RELATION OF DRAINAGE PROBLEMS TO HIGH GROUND-WATER LEVELS, COCONUT GROVE AREA, OAHU, HAWAII

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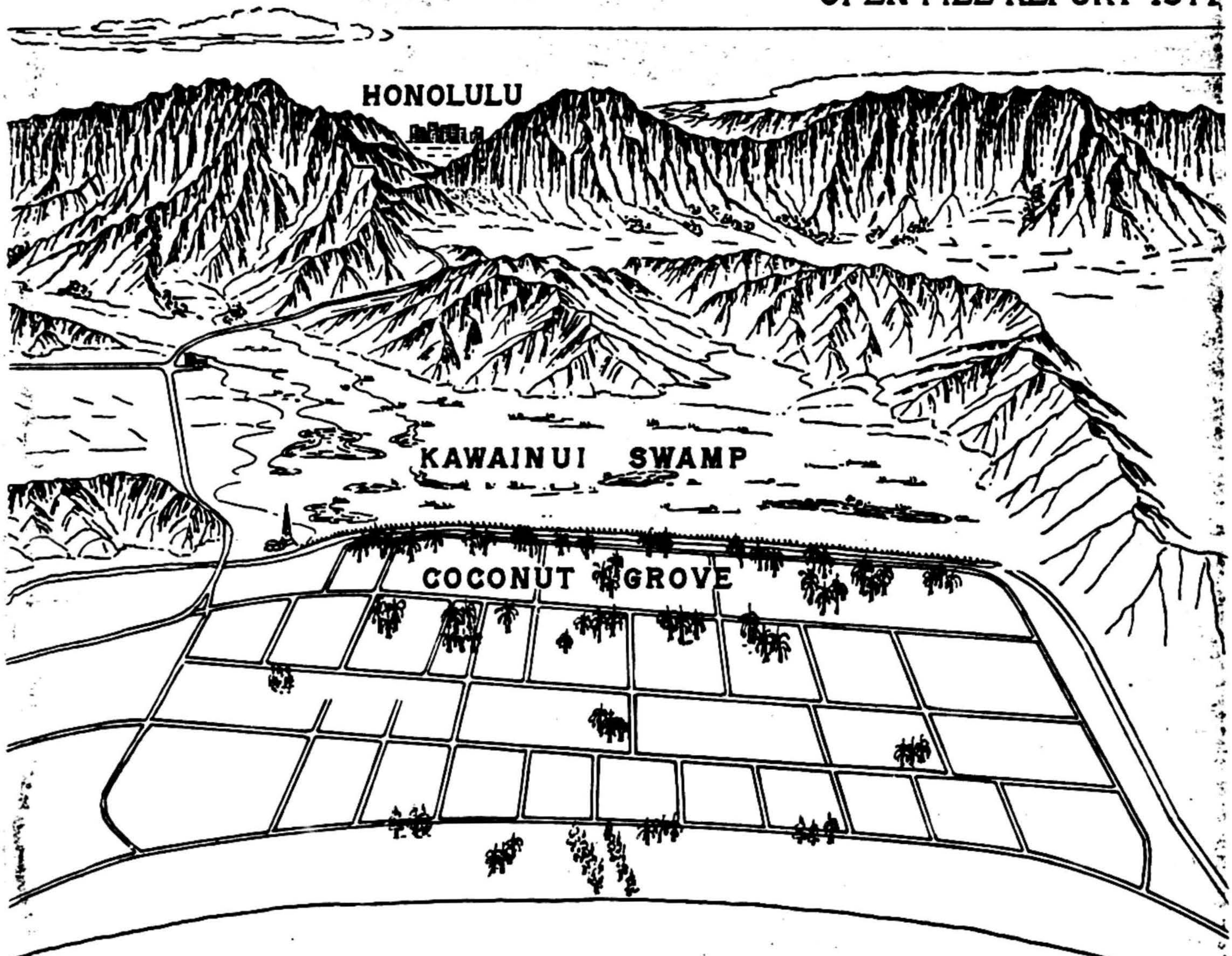
L.A. Swain

OPEN-FILE REPORT 1971



U.S. GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
HAWAII DISTRICT

Prepared in Cooperation with the Department of Public Works
City and County of Honolulu, Hawaii

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

RELATION OF DRAINAGE PROBLEMS TO HIGH GROUND-WATER LEVELS COCONUT GROVE AREA, OAHU, HAWAII

By

L. A. Swain and C. J. Huxel, Jr.

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INTRODUCTION

The Problem

Parts of the Coconut Grove residential area near Kailua, in windward Oahu, have experienced frequent and persistent inundation in past years. Cesspools often overflow during flooding and reportedly contaminate the standing water over an area of several blocks.

In March 1951, approximately 250 residents were evacuated from the area between Oneawa Street and Kawainui Swamp (fig. 1) because of flood waters flowing directly over the residential area from the Swamp. Again in April 1963, a four-block area was covered with about 3 feet of water. This time, about 60 families were evacuated from the area because water threatened to overflow a low levee between the Swamp and the residential area. Flooding again occurred to a depth of 4 feet on Kihapai Street and 3 feet on Oneawa Street in March 1965. Families in both areas were again evacuated as water entered many homes.

With completion, in 1966, of the Kawainui Canal to drain Kawainui Swamp and also of a 9-foot high levee to hold back storm water moving through the Swamp, it was hoped that the flooding problem had been eliminated. However, from December 1968 through January 1969, as much as 8 inches of water covered a large area from Oneawa Street to Kihapai Street (see fig. 1). The levee and Canal had eliminated direct overflow from the swamp, but flooding still occurred for reasons not clearly understood.

The City and County of Honolulu, through the Department of Public Works, requested the U.S. Geological Survey to initiate, in 1969, a study of the flooding problem to identify the cause of the flooding, the reason for the persistence of the ponded water in the low areas once flooding occurs, and to collect data on which to base decisions for remedy of the problem.

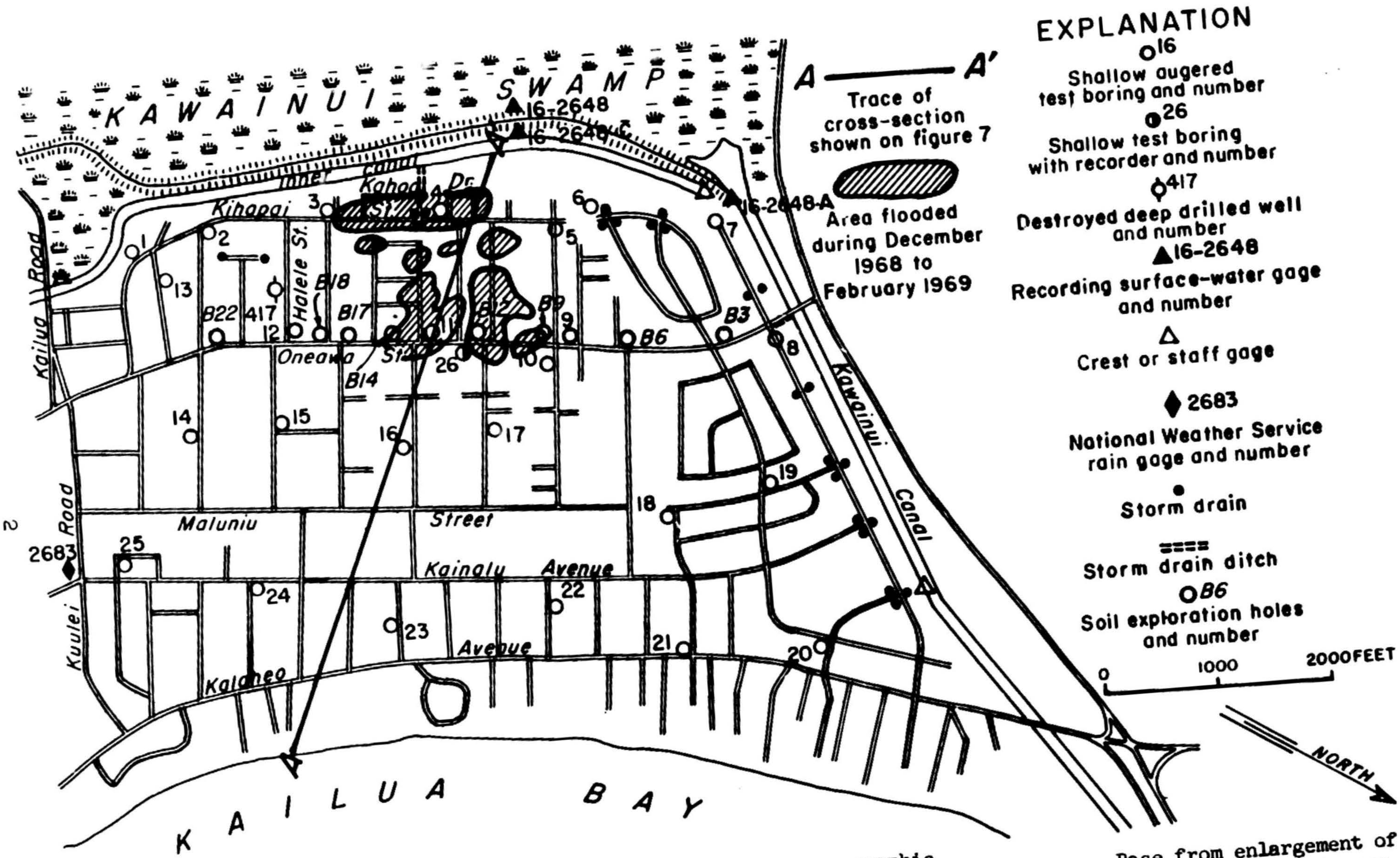

Figure 1. Coconut Grove area showing locations of significant geographic sections and data-collection points.

Base from enlargement of U.S. Geological Survey Mokapu Quadrangle, 1959.

Suggested reasons for the recurring flooding included: (1) concentration of intense rainfall in the low-altitude areas; (2) a slow infiltration rate caused by low permeability of the subsurface soil; (3) seepage of water from the Swamp through or underneath the levee into the residential area; (4) influence of tidal fluctuation on ground-water levels and rate of infiltration; and (5) a possible deep artesian connection which allowed water-level rise in the swamp to cause an artesian rise in the Coconut Grove area.

Purpose and Scope

In 1969, hydrologic data-collection sites were established in and around the Coconut Grove area for the purpose of measuring directly the relationship between rainfall, runoff, ground-water levels, the level of water in Kawainui Swamp and the canals, and tidal fluctuations. The primary objective was to identify the causes of the occurrence and persistence of flooding and to gain data on which to base recommendations for remedial action.

The scope of the study included establishing and operating flow and stage-recording gages on the Swamp, Kawainui Canal, and the inner canal; periodic and repeated measurements of ground-water level in test borings throughout the residential area; collection and analysis of soil and construction borings made for engineering purposes; the assembly and analysis of all available data relating surface and subsurface flow conditions, and the development of conclusions as to the causes and means to alleviate the flooding. This report summarizes the information collected from October 1969 to June 1971, includes analysis of the data, and discusses the probable causes of flooding.

DESCRIPTION OF THE AREA

Topography

The land surface in the 950-acre study area slopes gently from Kailua Beach toward the inner canal, from an altitude of about 12 feet above mean sea level on a ridge near the beach to less than 5 feet in the residential section nearest the Swamp. The Kahoa Drive and Kihapai Street sections are especially low-lying areas (fig. 2). The beach ridge and levees form the boundaries of a bowl-shaped, oblong depression, with about 15 percent of the residential area near the bottom of the bowl.

Coconut Grove was once, in fact, a coconut grove. Throughout the process of urbanization very little change was actually made in the original topography and many homes, lawns, and streets now occupy topographically low areas that have been little modified from their state of natural occurrence.

Geology

Sea-level changes during past glacial periods have been important to the development of the land form in the Coconut Grove area. During the third inter-glacial period (Waimanalo Stand), the Kawainui Swamp-Coconut Grove area was covered by the ocean up to the present-day altitude of 25 feet above mean sea level, as a result of eustatic sea-level rise (Stearns, 1935, p. 1945). As the sea retreated, the Swamp was formed and became separated from the ocean by a large barrier beach. This beach slowly increased in width as the sea level dropped and winds created onshore dunes. The narrow, crescent-shaped beach ridges, somewhat parallel to the present-day shoreline, can be seen in aerial photographs taken prior to urbanization.

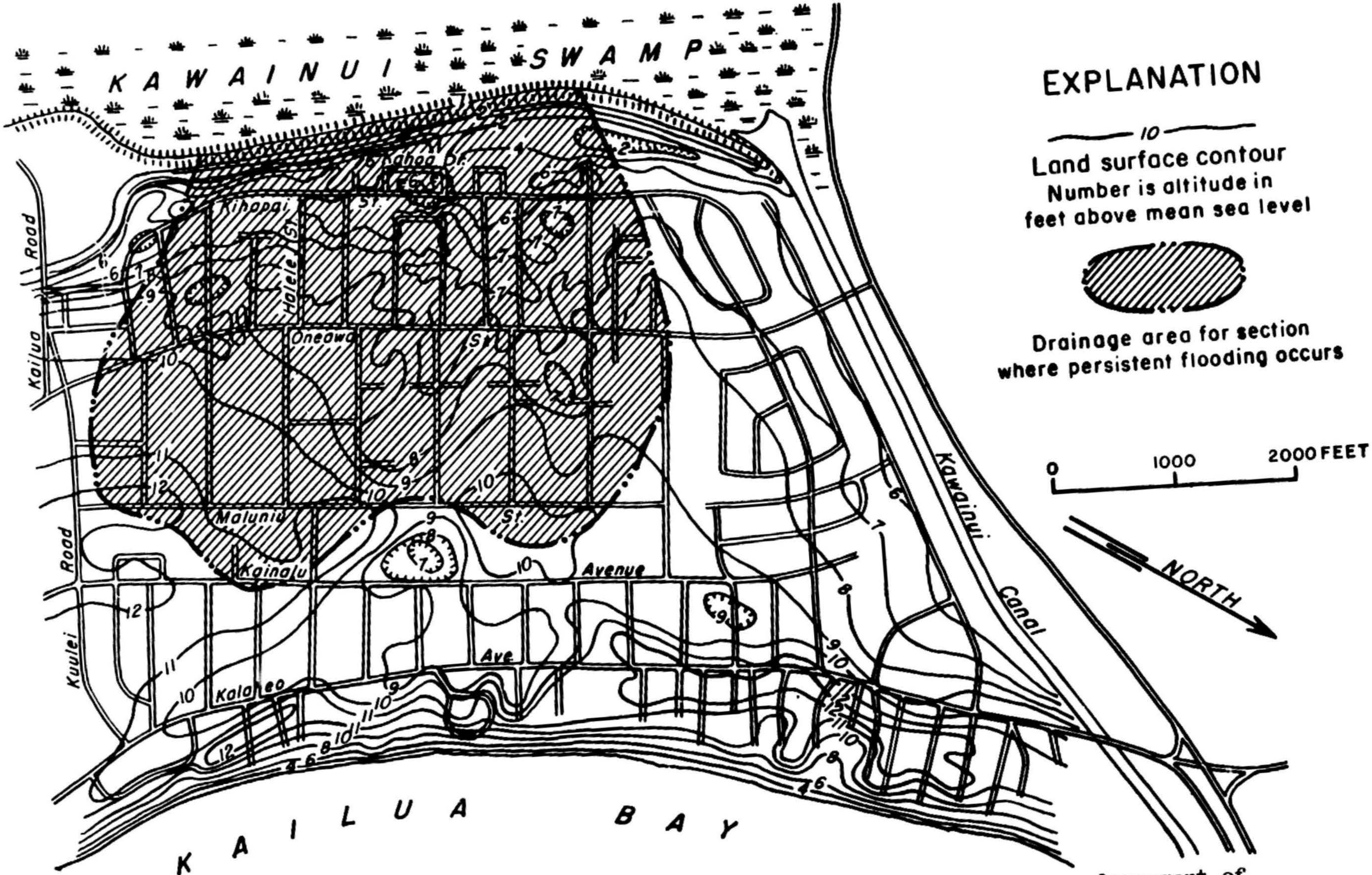

Figure 2. Land-surface contour map of study area.

Base from enlargement of U.S. Geological Survey Mokapu Quadrangle, 1959.

Coconut Grove is underlain by very fine to coarse silty coralline sand, silt, and sandy clay; all with occasional blocks of coral and scattered coral fragments. Drilled well 417, near Halele Street (shown in fig. 1), penetrated "...177 feet of beach sand, coral and coral mud..." (Stearns, 1940, p. 145). In sections throughout the Grove, the sand and coral of the barrier beach interfinger with and underlie the silt and clay deposits of Kawainui Swamp. Logs of soil-exploration holes[1/] along Oneawa Street near test boring 26 show fine to medium sands to a depth of 20 feet (B12 and B14, fig. 3). This differs from logs of soil-exploration holes away from this area along Oneawa Street, which show the sands to be intermixed with silt and clay, with clay layers at depths varying from 5 to 10 feet (fig. 3). The absence of silt and clay from the log of test boring 26 and nearby borings probably indicates the presence of an ancient stream channel, which was later filled with beach or dune sands.

Test borings in Kawainui Swamp[2/] show predominantly clay with some sand as deep as 125 feet. The top layer is a nearly impermeable mixture of clay and organic matter (fig. 3).

Ground Water

The ground-water body underlying Coconut Grove consists of fresh water floating on and grading into sea water. The thickness of the fresh-water part of the ground-water body has not been determined. In addition to rainfall infiltration, a significant contribution to the ground-water body comes from cesspools and from other domestic water use, such as lawn watering. This contribution over the area is approximately 2 million gallons per day.[3/]

1/ Walter Lum Associates, Inc., 1969, Preliminary soil exploration for Kihapai-Kainui Sewer Sections 1-B and 2, Kailua, Oahu, Hawaii.

2/ Dames and Moore, 1961, Graphic logs of test borings, Kawainui Swamp, Oahu.

3/ Honolulu Board of Water Supply, 1971, Data on domestic water supplied to Coconut Grove area, Oahu.

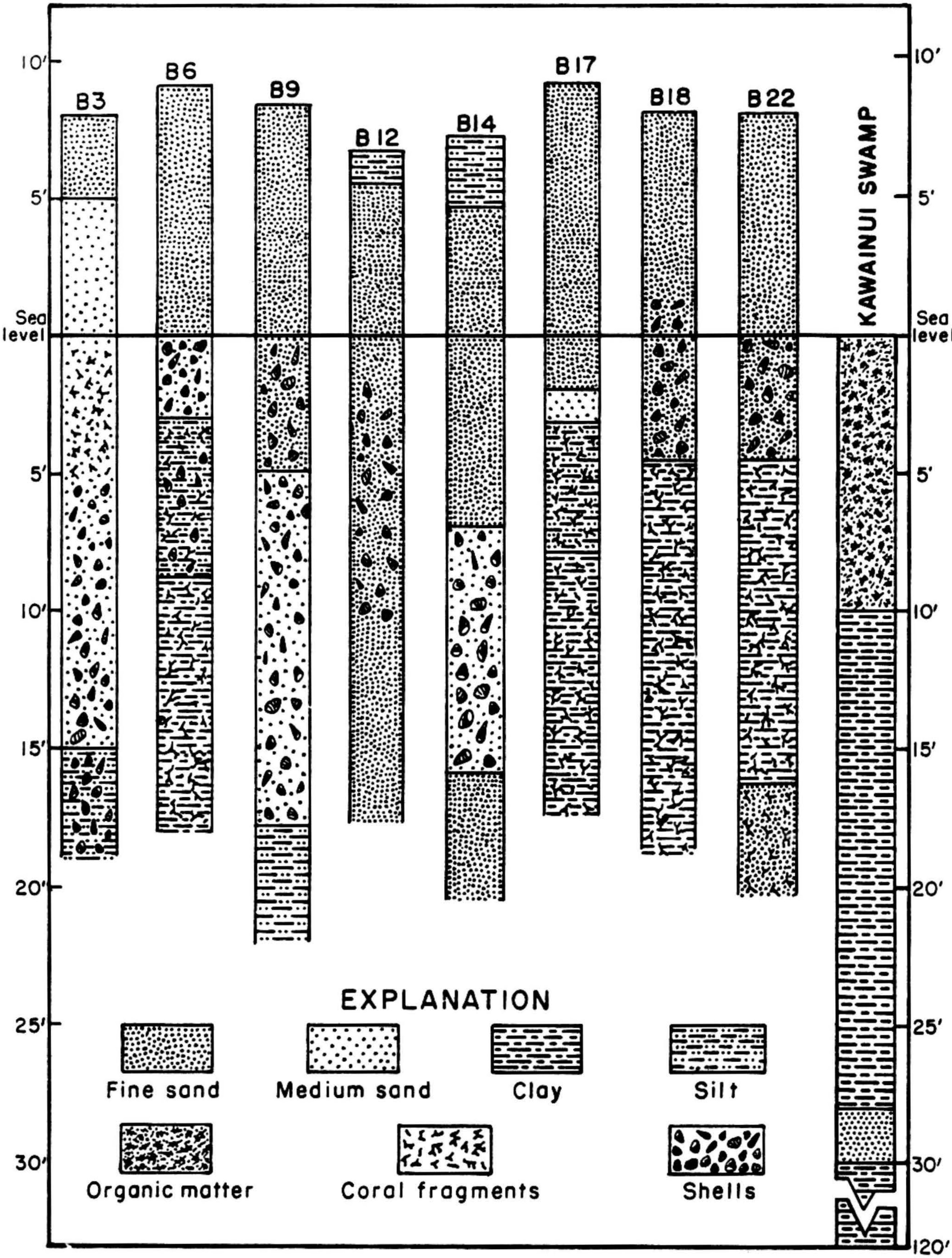

Figure 3. Geologic logs of soil-exploration holes along Oneawa Street and in Kawainui Swamp.

Water-level contours based on the periodic measurements show a ground-water mound in the area of Oneawa Street and Kihapai Street (fig. 4). Similar contour maps prepared for numerous periods show that this general pattern of ground-water occurrence predominated during the period of observation from October 1969 to June 1971. From the contour map it can be seen that ground-water flow is generally radially away from the mound toward the ocean, Kailua, Kawainui Canal, and the inner canal.

The ground-water gradient in Coconut Grove varies with time in any specific direction. From October 1969 to October 1970, the gradient of flow toward Kailua, Kawainui Canal, and the ocean ranged from 1 to 4 feet per mile. The gradient toward the inner canal, at this time, ranged from 7 to 10 feet per mile.

Following a period of high rainfall in November 1970 and when the mound was prominent below the area of lowest land-surface altitude, the gradients were much greater. At this time, the gradient in the mound area toward Kawainui Canal, Kailua, and the ocean was about 10 feet per mile, whereas the gradient to the inner canal was about 25 feet per mile.

The ground-water body reacts to rainfall infiltration almost instantaneously, exhibiting an extremely rapid rise in the water table. However, during drier periods, the rate of ground-water mound dissipation or lowering of the water table is much more gradual. The slow rate of dissipation is partly the result of reduced downward percolation caused by substantial thickness of silt and clay in the subsurface as indicated by logs shown in figure 3. Figure 5 shows the change of the water table during normal as well as flood conditions as recorded at test boring 26.

Rainfall

Rainfall estimates are based on daily records collected since 1960 at the National Weather Service rain gage 2683, located at Kailua Fire station (location shown on fig. 1). Mean annual rainfall at this station for the 10-year period, 1960-69, was about 44 inches. For this study, however, the intensity of rainfall in the area during short periods is of primary interest. The highest daily rainfalls recorded were 15.21 and 13 inches, which fell on March 26 and 27, 1951, respectively.[4/] Kawainui Swamp overflowed into the residential area following these 2 days of heavy rains. The daily and total rainfall amounts for more recent periods of flooding in March-April 1963, March-April 1965, and December 1968-January 1969 were recorded at gage 2683 and are shown in figure 6. The bracketed segments in the figure show the total rainfall for the periods when flooding was reported.

4/ U.S. Army Corps of Engineers, 1956, An unpublished design memorandum for Kawainui Swamp, Oahu, Hawaii.

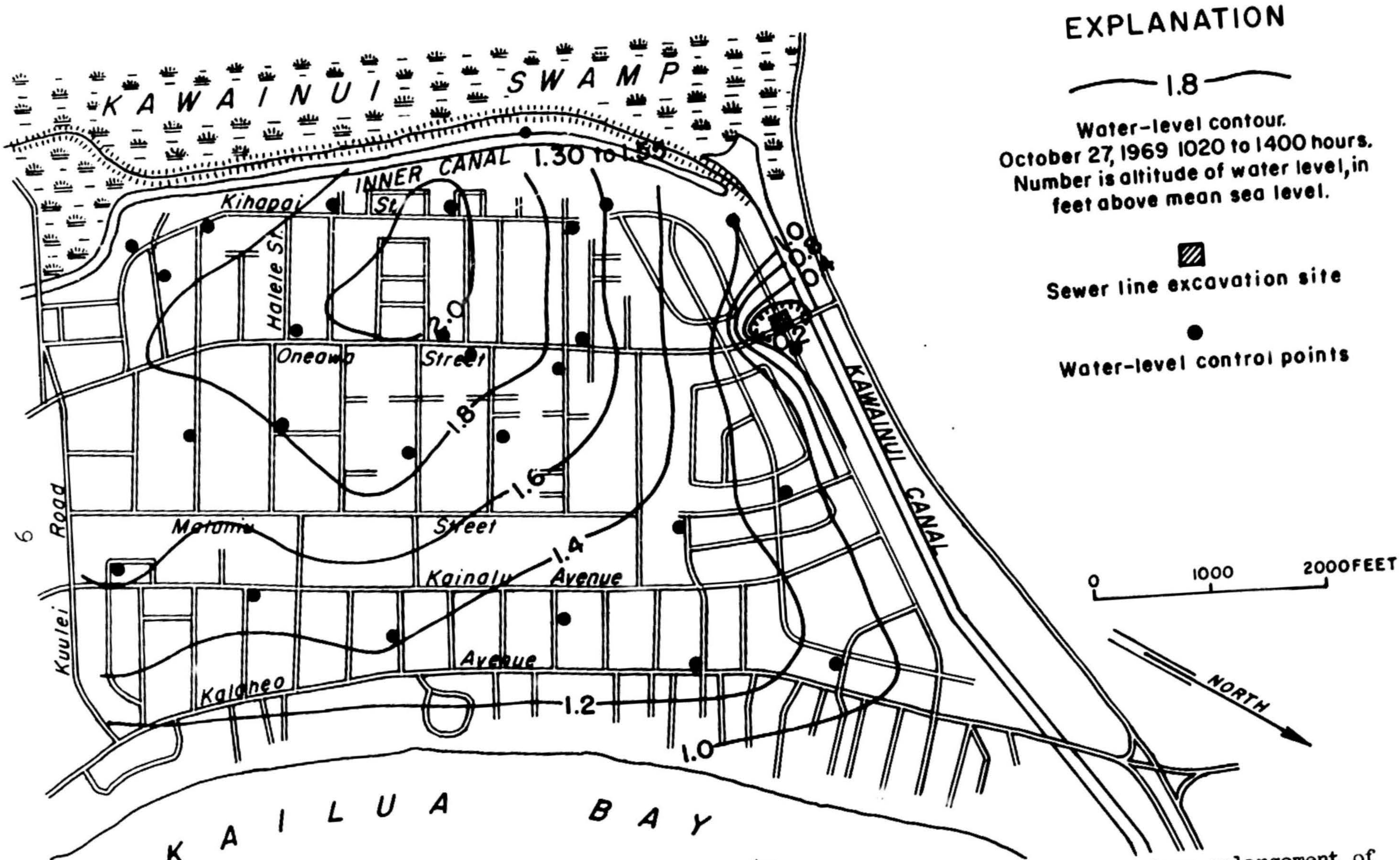

Figure 4. Ground-water levels based on measurements made on October 27, 1969.

Base from enlargement of U.S. Geological Survey Mokapu Quadrangle, 1959.

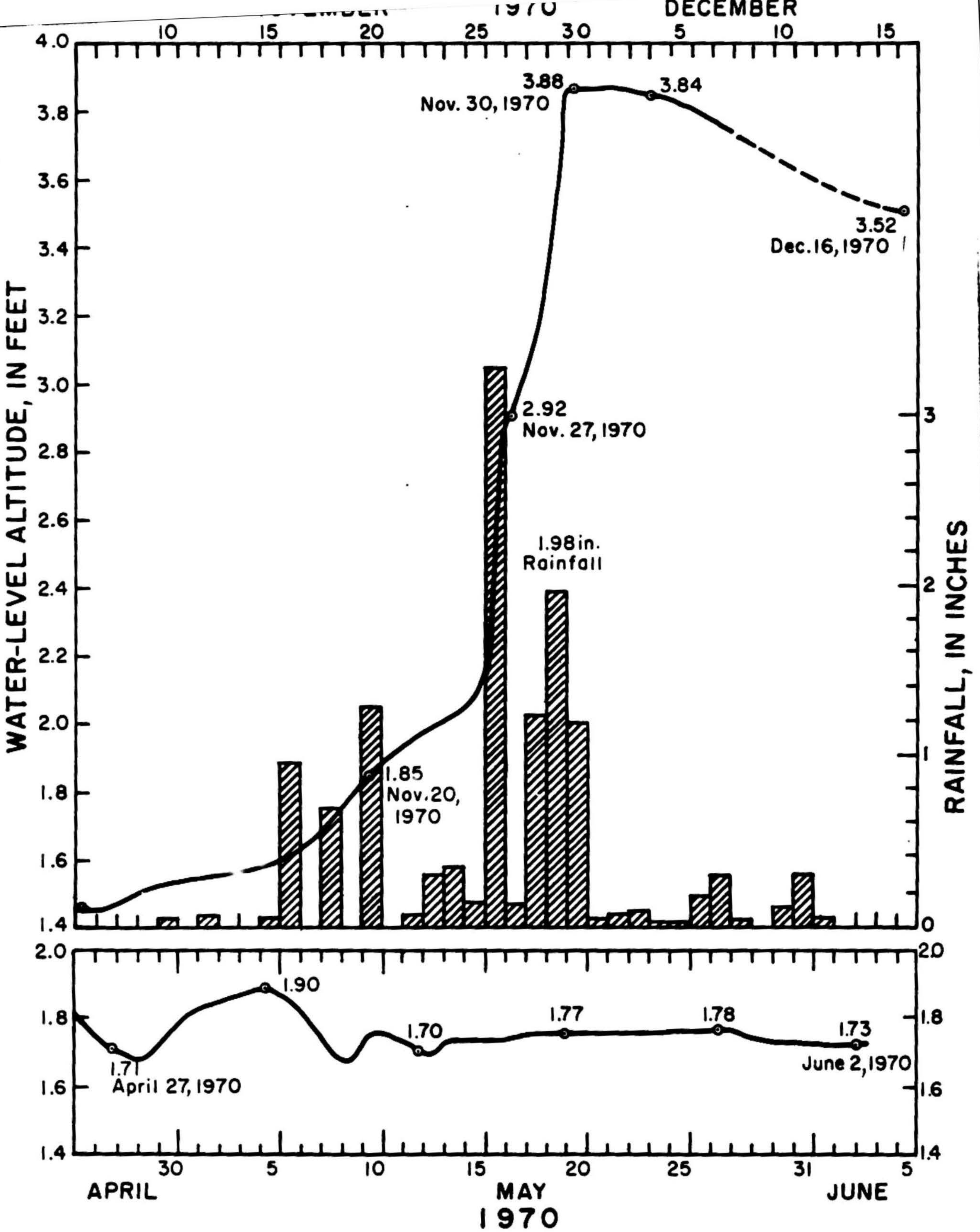

Figure 5. Water levels at test boring 26 showing fluctuations under normal (April-June, 1970) as well as flood (November-December, 1970) conditions. Rainfall bar graph for November-December period only.

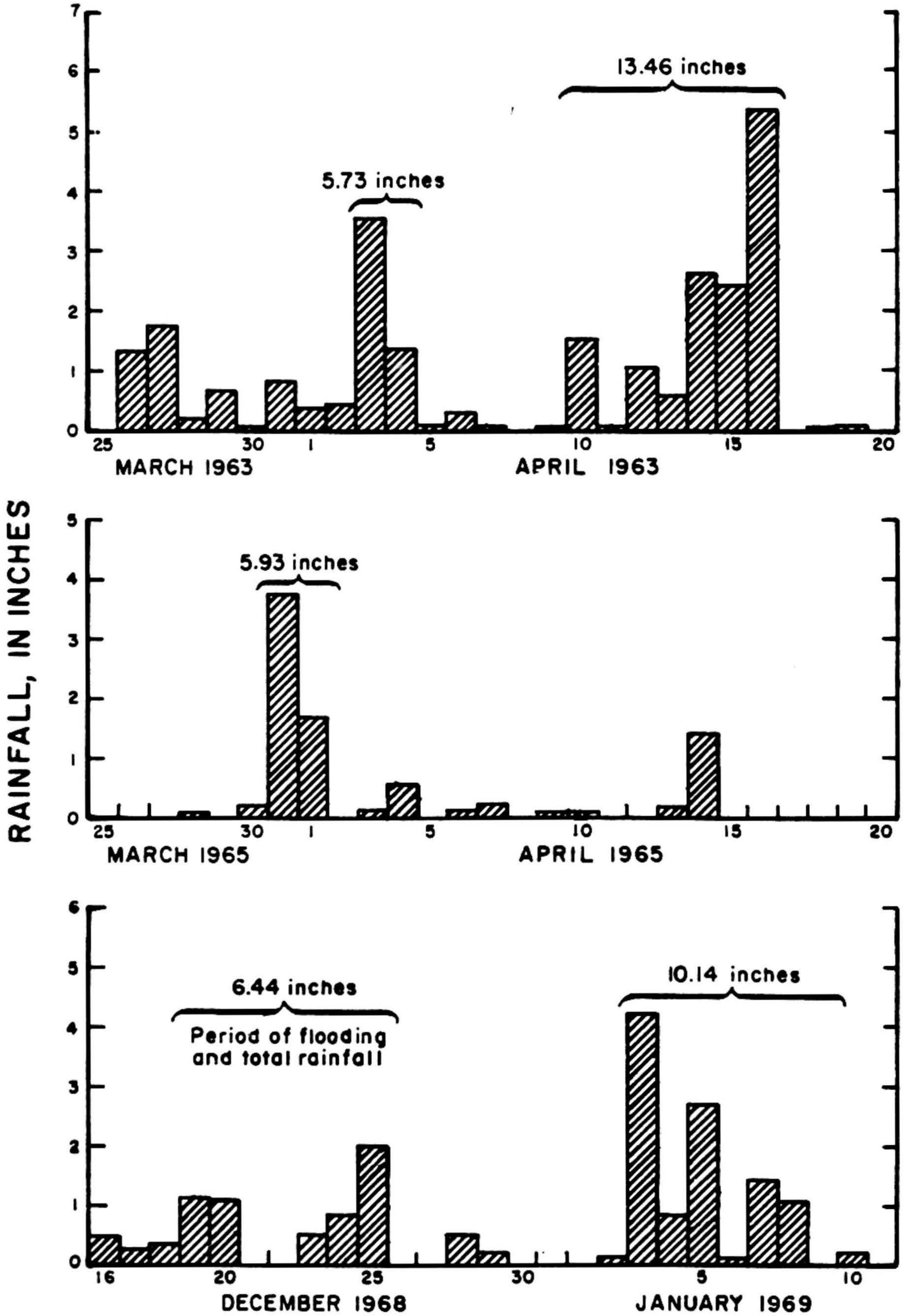

Figure 6. Daily rainfall at rain gage 2683 for periods when flooding was reported in Coconut Grove.

DRAINAGE SYSTEMS

Kawainui Swamp and Canal System

The Kawainui Swamp, covering approximately 500 acres, receives runoff from more than 10 square miles of watershed with a high annual rainfall and is subject to intense short-term storms. Because of thick vegetation and the large surface area of the Swamp, more water flows into the Swamp than can flow through it during periods of intense rainfall. Consequently, the water level rises rapidly as the excess inflow is held in temporary storage.

Kawainui Canal and the flood-control levee were constructed in 1966 to provide more direct drainage of the Swamp into Kailua Bay, and to aid in channeling the swamp drainage into the Canal.

Inner Canal

The inner canal extends about 6,500 feet along the southwest edge of Coconut Grove from the Kawainui Canal levee at its head to the Kailua Road bridge (fig. 1). It is separated from the residential section on the northeast side by a low marsh and from the swamp on the southwest side by the flood-control levee. The canal depth at the inner canal gaging station (16-2648-C) is 10 feet, and the average canal bottom altitude is about 6 feet below mean sea level. Water hyacinths normally cover the water surface, greatly retarding flows. Downstream from the Kailua Road bridge, the canal flows into the natural waterway of Kaelepulu Stream. The water level in the inner canal is controlled by the level of Kaelepulu Stream, which is partly dammed during low flow by a wave-built sand berm at Kailua Beach Park. When the berm is breached during high runoff, the water level of the inner canal is controlled for a time by sea level.

Storm Drains

Street drains are not provided to drain the runoff away from low-lying areas. In 1969, the first storm drain within the flooding area was installed along Kahoa Drive with its intake near the intersection with Kihapai Street at a location shown on figure 1. This was to drain surface water from Kihapai Street into the inner canal. Although other drains do exist within Coconut Grove, this is the only one which is directly effective in the area persistently flooded.

In addition to the lack of drains, there are no curbings or street gutters to channel the flow to the drain at Kahoa Drive and Kihapai Street. Thus, runoff follows streets and topographic depressions to points of lowest altitude in the Kahoa Drive area.

DATA COLLECTION

Ground-water levels in Coconut Grove were measured at 25 test borings ranging in depth from 6 to 12 feet. The location of these borings is shown on figure 1. Water levels were measured monthly and as soon as possible after major rainstorms. Water levels were recorded continuously in boring 26.

Surface-water levels in Kawainui Swamp, Kawainui Canal, and the inner canal were recorded continuously at gaging stations 16-2648, 16-2648-A, and 16-2648-C, respectively, whose locations are also shown on figure 1. Auxiliary staff gages and gages to record peak stages were also installed in the two canals.

CAUSES OF FLOODING

The data collected during this study indicate that the principal cause of flooding is the concentration of overland runoff and ponding in the low-lying areas from rainfall within the Grove. The resultant rise in ground-water level reduces infiltration rates and contributes to persistence of the flooding.

Ponding

Owing to the sloping land surface and absence of storm drains, heavy rainfall causes runoff that moves along the streets of Coconut Grove and concentrates in ponds where the altitude is lowest. The water remains ponded until it can infiltrate into the ground or evaporate. As this ponded water seeps through the ground to the water table below, the ground-water level beneath the ponded areas rises accordingly.

Ground-Water Rise

Where the land-surface altitude is lowest, as near test borings 1 through 4, the depth to ground water is only about 3 to 5 feet below the land surface during most parts of the year (fig. 7). This is also the area of greatest runoff concentration and consequent infiltration. When water inflow to the ground as infiltration exceeds the outflow as lateral underflow, a ground-water mound begins to form. If the inflow is sufficiently large and prolonged, the mound continues to rise. Where the depth to ground water is shallow, as in the low-lying area, the water table quickly reaches the land surface.

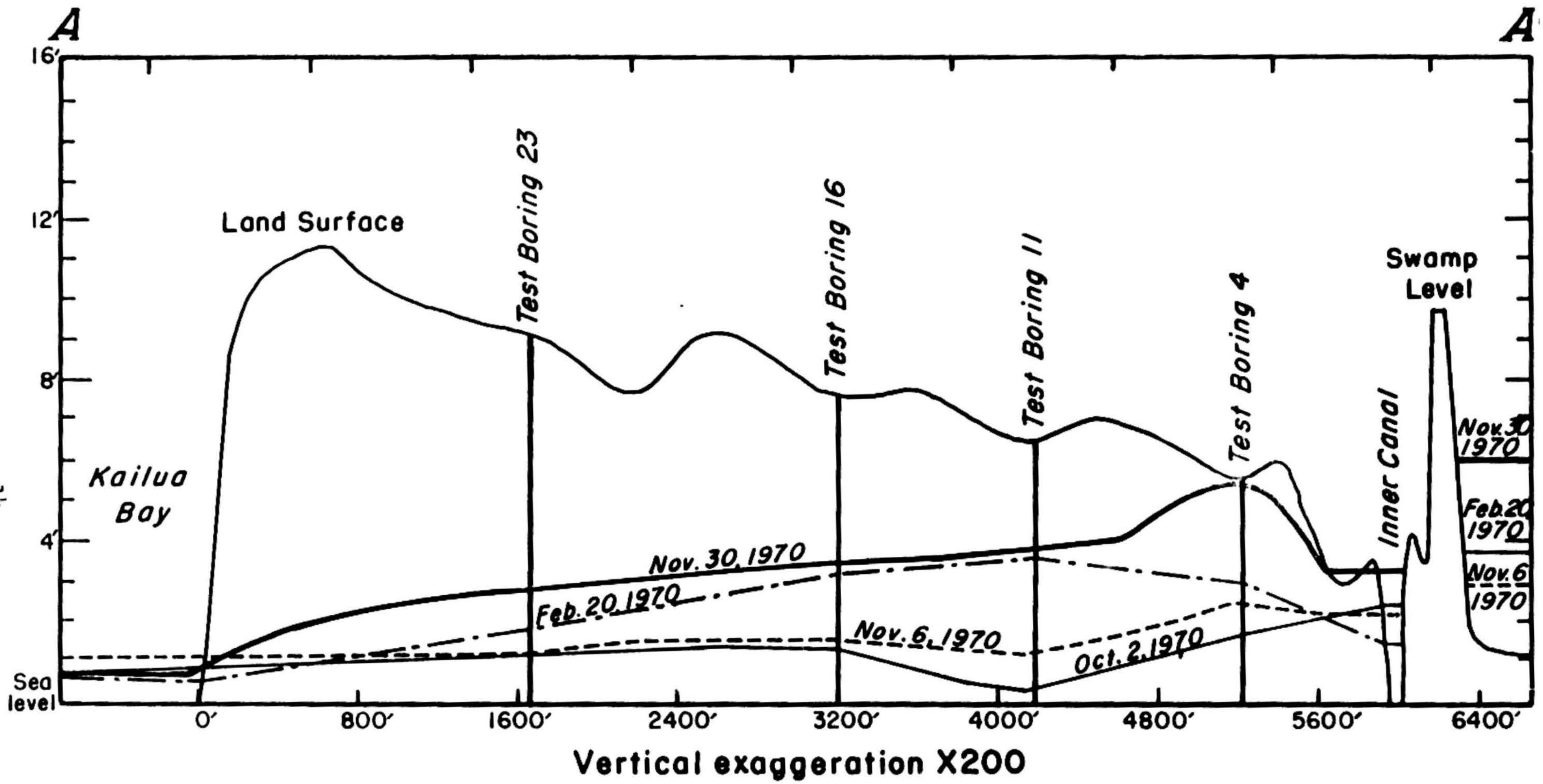

Figure 7. Section across Coconut Grove showing water-table profiles.

The intersection of the water table with the land surface is not only a principal cause of the flooding in the Coconut Grove area, but also a primary cause of the persistence of the flooding once the ponding occurs. This condition retards infiltration so that dissipation of the ponding is dependent upon evaporation and very slow lateral subsurface flow. On November 30, 1970, after 7.86 inches of rain fell on the area in 5 days, the water table in test boring 4 was within 0.3 foot of the surface (fig. 7) and was above land surface in nearby lower areas. At this time, adjacent homes had water standing in their yards and in the streets.

At such times of flooding, when the water table rises to or near land surface, cesspools cannot accept the additional domestic effluent and they overflow, further aggravating the flooding condition.

Capillary Fringe

Soil moisture and the capillary rise of moisture above the water table play an important role in determining the amount of storage capacity available for infiltration of ponded water. In fine sand or silty fine sand such as underlies the Coconut Grove flooding areas, capillary water may rise 1 to 5 feet above the water table. Because the zone between the land surface and the water table is normally only about 3 feet thick in the flooding area, it follows that this zone can be near saturation most of the time as a result of capillarity. Thus, only a small additional input of water will result in saturation and will cause a rapid rise in the water table. Consequently, the capacity of the sandy ground beneath the areas of storm-runoff ponding to accept additional infiltrating water is small.

THE SWAMP AS A FLOOD SOURCE

Prior to completion of the levee between Coconut Grove and the swamp, overflow water from the swamp was a major cause of flooding of the low-lying Coconut Grove areas. When flooding still occurred after completion of the canal and levee, it was suggested that water from the swamp was seeping through the levee and flooding Coconut Grove by raising ground-water levels or that the ground-water rise was in response to a water-level rise in the swamp.

The data from this study indicate that there is little, if any, seepage through or beneath the levee along the inner canal, and that water from or in the swamp no longer contributes significantly to the flood problem. From hydrographs of the swamp, the inner canal, and test borings within Coconut Grove, it can be shown that the water level in the swamp and test borings is normally higher than that of the inner canal (fig. 8). The flow direction for both water bodies is toward the lower-altitude inner canal, and it is not possible for the water of the swamp to move up-gradient to affect the ground-water body.

Observations of ground-water levels also indicate that there is no flow from the inner canal toward the swamp when the water level is higher in the inner canal than in the swamp.

As to the possibility that water-level rise in the swamp may be somehow transmitted through a deep connection to the ground-water body beneath Coconut Grove, and thus cause flooding, it must be noted that the inner canal between the two is excavated several feet below sea level. If a free connection exists, it must be quite deep and exceptionally well sealed from the canal base, otherwise the water-level head of the swamp would readily induce flow from the swamp into the canal. All evidence from logs and field observations of subsurface materials in the Coconut Grove area, the swamp area, and the canal walls show this situation to be unlikely. The long-term concurrent records of water-level rises in both the Coconut Grove area and the swamp show that the ground-water level beneath Coconut Grove rose previous to, or simultaneous with, the water level in the swamp. If an artesian pressure did exist, the Coconut Grove levels would have risen somewhat after that of the water level in the swamp and not before.

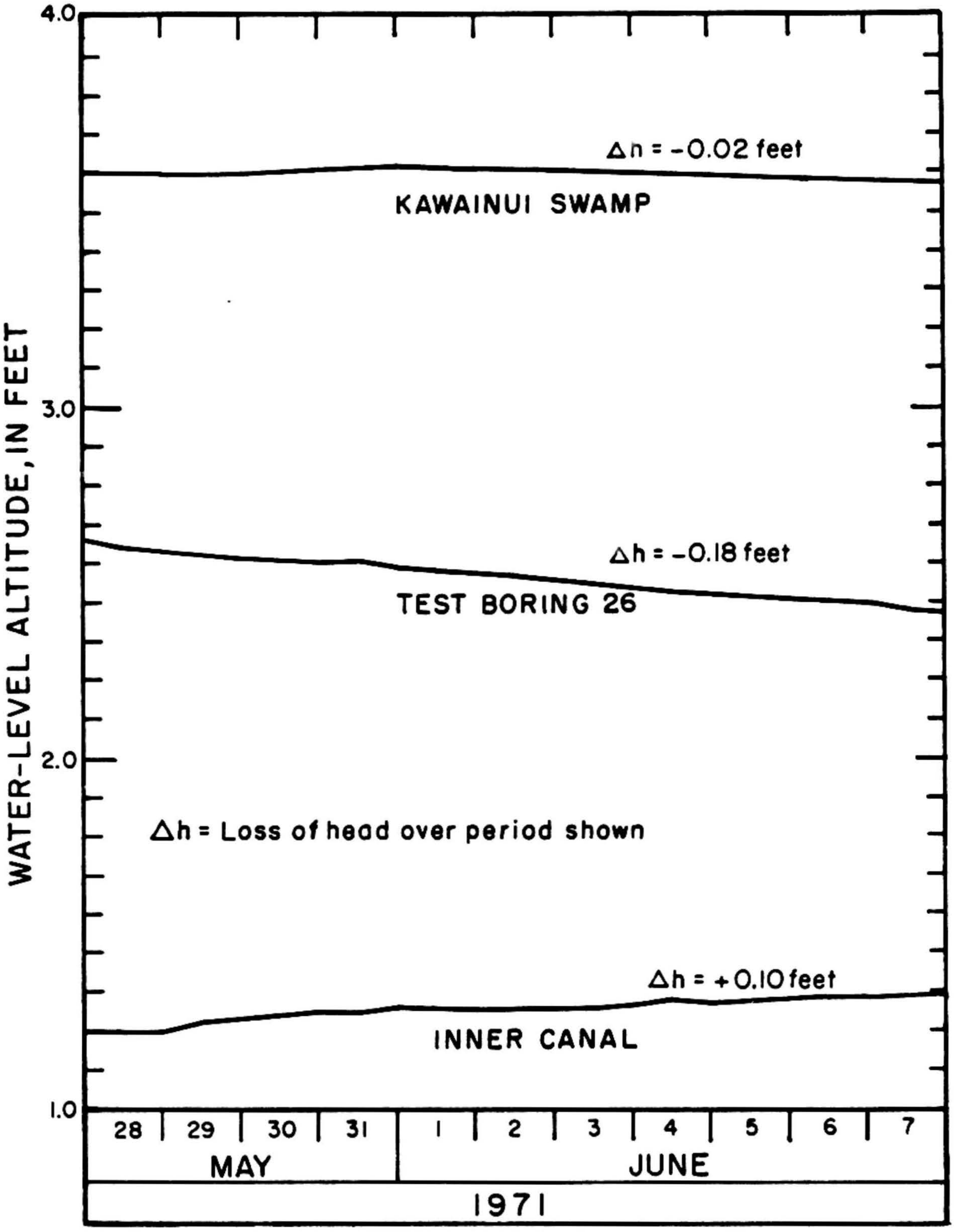

Figure 8. Hydrographs of important water bodies in Coconut Grove area showing altitudes of water levels.

Likewise, if this connection did exist, the ground-water levels beneath Coconut Grove should be rising continuously and approaching the level of the water in the swamp. From hydrographs it can be seen that the ground-water level beneath Coconut Grove approaches, but never reaches, that of the water level in the swamp during periods of high rainfall. During dry periods (fig. 8) the level of the ground water in Coconut Grove remains lower than the water level in the swamp and decreases at a rate greater than that of the swamp.

Thus, it is concluded that the swamp water level no longer contributes to flooding in Coconut Grove.

THE EFFECT OF TIDE

There have been suggestions that tidal fluctuations may contribute to flooding in Coconut Grove. Although tide effects can be observed in the streams and canals connected to Kailua Bay and in the wells nearest the ocean, ground-water levels in the flooded area show little, if any, response to tides, as indicated by the records of April 26, 1971 (fig. 9). Therefore, except as the tide may momentarily change the gradient of lateral subsurface ground-water flow a slight amount, there is no indicated connection between tidal change and flooding.

CONCLUSIONS

The principal cause of flooding in Coconut Grove is the concentration and ponding of rainfall and local-area runoff in low-lying areas owing to a lack of drainways to remove the water from these areas, and to the general topography of Coconut Grove.

This ponding is sustained and prolonged by the rapid rise to or near the land surface of the shallow water table beneath these areas. Under this condition, infiltration is retarded so that dissipation of the ponding is dependent on evaporation and a very slow lateral subsurface flow. The ground-water level is normally maintained at a shallow depth by slow lateral drainage under a low gradient and by a large and almost constant input of domestic water, largely through cesspools. Elimination of this input by sewering the area will cause the water table to be slightly lower during dry periods, will reduce the soil-moisture content now sustained by cesspool effluent, and will increase the capacity of the unsaturated part of the subsurface to accept storm-water infiltration. However, these changes will not be sufficient to eliminate the flooding problem unless the concentration of storm-water runoff in the low areas is reduced.

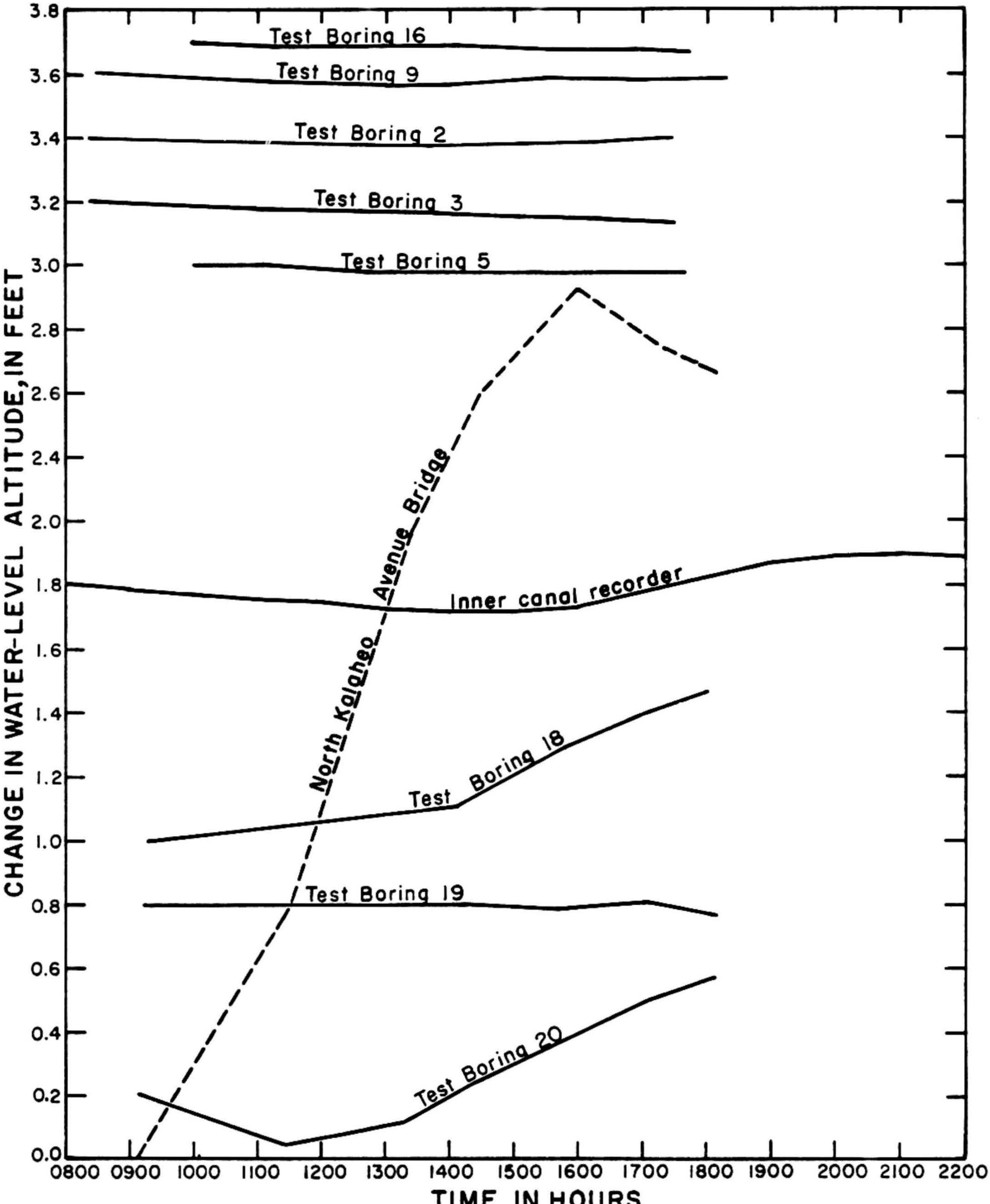

Figure 9. Hydrographs of selected test borings, inner canal, and water level at North Kalaheo Avenue bridge showing relative changes in water levels on April 26, 1971.

Tide changes have little or no effect on the water level in the flooding area. There was no evidence gained during the study to indicate that the tide has more than a minor and momentary effect on the subsurface flow gradient. As such, it may slightly delay ground-water flow toward the tide-affected areas, but does not significantly bear on the flooding problem.

The data indicate that the levee and inner canal are effective barriers between Kawainui Swamp and Coconut Grove and that there is no seepage from the swamp to the area that floods.

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