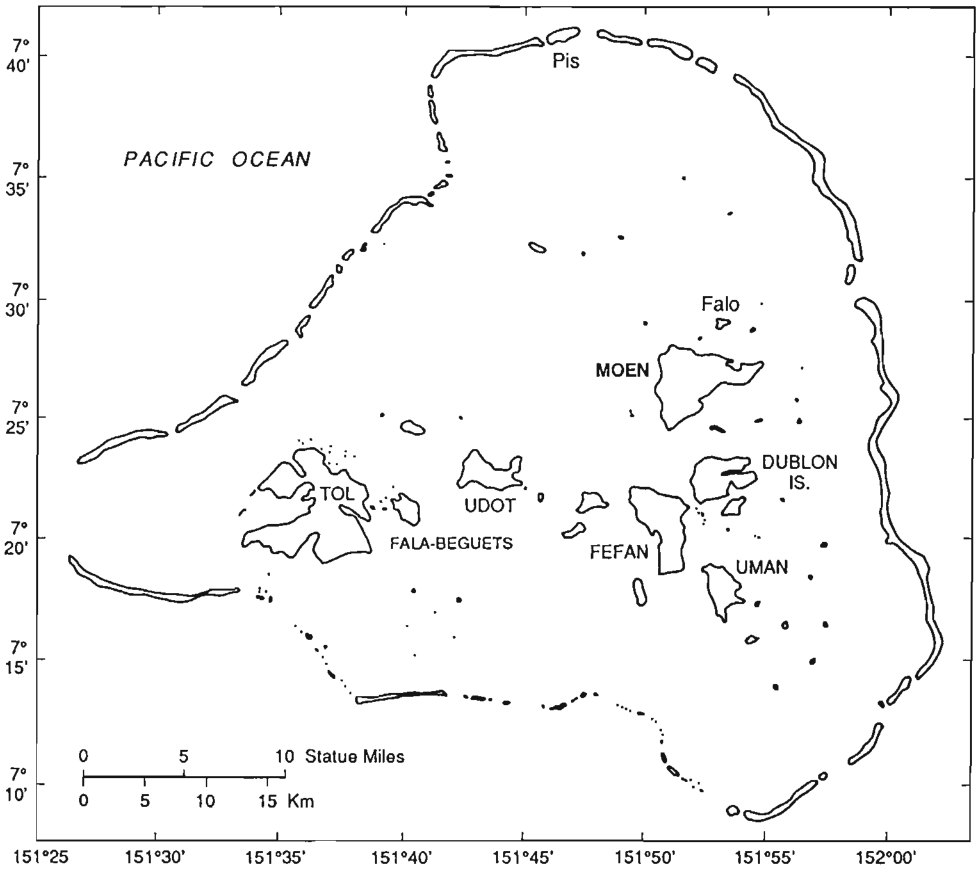


Figure 2. Map of Truk Islands

unprotected. Due to water shortages, water service is often limited to a few hours a day. This intermittent pressurization of the distribution system can result in back siphonage and subsequent contamination of sections of the system. The city water supply often contains suspended particles and fecal coliform bacteria. Neither chlorination nor any other form of water treatment is performed on a routine basis.

People in areas not served by the municipal system rely on rainwater and shallow groundwater. Even within the area served by the system, many houses are not connected to the line. Many people who do not want to depend on the erratic water service maintain their own storage tanks and wells.

Shallow groundwater is extensively utilized in rural areas throughout Micronesia. This resource, easily and inexpensively tapped, requires very simple technology. This water is largely unused for drinking purposes. One reason is that waste disposal practices in the area engender concerns of contamination both on the part of the inhabitants and outside consultants. John Mink, in his 1986 analysis of Micronesian groundwater resources, reported "...the careless location of cesspools, septic tanks, latrines, waste dumps, and animal pens near wells

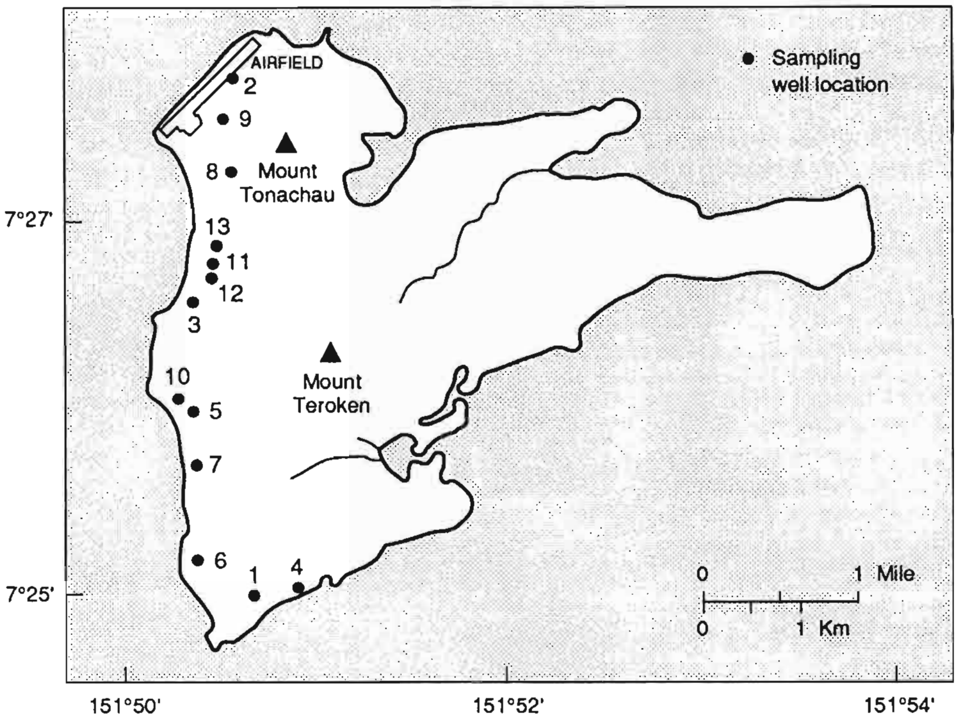
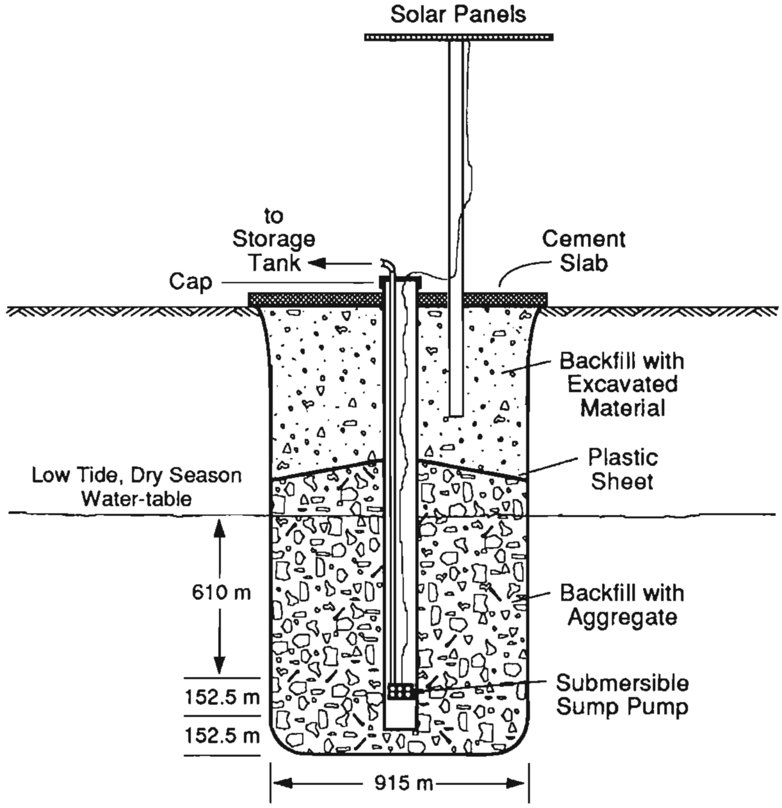


Figure 3. Moen Island showing sampling site locations

and other extraction points, including natural springs, inevitably will lead to pollution once the filtration capacity of the regolith is overburdened.... Where the subsurface formations are permeable, contamination from indiscriminately discarded concentrations of waste on and in the ground is almost certain."

Since the 1982 outbreak of cholera, the Truk Department of Health Services, Rural Sanitation Project (RSP) has been attempting to provide improved rain storage-tanks and water-seal latrines to those citizens in need. The tanks are of ferro-cement construction with a capacity of approximately 3,000 gallons. As of March 1988, 2,711 of 3,200 planned water-catchment tanks (WCTs) and 3,915 of 4,000 planned, water-seal toilets had been reported as completed by the RSP (Esikol and Ongrung 1988). In addition to installing tanks and latrines, the RSP has been involved in installing solar pumped wells based on the design developed by the Water and Energy Research Institute of the University of Guam (WERI) well (Fig. 4). This design helps to prevent contamination of well water resulting from such poor use habits as bailing with dirty vessels.

There are essentially two types of aquifers available for exploitation on Moen and the other Trukese high islands: those in weathered volcanic rock (saprolite), and those in unconsolidated alluvial and marine deposits on the coastal plains. The saprolite aquifers found in the interior areas of the islands are moderately productive and are the only formation where deep wells are



*Water and Energy Research Institute, University of Guam.

Figure 4. Schematic diagram of WERI well

practicable. The seaward edges of the coastal plains display a typical profile of marine and alluvial sediment overlying a massive karstified fossil reef. The overlying sediment has a moderate hydraulic conductivity, and the underlying limestone has a high hydraulic conductivity. The underlying formations risk seawater encroachment. Thus deep wells are not practical in these materials, though shallow wells in the overlying sediment can produce potable water (Mink 1986). The seaward edges of the high islands' coastal plains are the most densely populated areas on the islands, and the underlying shallow aquifers are the most frequently tapped. The high islands can have a considerable hydraulic gradient, which may contribute to the potential for groundwater contamination by accelerating the lateral movement of contaminated water that has made its way to the saturated zone.

The U.S. Department of Agriculture report on the soils of Truk (Laird 1983) identifies three classes of soils found on the coastal margins of Truk's high islands where habitation is likely:

1. Dublon soils—very deep, somewhat poorly drained, on coastal strands. Formed in

wind and water deposited sand derived dominantly from coral, they are sandy throughout.

2. Typic troporthents—urban land soils, filled areas of crushed coral found around the perimeters of some islands.
3. Ngerungor soils—very deep, very poorly drained, level and nearly level soils on bottom lands, found on the coastal plains. Ngerungor soils are mucky and peaty throughout. A high water table is at a depth of 0 to 15 cm year-round

Waste Disposal in Micronesia

Moen is partially serviced by a sewer line and treatment plant, but it has been reported that the treatment plant is not currently functioning, and that untreated sewage is being discharged into the lagoon. Hence, as with water supply, most people maintain an alternative system for excreta disposal, usually a water-seal or pour-flush latrine.

Traditionally in Truk, people use the ocean, bushes, and mangrove swamps as their toilet. The assimilative capacity of the ocean and bush can easily handle the relatively small volume of waste generated by a traditional Micronesian community, but there are health risks associated with this method of waste disposal when population densities become too great. There is a great potential for the transmission of infectious diseases when raw wastes are deposited into the same waters where people fish and swim, and onto the same ground where people walk barefoot. This has led to the widespread adoption of dry-pit and pour-flush latrines. As mentioned earlier, since the cholera outbreak of 1982, there has been a government-sponsored program of providing latrines to households. Attitudes and customs regarding human waste disposal practices are affecting the acceptance of this sanitation intervention. Sanphy William (1985) discussed this topic more completely.

The desirability of introducing sanitary disposal practices for human waste is obvious. What is less so is the fact that where latrine use has been accepted, latrine pits as constructed often penetrate the water table and are, in essence, disposal wells. This situation can readily lead to contamination of the groundwater. Wells and toilet pits are often constructed near one another for convenient access to flushing water. If the soil is permeable and pumping wells are nearby, there is a risk of contaminating groundwater (Todd 1980). On Moen there are many latrines clustered in small areas. If people drink the groundwater in these areas there is an implied risk of disease outbreak.

In addition to human wastes, there is also the problem of animal wastes being deposited on the ground. Pigs are popular food animals throughout Micronesia. There are many pigs on Moen; and these are generally allowed to roam at will, as are dogs, cats, and chickens.

Improper disposal of solid waste may affect groundwater quality. Moen has no domestic solid waste collection and disposal service. Large amounts of such nonbiodegradable litter as aluminum cans, bottles, paper, and old appliances can be seen strewn around the island. A large, open dump site exists where garbage remains uncovered, and serves as a magnet to vermin.

The results of our previous study (Miller et al. 1988) indicated that, with the exception of the presence of sullage, little correlation could be seen between parameters of sanitary condition and the degree of contamination of well water with fecal coliform bacteria. It must be emphasized that fecal contamination is only one type of contamination which can affect wells, and that chemical contamination poses another threat to groundwater.

Microbial Groundwater Contaminants

Biological contaminants of principal concern in groundwater are pathogenic bacteria and viruses. Of lesser concern, because of their size, are protozoans and the ova of parasitic helminths, which are readily strained out of infiltrating water by soil. Bacteria are rather less of a public health concern than viruses, which are generally hardier, and have longer average survival times under adverse environmental conditions. There is evidence that the infectious dose of an enteric virus is smaller than that of bacterial pathogens. Viruses usually survive longer and travel further in groundwater than bacteria, and are therefore more likely to make their way to a drinking water supply. According to Wilson et al. (1983), around 70% of the groundwater related disease outbreaks reported to the Centers for Disease Control in the United States probably can be attributed to diseases of viral etiology.

The likelihood of any waterborne pathogenic microorganism causing disease is a function, in part, of its ability to make its way to a drinking water supply. This ability, in turn, depends on a number of factors inherent in the microorganism and the environment. In particular, the potential for a pathogenic organism to contaminate a well or spring is a function of the time it takes for that organism to reach the water source. If the microorganism is delayed by being strained out by soil or adsorbed to the solid phase of the soil, it stands a greater chance of dying before reaching the water supply.

Factors that kill microorganisms are more numerous and powerful at the surface of the ground than below it. The nature of the soil is an important determinant of the potential for contamination of the groundwater, because different soils have varying degrees of efficiency in detaining microorganisms enroute to the saturated zone. Some soils contain flora and fauna which are antagonistic toward foreign microorganisms. For a more complete discussion, see Miller et al. (1988).

STATEMENT OF OBJECTIVE/CONTRIBUTION OF THIS STUDY

This study serves to clarify the situation on the island of Moen, and islands like it, in regard to the potential for groundwater contamination presented by the islands' environmental and sanitary conditions.

The overall objective of the study was to assess the impact of environmental factors on the microbial quality of groundwater resources on Moen.

Little is known about the effects of waste disposal practices on groundwater in Micronesia, however given the combination of geological and sanitary circumstances, concern about the potability of this water is definitely valid. Specific data regarding the transport and fate of microorganisms in Micronesian environmental settings is lacking.

The fact that shallow groundwater represents a readily and inexpensively accessed water resource, emphasizes the need for careful appraisal of this water's quality. Toward that end this study was designed to gather data regarding waste disposal practices and groundwater quality on Moen, thereby obtaining a more complete and useful picture of the situation. Shallow groundwater in Micronesia is an important supplement to deep groundwater and rainwater. As populations continue to grow on these islands it is almost inevitable that groundwater use will increase. We perceive a need to plan for this eventuality in order to avoid possible future hardship and difficulties.

Another objective of the study was to assess the microbial quality of water in rainwater catchment tanks on Moen and to identify factors that may affect the quality of this water.

METHODOLOGY AND RESEARCH DESIGN

General Methods

INDICATOR ORGANISMS. The theoretical basis for looking at the coliform bacteria content of water samples, as done in this study, is that the presence of these organisms is indicative of the presence of fecal matter and the possible presence of pathogenic bacteria and viruses. Coliforms are not necessarily pathogenic in themselves, but they are abundant in fecal matter and are readily culturable, in contrast to most pathogenic microorganisms which are difficult to grow in the laboratory. Viruses are particularly difficult to cultivate in vitro. Coliforms, therefore, are widely used as a surrogate for detecting the presence of pathogens. Coliform assays have severe limitations in predicting the potability of water. It has been demonstrated that the correlation between numbers of indicator organisms and numbers of pathogenic organisms is often poor (Berg 1978). Survival times of indicator organisms and pathogenic organisms in the external environment differ considerably. Nevertheless, total and fecal coliform determinations remain the standard tests of water microbial quality; and water quality is often expressed in terms of the presence of these organisms. Fecal coliforms are a subset of total coliforms and are more strictly indicative of fecal contamination while total coliform may indicate nonfecal contamination.

The membrane filtration method for the enumeration of coliform bacteria in water is simple and well known. Results obtained by membrane filtration are numerically quantifiable and rapidly obtained. The methods for the detection of total and fecal coliforms are described in *Standard Methods for the Examination of Water and Wastewater*, 16th ed. A brief description of the fecal and total coliform assay procedures follows, and any diversions from the prescribed methodology are noted.

Groundwater

SELECTION OF SITES. Test-hole sites were selected on the basis of surface geology and proximity to latrines. Generally the holes were located in inhabited areas, that is, on the coastal margin of marine deposits encircling Moen. An attempt was made to construct the test holes in a variety of soil types and to place holes at measured distances from latrines. It was felt that this strategy would clarify the role that these two variables might play in determining the potential for groundwater contamination. Consideration was also given to locating the test holes in places where they could be of some utility to the local residents after the tests were completed.

GROUNDWATER TEST-HOLE CONSTRUCTION. In our previous (Miller et al. 1988) investigation, wells of all types were used as sampling points; however, it was felt that such factors as well use habits and well effects may have confused the issue of whether the water in the aquifer was indeed contaminated. In this study, care was taken to avoid this confusion by sampling only holes of our own construction and existing, well-protected WERI wells.

The holes we constructed were dug either by hand or with a small backhoe. These holes were then cased with perforated screened 0.15-m-diameter polyvinyl chloride (PVC) pipe. The hole around this PVC casing was backfilled with a layer of rock and gravel, and the rest of the hole was filled with the removed material. These wells were pumped for a period to allow the water to clean up and the well to stabilize before sampling was conducted, thus ensuring the minimization of any effects related to the disruption of the soil around the hole. It was believed that samples taken after the holes had been pumped for some time would be more representative of the water in the aquifer, and, therefore, times series samples were taken in the holes we dug and in existing wells when possible to monitor the effect of continued pumping on the degree of coliform contamination. The water was pumped with a low capacity 1–3 gallons per minute (gpm) electrical pump. Even this low rate exceeded the recharge rate of some sampling holes, and pumps had to be turned off periodically to allow these holes to refill.

GROUNDWATER TEST-HOLE SITE ASSESSMENT. The amount of sullage and standing water present in areas around sampling points were rated. These areas were also rated for the amount of litter present. Litter is probably a less critical determinant of groundwater quality than is sullage; however, the amount of litter in an area is indicative of the general, overall sanitary conditions. Leachate from garbage in pits and from loose litter lying on the ground can contaminate the groundwater. As with sullage, litter was scored on a scale of 0 to 10. The presence of pigs, chickens, and dogs at survey sites was noted because these animals may contribute fecal contamination to the groundwater. It was impossible to conduct any kind of census because the animals were mostly free ranging, therefore, the presence or absence of animals was simply noted.

Parameters of latrine construction, location, and usage were surveyed; because of their importance in assessing the potential for groundwater contamination. Respondents were asked how many and what kind of toilets there were in the vicinity of the sampling point. The more toilets there were in an area, the greater the probability of groundwater contamination.

GROUNDWATER SAMPLE COLLECTION. In each test hole or well, a time series of samples was taken whenever recharge rates of the holes permitted. When it was not possible to maintain a constant flow due to slow recharge, the holes were pumped repeatedly until clear water from the aquifer was obtained. Water samples from each well were collected in sterile 250 or 500 ml Nalgene bottles with care exercised not to include floating debris or to introduce surface contamination. Samples were taken from holes with 12-volt electrical bilge pumps powered by a car battery or solar panel. Samples were iced during transport and analyzed as soon as possible on the day of collection in the laboratory of the Truk Department of Health.

GROUNDWATER SAMPLE ANALYSIS. The groundwater samples, or dilutions thereof, were filtered through Millipore 0.45 μm pore size Teflon filters. Three different size aliquots of each sample were filtered: 1 ml, 10 ml, and 25 ml. If a sample appeared especially dirty, or if there were other reasons to believe that it might be heavily contaminated, greater dilutions were used. The glass filtration funnels used were sterilized in an ultraviolet (UV) sterilizer for a minimum of 4 minutes between samples; and a sterile phosphate buffer solution was used to rinse the funnels after samples had been put through. Negative blanks were run during and after each series of samples to ensure the sterility of the media, glassware, and buffer solution. Positive controls were run on each batch of media made, using known *E. coli*.

The fecal coliform analysis employed standard m-FC agar, containing lactose, protein digest, vitamins, bile salts, selective chemicals, aniline blue dyes, and 1% rosolic acid. The plates were incubated inverted at 44.5° C for 24 hours in either a simple water bath, or a portable dry incubator. This temperature is some 10° C higher than that employed in the determination of total coliform. Fecal coliform are thermophilic, and incubation at this higher temperature inhibits the growth of nonfecal coliforms and other interfering organisms. Due to occasional power outages, some plates had to be discarded; thus some data were lost.

Rainwater

Thirty-two water-catchment tank (WCT) samples were collected in 250 ml Nalgene bottles from the tank spigots from which water was usually drawn. Both fecal coliform and total coliform analyses were performed on these samples. Different dilutions were done for the total coliform analyses, and a single 100 ml sample was run for each of the fecal coliform analyses.

The methodology used for the analysis of total coliform was the same as that for fecal coliform, with the following exceptions:

1. The medium used was m-ENDO (containing lactose, protein digest, vitamins, selective chemicals, and Schiff's Reagent). This is the standard medium for enumerating total coliform bacteria in water samples.
2. Incubation took place for 24 hr at 35° C in a dry incubator.

RESULTS

General Findings

Sanitary conditions were found to be very poor in the densely populated areas around most villages on Moen. Many of the villages were situated on former swamps. These areas had been filled in order that people might build on them. Unfortunately no provision was made for drainage of runoff from the high ground; and as a result, many inhabitants of Moen were found to be living in the middle of swamps with their houses surrounded by water as much as 0.3 m deep.

Excreta disposal was found to be haphazard. Most households surveyed maintained pit latrines, even when they had sewer connections. Water-seal pit toilets provided by the Truk government's Rural Sanitation Project (RSP) were very common. About 1,000 of them had reportedly been built on Moen. Acceptance of these toilets was limited, however, and many people continued to use the shore and mangrove swamps for purposes of excreta disposal. Other systems of waste disposal were encountered infrequently. At the time of the study, a program was underway to connect the villages on Moen to the sewer line, but most of the houses had not been connected.

Within the sample, the average number of people who used each latrine was 14, the minimum, 7, and the maximum, 30 (discounting one school). These numbers were, of course, extremely high. It should be understood that these estimates merely represent the number of people with access to a particular latrine, not necessarily the number of regular users.

Free ranging animals—dogs, pigs, and chickens—were common in most areas visited. These animals contributed fecal matter to the ground surface near many wells.

Litter was very much in evidence. There was no garbage collection service and no sanitary landfill site on Moen. There was an uncontrolled, unofficial dump in the Mwan area, and only persons with a vehicle could bring their garbage to this site; therefore, it was common practice to deposit garbage in ditches by the side of the road, in the bush, or mangrove swamp.

The following section is a description of sanitation parameters for each of the sampling holes employed in this study.

SAMPLING HOLE 1: House Near Continental Hotel		
Sullage score:	7	
Litter score:	3	
Pigs:	no	
Other animals:	yes	
Nearest latrine:	10 m upgradient	
Number of users:	~10	
Soil type:	0 to 0.8 m	very rocky brown clay
	0.8 to 1.4 m	peaty organic matter
	1.4 m	marine deposits: sand, coral, etc.
Recharge rate:	extremely rapid, no drawdown detected at 2 gpm	

SITE LOCATION–HOLE 1. This sampling point was located in a yard in the village of Neiwe in the southwest corner of Moen (Fig. 3). This site was on a broad area of coastal flat, some 400 m from the base of the slope, and 300 m from the shoreline. The area around the sampling point was of relatively low population density. The property on which the hole was dug was about a half acre in area.

According to informants, the entire area was formerly a mangrove swamp. In the 1930s the Japanese occupation forces filled the area for a landing strip using soil and small pieces of basalt quarried from the high part of the island.

The sampling hole was located 10 m downgradient of the nearest toilet, a water-seal latrine. Also, there was a sewer-connected toilet 13 m upgradient. In addition to these two toilets, another potential source of groundwater contamination was identified; the bath shed, approxi-

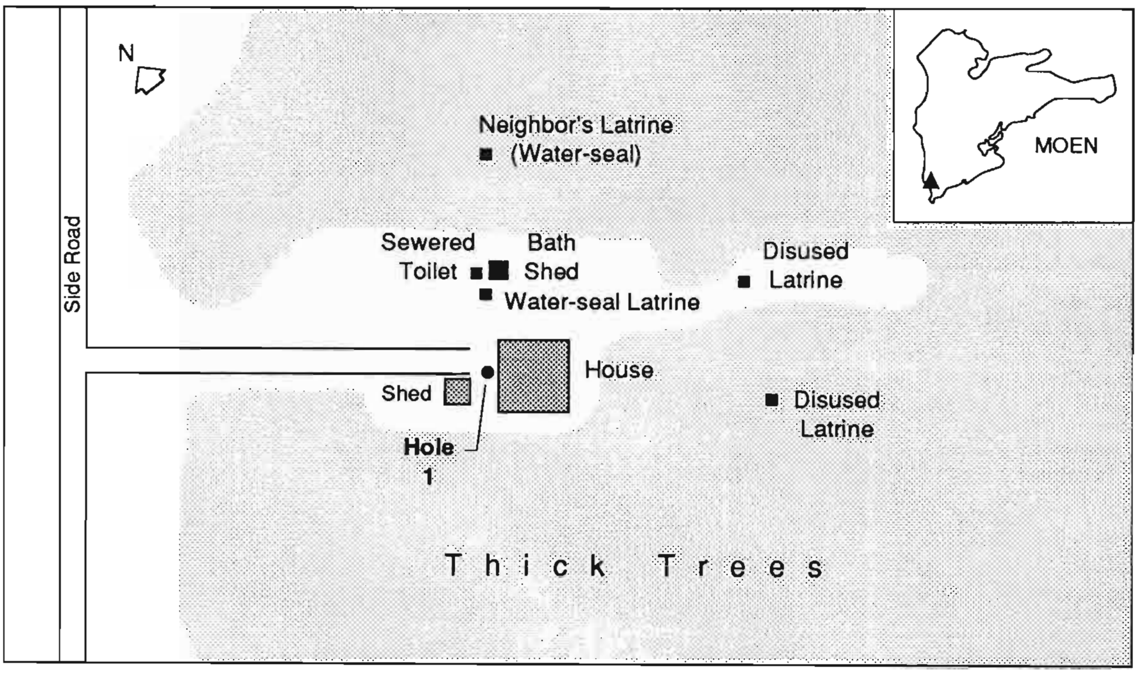


Figure 5. Sampling Site 1

practicable. The seaward edges of the coastal plains display a typical profile of marine and mately 13 m upgradient. The surrounding neighbors had one disused latrine 30 m from the sampling hole in a lateral direction relative to gradient, and one currently used water-sealed latrine 30 m upgradient (Fig. 5). A second disused latrine was situated 30 m downgradient. About 10 people used the two nearest latrines and the bathing shed, and most of their laundry was done at the bathing shed.

Dogs, cats, and chickens were found in the area, but no pigs. Sullage and standing water were an obvious problem, with the site being scored as 7 on a subjective scale, with 1 for totally dry and 10 for completely inundated. On one of the sampling days (after a heavy rainfall) this hole was surrounded by standing water. On another day there was less standing water on the ground, and the sampling was repeated. Not much litter was in evidence, although there was one rather large pile of cans, old metal objects, wood, and paper standing about 5 m downgradient of the sampling hole.

The area was one of lush vegetation, with many large trees and a dense ground covering of grass and small shrubs. The sampling hole was dug by hand to a depth of 1.4 m, and a screened, perforated, 0.15-m-PVC pipe was emplaced (this type of casing was used for all sampling holes).

Digging this hole presented some difficulty because there were many stones (up to 0.3 m in diameter), which had to be removed. At a depth of about 0.8 m there was evidence of the area's having been a mangrove swamp; undecomposed plant remnants were found. At a depth of around 1.4 m marine deposits; shells, coral fragments, and sand were encountered.

The hole filled with water as it was being dug. Water began to enter at about the 0.3 m level. Digging was discontinued when the layer of marine debris was reached. The perforated, screened PVC pipe was held in place, while the hole was backfilled to the top of the perforations with basalt rocks gleaned from the removed materials. The rest of the hole was backfilled with the remaining excavated materials. The nonpumping water level in the hole was 60 cm below the ground surface. The hole was immediately pumped at a rate of 2 gpm until the water became relatively clear (approx. a half hour). The next day, the water was again pumped at 2 gpm and a series of samples was taken over time. These samples were taken to the laboratory and analyzed for fecal coliform content. The results of these determinations are found in Tables 1 and 2.

TABLE 1. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 1, DRY DAY

PUMPING TIME (min)	PUMPING RATE (gpm*)	FECAL COLIFORM COUNT (cfu†/100 ml)
0	1 - 2	5,500
60	1 - 2	6,200
120	1 - 2	7,000
180	1 - 2	7,000
240	1 - 2	6,800
300	1 - 2	8,000

*gpm = gallons per minute.
†cfu = colony forming units.

TABLE 2. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 1, WET DAY

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
0	1 - 2	4,600
60	1 - 2	7,000
120	1 - 2	18,000
180	1 - 2	20,000
240	1 - 2	18,500
300	1 - 2	19,400

SAMPLING HOLE 2: Iras Village		
Sullage score:	8	
Litter score:	8	
Pigs:	many	
Other animals:	yes	
Nearest latrine:	20 m lateral, water seal	
Number of users:	~15 to 20	
Soil type:	0 to 1.5 m	complex fill consisting of basalt rock fragments, dredged coral, and heavy brown clay
Recharge rate:	extremely rapid, no drawdown detected at 2 gpm	

SITE LOCATION–HOLE 2. Sampling point 2 was located in the village of Iras situated on the northwest shore of Moen (Fig. 3). This site was on the coastal flat some 500 m from the ocean, and 300 m from the base of the steep slope of Mt. Tonachau. To permit building, this swampy area was filled with a variety of materials including dredged coral and quarried basalt rock fragments. The hole was originally installed as a WERI-design solar pumping well; however, it had been out of service for several years because of a failed pump.

The hole was located 20 m laterally from the nearest latrine (a water-seal unit). There were numerous latrines and bathhouses located 50 to 100 m upgradient of the hole. It was difficult to determine the number of persons using these toilets because households in Iras were large—average size 11 persons (Miller et al. 1988)—variable due to the migration of persons to and from the other islands. Fifteen to 20 persons were using the latrine located 20 m downgradient of the hole (Fig. 6).

Iras village is home to many small children and free-ranging pigs, dogs, cats, and chickens. All deposit fecal matter on the ground surface. Sullage and standing water were found to be an acute problem. The entire flat area of the village was inundated whenever there was rainfall of any magnitude. Seeps and springs issuing from the slope of the mountain, as well as waste water from upgradient houses, drained through the village and collected on the lowland flat. One inadequate drainage ditch ran parallel to the road. Sullage was rated 8, on the scale from 0 to 10. Litter was very much in evidence, most of it deposited into the swampy wet areas.

The area was sparsely vegetated with grass, small shrubs, and few trees. In the area immediately surrounding the sampling hole, so many houses had been built that little room remained for any kind of vegetation.

The hole was dug to a depth of 1.5 m and was finished according to the specifications of the WERI well design illustrated in Figure 4. The well had a concrete apron with an

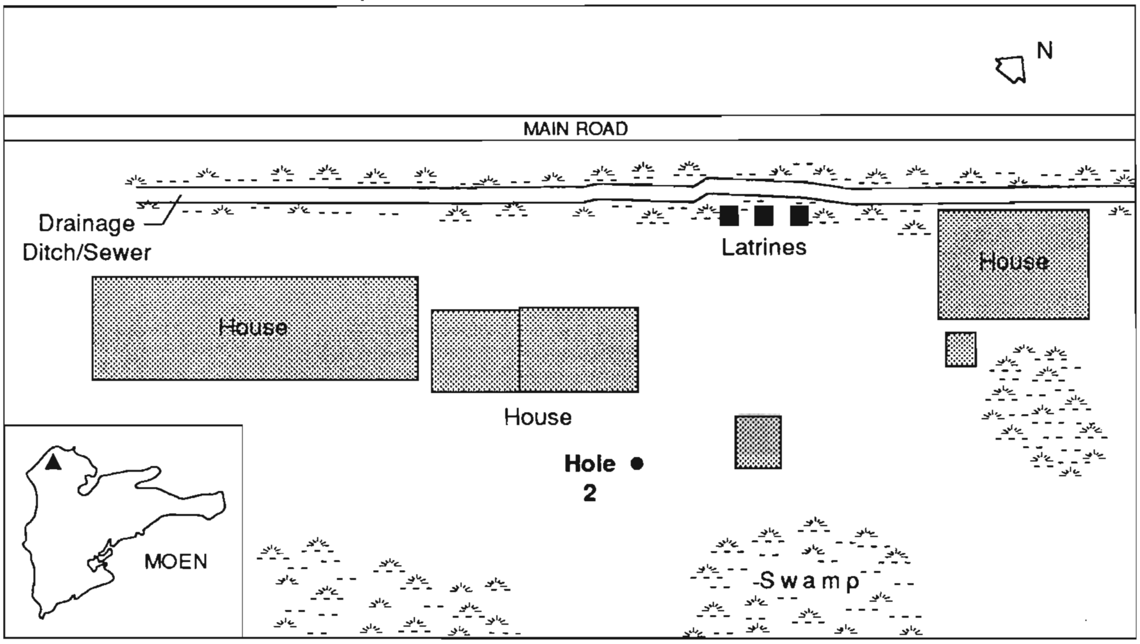


Figure 6. Sampling Site 2

approximate diameter of 1 m. The area immediately surrounding this apron was backfilled with coarse basalt rock, to a radius of ~3 m.

As this sampling point was an existing hole, the geology was derived from the USDA soils report on Truk (Laird 1983), discussions with local residents and observations of surface conditions.

The hole was pumped and sampled over time, and the results of the fecal coliform analyses are found in Tables 3 and 4. During pumping, it was noted that the water had an unpleasant sulfurous smell.

TABLE 3. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 2, WET DAY

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
0	2	4,200
15	2	460,000
30	2	410,000
60	2	440,000
120	2	400,000
180	2	380,000
240	2	310,000
300	2	360,000

TABLE 4. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 2, DRY DAY

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
0	2	50,000
30	2	230,000
60	2	200,000
90	2	100,000
120	2	90,000
180	2	96,000
240	2	90,000
300	2	88,000

SAMPLING HOLE 3: Across the Mobil Oil Tank Farm

Sullage score:	2	
Litter score:	4	
Pigs:	many loose pigs, pens at 12 m upgradient - 5 pigs, penned	
Other animals:	yes	
Nearest latrine:	12 m downgradient septic tank, 30 m upgradient water-seal toilet	
Number of users:	~15 to 20	
Soil type:	0 to 0.1 m	sand mud, clay
	0.1 to 1.3 m	marine deposits: sand, coral fragments, etc.
Recharge rate:	extremely rapid, no drawdown detected at 2 gpm	
Precipitation:	negligible last few days	

SITE LOCATION–HOLE 3. This out-of-service WERI well was located on the west coast of Moen, on the broad coastal flat that runs along this side of the island (Fig. 7). The area was adjacent to an intertidal mangrove swamp that was inundated daily with brackish water. The water originated from the distant mountain side and the ocean. The area apparently was not filled in, but rather was a naturally occurring sandspit that formed between the coastal swamp and the ocean. The soil was very sandy.

The sampling hole was about 12 m upgradient of the nearest toilet facility, a primitive septic tank. A water-seal latrine was located some 30 m upgradient of the hole. Both of these facilities were used by 20 to 25 individuals. The nearby mangrove swamp served as an alternate excrement disposal site. Also, there was a bath house 30 m upgradient from the hole, where 20 to 25 people bathed and washed their clothes.

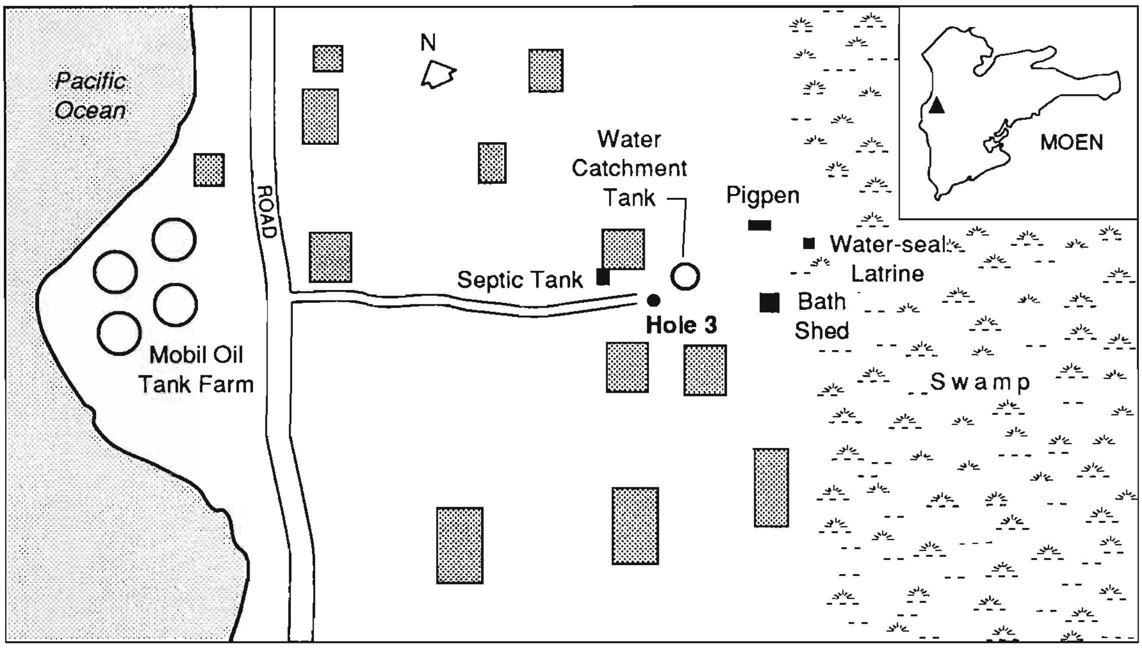


Figure 7. Sampling Site 3

Many pigs were roaming this area, and their droppings were very much in evidence on the ground. In addition to the ranging pigs, there were 5 pigs penned 12 m upgradient of the hole. Although the entire area was virtually surrounded by mangrove swamp, the area immediately around the sampling hole was quite dry for a radius of about 35 m. Similarly, although there was much litter in evidence in the mangrove swamp, there was little litter found in the area around the hole.

Vegetation was mostly limited to short grass and a few fruit trees. The nearby mangrove swamp was very lush and overgrown.

This hole was reportedly dug almost exclusively through sandy marine deposits. The first 10 to 20 cm was a layer of organic soil/sand mixture. The water level in the hole, both at the time of pumping and prior to pumping, was 0.6 m below the ground level. As with the other holes, a series of samples was taken over time as the hole was continuously pumped at a rate of approximately 2 gpm. The results of the analyses of these samples are tabulated in Table 5.

TABLE 5. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 3

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
0	2	100
30	2	0
60	2	0
120	2	20
180	2	12
240	2	30
300	2	18

SAMPLING HOLE 4: School on the Road to Wichap Village	
Sullage score:	5
Litter score:	1
Pigs:	no
Other animals:	no
Nearest latrine:	7 m downgradient, dry pit, 2 toilets
Number of users:	~200 (school)
Soil type:	0 to 1.2 m very rocky brown clay
Recharge rate:	extremely slow
Precipitation:	none for 3 days

SITE LOCATION–HOLE 4. This site, about 20 m from the ocean across the road from a school (Fig. 8), was chosen because possible sources of fecal contamination were considered negligible, except for the two nearby latrines. Thus, it was felt that demonstrating fecal contamination of the water in this hole would support the contention that latrines could be contaminating groundwater at other locations around the island.

The area was one of the many sites that the Japanese filled-in during the occupation of Truk. The school yard across the road from the site was a well-groomed, dry grassy area. Two latrines servicing the school were located 7 m downgradient of the hole. No other latrines were seen anywhere within 200 m. There was evidence that the seashore adjacent to the latrines was also being used for excreta disposal. No ranging pigs or any other animals were seen in the vicinity of the hole, nor were there any bath houses or evidence of laundering nearby. There was virtually no litter at the site, reflecting the fact that no one was living in the immediate vicinity.

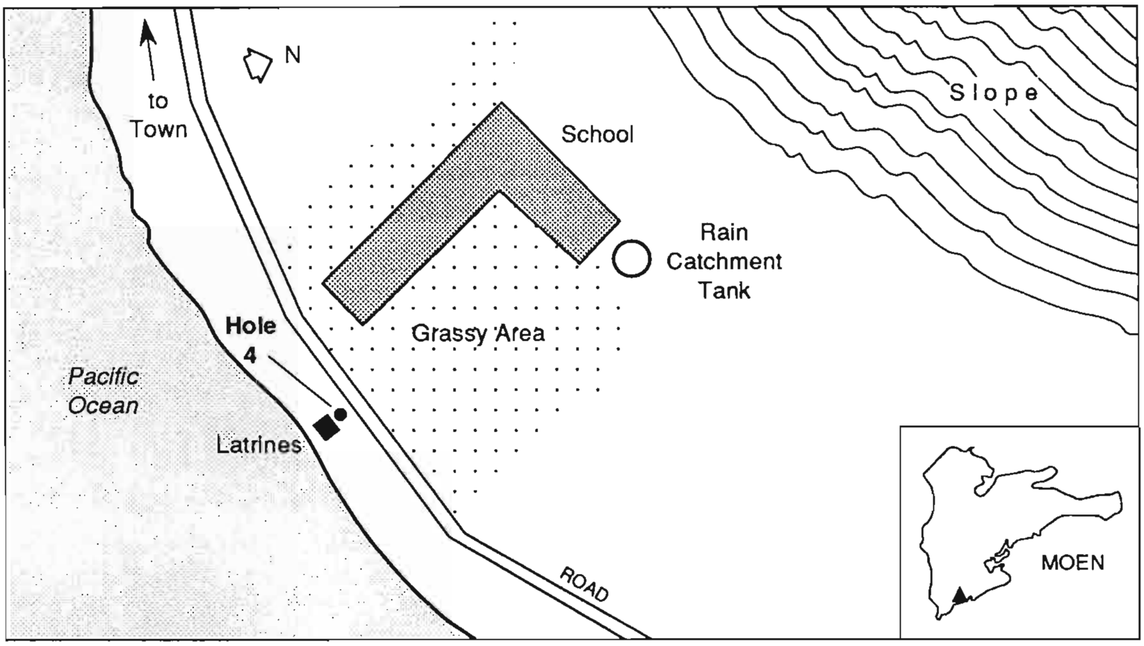


Figure 8. Sampling Site 4

The soil, a very thick, heavy brown clay, was interspersed with large basalt rocks, 10–30 cm in diameter. Difficulties were encountered in trying to sample the hole, because recharge was very slow and the hole was pumped dry very quickly. Hence, it was impossible to perform a time series of coliform analyses as was done in the other holes. Furthermore, the samples obtained were so turbid that analysis was difficult; and it was felt that the growth of the bacterial colonies on the media may have been altered by the interference of this dirt. Therefore, no bacteriological results can be reported for this sampling site.

SAMPLING HOLE 5: Mwan Village	
Sullage score:	4
Litter score:	6
Pigs:	few, penned 100 m upgradient
Other animals:	yes
Nearest latrine:	10 m upgradient water-seal, 15 m upgradient water-seal
Number of users:	~15 to 20
Soil type:	0 to 1.6 m heavy brown clay with large basalt rocks
Recharge rate:	slow, hole gradually dried up at pumping rate of 2 gpm
Precipitation:	moderately heavy for 2 days

SITE LOCATION–HOLE 5. The site was in the village of Mwan on the west coast of Moen. The hole location was chosen to be directly downgradient from two toilets to see if the groundwater at this point was being contaminated by the toilets. This site was located near the base of a hill. Fifteen to 20 people used the two latrines on a regular basis. Additional possible sources of groundwater contamination in the area of the sampling hole included some pigpens 100 m upgradient, and some houses located approximately 150 m upgradient. A few pigs were seen wandering around the area. The laundry area was located 50 m downgradient of the sampling hole.

Sullage was rated as 4 on a scale of 0 to 10, reflecting the site's good drainage due to position on the side of a gentle slope. Litter was rated as 6 on a similar scale of 0 to 10. There were several houses in the area, and these seemed to deposit a fair amount of refuse on the ground. The area was mostly grassy with few trees or shrubs immediately by the hole; however, there were a number of large trees nearby (Fig. 9).

The sampling hole was dug to a depth of 1.6 m, in rocky brown clay. Water was seen seeping in at a depth of around 1.5 m. Digging was discontinued when the soil became too rocky to proceed. A screened, perforated PVC pipe was put in place and the hole was backfilled with basalt fragments to the top of the perforations. The hole was pumped intermittently, at 2 gpm, to allow the hole to recharge. This was repeated 15 times to allow the water to clear and to attempt to obtain a representative sample of the groundwater. The water sample taken at this time had a fecal coliform content of 630 cfu/100 ml.

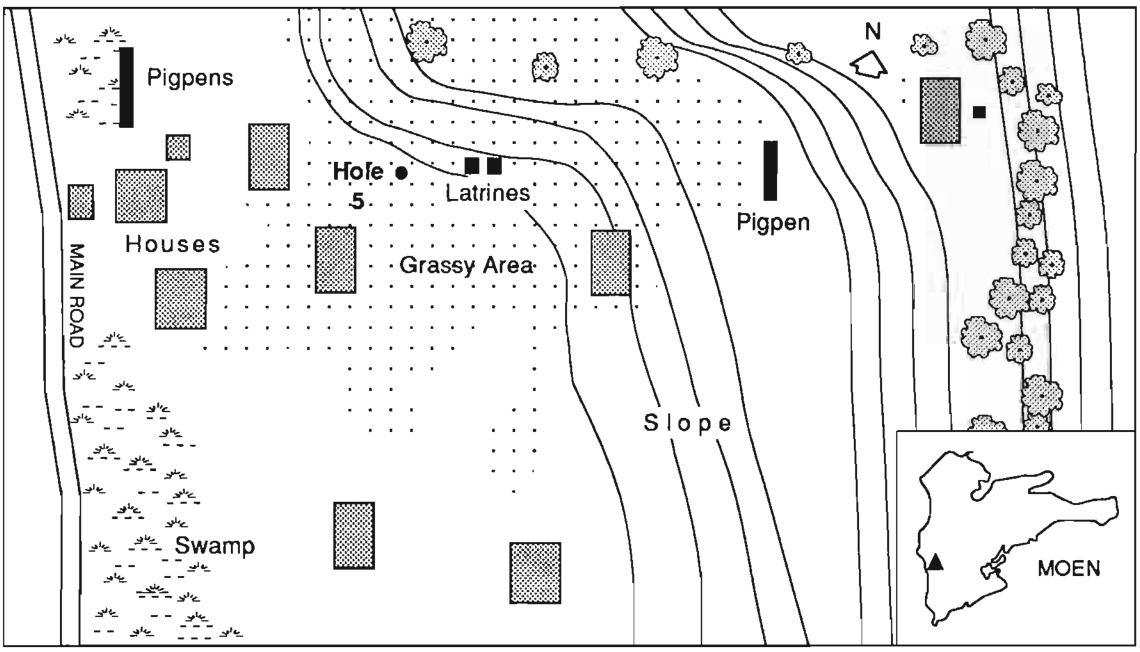


Figure 9. Sampling Site 5

SAMPLING HOLE 6: Witau Village	
Sullage score:	5
Litter score:	6
Pigs:	no
Other animals:	no
Nearest latrine:	25 m upgradient/lateral, 30 m upgradient/lateral, both water-seal
Number of users:	~10, 10
Soil type:	0 to 0.8 m marine deposits: sand, coral, etc.
Recharge rate:	moderate, drawdown of 0.25 m at 2 gpm
Precipitation:	none past 2 days

SITE LOCATION–HOLE 6. This site was located near the ocean in a very low-lying area about 30 m from the shore. This area was not filled but consisted rather of the natural marine deposits of sand and coral, found between the sea and the inland swampy areas at the bases of the mountains of Truk's high islands. The area had a low population density, with the nearest neighbor's house being some 100 m away. The sampling point was a preexisting WERI well that was unused for some months. This well had a small (0.6 m) cement apron around it, and a tight-fitting cap. The nearest latrines to this hole were located 25 m and 30 m away in a lateral/upgradient direction. Both latrines served from 5 to 10 people. Other potential sources of groundwater pollution included large trash pits located in the swampy area inland of the well site (Fig. 10).

Few animals were in evidence at this site. The area was extremely low-lying, with a large swampy area filled with litter just inland. The soil was a very permeable coarse marine sand. The site was about 1 km down the road that passes through the island's garbage dump. There was much litter enroute to the site, although the site itself had only a moderate amount of litter.

The area was well-treed, with a thick cover of undergrowth in the swampy inland area. In the area of the house and well, however, the ground was bare sand with a few palm trees.

The cap was removed and the well was pumped for several hours at a rate of 2 gpm. The water level fell from 0.21 m below the ground level to 0.46 m below the ground level almost instantly during pumping. The hole itself was only 1 m deep. Samples were taken periodically during this pumping, and these were taken to the laboratory for analysis. The results of these analyses are found in Table 6.

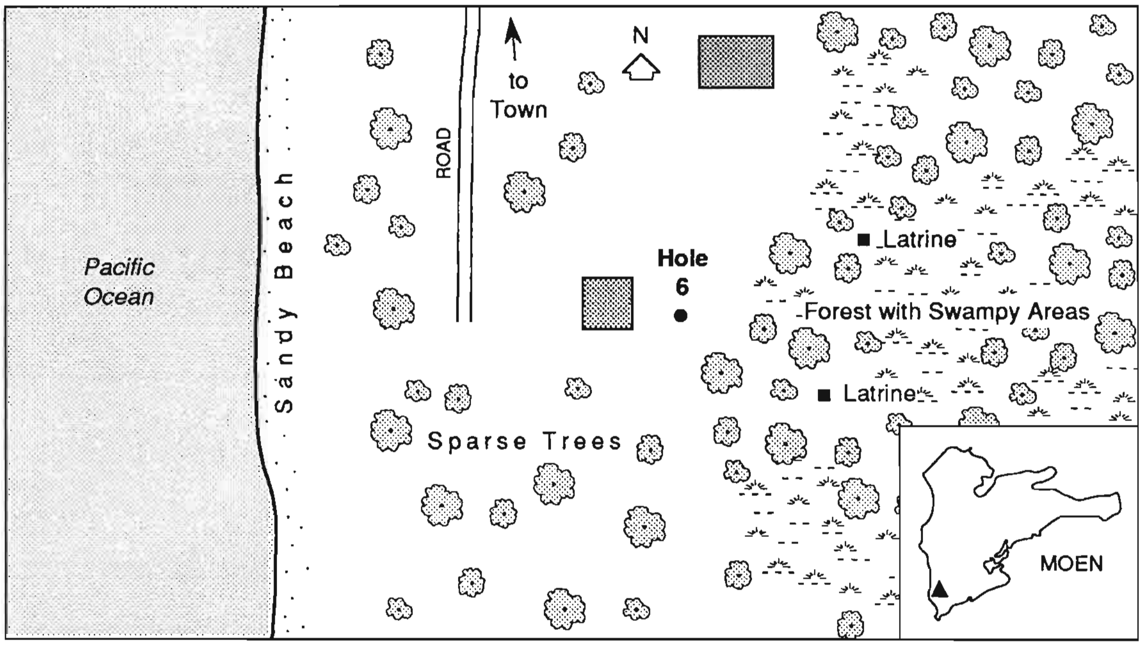


Figure 10. Sampling Site 6

TABLE 6. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 6

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
0	2	24
60	2	1,800
120	2	1,100
180	2	1,500
240	2	2,100

SAMPLING HOLE 7: Mwan Village		
Sullage score:	9	
Litter score:	3	
Pigs:	1 penned at 45 m lateral	
Other animals:	no	
Nearest latrine:	50 m laterally	
Number of users:	15	
Soil type:	0 to 0.3 m	brown, organic peat/humus
	0.3 to 1.5 m	grey sand, shells, coral fragments
	1.5 m	fossil reef
Recharge rate:	rapid	
Precipitation:	light, previous day	

SITE LOCATION–HOLE 7. This sampling point was located to the south of the village of Mwan, in a flat swampy area surrounded by a taro patch. There were only two houses in the immediate vicinity (Fig. 11). The area around the sampling hole was uninhabited, and the hole was dug adjacent to an unoccupied house. The nearest obvious potential source of groundwater contamination was a pigpen located 45 m in a lateral direction to the hole. The nearest latrine was 50 m away, also situated laterally. The surrounding taro patch received runoff from a hill some 200 m inland, and there were one or two houses near the base of the hill.

No other animals were in evidence around the area; however, it was later reported that one of the houses at the base of the hill had more than 30 pigs. The hole, on the edge of a taro swamp, was assigned a sullage score of 9 (10 being completely inundated). There was almost no litter to be seen and the site was assessed as a 3 on the scale of 0 to 10. The surrounding area was thickly vegetated with taro, grasses, and many breadfruit and palm trees.

The sampling hole was dug to a depth of 1.5 m. The first 0.3 m was a layer of decayed and decaying plant material. The next 1.2 m consisted of grey sand and shell fragments; and at a depth of 1.5 m a consolidated marine deposit layer was encountered. The water table was very shallow, about 0.5 m, and the hole rapidly filled with water as it was being dug. A 0.15-m-diameter length of perforated, screened PVC pipe was put in the hole, and the hole was back-filled with aggregate to the top of the perforations. The hole was filled with the excavated material. Water was pumped out at a rate of ~1 gpm for several hours, and samples were periodically taken for coliform analysis. The results of the analyses are found in Table 7.

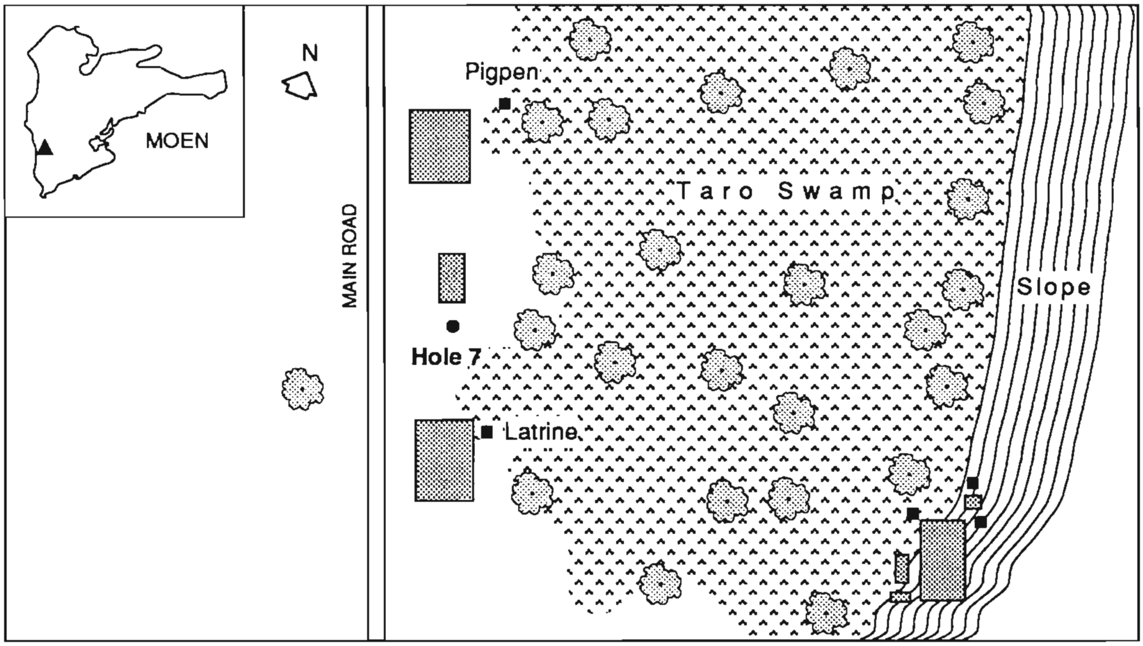


Figure 11. Sampling Site 7

TABLE 7. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 7

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	1	660
120	1	440
180	1	200
240	1	220

SAMPLING HOLE 8: Iras Village		
Sullage score:	7	
Litter score:	2	
Pigs:	no	
Other animals:	no	
Nearest latrine:	10 m upgradient, septic tank	
Number of users:	30, intermittent	
Soil type:	0 to 0.3 m	brown, organic peat/humus
	0.3 to 0.9 m	rocky brown clay
	0.9 to 1.5 m	sand, shells, coral fragments
Recharge rate:	extremely rapid	
Precipitation:	very heavy, previous day	

SITE LOCATION–HOLE 8. This site, located in a private yard, had been a taro patch but was filled some years ago. The hole was dug behind a row of buildings which lined the main road. The area was grassy and well kept. There were two toilets in the immediate area, a septic tank 10 m upgradient, and a sewer-connected toilet 12 m lateral of the hole. The toilets were used on an intermittent basis by about 30 people.

The only animal seen on the premises was a single dog; however, the yard was not entirely fenced off, so other roaming animals may have frequented the yard.

The area immediately around the hole was a well-cared-for lawn on one side and a gravel parking lot/storage yard for a building supply store next door (Fig. 12).

The day the hole was dug there was no rain, and the ground was quite dry. However, because it rained the night before the first sampling, the ground around the hole was inundated, and the casing sat in several inches of water. On this basis, the area was assessed an 8 on the sullage scale of 0 to 10. There was very little litter in the yard (3 on a scale of 0 to 10).

The water table was found to be very shallow in this area. Water was encountered in the first 30 cm of digging. Once the hole was cased and backfilled in the usual fashion, it was found that the recharge rate was extremely rapid. It was pumped at 4 gpm for 4 hours, with no measurable effect on the water level. The first 0.3 m of soil consisted of brown organic humus/peat, the next 0.6 m was rocky clay fill, and the last 0.6 m was sand, shells and other unconsolidated marine debris.

Samples were taken at half-hour intervals and transported to the laboratory for fecal coliform analysis. Table 8 illustrates the results of these analyses.

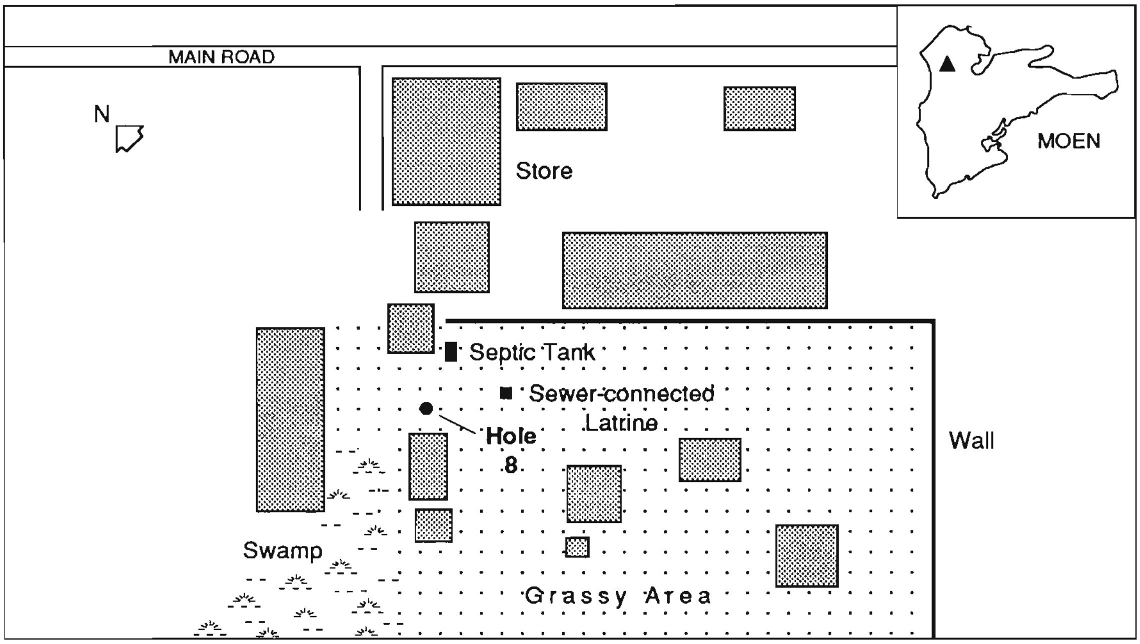


Figure 12. Sampling Site 8

TABLE 8. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 8

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	2	5,000
120	2	4,200
180	2	4,400
240	2	4,500

SAMPLING HOLE 9: Near Airport		
Sullage score:	10	
Litter score:	6	
Pigs:	1, penned 12 m downgradient	
Other animals:	yes	
Nearest latrine:	12 m downgradient, water seal	
Number of users:	~10	
Soil type:	0 to 1.5 m	heavy brown clay with large basalt rocks
Recharge rate:	rapid	
Precipitation:	very heavy, previous day	

SITE LOCATION–HOLE 9. This sampling hole was dug adjacent to a house in a swampy area inland from the Truk airfield. The area was evidently wet most of the time, because algae was seen growing on the ground, and small fish were observed swimming in large puddles. Houses in the area were built on pedestals of cement blocks and wood. Like most of the sampling sites, hole 9 was situated on the low-lying coastal flat, a naturally swampy area. The sampling location was 200 to 300 m away from any neighbors' latrines, but the latrine belonging to the household at the well site was 12 m downgradient of the sampling hole. Adjacent to this latrine, there was one small penned pig. Several dogs were also seen around the site. There was a bathing/laundry shed 12 m upgradient of the sampling hole (Fig. 13).

There was a relatively thick covering of vegetation in the area, consisting of grasses and shrubs with a few scattered palm trees. The general impression was of a light, open area.

From the ground surface to a depth of 1.5 m, when digging ceased, the soil was found to be a thick, brown, clay-rich muck with large basalt stones. Water was pumped from the hole at a rate of approximately 2 gpm for 4 hours and samples were taken hourly. These samples were analyzed for fecal coliform content. The results of these analyses are found in Table 9.

TABLE 9. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 9

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	2	380
120	2	400
180	2	350
240	2	340

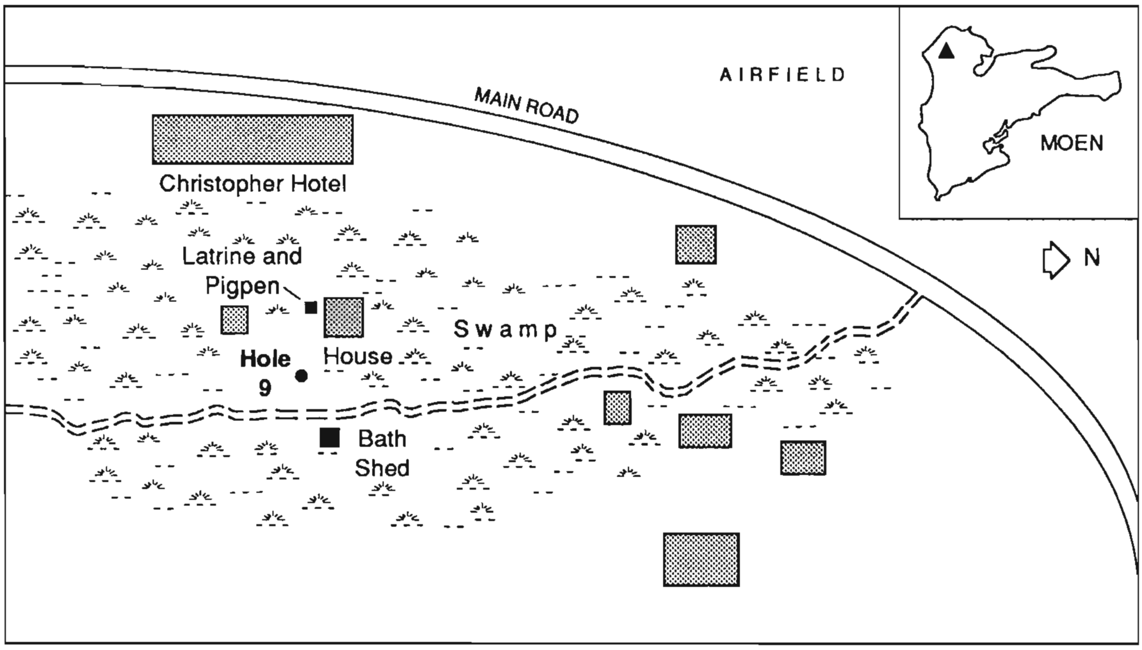


Figure 13. Sampling Site 9

SAMPLING HOLE 10: Mwan Village		
Sullage score:	7	
Litter score:	5	
Pigs:	no	
Other animals:	yes	
Nearest latrine:	10 m upgradient, water seal	
Number of users:	~7	
Soil type:	0 to 0.3 m	light humus, sod
	0.3 to 1.4 m	beige-colored sand
Recharge rate:	very fast	
Precipitation:	none for 3 days	

SITE LOCATION–HOLE 10. This sampling hole was dug in a grassy lawn area near a mangrove swamp (Fig. 14). The nearest latrine was 10 m upgradient of the hole, and there was evidence of runoff from a bath shed adjacent to the latrine 8 m from the hole. The area immediately around the sampling hole was relatively free of litter; however, the mangrove swamp surrounding the property on two sides was full of litter. Similarly, there was little standing water within 30 m or so of the hole; however, beyond this distance in the upgradient

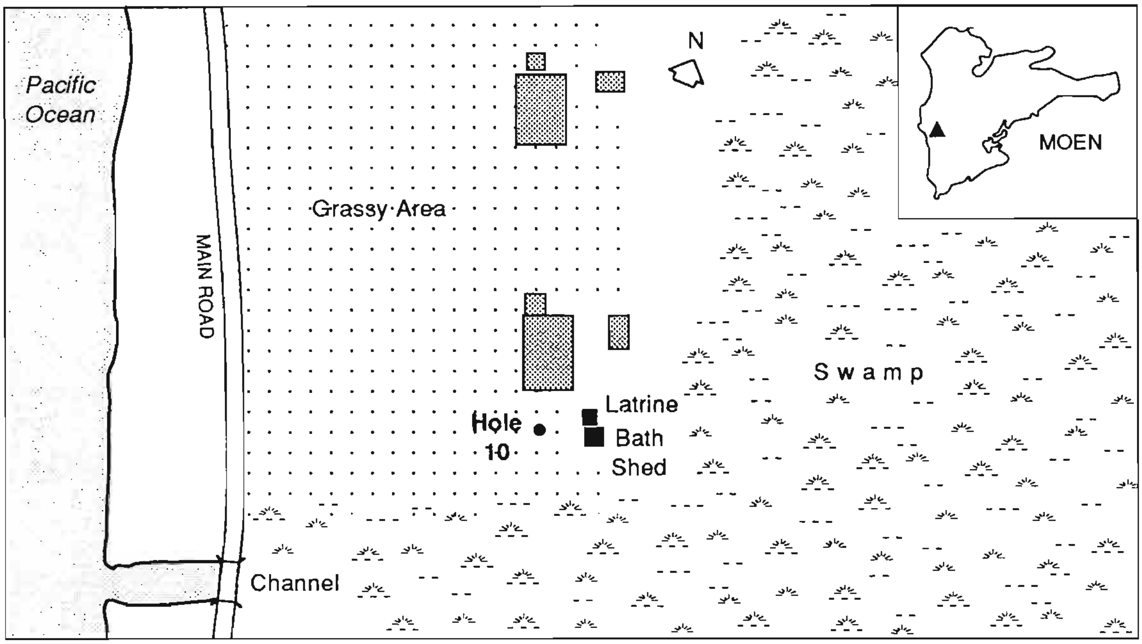


Figure 14. Sampling Site 10

direction, was the mangrove swamp. The area was one of relatively low population density. No pigs were in evidence, but several loose dogs and chickens were seen.

The soil at this sampling point was very light and sandy. At a depth of 0.3 m, a light-colored marine sand was encountered. Digging was easy and rapid. Water flowed rapidly into the hole, and it was possible to pump the hole continuously at ~2 gpm, without detectable drawdown. Samples of the water were taken and analyzed for fecal coliform. The results of these analyses are found in Table 10.

TABLE 10. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 10

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	2	55
120	2	20
180	2	30

SAMPLING HOLE 11: Behind the Post Office		
Sullage score:	5	
Litter score:	5	
Pigs:	yes	
Other animals:	yes	
Nearest latrine:	15 m lateral, water seal	
Number of users:	~15	
Soil type:	0 to 1.4 m	rocky clay
	1.4 m	light-colored sand with shells and coral fragments
Recharge rate:	moderate	
Precipitation:	light, previous day	

SITE LOCATION–HOLE 11. This WERI well was located in an area of extremely dense housing behind the Truk post office. The area was quite wet; and a nearby hole, from which sand for building purposes had been excavated, was filled with water to a point 0.2 m below the ground level. The soil consisted of rocky clay fill over sandy marine debris. Many pigs, dogs, and chickens were seen roaming this area. A moderate amount of litter was in evidence on the ground.

The well was 25 m distant laterally from the nearest latrine, a water-seal unit. There were numerous other latrines in the area. The mangrove swamp was approximately 300 m inland of the well site, and the intervening area was relatively lush and well treed. There were many houses in this area and most were equipped with a latrine. Many latrines had recently been connected to the city sewer system as part of the ongoing household sewer-connection program currently underway on Moen. There was a bathing shed 10 m in a lateral direction from the well (Fig. 15).

This well was functioning, in contrast to most of the solar-powered wells seen in Truk. At the time of sampling (2:00 pm) the well was being pumped at a rate that varied from 1 to 2 gpm. The water was piped to one of the nearby houses. The sample was taken on a sunny day, and it is assumed that the well had been pumping steadily for the better part of the day. Thus, it was felt that a sample taken at this time would be representative of the groundwater in the area. The sample was found to have a fecal coliform count of 3,000 cfu/100 ml.

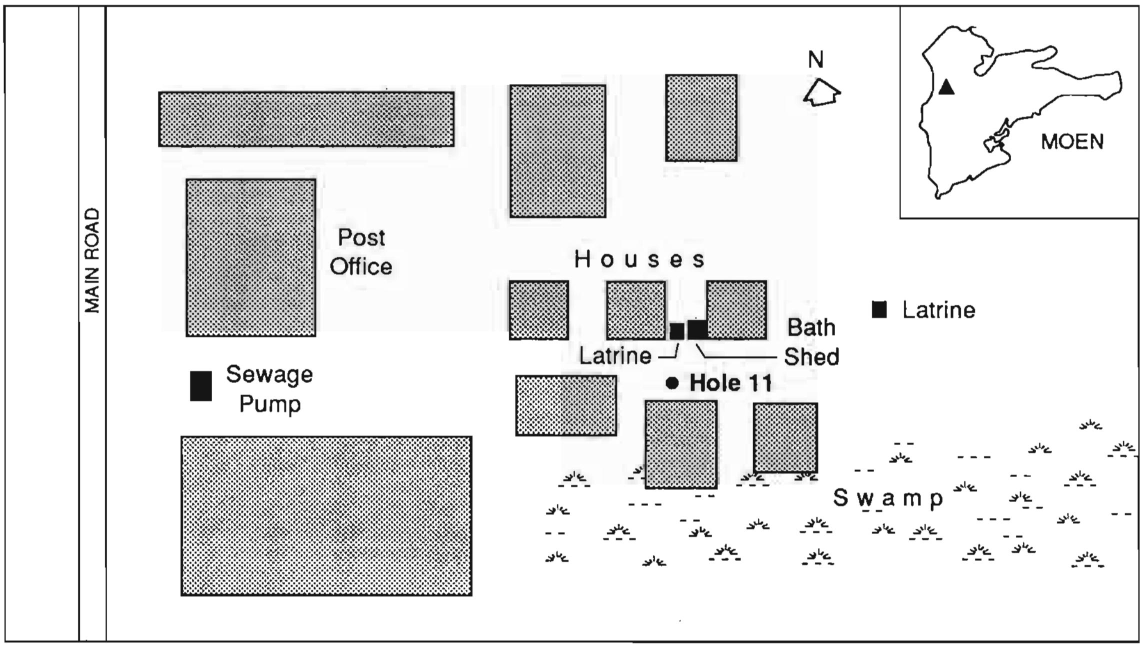


Figure 15. Sampling Site 11

SAMPLING HOLE 12:	Behind Green Store Near Mobil Oil Tank Farm, Mwan Village
Sullage score:	1
Litter score:	3
Pigs:	yes
Other animals:	yes
Nearest latrine:	8 m downgradient, dry pit
Number of users:	~8
Soil type:	sandy clay
Recharge rate:	rapid
Precipitation:	light, same day

SITE LOCATION–HOLE 12. This nonfunctioning WERI well was located across the main road from the Mobil Oil tank farm in Mwan village. The area was very densely built up with small houses, and there were numerous latrines and pigpens in the immediate vicinity of the well (Fig. 16). The area was very dry and considerably distant from any mangrove swamp. Vegetation was limited to some grassy areas and a few palm trees. The wellhead was protected by a square wooden crate about 1 m on each side. No ranging animals were seen in the vicinity of this well.

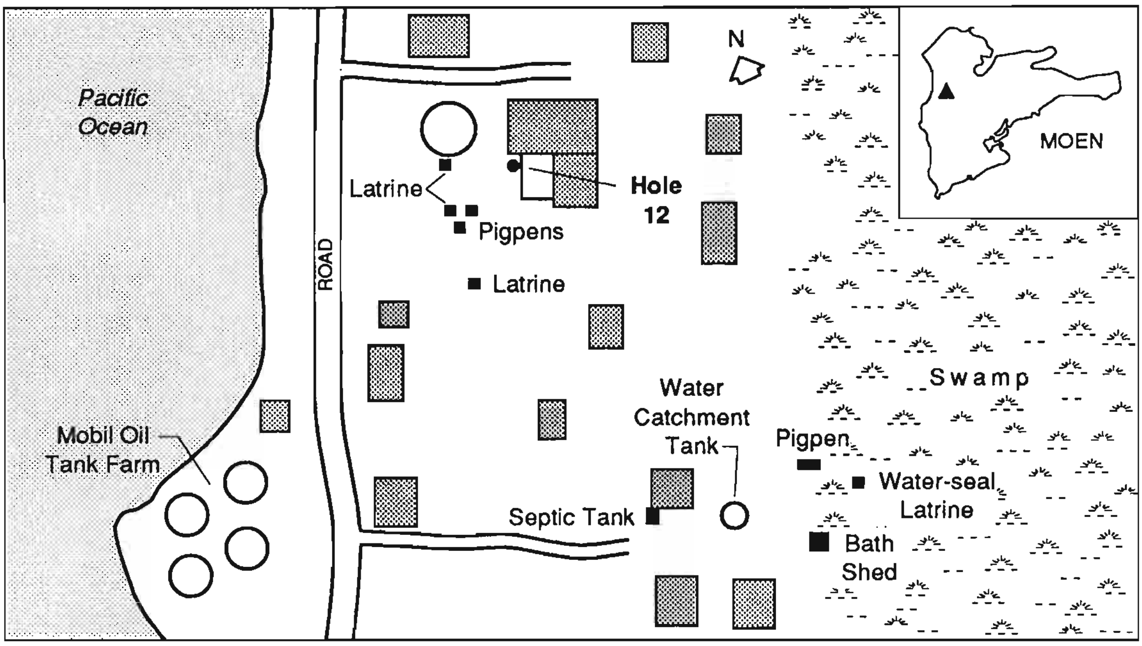


Figure 16. Sampling Site 12

The existing pump in this well was found to be functional, therefore it was connected to a solar panel and allowed to pump for three hours. Samples were taken at hourly intervals and transported to the laboratory for analysis. The results of these analyses are tabulated in Table 11.

TABLE 11. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 12

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	1 - 2	18
120	1 - 2	15
180	1 - 2	16

SAMPLING HOLE 13: Behind New Church, Mwan Village		
Sullage score:	8	
Litter score:	7	
Pigs:	yes	
Other animals:	yes	
Nearest latrine:	7 m lateral, water seal	
Number of users:	~7	
Soil type:	0 to 0.33 m	heavy, rocky, brown clay
	0.33 to 2 m	white sand, shell and coral fragments
Recharge rate:	rapid	
Precipitation:	very heavy, previous day	

SITE LOCATION–HOLE 13. This hole was dug in a very swampy, heavily populated area of Moen, just inland of the most developed region of the island. This area was on the narrow strip of land between the ocean and the inland mangrove swamp. The nearest latrine was a water-seal unit located 7 m in a lateral direction from the hole. Another latrine was situated some 12 m downgradient (Fig. 17).

An interesting feature of this hole was that after digging through 0.3 m or so of the dark, heavy soil that had been used to fill the area for building, a very clean sand/coral debris was encountered. This sand appeared to have a high hydraulic conductivity. The water level rose rapidly in the hole, and continuous pumping at a rate of approximately 2 gpm resulted in a drawdown of about 0.2 m.

The area around hole 13 was very dirty. Litter was assessed as 7 on a scale of 0 to 10. The area was also very wet. There were numerous holes and depressions filled with muddy water nearby. There was also a large taro swamp on the far side of the nearest latrine. Vegetation in the area consisted of low grasses with a sparse overstory of palms and breadfruit trees. Much of the area was bare dirt due to the heavy foot traffic in the vicinity. This bare area quickly turned to mud when it rained.

The sampling hole was dug to a depth of 2 m. It was then cased and backfilled in the usual fashion. Water was pumped from the hole at a rate of 1 to 2 gpm for 4 hours, and samples were taken hourly. Results of the analyses of these samples are tabulated in Table 12.

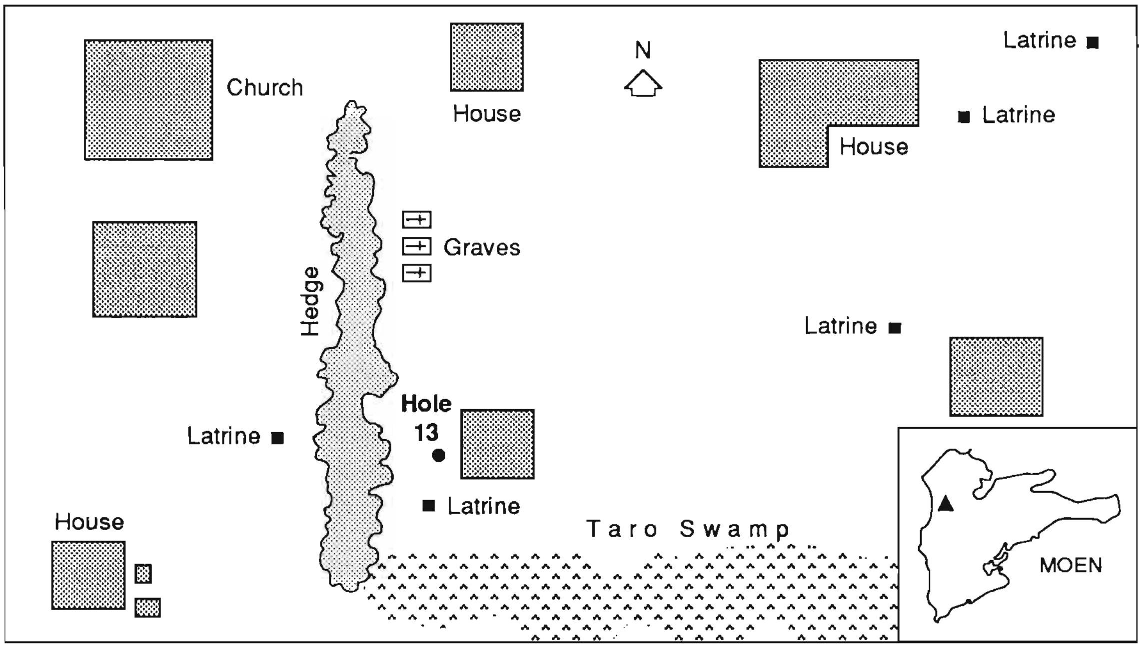


Figure 17. Sampling Site 13

TABLE 12. FECAL COLIFORM DETERMINATIONS, SAMPLING LOCATION 13

PUMPING TIME (min)	PUMPING RATE (gpm)	FECAL COLIFORM COUNT (cfu/100 ml)
60	1 - 2	4,000
120	1 - 2	2,200
180	1 - 2	200
240	1 - 2	60

ANALYSIS AND DISCUSSION

Groundwater Results

All but two of the groundwater samples analyzed tested positive for fecal contamination. The maximum fecal coliform count found in any sample was in hole 2, where a sample taken after 15 minutes of pumping at ~2 gpm had 460,000 cfu/100 ml. This levelled off to 360,000 after 300 minutes of pumping (Table 13).

TABLE 13. SUMMARY OF SAMPLING-HOLE PARAMETERS N = 13

	Average	Maximum	Minimum	Standard Deviation
Sullage score (0 = little, 10 = lots)	6.00	10.00	1.00	2.65
Litter score (0 = little, 10 = lots)	4.54	8.00	1.00	2.07
Nearest latrine (distance in m)	15.08	50.00	7.00	11.71
Users/latrine	28.62	200.00	7.00	51.94
Well depth (m from ground)	1.45	1.70	1.00	0.23
Water level (m from ground)	0.42	1.30	0.10	0.36
Fecal coliform count				
Wet day (cfu/100 ml)	41,723.78	360,000.00	16.00	119,384.49
Dry day (cfu/100 ml)	26,960.00	88,000.00	60.00	41,685.90
Best estimate* (cfu/100 ml)	2,241.27	13,700.00	16.00	4,082.75

*Excludes hole 2, an extreme outlier.

Both wells 1 and 2 were sampled on two different occasions; once on a dry day after several rainless days, and once on a rainy day after several wet days. In Figure 18, in both holes 1 and 2, the fecal coliform counts were significantly higher on the wet days. This phenomenon is believed to be attributable to enhanced transport of fecal bacteria with water infiltrating from the surface. This observation has important implications for the interpretation of the results of sample analyses from the other test holes. The prevailing conditions of precipitation should be considered when reviewing the bacteriological data. A further implication of this finding is that areas with large quantities of standing water may have a greater potential for groundwater contamination. In our previous study (Miller et al. 1988) of sanitary conditions in Truk and Palau, the only parameter found to have a correlation with the bacteriological quality of the water in nearby wells was the amount of sullage in the area. Hole 2 was found to have extremely high fecal coliform counts even on a dry day. This well was included in Miller et al. (1988) and, at the time of the 1988 study, was found to have a fecal coliform count of 47,000 cfu/100 ml. Although the sanitary conditions surrounding this well were very poor, they were no worse than those seen at many of the other sites. The extremely

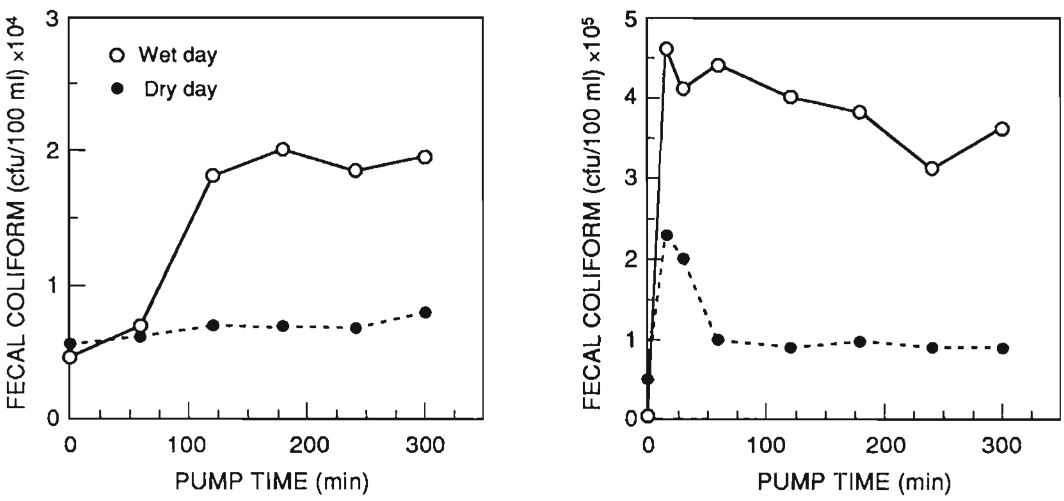


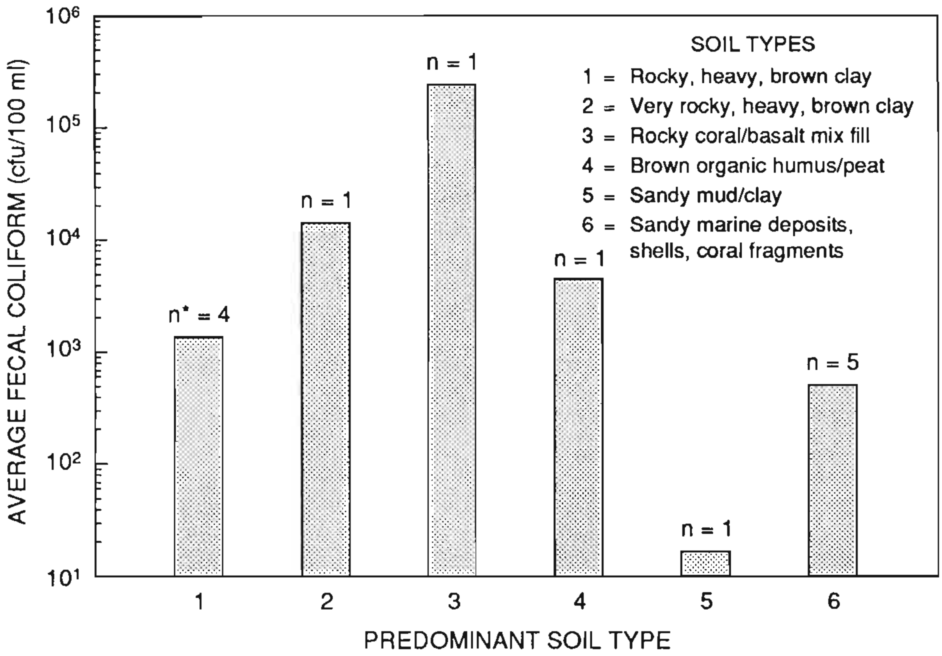
Figure 18. Comparison of fecal coliform in sampling holes on wet and dry days

high bacteria counts seen in hole 2 were probably related to the type of soil/fill surrounding the hole. It was noted that an area 3 m in diameter around the hole seemed to be filled with coarse (~0.13 m to 0.18 m) basalt stones. This extremely coarse medium would provide numerous large channels for the direct flow of contaminated water to the water table (Fig. 19).

Water levels in the holes were found to be quite close to the surface (average distance 0.42 m). This proximity of the water table to the ground surface implies rapid transport of contaminants from the surface to the saturated zone and potentially to the water supplies.

The minimum fecal coliform count found in any sample taken after sufficient pumping to negate well effects was 18 cfu/100 ml, found in hole 3 after 300 minutes of pumping. It is of interest to note that two fecal-coliform-free samples were taken at 30 and 60 minutes from this well. Reviewing the data on the conditions surrounding this sampling point, it can be concluded that the area was not especially clean, had an abundance of ranging pigs, and was quite close to the mangrove swamp. Furthermore, the recharge rate was extremely rapid in this hole, indicating quick lateral water movement in the area. The soil in the area of hole 3 consisted of sandy marine deposits that allowed relatively rapid passage of water, but provided good mechanical filtration and contained little nutritive material to sustain bacteria. The fecal coliform content of the water samples, by the predominant soil type, is shown in Figure 20.

From this small sample, it appears that holes in the coarser soils and soils containing organic clay and humus had higher fecal coliform counts than did holes dug in marine sand soils. The marine-derived soils encountered tended to be more homogeneous, possibly belying their method of deposition. In contrast, the rocky clay-fill soils were often a patchy mixture of clay and rocks of different types and sizes.



*n = number of sampling holes.

Figure 19. Average fecal coliform content by soil type

Although there may be a relationship between soil type, or any of the other parameters examined, and level of fecal contamination, no parameter has a significant predictive value for the fecal coliform content of the sampling holes in this small data set. In all cases the correlation coefficient between fecal coliform content and the parameters examined was less than 0.3. Figure 20 illustrates the relationship between several of the environmental parameters examined and fecal coliform content in the sampling holes.

In some cases fecal coliform counts increased with prolonged pumping. In other cases the opposite was true. The existing, nonfunctioning WERI wells initially had lower bacteria counts, possibly reflecting the effects of bacteria die-off in the stagnant well water. The holes dug especially for the purposes of this study had initially higher counts that seemed to decrease with continued pumping. These higher counts could be the result of the introduction of fecal bacteria into the water from the surface during the digging process. Wells in sandy soils seemed to have lower bacterial counts than clay rich soils. This result ran counter to our expectations. It was believed that thicker soils containing more clay would be more efficient at detaining bacteria.

Latrine use was found to be very high, with an average number of users of 28.62 per latrine. This number includes one school with 200 students, which skews the mean upward. When the school is omitted from the calculation, the average number of users becomes 14.33.

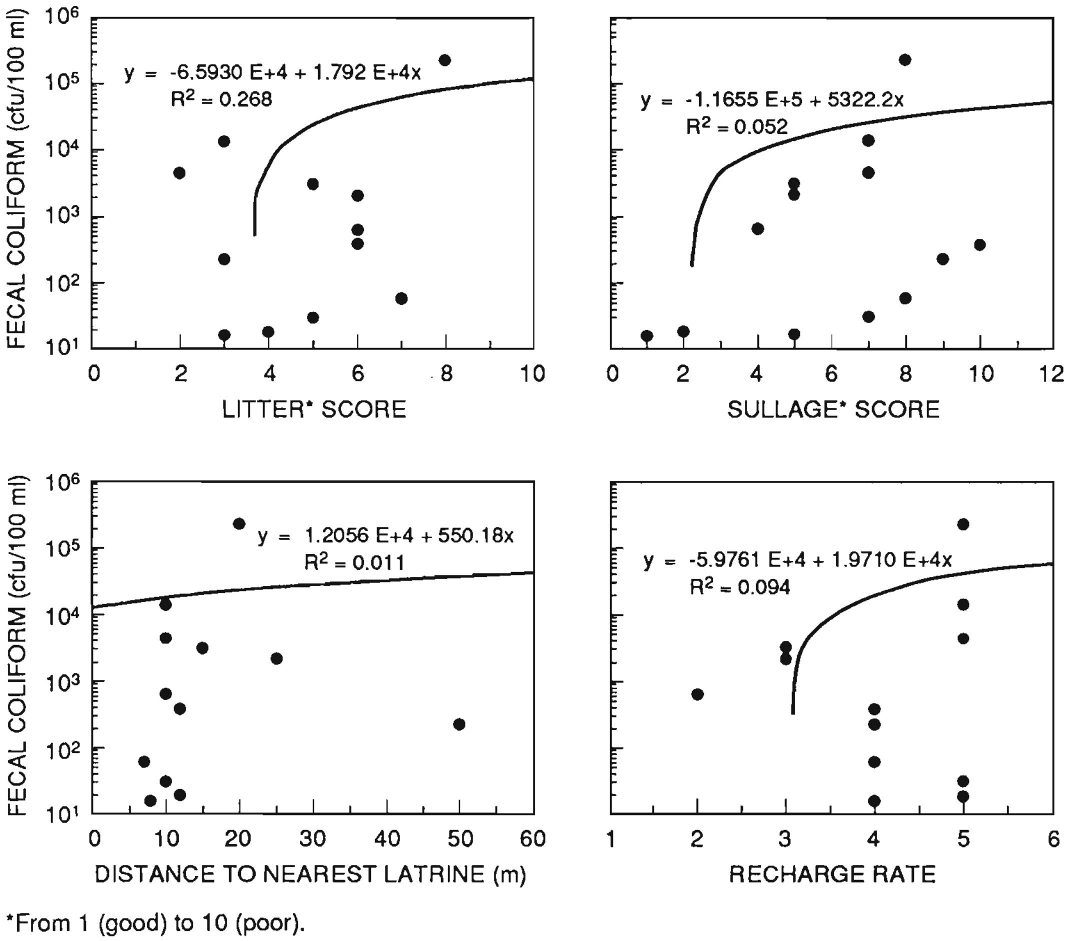


Figure 20. Sanitation parameters and fecal coliform (FC) counts, with correlation coefficients

The traditional custom of using the beaches and mangrove swamps as excreta disposal sites was still widely practiced on Moen, although no attempt was made to quantify this use.

Rainwater Results

By far the most common type of rain storage-tank in the sample was made of ferro-cement; cement plastered onto a circular framework of reinforcing bar and perforated sheet metal. Construction of these tanks has been a government-subsidized program in Truk over the last several years. The tanks were generally well built, and the design included covers and inflow screens. One steel and two fiberglass tanks were also included in the sample. Tank capacity ranged from 700 to 48,000 l and averaged 12,268 l. Seven of the 32 tanks inspected were found to have cracks, although these were generally minor and did not seriously impair the functioning of the tanks. All of the roofs examined were constructed of corrugated sheet metal.

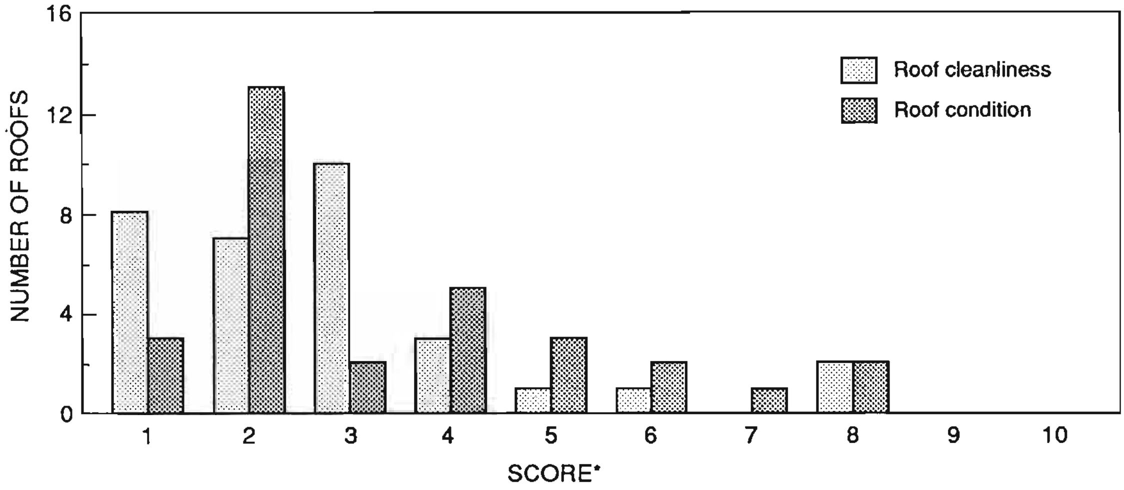
The condition of these roofs varied considerably; rust, and debris from trees were the principal problems (Fig. 21). The average proportion of total roof area equipped with gutters was 0.47.

Tables 14 and 15 summarizes some of the other parameters of rain-catchment systems that were examined.

The water in the rain catchment tanks was of good quality (average total coliform count 110 cfu/100 ml), compared to the groundwater samples examined. The small sample size and skewed distribution (Fig. 22) of the bacteriological results make it difficult to draw conclusions regarding the importance of these parameters in determining the quality of the stored water. However, certain results suggest that a relationship existed between these parameters and the bacteriological quality of the water in the tanks.

None of the systems examined included any type of first flush device (to shunt the initial portion of runoff away from the storage tank in order to preclean the roof). Sixty-nine percent of the tanks had screens in place to prevent debris from entering. The average total coliform count in the 22 tanks with screens was 78.68 cfu/100 ml, while the average count in the 10 unscreened tanks was 178.2 cfu/100 ml. Related to the presence of screens was the amount of sediment seen on the bottom of tanks and the presence of insect larvae in the water. In 17 cases, it was not possible to see into the tanks to determine the amount of sediment, algae, and presence of insects.

Only three of the tank owners interviewed said that they ever put water from the government distribution system into their tanks, however, this figure should be viewed with some caution, for it was reported that illegal connections to the city water line are common, and tank owners may have been reticent to admit having access to city water. As mentioned earlier, the city water supply was often contaminated with coliform bacteria. The three tanks that reportedly had piped water put in them had an average total coliform count of 383.3 cfu/100 ml, standard deviation 205.5. The average and standard deviation of the tanks that did not pipe in city water was 81.48 and 117.94, respectively. Of the 32 systems examined, 5 had trees overhanging the roof. This is of interest, because overhanging trees can contribute to tank contamination by dropping detritus onto roofs and by providing a gathering place over the roof for birds and rodents. The 5 systems with overhanging trees had an average total coliform count of 194.2 cfu/100 ml, standard deviation 156.96. The remaining 27 tanks had an average total coliform count of 94.15 cfu/100 ml, standard deviation 149.47.



*From 1 (good) to 10 (poor).

Figure 21. Roof conditions in rainwater catchment systems on Moen

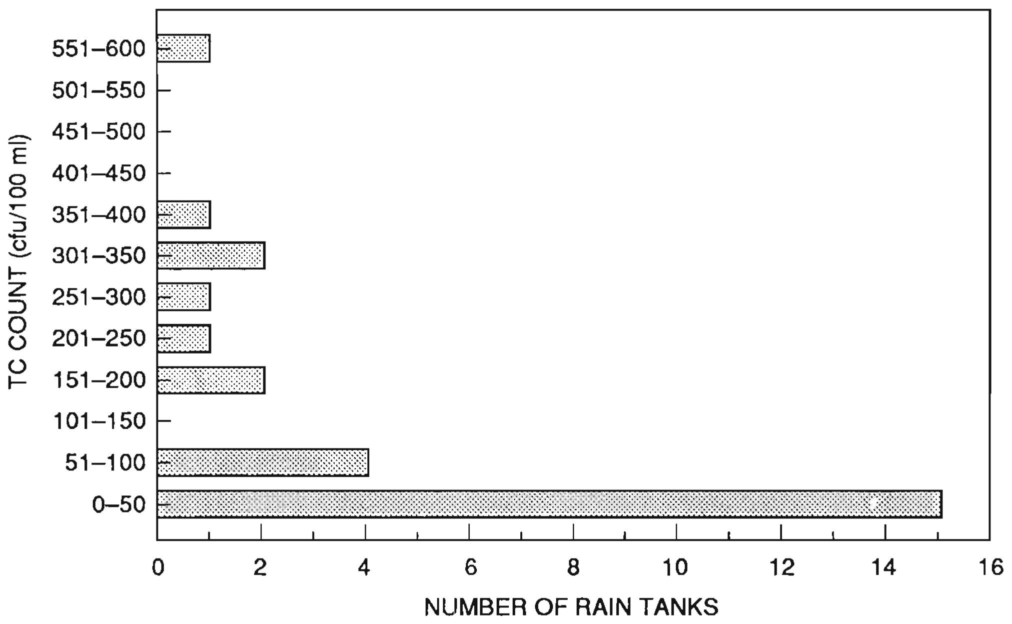


Figure 22. Total coliform (TC) counts in samples from Moen rain tanks

TABLE 14. RAINWATER CATCHMENT SYSTEM PARAMETERS

	Maximum	Minimum	Average	Standard Deviation
Tank capacity (l)	48,000	700	12,268	8,012
Tank users	300	4	33	56
Roof gutters (%)	100	10	47	25
TC* cfu/100 ml	580	0	110	153
FC† cfu/100 ml	400	0	14	70

*TC = total coliform.
†FC = fecal coliform.

TABLE 15. SUMMARY OF ADDITIONAL CATCHMENT SYSTEM PARAMETERS

	Yes*	No*	Partial	Missing
Tank covered?	28 (103.5)	1 (8)	3	0
Inflow screen?	22 (78.68)	10 (178.2)	0	0
Insects in tank?	0	15		17
First flush device?	0	32		0
Tank leaks?	7	25		0
Trees over roof?	5 (194.2)	27 (94.15)		0
City water in tank?	3 (383.3)	29 (81.48)		0

*Numbers in parentheses are average total coliform counts in cfu/100 ml sample.

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REFERENCES

Adesiyun, A.A.; Adekeye, J.O.; Umoh, J.U. 1983. Studies on well water and possible health risks in Katsina, Nigeria. *J. Hyg. Camb.* 90:199-205.

Althaus; H.; Jung, K.D.; Matthess, G.; Pekdeger, A. 1982. Survival of bacteria and viruses in groundwater. *Umweltbendesamt Materialien,* 82:190. Schmidt Verlag.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. New York: APHA, AWWA, and WPCF.

Austin, Smith and Associates, Inc. 1967. Pacific Islands Trust Territory. Engineering report covering a master planned water supply and distribution system as well as a sewerage system for the Koror area of the Palau Islands, Western Caroline Islands. Agana, Guam and Honolulu.

Berg, G. 1978. The indicator system, in *Indicators of viruses in water and food*. Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc. 424 p.

Blum, D.; Huttly, S.R.A.; Okoro, J.L.; Kirkwood, B.R; and Feachem, R.G. 1987. The bacteriological quality of traditional water sources in northeastern Imo State, Nigeria *Epidem. Inf.* 99: 429-37.

Canter, L.W., and Knox, R.C. 1985. *Septic tank system effects on ground water quality*. Chelsea, Michigan: Lewis Publishers, Inc.

Clayshulte, R.N., and Zolan, W.J. 1980. Well water quality on Moen Island, Truk. *Tech. Rep.* 13. Water and Energy Research Institute of the Western Pacific, University of Guam, Agana. 36 p.

Comprehensive groundwater protection strategy for the Federated States of Micronesia. 1987. Prepared for the Trust Territory Environmental Protection Board. 87 p.

Craun, G.F. 1979. Waterborne disease—A status report emphasizing outbreaks in groundwater systems. *Ground Water* 17(2):183-96.

DeWalle, F.B.; Schaff, R.M.; and Halten, J.B. 1972. Well water quality deterioration in central Pierce County, Washington. *J. Am. Water Works Assoc.* 72:533-36.

Drewry, W.A., and Eliassen, R. 1968. Virus movement in ground-water. *J. Water Pollut. Control Fed.* 40(8), Part 2, R257-71.

Esikol, R.D., and Ongrung, R. 1988. Proposed project plans for water supply and toilet system on Truk for USEPA federal grant application.

Fischer, Ann. 1950. Trukese privacy patterns Scientific investigation of Micronesia. Washington, D.C.: Naval Research Reviews. 15 p.

Gerba, C.P. 1985. Microbial contamination of the subsurface in *Ground water quality*, ed. C.H. Ward, W. Giger and P.L. McCarty, New York: A Wiley-Interscience Publication, pp. 53-64.

Gerba, C.P., and Keswick, B.H. 1981. Survival and transport of enteric viruses and bacteria in groundwater. In *Quality of groundwater, proceedings of an international symposium*, Noordwijkerhout, The Netherlands. Studies in Environmental Science, vol. 17. The Netherlands: Elsevier Publishing Co. pp. 511-15

Gerba C.P.; Wallis, C.; and Melnick J.L. 1975. Fate of wastewater bacteria and viruses in soil. *J. Irrig. Drain. Div., Am. Soc. Civ. Eng.* 101:157-75.

Gilbert, R.G.; Gerba, C.P.; Rice, R.C.; Bouwer, H.; Wallis, C.; and Melnick, J.L. 1976. Virus and bacteria removal from wastewater by land treatment. *Appl. Environ. Microbiol.* 32(3): 333-38.

Hawaii Architects and Engineers Inc. 1978. Road, water system and container storage yard improvements, Palau District, Western Caroline Islands, Trust Territory of the Pacific Islands. Honolulu, Hawaii.

Keswick, B.H. 1984. Sources of groundwater pollution. *Groundwater pollution microbiology*. New York: John Wiley and Sons. 377 p.

Laird, William E. 1983. *Soil survey of Islands of Truk, Federated States of Micronesia.* United States Department of Agriculture, Soil Conservation Service.

Lewis,W.J.; Farr, J.L.; and Foster, S.S.D. 1980. The pollution hazard to village water supplies in eastern Botswana. *Proc. Inst. Civ. Engineers.* 69:281-93.

Miller, F.D.; Moravcik, P.S.; Siren, N.; Convard, N.S. 1988. A study of potential contamination of water resources in unserved areas in Truk and Palau, Micronesia. 105 p.

Mink, J.F. 1986. *Trust Territory of the Pacific Islands water supply initiative: groundwater resources and development.* U.S. Environmental Protection Agency.

O'Meara, C. 1982. "An investigation of social aspects of fresh water use in selected hamlets of Belau." Spec. Rep. 1, Micronesian Area Research Center, University of Guam. 46 p.

Pacific Islands, (Trust Territory), Office of Health Services. 1983. Truk state five year comprehensive health plan/prepared by Office of Health services, Trust Territory of the Pacific Islands and Truk State Health Planning Office.

Pekdeger, A. 1984. Pathogenic Bacteria and Viruses in the Unsaturated Zone. *Pollutants in porous media: The unsaturated zone between soil surface and groundwater,* ed. B. Yaron., D. Dagan., and J. Goldschmidt. Berlin: Springer-Verlag. pp. 195-205.

Reddy, K.R.; Khaleel, R.; and Overcash, M.R. 1981. Behaviour and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *J. Environ. Qual.* 10:255-66.

Smith, Christopher W. 1983. *Soil survey of islands of Palau, Republic of Palau.* Washington, D.C.: United States Soil Conservation Service. 120 p.

Stark, J.T. 1958. *Military geology of Truk Islands, Caroline Islands.* U.S. Army Pacific, U.S. Geological Survey. 205 p.

Stickel, B. 1980. "A study of factors related to diarrheal diseases on Moen, Truk." Master's thesis (Public Health), University of Hawaii at Manoa, Honolulu.

Trust Territory of the Pacific Islands water supply initiative: groundwater resources and development. 1986 report prepared for the U.S. Environmental Protection Agency. Region 9.

Todd, D.K. 1980. *Groundwater hydrology,* 2d ed. New York: John Wiley and Sons. 535 p.

Todd, D.K., and McNulty, D.E.O., 1976. *Polluted groundwater:* A review of the significant literature. Huntington, New York: Water Information Center, Inc. pp. 86-7.

Van der Brug, O. 1983. *Water resources of the Truk Islands*, U.S. Geological Survey. Water resources investigations report 82-4082, Honolulu, Hawaii. 223 p.

______. 1984. *Water resources of the Palau Islands*, U.S. Geological Survey. Water resources investigations report 83-4140, Honolulu, Hawaii. 223 p.

William, S. 1985. "Moving inland: an evaluation of the rural sanitation program which replaces the prevailing over the water benjo to overland benjo." Master's thesis (Public Health), University of Hawaii at Manoa, Honolulu.

Wilson, R.; Haley, C.E.; Relmar, D.; Craun, G.F.; Morris, J.G.; and Hughes, J.M. 1983. Waterborne outbreak, related to contaminated ground water reported to the Centers for Disease Control, 1971-1979. In *Microbial health considerations of soil disposal of domestic wastewaters*. U.S. Environmental Protection Agency, no. EPA-600/9-83-017: 264-88.

Winter, S.J., and McCleary, L.D. 1985. Solar-powered wells for atoll island water supplies—Part 1. *Tech. Rep.* 60. Water and Energy Research Institute of the Western Pacific, University of Guam, Agana. 13 p.

Winter, S.J.; McCleary, L.D.; and Watters, R.D. 1983. The WERI well on Truk: A solar photovoltaic pumping project. *Tech. Rep.* 39. Water and Energy Research Institute of the Western Pacific, University of Guam, Agana. 27 p.

Winter, S.J., and Stephenson, R. 1983. The development of a village water supply system in Truk. *Tech. Rep.* 28. Water and Energy Research Institute of the Western Pacific, University of Guam, Agana. 45 p.