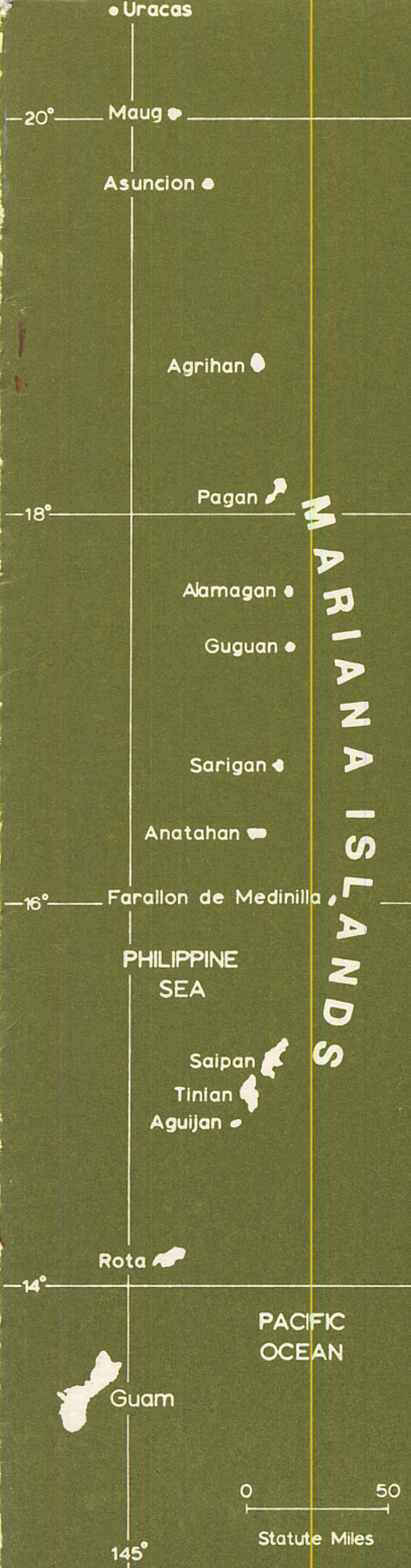


# THE GHURA-DEDEDO DEEP MONITORING WELL PLANNING AND DESIGN

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*Water Resources Research Center*

UNIVERSITY OF GUAM

Technical Report No. 15

May 1980

OFFICE OF WATER RESEARCH AND TECHNOLOGY
PROJECT NO. A-008-GUAM

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# PLANNING AND DESIGN


By

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Project Completion Report

for

GUAM BASAL GROUND-WATER MONITORING WELL SYSTEM--

CONSTRUCTION AND DEVELOPMENT

Project No. A-008-Guam, Grant Agreement No. 14-34-0001-8012

Principal Investigators: Stephen J. Winter and Charles J. Huxel

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## *ABSTRACT*

*The final design of Guam's first deep monitoring well has evolved from an open borehole concept through a three-well system and finally to the present one-well system. The one-well system utilizes an inflatable packer assembly which will permit the accomplishment of several goals:*

1) *Observation and simultaneous recording of point-water heads at 2 different levels.*

2) *Collection of water samples from isolated aquifer intervals.*

3) *Definition of a depth-salinity curve for the water column in the monitoring well.*

*Although the one-well system is presently under construction, the design process is still continuing. A satisfactory method for emplacing and sealing the casing is still being worked out. Also, the precise location of the alternating perforated and sealed casing intervals must be determined.*

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## PURPOSE AND SCOPE

This report summarizes briefly the planning and design history of Guam's first deep monitoring well. The purpose of the report is to describe the general course of events and the design changes leading to the present monitoring well concept.

## RESOURCE MANAGEMENT AND THE DEEP MONITORING WELL

The basal ground-water body underlying the northern Guam limestone plateau constitutes the main fresh-water supply of the island. This water body, commonly known as the fresh-water lens, has proved to be an abundant source of relatively cheap, good quality water. It is cheap because it may be developed through pumping wells[1] and it is good quality because it is overlain by up to 500 feet of limestone which acts as a protective filtering mechanism.[2]

It is obvious that underground sources of water such as the northern Guam fresh-water lens compare favorably with alternative surface water sources in most regards.

The main problem in developing water from the fresh-water lens lies in the fact that it floats directly on underlying salt water (sea water). Careless development of the lens may cause upwelling sea water to intrude into areas normally occupied by the fresh water, thus seriously contaminating the lens from below.

A related problem stems from the need to maintain an uninterrupted flow of fresh-water recharge to the lens. Without continued recharge, the lens will diminish in size and capacity. As development proceeds on the watershed overlying the lens, areas of natural recharge are eliminated or altered. Rainfall on these areas is collected into storm drains and channeled into ponding basins within the recharge areas so it will not be lost to the lens. However, it is not known to what extent toxic pollutants carried in the rainfall runoff may be carried to the lens in percolating recharge. Thus, contamination of the fresh-water lens may take place either from below through upwelling salt water or from above through recharging pollutants.

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[1]It would require about 30 wells to produce the ten million gallons per day (mgd) which is the combined capacity of Fena Reservoir and the Bona-Almagosa Spring System. It would cost only between two and three million dollars to construct the wells, but it would cost 10 to 15 times this amount to construct Fena Dam today.

[2]Freshwater lens water requires no treatment other than chlorination.

If the lens does become contaminated, it may be a long-term effect. Water moves through surface-water reservoirs very freely and the entire contents of a contaminated reservoir may be replaced by new uncontaminated water during a single season. But in underground reservoirs consisting of saturated rock, the flow of water is very slow. It may require years, rather than days, for the contaminated ground water to be replaced by uncontaminated recharge.

Inasmuch as the northern fresh-water lens is the sole source of fresh water for a majority of people of Guam, it is essential that its development be managed so as to eliminate the possibility of any serious or wide-spread contamination from above or below.[3] Whether or not such a degree of resource management can be achieved depends entirely on how much we know the dynamics of the fresh-water lens and our ability to observe lens behavior under developmental stress.

What do we need to know about the lens in order to manage it effectively? At the least, we have to know the areal extent and thickness of the lens. We should also know where and how the thickness and quality of the fresh-water lens is being affected by development. In a broad sense, we need to know the relationship between the shape, size and quality of the fresh-water lens on the one hand and developmental activities on the other hand.

What is the present state of our understanding? Very simply, we start from an understanding that there is a theoretical relationship which governs the behavior of fresh water floating on salt water in a ground-water environment. This is the well-known Ghyben-Herzberg relationship which states that there should be 40 feet of fresh water displacing sea water below sea level for every foot the fresh-water lens floats above sea level. The elevation of the fresh water lens surface above sea level is called the fresh-water head (Figure 1).

Direct knowledge of the fresh-water lens in northern Guam has been limited to observations made on wells which only partially penetrate the lens. Observations of fresh-water head changes are made in selected wells and chemical quality analyses are run periodically on water from nearly all production wells. These observations are necessarily restricted to the upper part of the lens, since most wells are drilled only 35 to 40 feet into the lens.

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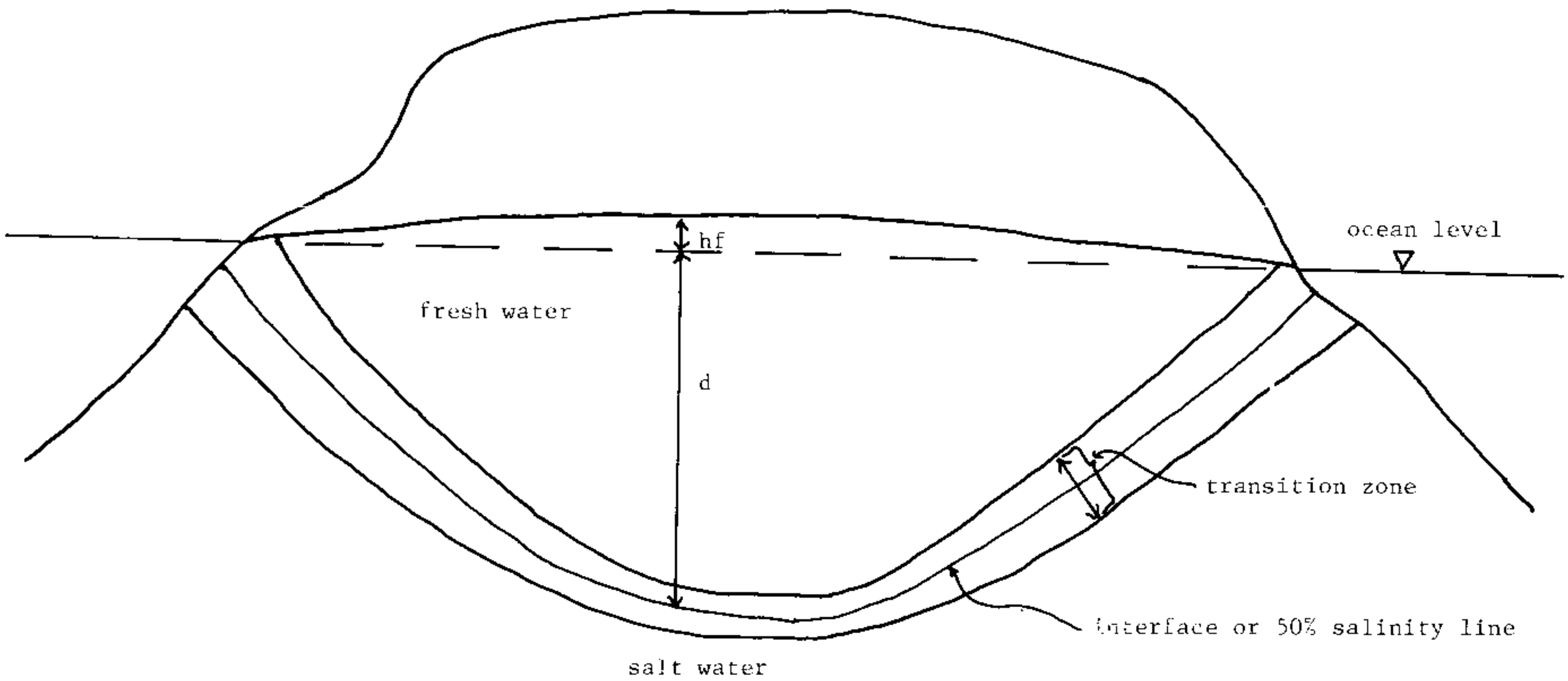
[3]The Federal Government recognized the importance of Guam's northern ground-water lens by designating it as a sole-source aquifer system in 1978, one of only 2 such designations in the country.




hf = fresh-water head
d = distance from ocean level to interface

Figure 1. Idealized Cross-sectional Diagram of an Unconfined Ghygen-Herzburg Lens System.

(not to scale)

From these well observations we know that the elevation of the fresh-water lens surface (fresh-water head) in northern Guam ranges from two to five feet above sea level. According to the Ghyben-Herzberg relationship this means that the interface between fresh and salt water should lie between 80 to 200 feet below the water table. However, the Ghyben-Herzberg relationship assumes hydrostatic conditions in a homogeneous unconfined aquifer system (composed of fine sand in the Netherlands where the relationship was first applied). In the northern Guam aquifer, conditions are not static and fresh water flows continually from the aquifer to the surrounding sea. The lithologic environment is one of highly permeable and heterogeneous coralline limestone. There is no guarantee that the relationship applies to the same degree everywhere in Guam's limestone. We are really only guessing when we apply the relationship to measured fresh-water head in estimating the lens thickness.

An even more serious gap in our knowledge is related to the thickness of the transition zone between fresh water and the underlying sea water (Figure 1). Under some circumstances the transition zone between the fresh water and sea water may be quite thin and, under others, quite thick. As the transition zone thickens, the available fresh water in storage becomes less. Unfortunately, fresh-water head measurements at the surface of the lens may not indicate transition zone thickness.

The deep monitoring well is the only means by which to observe the effects of development throughout the entire thickness of the lens. The data collected from the deep monitoring wells will contribute to the resolution of some of the most basic problems facing those responsible for developmental planning on Guam. Ultimately, the data collected from the deep monitoring wells along with data previously collected from the shallow observation wells and production wells may be used to design and operate a mathematical model of the northern Guam ground-water system. Finally, the deep monitoring wells will provide a unique opportunity for research hydrologists to make direct observations on the entire thickness of an unconfined island lens system.

Without the deep monitoring wells, Guam's resource managers will be faced with the impossible task of solving a complex 3-dimensional puzzle with only a few scattered pieces from the top. Knowledge of what is happening at the bottom of the lens and throughout its thickness is absolutely essential in solving the puzzle.

## PLANNING HISTORY AND DESIGN CHANGES

The first official proposal for a deep monitoring well on Guam was made in a memorandum report to the U. S. Navy OICC (Davis, 1964, p. 7). It was proposed in this report that a monitoring well be drilled to a depth of 100 feet below the water table in the Marbo area of northern Guam. This well was to be a simple, open borehole. In a later administrative report (Davis and Huxel, 1968, p. 10) it was suggested that the U. S. Air Force drill five deep exploratory and monitoring wells in northern Guam. General monitoring well proposals were also made in 1973 (Huxel, p. 4) and 1974 (Mink, 1976, p. 128).

By 1974, the need for a system of deep monitoring wells had become apparent to local officials involved in water resource management and development. In early 1974, an accountability plan was devised by the Guam Environmental Protection Agency (GEPA) for application to developers who wished to dispose of urban storm runoff in ponding basins. Under this plan the developers of Barrigada Heights subdivision were asked to fund half the cost of a monitoring well system to be constructed on Navy land adjacent to their ponding basin. The other half of the cost was to be supplied by the Government of Guam and administered through the Public Utility Agency of Guam (PUAG).

In August, 1974, a specific plan for construction of a deep monitoring well system at the Barrigada Heights drainage pond was prepared and submitted to PUAG. This plan, called "Technical Guidelines", proposed the drilling of a three-well monitoring system. The plan for the three-well monitoring system is shown in Figure 2. It consisted of an eleven-inch borehole completely penetrating the fresh-water lens and to be cased with blank 4 ½-inch steel casing to the water table and perforated 4 ½-inch PVC casing to the bottom of the well. In addition, two 7 7/8-inch boreholes were to be drilled, one fully penetrating the fresh-water lens and the other penetrating only to the water table. The two smaller boreholes were to be cased with 4 ½-inch steel casing to the water table and 4 ½-inch PVC casing thereafter. Details were included in this plan with regard to collection of drill cutting samples, recording of drillers logs, gravel-packing, and developing the well.

The basic purposes of this three-well monitoring system were as follows:

1) To monitor the changes in the chemical quality of the fresh-water lens, including the presence of surface contaminants.

2) To determine the thickness of the fresh-water lens and to monitor changes thereof.

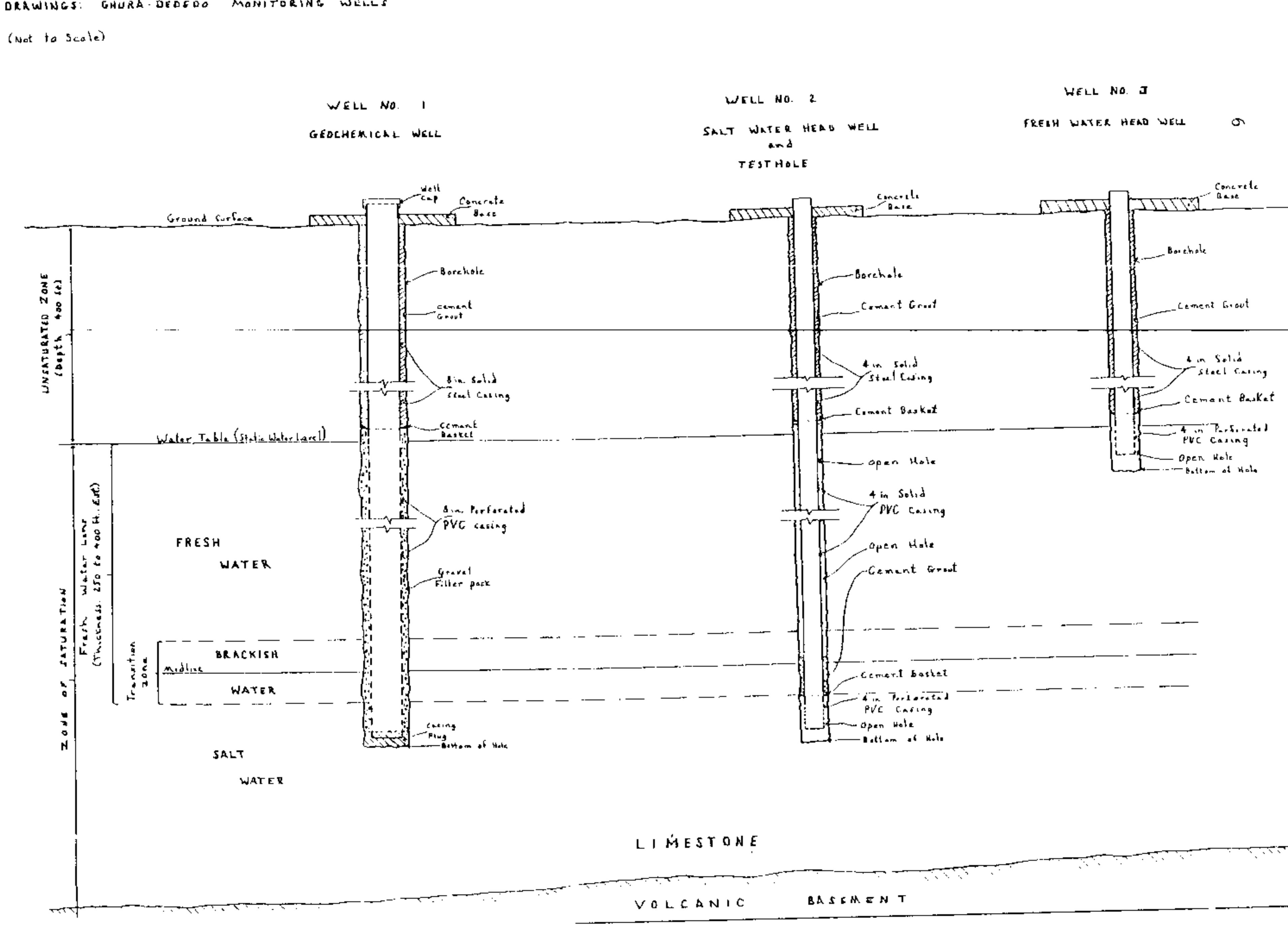



Figure 2. --The Three-well Monitoring System

3) To determine the thickness and position of the zone of transition between the fresh-water lens and the underlying salt water and to monitor changes thereof.

4) To determine the relation of all the above factors to changes in point water heads at the well site and to changes in ocean level.

5) To relate all of the above to climate, pumpage, and watershed development.

Each of these wells was to have a distinct and separate function:

Well one was called the geochemical well. It was to be drilled entirely through the fresh-water lens into the underlying salt water. It would be cased with perforated pipe of sufficient diameter to accommodate either a thief sampler or a conductivity probe, or both. The well would be carefully sealed from the surface down to the water table to prevent the influx of surface drainage through the annular space between the casing and the drilled hole.

The geochemical well was the most important of the three wells. It would be used to monitor the chemical composition of the fresh-water/salt-water system throughout its thickness.

The two smaller diameter wells were to function as piezometers. Well two, the salt-water head well, was to be drilled entirely through the lens and into the underlying salt water. It was to be cased with blank, unperforated casing and used to monitor point salt-water head below the salt-water water/fresh-water interface.

Well three was called the fresh-water head well. It was to be drilled a short distance below the water table and would be used to monitor fresh-water head at the top of the lens.

In September, 1974, a local drilling contractor estimated a price of $65,500 for drilling the 3-well system described in the "Technical Guidelines". Another local firm, at the same time, estimated a price of $68,000 for the same job, with the exception that casing would not be supplied by the contractor. Subsequent uncertainties in securing permission to site the wells on Navy land along with problems created by the stringent safety precautions required by the Navy created a delay in the Barrigada Heights project, and it has never been completed.

In 1975, GEPA informed officials of the Guam Housing and Urban Renewal Agency (GHURA) that operation of a proposed storm drainage pond to serve the 501 low-cost housing sites in Dededo might have an adverse effect on ground-water quality in the Dededo well field. On the basis of this possibility, GEPA was inclined to deny permission for the drainage pond. However, permission was ultimately granted with the stipulation that GHURA fund construction of a deep monitoring well system adjacent to the pond.

GHURA agreed to fund construction of a monitoring well system and requested that the "Technical Guidelines" be furnished to their prime contractor for review. It was decided at this time that the project would be put out for bid as soon as final plans, specifications, and bid documents had been prepared.

In the early part of 1976, the original "Technical Guidelines" were revised to provide for a large diameter borehole (15 inches) and casing (8 inches) in the geochemical well. The plans for the salt-water head piezometer and the fresh-water head piezometer were not changed.

In order to determine the approximate amount of money needed for the project, a local drilling contractor was consulted by GHURA and estimated a price of $77,500. This price was probably too low for successful completion of the well system as called for in the revised "Technical Guidelines"; but,on the strength of this estimate. the total cost was set at nearly $90,000, including design fees to the GHURA prime contractor.

In May of 1976, it was decided to add the project to the original contract specifications for the GHURA 500 Low-cost Housing Project through a change order. Detailed specifications and drawings were prepared for the first time and submitted to GHURA's contractor representative in November, 1976. It should be pointed out that the original "Technical Guidelines" prepared for this project were not intended as a substitute for detailed specifications and drawings. They were meant to provide a guide to the preparation of the more detailed and comprehensive plans. GHURA's prime contractor stated that the effect of the detailed specifications submitted in November was to increase the cost of the project construction, beyond the funding level of $77,500 determined in early 1976. In order to lower projected construction costs the plans were revised again and resubmitted early in 1977.

A major design change was introduced into the plans in July, 1977. The change was from a three-well to a single-well monitoring system. The single-well system is discussed in more detail in the final section of this report (p. 12). Reduction from three wells to one well was made possible by a new inflatable packer system designed by the U. S. Geological Survey Hydroequipment Unit in Denver, Colorado (see Figures 3 and 4. The advanced packer system made it possible to measure point-water head and collect water samples from isolated portions of the aquifer original geochemical well of the 1974 "Technical Guidelines" into a multiple piezometer nest. The advantage of the new packer system over the old ones was its lighter weight and the ease with which it could be shifted to different levels in the well.

On the basis of the design change, the well construction plans were revised again and resubmitted in August, 1977, to the prime contractor for GHURA's 500 project. In December, 1977, the prime contractor's representatives stated that only $54,000 of the original $89,000 would be avaialble for well construction. The remaining $35,000 was earmarked for other work including design fees. It was clear that the project could not have been successfully completed for $54,000.

In January, 1978, a decision was made to put the project out for bid. At the same time, GHURA agreed to increase the project funding to $100,000. The specifications were again revised and were submitted for bid in April, 1978. The two bids received were far in excess of available project funding, so the well construction plans were again revised to lower construction costs. A contract was then negotiated with a local drilling firm. The contract was based on the revised plans and amounted to $98,850. A notice to proceed was issued on October 19, 1978, and drilling began in August of 1979.

The basis design of the deep monitoring well system has changed markedly since it was first proposed in 1964. The original concept was fairly simple. It called for an open borehole to be drilled entirely through the fresh-water lens and to finish in the underlying salt water. Water samples would be collected at selected depths in the open borehole by a thief sampler. The chloride concentration of samples at various depths would indicate the position of the salt-water/fresh-water interface and the thickness of the transition zone. Once a relationship between chloride concentration and conductivity has been established in the well, the interface and transition zone can be defined by measurements obtained with a conductivity probe. Water samples collected from the borehole could be analyzed to determine the quality of ground water throughout the saturated thickness penetrated by the borehole. The open borehole was particularly advantageous because of its lower cost. However, uncased open boreholes may not be suitable for long-term comprehensive monitoring purposes.

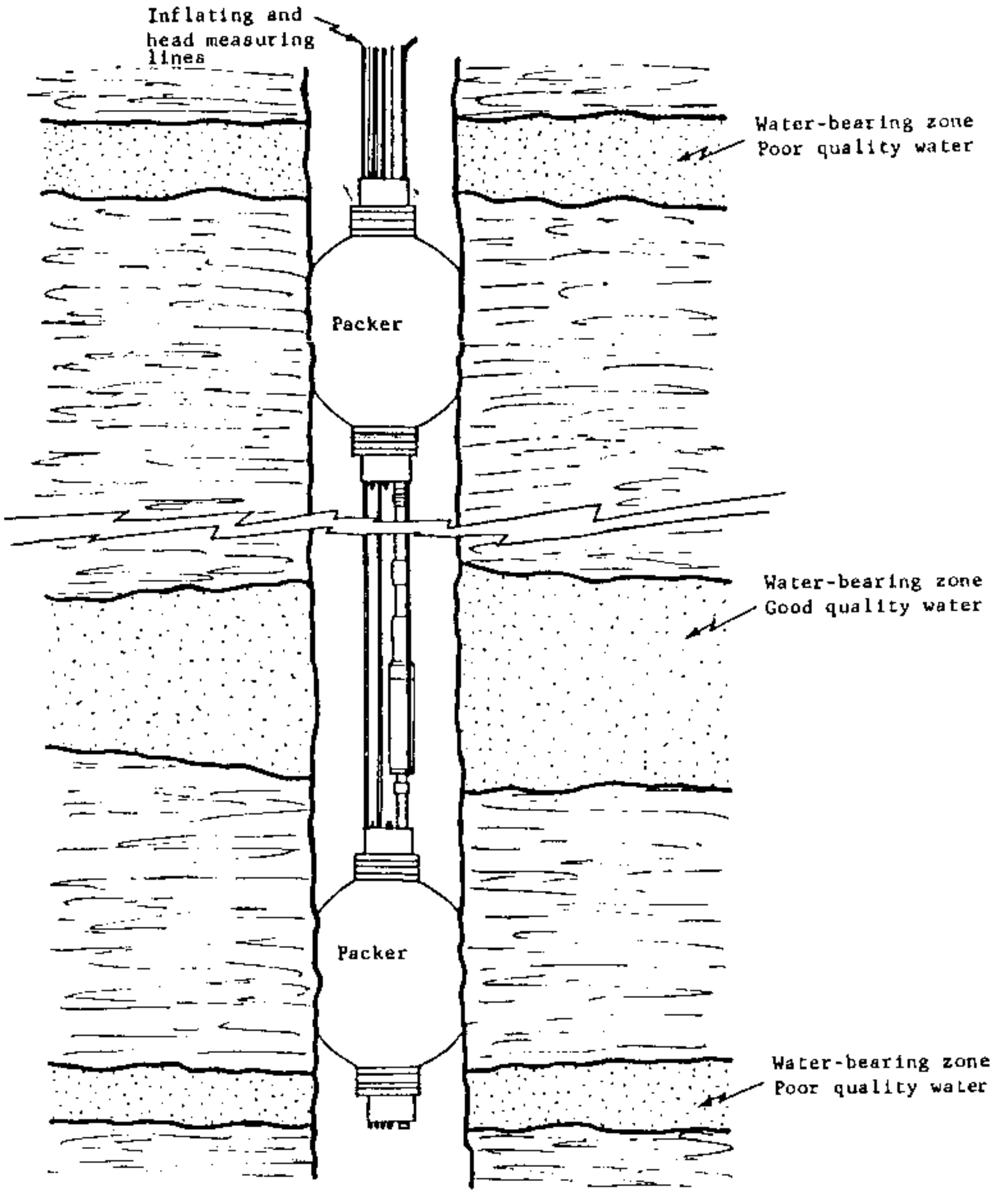



Figure 3. Airflate packer with pump installed between packers.

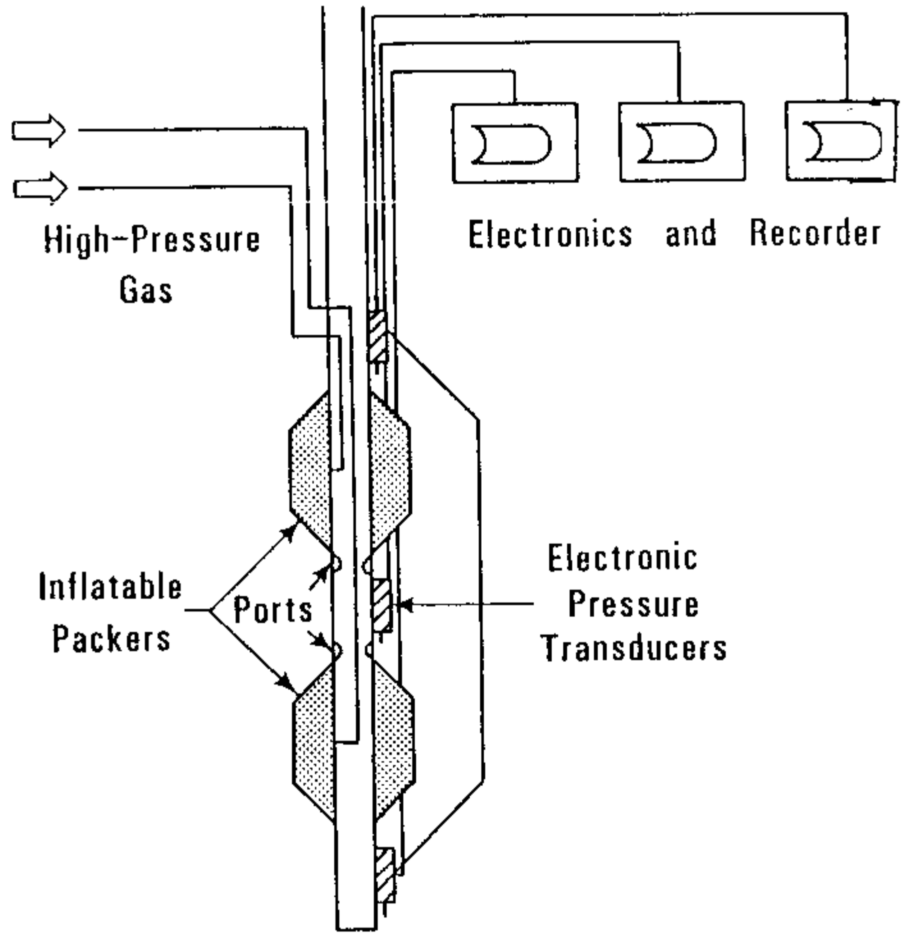



Figure 4. Schematic of tool setup for stress measurements.

There is a very real possibility that an open borehole might cave in, rendering the well unusable. Northern Guam dry wells used for storm drainage disposal experience some caving. These wells must be periodically cleaned and bailed or redrilled in order to remain effective.

Another problem is that uncased open boreholes are not reliable if used to monitor the lens for contamination introduced through surface recharge. It is quite important to determine whether toxic constituents from surface sources, such as ponding basins, are carried to the lens in recharge water percolating naturally through the unsaturated zone. Wherever the open borehole intersects surface-connected fissures or cracks it will short circuit the natural percolation paths and channel the recharging water directly to the lens. In order to eliminate the possibility of short-circuiting recharge, wells which monitor for surface contaminants must be cased and sealed from the ground surface to the water table.

Point-water heads cannot be accurately measured in open boreholes. The requirement that the hydrostatic head conditions in the lens be measured accurately is an important one. The point-water head values of ground water in the aquifer at various depths are related to the movement and occurrence of ground water in the fresh water/salt water system. There are three general aquifer regions or intervals where head values should be measured. These are (1) below the salt water-fresh water interface in the zone of salt water, (2) in the transition zone above and below the interface, and (3) in the fresh water above the transition zone. Heads in the intervals can be measured through piezometer tubes. The two cased piezometers (the salt-water head and fresh-water head wells) described in the 1974 3-well monitoring well proposal were designed to measure point-water heads in the salt water below the interface and in the fresh water at the top of the lens. In an uncased open borehole, the only way point-water heads can be measured is by isolating or packing intervals of the borehole and measuring the pressure and density in the isolated intervals. However, there is a high risk in using packers in uncased boreholes due to the possibility of the borehole caving in or the rupture of packer heads against the rough borehole wall. As mentioned previously (p. 9 ), recent design improvements have made the employment of packer systems in cased ground-water monitoring wells feasible. With the use of the improved packer system in mind, the geochemical well of the 1974 proposal was redesigned to fullfill the functions originally accomplished by the two piezometers.

In regard to the monitoring of chemical quality of ground water, there is an additional reason why boreholes, whether they are open or cased with perforated pipe,may not be the ideal solution. The borehole permits the free flow of ground water from the aquifer through the well. Depth-salinity measurements in the borehole may provide an estimate of the salt-water/fresh-water interface position and the transition zone thickness as well as a picture of the depth-intergrated geochemistry of the lens. However, the depth salinity curves may be distorted by ground water flowing up or down the borehole. The normal paths of ground-water flow may be short circuited by the conduit which the borehole opens up in the aquifer. In a recharge area there will be a large component of vertical ground-water flow downward through the aquifer whereas in a discharge area the flow will be upward in the borehole. The flowing water will take the path of least resistance from areas of higher head to areas of lower head. The borehole, whether it is open or cased with perforated pipe, provides the path of least resistance. The monitoring well described in the following paragraphs is designed to minimize this problem of ground water flowing up or down the open borehole or the borehole cased with perforated pipe.

## THE SINGLE-WELL MONITORING SYSTEM

The monitoring well proposed for the GHURA-Dededo site is shown in diagramatic form in Figure 5. The design for this well is still evolving, even as construction proceeds.

The final plans for sealing the annulus and joining and emplacing the casing are not yet firm. For this reason, the design shown in Figure 5 and the description which follows is general in nature.

The single well shown in Figure 5 replaces the three-well system described previously (p. 6, Figure 2). The well is cased with eight-inch plastic casing alternately slotted and solid below the water table. The well is sealed with grout opposite the solid casing. The perforated casing is left open to the aquifer. The aquifer intervals opposite the perforated casing may be isolated by packers inflated opposite the sealed casing. In Figure 5 the open aquifer interval (b) between sealed intervals (4) and (5) is isolated by the packer. With the packers in place several types of data may be collected from the well simultaneously.

Pressures at open aquifer intervals (a) and (b) (Figure 5) may be measured with transducers extending through the packers. The pressures may be measured and recorded simultaneously on either an instantaneous or continuous basis for as long as the packers are left in place. The packers may be deflated and moved, then reinflated at different intervals in the well, without withdrawing the entire packer assemblage. In this way, pressure measurements in successively different packer intervals may be obtained within a relatively short space of time. The ground-water head in the intervals (c) through (f) above the top packer at (4) (Figure 5) may also be measured and recorded simultaneously.

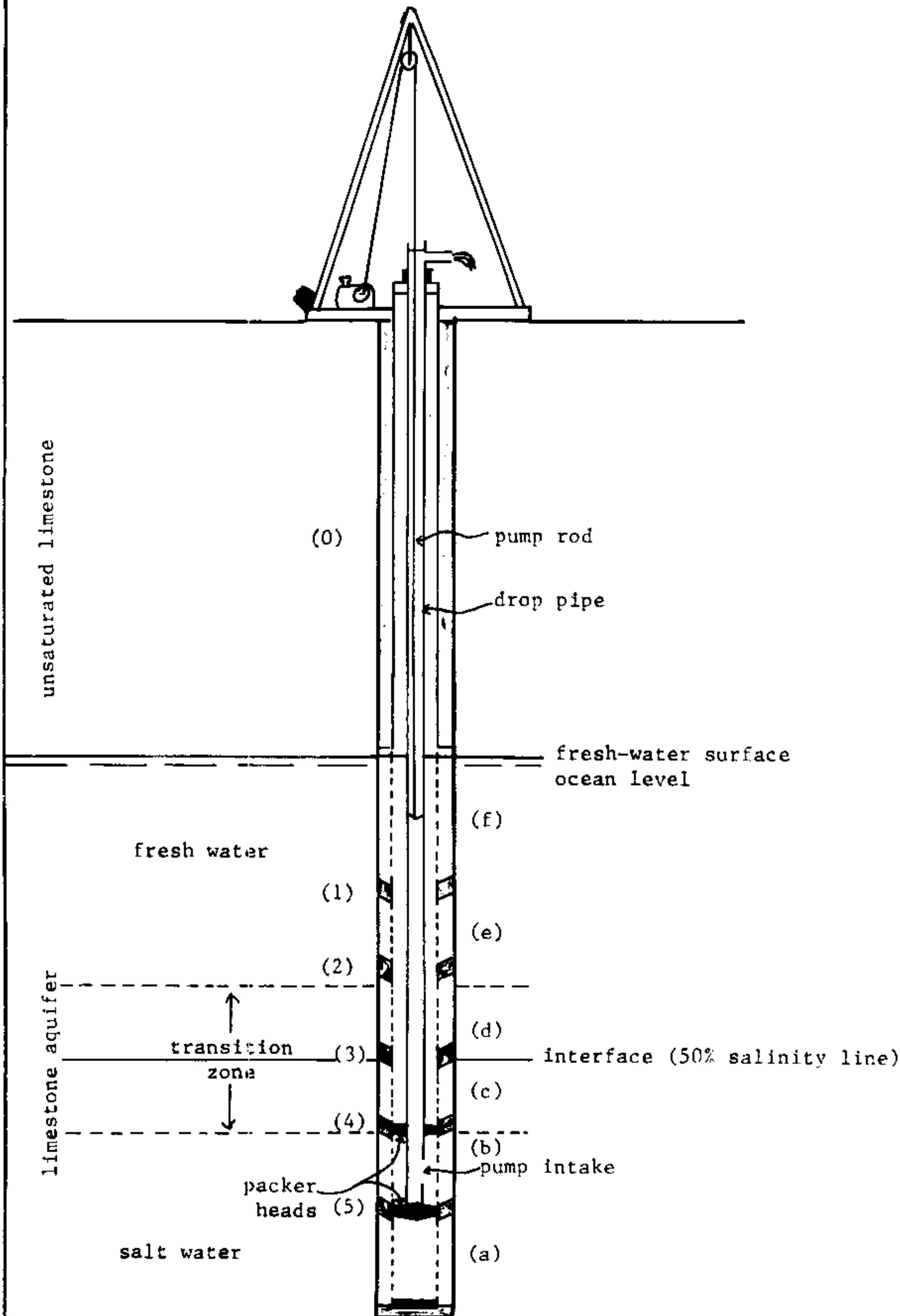



Figure 5. --The Single-Well Monitoring System

Water samples may be withdrawn from the isolated aquifer interval (d) in Figure 5. The samples would be representative of ground water in the isolated interval of aquifer. A complete suite of samples drawn successively from each isolated aquifer interval over a relatively short period of time will permit an accurate and undistorted definitiion of the interface position, the transition zone thickness, and depth-salinity curve. The geochemistry of ground water at various levels in the aquifer can be determined with a high degree of accuracy from samples collected in the well. Both short-term and long-term changes in water quality characteristics can be monitored throughout the entire water column penetrated by the well. These changes can be related to developmental activities in the aquifer or the overlying watershed. These correlations will permit the establishment of effective resources management practices.

## SUMMARY

Construction of the GHURA-Dededo deep monitoring well was begun in August, 1979, and will be completed in the spring of 1980. The borehole for the GHURA-Dededo monitoring well has been drilled and reamed to a depth of 785 feet. A drilling and sample description log has been prepared for the pilot hole and is now being reviewed by the U. S. Geological Survey District staff. The first battery of geophysical logs have been collected from the borehole and include electric, conductivity, and caliper logs. Depth-integrated water samples collected from the open borehole have permitted construction of a depth-salinity curve. The position of the salt-water/fresh-water interface has been defined in the open borehole on the basis of the water sample analyses.

The actual start of construction was preceeded by a long and difficult period of planning and design. The design process for the monitoring well has been continuous. The original design has evolved from an open borehole concept through a three-well system and finally to the present one-well system. The next step in the design process will be to determine the precise location of the alternating perforated and sealed casing intervals in the saturated aquifer. The locations of these intervals will be determined on the basis of caliper logs and depth/salinity curves obtained in the open borehole. A satisfactory method for emplacing and sealing the casing is still being worked out.

Use of the inflatable packer assembly with the one-well monitoring system will permit the accomplishment of several goals:

1) Observation and simultaneous recording of point-water heads at 2 different levels.

2) Collection of water samples from isolated aquifer intervals.

3) Definition of a depth-salinity curve for the water column in the monitoring well.

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