HYDROGEOLOGIC INVESTIGATION OF AGANA SWAMP

NORTHERN GUAM

By

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and

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HYDROGEOLOGIC INVESTIGATION OF AGANA SWAMP, NORTHERN GUAM

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ABSTRACT

An attempt was made to investigate the hydraulic relationship between Agana Swamp, located near the village of Agana, and the freshwater lens beneath the limestone plateau of northern Guam. A number of problems developed during the course of the study which prompted a change in the project objectives. The main problems were access to the study area and artificial features which prevented the full application of geophysical surveys and the installation of an observation-well network.

The study, however, points out a number of aspects such as the general geology and physiography of the swamp area, its drainage characteristics, and the occurrence of groundwater. In addition, the results of the investigation have been useful in constructing a set of guidelines for further study.

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INTRODUCTION

General

Beneath the limestone plateau of northern Guam, groundwater occurs as a discontinuous freshwater lens. The flow system is contained within carbonate rocks of Miocene to Pleistocene age and, in part, directly overlies older impermeable volcanic rocks of the Alutom formation. Recharge to the lens is by infiltrating meteoric water generated by seasonal rainfall. Surface drainage networks are poorly developed on the highly permeable limestone; most runoff is of short duration. An exception is an area in the southwestern portion of the plateau near the limestone-volcanic fault contact. Here, the moderately developed Agana-Choat river basin drains an area of about 8.7 square miles (Randall and Tsuda, 1974) and includes the largest expanse of wetland on Guam. This region of the basin includes marsh and swamp land collectively known as the Agana Swamp.

Initially, this study was to investigate the hydraulic link between Agana Swamp and the surrounding fresh groundwater resource. However, because of a number of unforseen problems that developed during the course of the investigation, the objectives of the study had to be modified accordingly. Limited access to the site was the major setback of the study and resulted in a severe restriction of the application of field geophysical surveys. As a consequence little information was obtained concerning subsurface structure and composition. In addition, a lack of appropriate drilling equipment prevented the direct sampling of subsurface material and the installation of observation wells.

Inspite of the setbacks experienced during field work, a number of important points on the hydrogeology of Agana Swamp are presented in this report.

Purpose and Scope of Work

Field work originally planned to achieve the objectives of the study was curtailed by a number of unanticipated factors. The most serious was a lack of access to most of the study area because of a limited number of roads and because of non-clearance by land owners. Except for the public access to Agana Spring and driveways to private dwellings, only one road provided access to the interior of the swamp, a power-line easement. Although seismic-refraction lines were run along part of this road, electrical resistivity could not be used due to the presence of high-voltage power lines. In addition to these problems, a lack of appropriate drilling equipment prevented the installation of observation wells. Because of the type of material composing the surface unit of the swamp fill, the installation process would have required special drilling capabilities and the casing and screening of the bore hole. These requirements could not be satisfied with the available equipment of the Water and Energy Research Institute.

In light of the problems encountered during the field work, the purpose of the study is to describe, from available data, the hydrogeologic significance of Agana Swamp and suggest a realistic approach to obtaining additional information about the interrelation between the swamp and the groundwater-flow system.

Location of the Study Area

The study area is located along the west coast of Guam. Agana Swamp is situated within the southern region of the limestone plateau that dominates the physiography of the northern half of the island. The map of Figure 1 shows the location of the study area relative to other prominant features of Guam.

DESCRIPTION OF THE STUDY AREA

The following description of the study area is based on observations during the field work and on the work of Randall and Tsuda (1974). Three main topics are addressed, namely (1) physiographic features of the swamp area, (2) drainage characteristics of the swamp, and (3) geologic aspects of the swamp sediments and bedrock.

Physiography

Agana Swamp occupies the low lands of the Agana-Choat river basin and consists of a broad belt of marshy and swampy area that trends northwest to southeast. The swamp area attains a maximum width toward the northwest end between the villages of Sinajana and Mongmong. Bordering the study area are low limestone ridges (20 to 40 feet in altitude) that project into the generally flat floor of Agana Swamp. Limestone crops out within the swamp as isolated hills and hummocks. The map of Figure 2 and the photographs of Figures 3 and 4 show the general physiographic features present within the study area.

Vegetation within Agana Swamp is predominately a tall reed, Phragmites karka (Figure 5), with lesser occurrences of other herbaceous woody trees, and shrub types. The latter are primarily associated with the border area and limestone hummocks.

Located at the base of a hill along the southern perimeter of the swamp is Agana Spring (Figure 2). Water discharges from the Agana argillaceous member of the Mariana limestone (Tracey et al., 1964) and collects in a concrete reservoir. The spring outflow is situated a few feet above the general level of the swamp area.

Much of Agana Swamp has been infilled by artifical means in order to expand the village of Agana. The most recent fill is the substrate upon which the Agana Shopping Center is situated. Most of East Agana sits upon artificial fill.

Drainage Characteristics

The study area is drained primarily by the Agana River; however its course is not well defined except near the outflow where the channel has been maintained through East Agana. Elsewhere, siltation and vegetation have nearly obliterated the course of the river. What remains is a shallow depression which leads to Agana Spring and probably represents the river channel before infilling and overgrowth.

The following excerpt from Randall and Tsuda (1974) describes an early attempt at improving the drainage of Agana Swamp.

> According to an account given by Lieutenant (Jr.) Claire C. Seabury, (C.E.C.), U.S.N. (1934), the Agana River was dredged from the "Maxwell Bridge" in Agana Springs Reservoir, a distance of over 5,700 feet. A board was appointed by Governor E. S. Roat in March, 1933, to

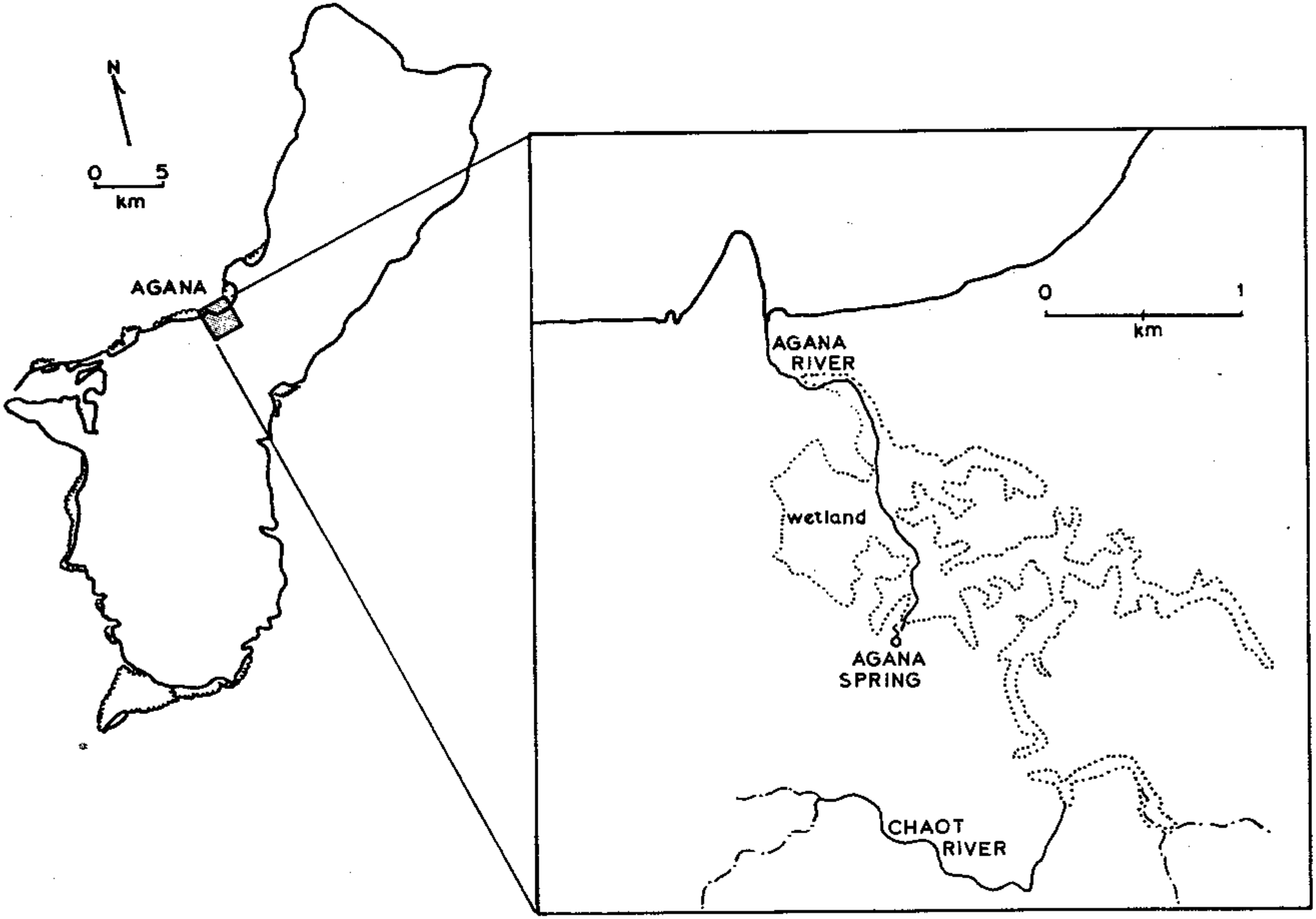

Figure 1. Map of Guam showing the location of the study site.

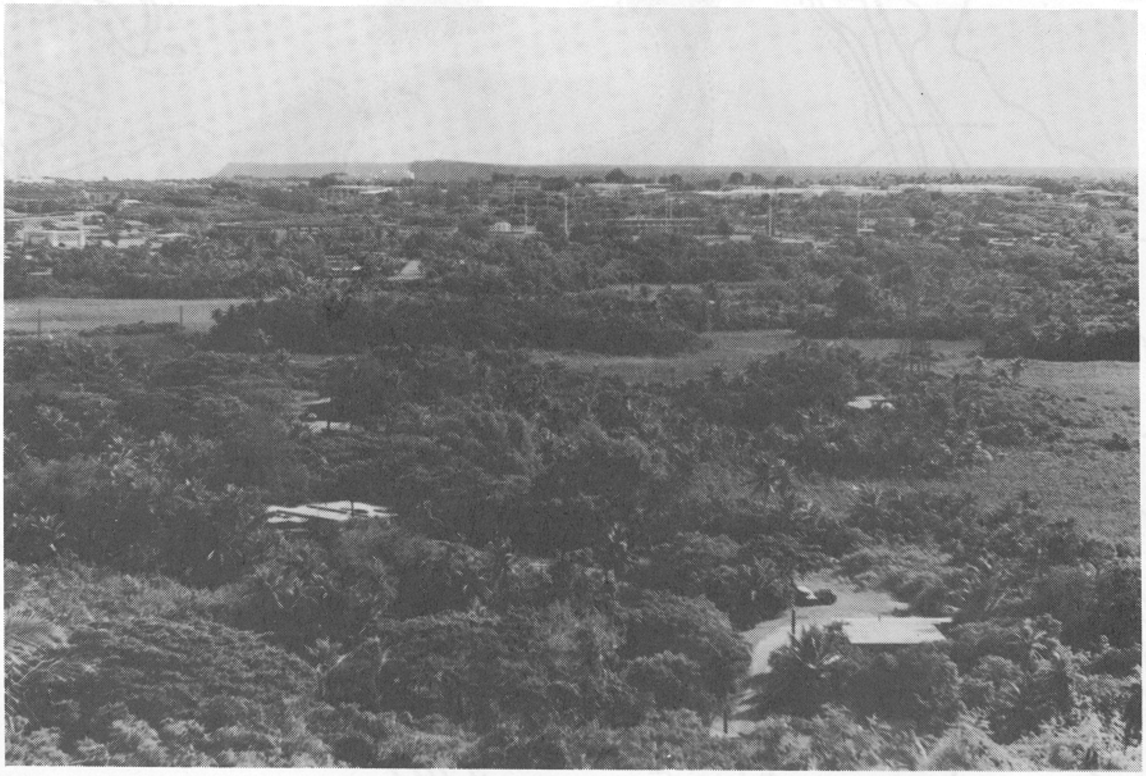

Figure 3. Overview of the study area. Top photograph shows the western portion and the bottom photograph shows the eastern portion of Agana Swamp.

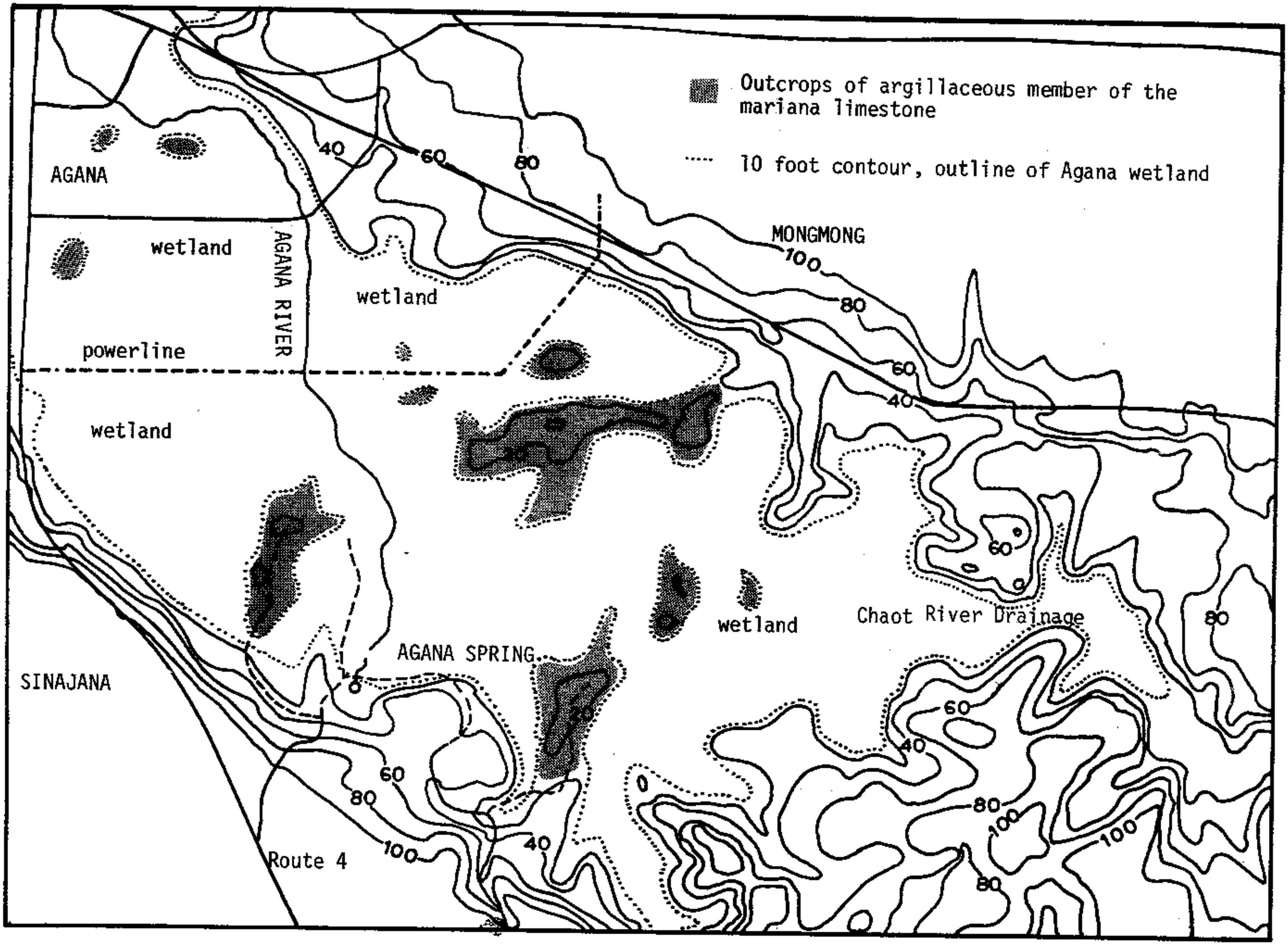

Figure 2. Map of the study area showing prominant physiographic features.

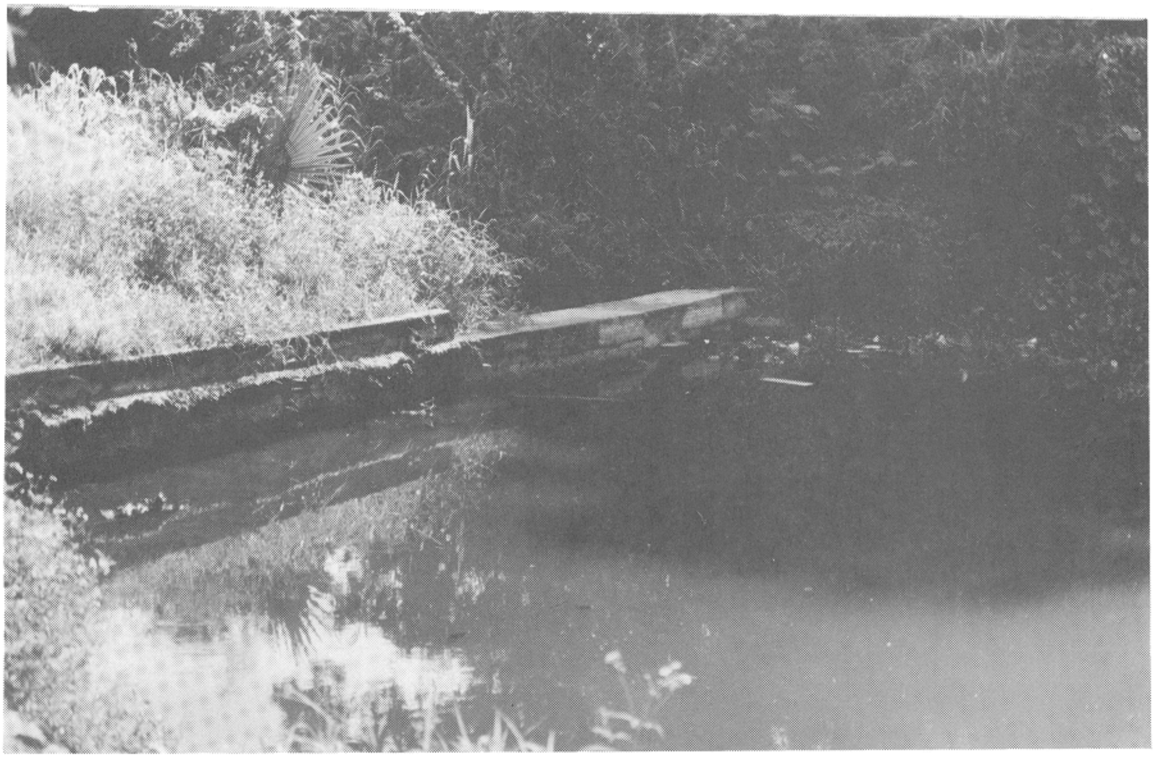

Figure 4. View of a portion of Agana River and Agana Spring. Top photograph shows the vegetation-choked river channel and the bottom photograph shows the reservoir at Agana Spring.

Figure 5. Views of the predominant swamp vegetation, Phragmites karka, along the power-line easement.

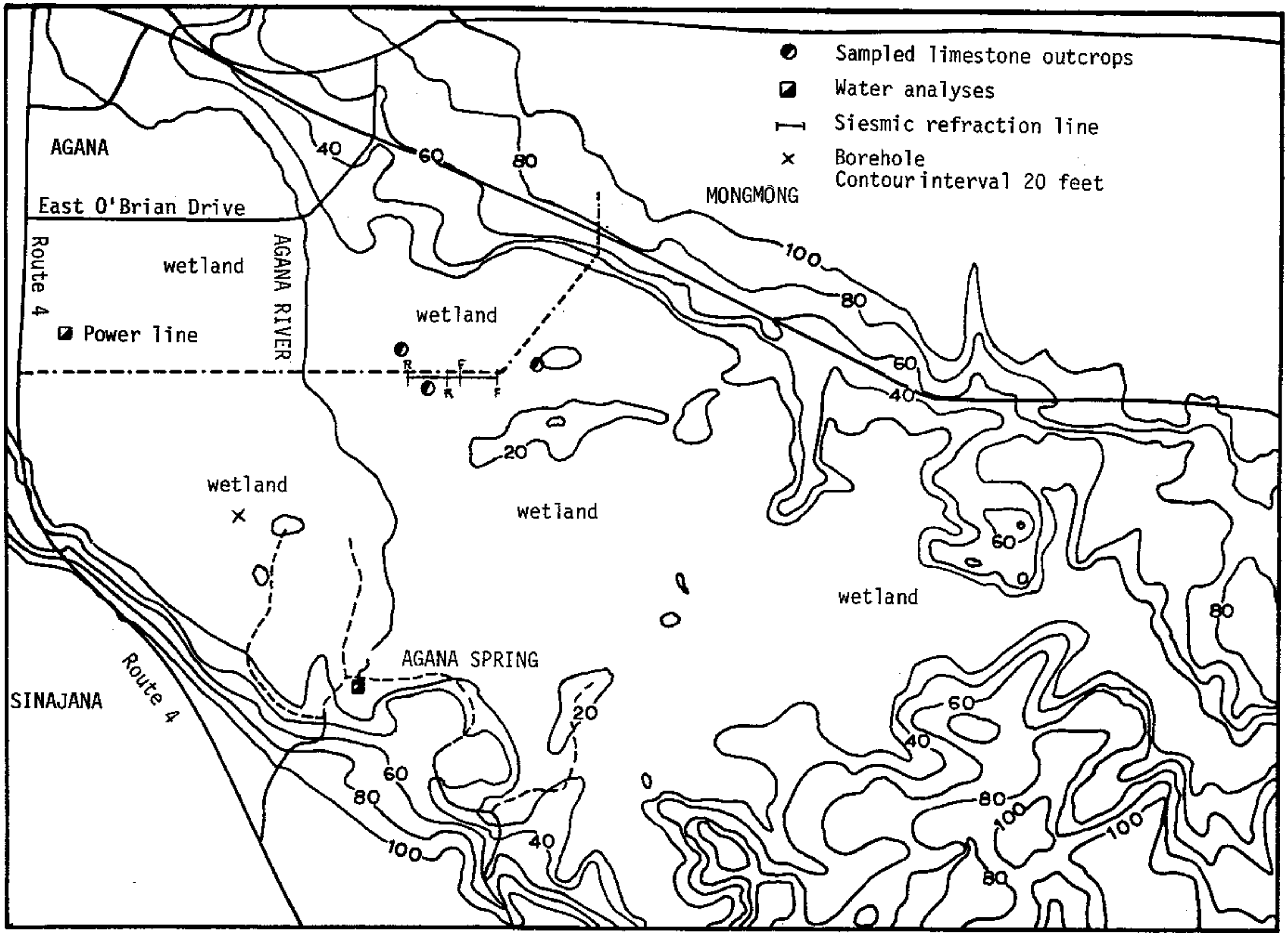

Figure 6. Map of the study area showing the location of seismic-refraction lines and sampling sites.

investigate the feasibility of draining the "Agana Swamp" and converting it into arable land. A favorable report was returned and dredging started in June, 1933, by using a floating pontoon hoist with a half cubic yard bucket. At this time the river channel was reported to have been filled with silt and overgrown with cane, so that it could hardly be distinguished. A channel was cut 20 feet wide and 3 feet deep to Agana Springs. Completion of this dredging lowered the river level three feet at Agana Springs and large areas became sufficiently drained to permit cane to be burned; the land was then prepared for corn planting. A 1,500 foot long lateral channel was dredged to the east toward San Ramon Hill about halfway between the "Maxwell Bridge" and Agana Springs. The entire project was completed in February, 1934, and it was estimated that over two thirds of the entire area was drained free from surface water and the ground water level dropped considerably over the entire area. The most apparent result of the dredging was the increasing flow of the Agana River, especially during dry periods.

Geological Aspects

Bedrock underlying the study area is composed of the Agana argillaceous member of the Mariana limestone. According to Tracey, et al. (1964) and field observations, the unit is a yellowish-tan to buff or light brown limestone with a significant clay content. Except for the clay, the lithology of the Agana member is similar to the pure limestone of the Mariana. Essentially, the Agana member represents near-shore facies of the Mariana limestone which have been contaminated by clay-rich runoff from the volcanic terrane during Mariana time. The amount of clay in the argillaceous member is small. A representative range is from 3 to 5 percent. Usually, the clay is disseminated through the matrix; however, the amount of clay filling cavities in weathered limestone may be large.

Bedrock seismic velocities obtained from lines 1 and 2 are 4149 ft/sec and 5752 ft/sec respectively (see Figure 6 for locations and Appendix for details). These values, although low for limestone, probably reflect the lithology and secondary features (particularly clay-filled solution cavities) of the Agana argillaceous member. Similar to slightly higher velocities were measured by Biehler and Walen (1981) for pure limestones (layer 2) of the northern plateau.

Seismic refraction work also revealed a higher velocity layer beneath that indicated above. From the analyses of lines 1 and 2, the higher velocities were 9332 ft/sec and 6728 ft/sec respectively. These higher values may indicate either a denser argillaceous unit of the Agana member, a change in facies, or a different geologic unit altogether.

According to boreholes installed within the swamp area (Randall and Tsuda, 1974), the bedrock is overlain by unconsolidated marine sediments and organic material. The borehole log below summarizes the stratigraphy overlying the bedrock (Randall and Tsuda, 1974; p 12-13; see Figure 6 for borehole location):

quickly to recharge input. Thus water levels fluctuate over a greater range than elsewhere within the groundwater flow system. These seasonally induced water-table fluctuations no doubt influence not only the thickness and maintenance of the the transition zone in the vicinity of the swamp but also in the surrounding system since the swamp groundwater body is in hydraulic continuity with the remainder of the northern lens.

Limited water quality data for Agana Swamp are listed in Table 1. The data are from Smith and Hedlund (1978) and were obtained from the analysis of samples collected near O'Brian Street (Figure 6). As indicated by the data, the near surface water is low in chloride, nitrate, nitrite, and orthophosphate and, in general, is low in total dissolved solids (low specific conductance). As might be expected, turbidity and suspended material are relatively high since the samples were taken in a near surface environment and not from specially constructed groundwater sampling facilities. The pH measurements indicate a water near neutrality; however, the range of values appears to take in slightly acidic water. This no doubt is due to the high level of organic activity which influences the near surface environment.

0 to 6 inches. Black to very dark-brown silty muck and peat; extremely high in organic matter content; contains some silt; water table surface is at bottom of this layer; pH 7.0.

6 to 24 inches. Very dark-brown muck; somewhat sticky; contains many fibrous old roots, and some silty clay; pH 7.5.

24 to 72 inches. Very dark grayish-brown muck, containing partly decomposed plant material; slightly stick; pH 8.0.

72 to 84 inches. Gray silty coarse limesand; sticky; consists largely of subangular to angular shells and fragments of marine animal skeletons; some vegetal organic matter; pH 8.0.

Apparently during a Holocene high sea-level stand (6 ft above present sea level), Agana Swamp was essentially an embayment. Carbonate sediments derived from the reef and reef-associated facies were deposited upon the Agana argillaceous member within the low-energy environment of the embayment. Later, following the lowering of sea level to its present-day position, the area infilled with organic material as the swamp developed within a freshwater environment. Similar environments of deposition have been found in southern Guam (Ayers and Clayshulte, 1983).

Groundwater Occurrence

Fresh groundwater occurs at very shallow depths within the swamp area. Often, during the wet season, the water table rises above the land surface and water stands in open ponds. Other times, during the dry season, the water table declines in response to the seasonal decrease in rainfall and runoff.

From data obtained by recent exploratory drilling operations (Ayers, 1982), the Agana member of the Mariana limestone extends well below sea level. This member exhibits a hydraulic conductivity of 100 ft/day to 200 ft/day (Mink, 1976; Contractor et al., 1981) and is therefore relatively permeable. Additional information from a nearby observation well indicates that the fresh groundwater occurs, at least in part, as a lens underlain by seawater and separated by a thick transition zone (Camp, Dresser, and McKee, 1982). Therefore, it seems reasonable to assume that the fresh groundwater of the swamp area is underlain by seawater and contained within the permeable Mariana limestone. The boundary between saltwater and freshwater is probably represented by a relatively thick transition zone.

Rainfall and runoff are the main sources of recharge water to the subsurface flow system. Minor amounts of recharge water are contributed by Agana Spring and other springs that occur along the southern perimeter of the swamp area. Since the prime contributors of recharge are seasonal in nature and non-uniform in distribution (in both time and space) and since the water table is a near-surface phenemonon, the system responds rather

DISCUSSION

A number of important points can be derived from what is known of the Agana Swamp region. In this section, these points are raised and their significance is discussed.

Agana Swamp and the Freshwater Lens

It is probably safe to assume that the groundwater beneath the swamp area is in hydraulic continuity with both the northern Guam freshwater lens and the sea. If this assumption is correct, then there must exist a complex interaction between the responsive swamp flow system, the northern lens, and the underlying salty groundwater which involves non-equilibrium hydraulic conditions controlled by seasonal changes in recharge and short- to long-period oscillations in sea level.

Water-table fluctuations within the swamp are caused by three major factors. Specifically, these factors are: 1) influx of recharge by rainfall and runoff; (2) evapotranspiration processes; and (3) sea-level oscillations. Water-table fluctuations caused by factors 1 and 2 range over a much larger set of values than that caused by the third factor because a large volume of water is introduced into the swamp basin in a short period of time. Water-table changes related to short-period sea-level oscillation are minor due to the dampening effect of the aquifer material; however longer term oscillations may induce fluctations in groundwater levels on the order of one foot (Ayers, 1981).

Water-table fluctuations in the northern lens are much less pronounced. Infiltrating meteoric water, because it passes through a thick rock overburden, has a more subtle effect on the flow system. In addition, direct evapotransporation is not an influential factor. Because of the difference in the character of influx to the system, sea-level related water-table fluctuations may become the dominant feature of hydrogrpahs obtained from observation wells in the northern lens.

The magnitude of water-table movements in coastal or insular hydrogeologic environments determines, in part, the thickness of the transition zone. If one considers two aquifers with identical properties and initial hydraulic conditions and introduces a change which causes the water table in one to oscillate over a greater range of elevation relative to the other, then the transition zone associated with the greater fluctuation range will be the thickest. Therefore, if the water table within the swamp moves over a greater range of elevations than in the nearby lens, the transition zone will be considerably thicker beneath the swamp than within the freshwater lens.

An exception to this would be that portion of the lens adjacent to the swamp. The influence of water-table movements would extend for some distance into the surrounding aquifer. Two conditions would then occur: (1) the transition zone adjacent to the swamp would be thicker than otherwise expected; and (2) changes in flow directions would occur on both a short-term and seasonal basis.

Table 1. Limited water-quality data for surface samples from Agana Swamp. (Source: Smith and Hedlund, 1978; p 27).

Parameters	Station 1	Station 2	Station 3
Field pH	6.95	7.00	7.20
Turbidity (NTU)	6.0	4.3	2.4
Specific Conductance (μmho/cm)	72	65	80
Seattleable Solids (mg/l)	0.2	1.1	0.4
Dissolved Oxygen (mg/l)	1.18	0.41	4.32
Chloride (mg/l)	35.5	35.2	34.1
Nitrate Nitrogen (mg/l)	.002	.002	.001
Nitrite Nitrogen (mg/l)	.000	.002	.003
Ortho-Phosphate (mg/l)	.002	.008	.005

Swamp, it is known to occur elsewhere. In groundwater investigations involving marsh land in Bermuda (Ayers, 1980), pencil-sized solution tubes were observed near the water table within infiltration tunnels extending away from marshy areas. Occurrence of the dissolution features decreased as the distance from the marsh perimeter increased. The consequence of this chemical aggressiveness of water toward limestone is a significant increase in permeability in the aquifer adjacent to the marsh. This same type of activity is probably occurring within the study area.

Groundwater Flow Characteristics

Head changes within the lens are much less pronounced and occur over a longer time period than those of the swamp basin. The reason is related to the time lag between when a recharge event occurs and when the infiltrating water reaches the water table. This time lag is dependent on magnitude and duration of the recharge event, permeability and moisture content of the overburden, water quality,and a number of other factors. In the case of Agana Swamp, there is essentially no time lag to consider and water table movements are practically coincidental with the occurrence of recharge events.

The point to be made is that because there is a time lag in water-table responses between the swamp and the lens for a given hydrologic event, there necessarily is an exchange of groundwater between the two flow regimes due to a head differential. For example, during the wet season when the swamp receives a high influx of rainfall and runoff, the water table rises rapidly while the lens surface essentially remains stationary. Head values in the swamp are greater than in the lens (for the sake of argument, the two regimes where initially hydraulically equal) and groundwater will move into the lens aquifer motivated by the head differential. Likewise, during the dry season when there is reduced rainfall and high evapotranspiration (directly from the shallow water table), water levels decline in the swamp and a reverse of the flow direction occurs. Similar conditions to that of the dry season where created with the early attempts at draining the Agana Swamp for agricultural purposes. Water was allowed to exit the swamp via Agana River, thus lowering the water table in the region. It is probable that heads declined within the aquifer bordering the swamp. This response would have resulted in a general thinning of the freshwater column.

Water-Quality Characteristics

With the exchange of groundwater between Agana Swamp and the adjacent aquifer, there necessarily must be a change in the chemical nature of the water within the border zone of the two flow regimes. During the wet season, water of low total dissolved solids and probably slightly acid enters the adjacent aquifer. In reverse fashion, during the dry season, water of relatively high total dissolved solids and probably alkaline enters the swamp flow system. This seasonal exchange of water prompts the question of potential contamination of the freshwater lens by pollutants that might be introduced into the swamp environment. Apparently the military used the swamp as an equipment dump in the past (Dr. James Craig, personal communication). It is unknown what types of materials have been introduced into the area either as refuse or artificial fill.

As mentioned above, the water within the swamp flow system is probably acidic due to the high organic activity of the surface environment. If this is the case, then dissolution of the adjacent limestone aquifer is probably taking place. Although not observable in the vicinity of Agana

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RECOMMENDATIONS FOR FURTHER STUDY

This study of the hydrogeology of Agana Swamp and its relationship with the groundwater-flow system of the northern lens has raised more questions than have been addressed. Before the nature of the hydraulic link between the swamp area and the freshwater lens can be defined, the hydrogeologic environment of the swamp system must be investigated in detail and the time-dependent behavior of the flow system must be monitored. The major concern is the potential for pollutant contamination of the freshwater resource of the island. Therefore it will be important to obtain time-series data on water-table elevations and water quality within the swamp area and within the adjacent aquifer.

One of the major problems faced by the investigation was limited access to the study site. The problem was caused by three factors: (1) inadequate number of access roads; (2) denial of permission to conduct field work on private land; and (3) nearly impenetrable vegetation and soft water-saturated ground. It was soon realized that special equipment would be needed to achieve the objectives of the study. To overcome the problems experienced, future studies will require a lengthy lead-in time to meet with village commissioners and land owners in order to acquire access permission, to obtain specialized seismic geophones (designed for wetland use), to make arrangements for the use of explosives, and to prepare the area for field work.

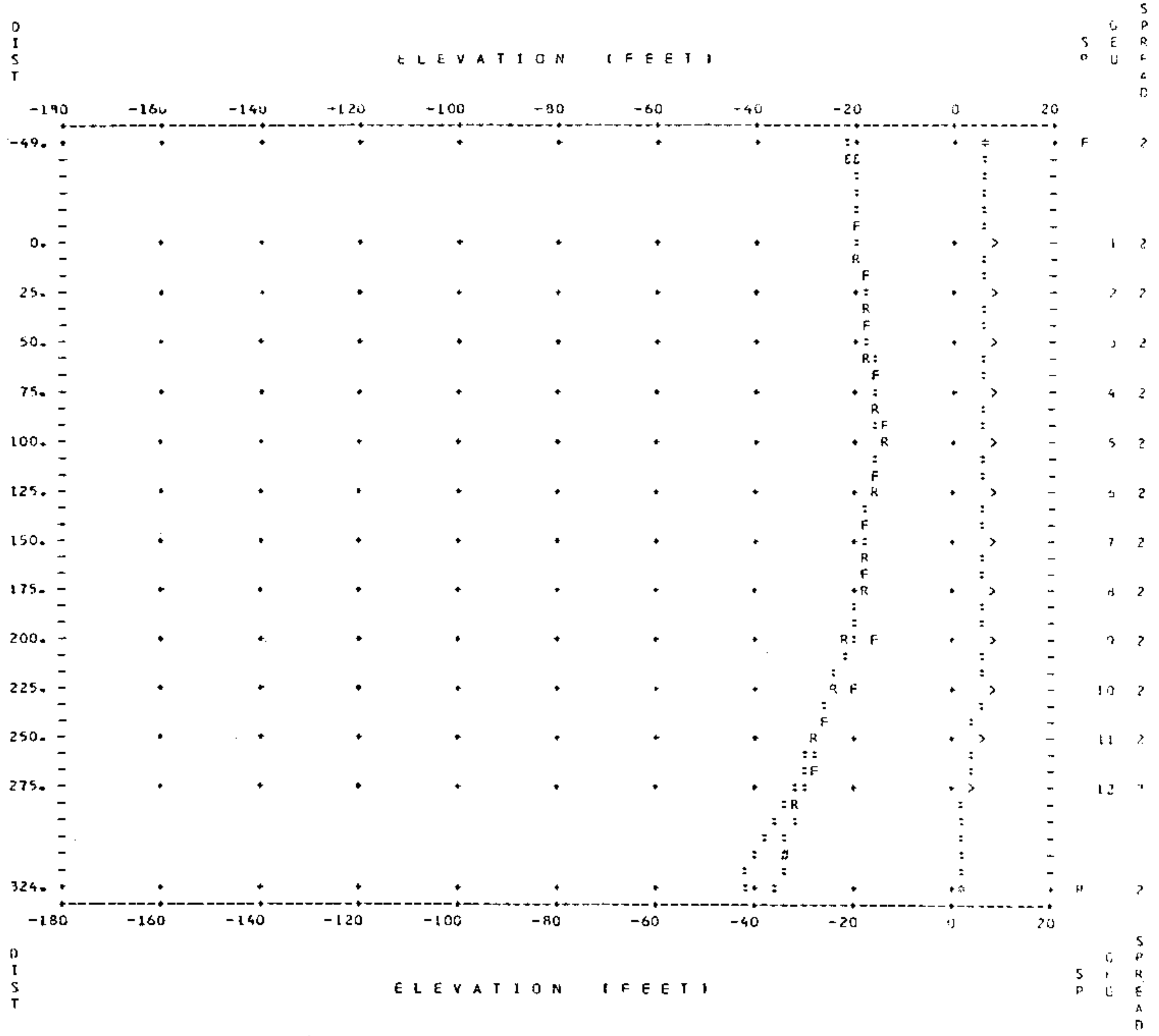
Further investigations of the hydrogeology of Agana Swamp and adjacent aquifer should include field work oriented toward the collection of subsurface data related to geologic properties, hydraulic characteristics, and water quality. In order to obtain the information it will be necessary to install a network of observation and monitoring wells both within the swamp and within the adjacent aquifer. Geologic information can be obtained by the drilling operation (coring where possible is recommended) and water-quality and hydraulic data can be obtained by a program of periodic or continuous sampling. Observation wells should penetrate the fresh-water column and transition zone in order to allow sampling of the major components of the system (unsaturated zone, freshwater phreatic zone, transition zone, saltwater phreatic zone) and to allow monitoring of positional and thickness changes of the transition zone. Changes in hydraulic head with depth and location should be monitored through time. It is recommended that electrical transducer type piezometers be used for measuring head values since they can be quickly installed at any depth and are portable. Seismic-refraction methods should be included in the program of data acquisition. Seismic surveys could give valuable information on the position of the limestone-volcanic contact if an adequate energy source is applied. It is doubtful that reliable data can be obtained from the application of earth resistivity techniques due to the presence of high-voltage transmission lines and the presence of buried metallic debris.

```
AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 1

 SPREAD 1   SMOOTHED POSITION OF LAYERS BENEATH SHOTPOINTS AND GEOPHONES

                                     LAYER 2          LAYER 3

 SP   POSITION  SURF ELEV        DEPTH  ELEV       DEPTH  ELEV
 ---  --------  ---------      -------------     -------------
  F     -47.0         9.9        0.3     9.6       88.9  -79.0
  R     326.0         5.3       11.7    -6.4       57.8  -52.5

 GEO
 ---
  1       0.0         8.5        1.8     6.7       83.7  -75.2
  2      25.0         9.0        0.9     8.1       82.3  -73.3
  3      50.0         7.9        1.7     6.2       79.6  -71.7
  4      75.0         7.6        5.4     2.2       77.7  -70.1
  5     100.0         6.9        5.4     1.5       74.5  -67.6
  6     125.0         6.1        5.7     0.4       70.9  -64.8
  7     150.0         5.6        9.4    -3.8       70.9  -65.3
  8     175.0         5.4       12.3    -6.9       68.8  -63.4
  9     200.0         5.2       13.1    -7.9       66.8  -61.6
 10     225.0         4.8        8.8    -4.0       64.6  -59.8
 11     250.0         4.3        8.6    -4.3       62.3  -58.0
 12     275.0         4.5       10.8    -6.3       60.7  -56.2

VELOCITIES USED:
                  LAYER 1          LAYER 2          LAYER 3

      VERTICAL     1500.            4149.
    HORIZONTAL                      4149.            9339.
```

APPENDIX

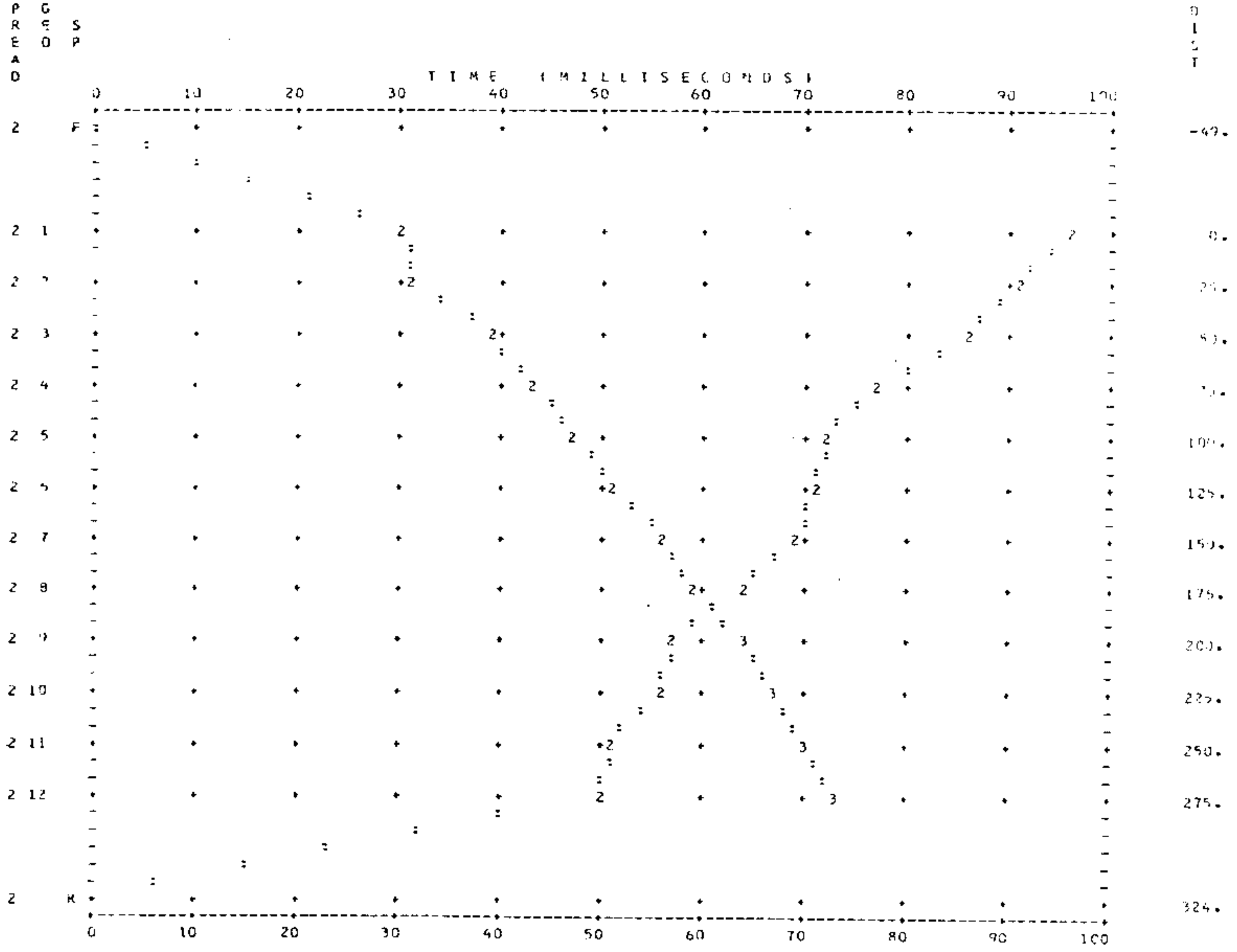
Seismic-Refraction Survey Results

AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 2



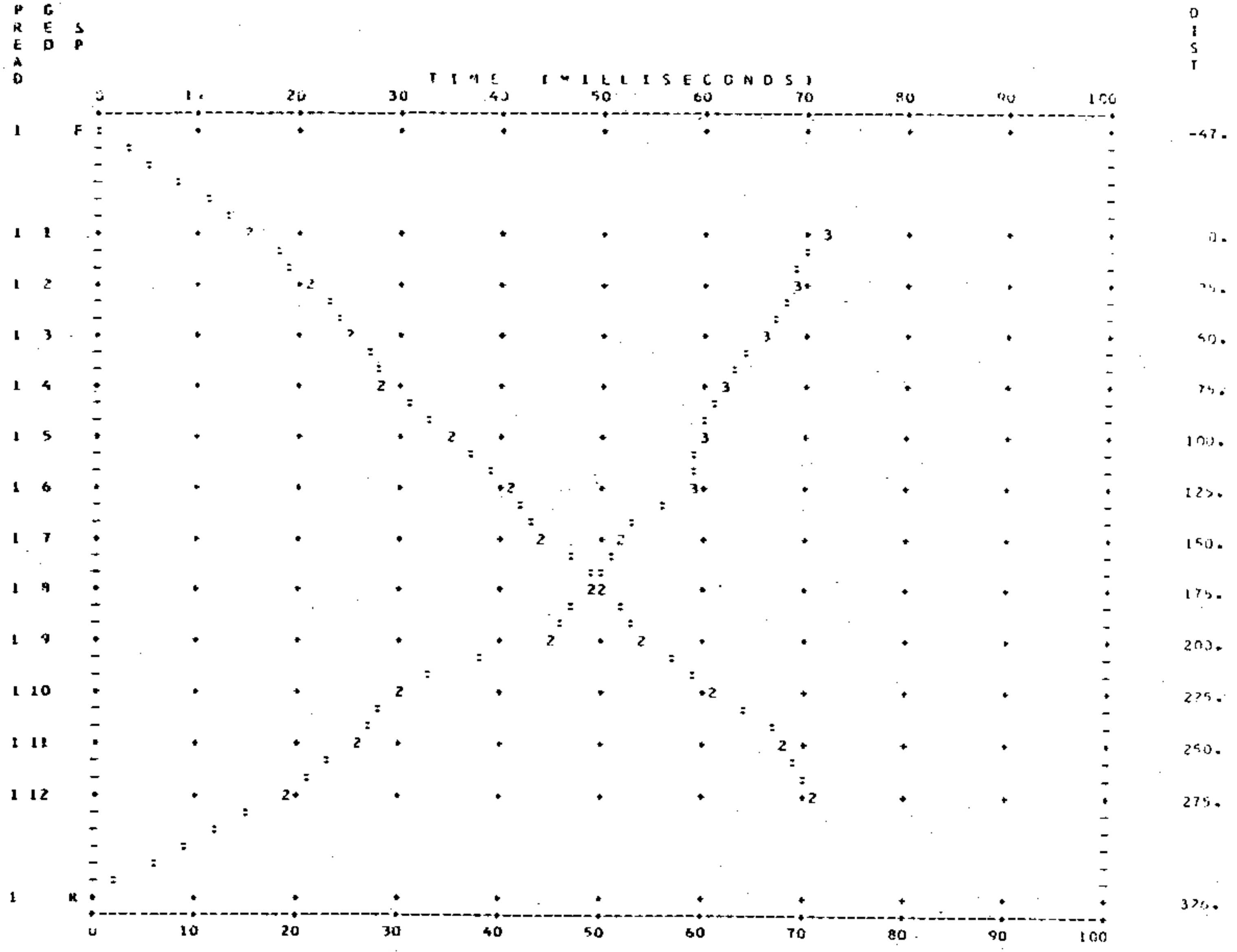
AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 2

TIME-DISTANCE PLOT -- RAW DATA WITH NO CORRECTIONS APPLIED



AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 1

TIME-DISTANCE PLOT -- RAW DATA WITH NO CORRECTIONS APPLIED



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AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 2

 SPREAD 2   SMOOTHED POSITION OF LAYERS BENEATH SHOTPOINTS AND GEOPHONES

                                          LAYER 2            LAYER 3

 SP    POSITION   SURF ELEV          DEPTH   ELEV         DEPTH   ELEV
 ---   --------   ---------        -------------        -------------
  F       -49.0         5.3         26.4    -21.1        26.4    -21.1
  R       324.0         2.0         37.4    -35.4        45.0    -43.0

 GEO
 ---
  1         0.0         5.3         24.8    -19.5        24.8    -19.5
  2        25.0         5.4         23.5    -18.1        23.5    -18.1
  3        50.0         5.6         23.2    -17.6        23.2    -17.6
  4        75.0         5.7         21.3    -15.6        21.3    -15.6
  5       100.0         5.8         20.6    -14.8        20.6    -14.8
  6       125.0         5.8         22.3    -16.5        22.3    -16.5
  7       150.0         5.7         23.7    -18.0        23.7    -18.0
  8       175.0         5.6         24.2    -18.6        24.2    -18.6
  9       200.0         5.6         26.6    -21.0        26.6    -21.0
 10       225.0         5.4         29.6    -24.2        29.6    -24.2
 11       250.0         4.5         31.7    -27.2        31.7    -27.2
 12       275.0         2.6         32.9    -30.3        34.7    -32.1

VELOCITIES USED:
                    LAYER 1             LAYER 2             LAYER 3

      VERTICAL       1500.                5752.
    HORIZONTAL                            5752.                6728.
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AGANA SWAMP PROJECT--SEISMIC REFRACTION SURVEY RESULTS LINE 1