UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

PROBABLE EFFECT OF CANAL 111 ON SALT-WATER ENCROACHMENT, SOUTHERN DADE COUNTY, FLORIDA

By

Howard Klein

OPEN-FILE REPORT

Prepared by the
U.S. Geological Survey
for the
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INTRODUCTION

The development of a large industrial complex in the low-lying coastal marshes at the southeastern tip of the Florida mainland in southern Dade County, about 30 miles southwest of Miami, includes construction of Canal 111 and associated flood-control and water-control works (fig. 1). Canal 111, as used in this report, also

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Figure 1. -- Map of southeastern Dade County, Florida, showing hydrologic features in area of investigation

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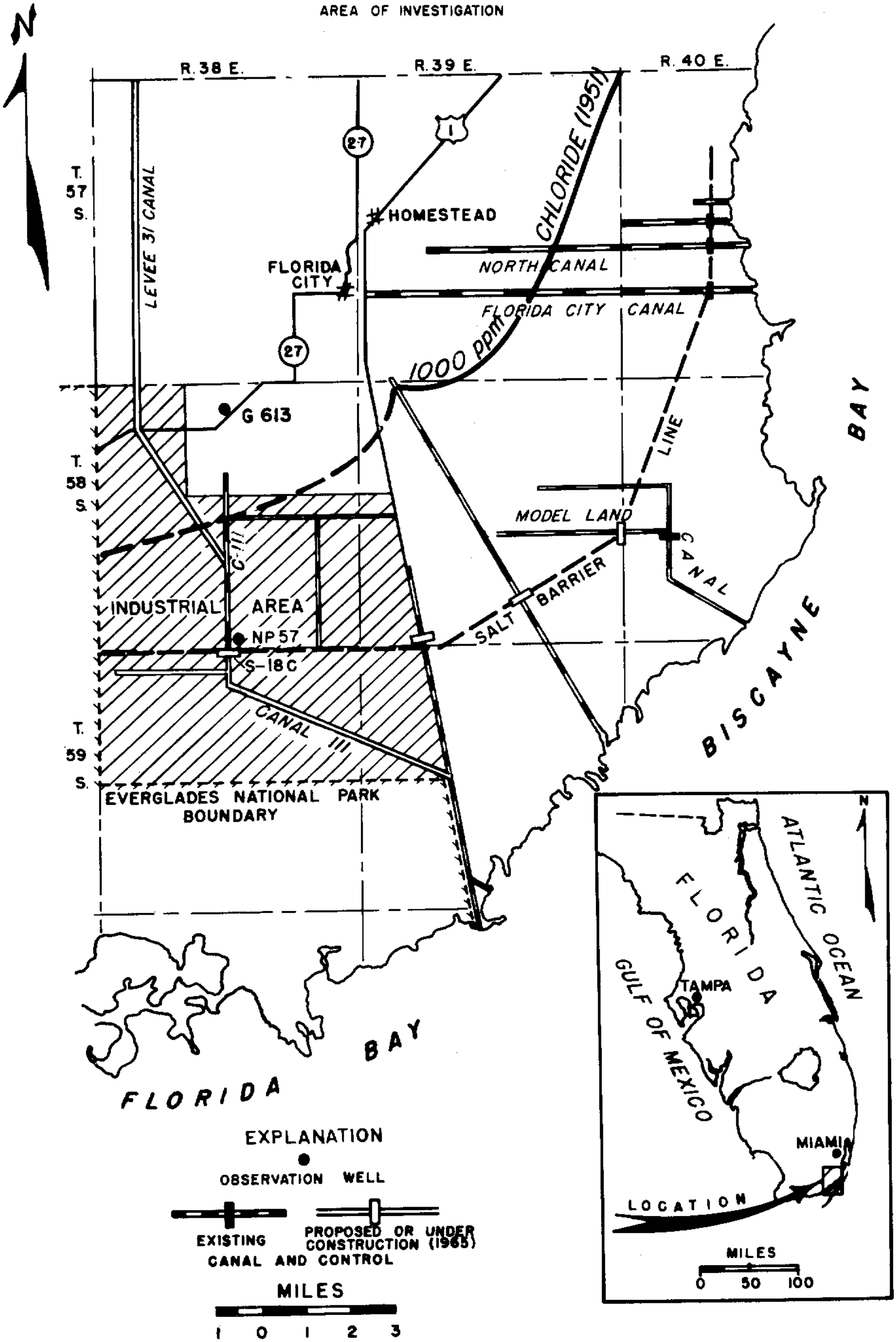
includes the lower 4 miles of the canal along U. S. Highway 1.

The design and alinement of Canal 111, one of the main canals of the Central and Southern Flood Control Project in southern Dade County, were undertaken by the U. S. Corps of Engineers and planning was completed by the end of 1963. Construction of Canal 111 began in 1964 and progressed in a downstream direction during 1965. A gated control structure (S-18C) is being built near the southern end of the north-south reach. The lower 8-mile reach of the canal, however, will be uncontrolled. A 2½-mile east-west spur will connect with the uncontrolled reach a short distance downstream from structure S-18C.

FIG. 1 — MAP OF SOUTHERN DADE COUNTY, FLORIDA, SHOWING HYDROLOGIC FEATURES IN AREA OF INVESTIGATION



The land surface within the southern part of the industrial complex is less than 2 feet above msl (mean sea level). Because of the flatness of the land, surface runoff during the rainy season is sluggish and normally extends into the dry season. As a result, flooding or swampy conditions prevail for several months of most years. Installations and roads within the complex are built on fill which is obtained from land-locked canals and borrows, and built up high enough to protect against floods. The area was not drained by canals open to the ocean because to do so would have accelerated seasonal runoff of fresh water and would have provided during other times of the year inland access for sea water and the consequent outward leakage of salt water into the underlying highly permeable Biscayne aquifer.

During periods of extended drought water levels decline below the land surface, and at times below sea level, as shown in the hydrograph of well NP-57 (fig. 2), near the center of the industrial

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Figure 2. -- Hydrograph of well NP-57 for the period 1961-63.

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area, and G-613 (fig. 6), north of the area. The records of well G-613 show that in 7 years out of 14, water levels have approached and at times gone below sea level (fig. 6). Comparison of water levels in figure 6 indicates that the period mid-1961 to mid-1963 was one of generally low water levels, and weather data indicate it was preceded by a period of deficient rainfall. Similar periods of low water levels, and antecedent deficient rainfall, occurred in the past---for example, the period 1955 to mid-1958, and similar occurrences may be expected in the future. The record for well NP-57 (fig. 2) is almost entirely within a period of depressed water levels, compared to water levels in the preceding 3-year interval (fig. 6).

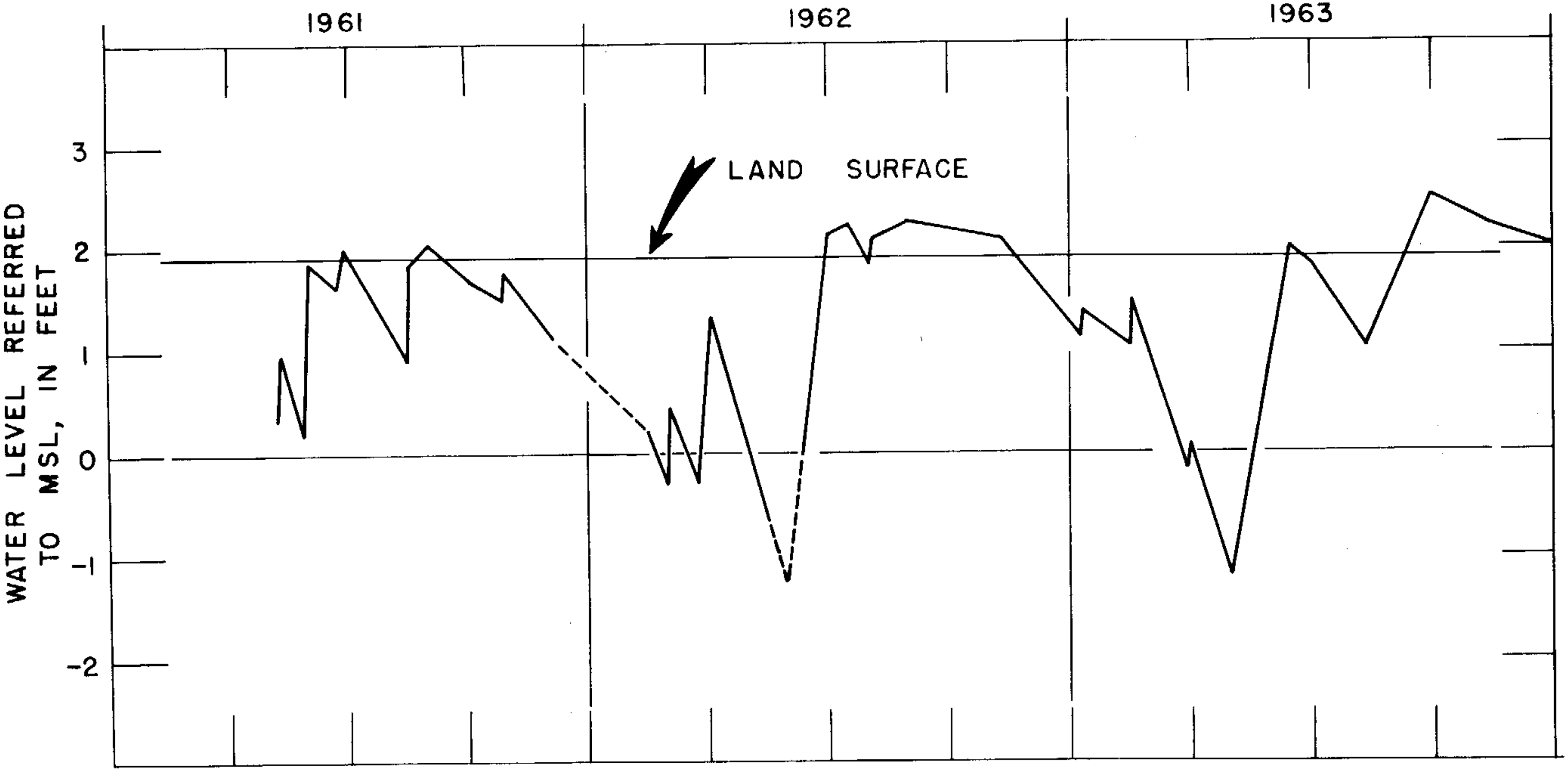

FIG. 2 — HYDROGRAPH OF WELL NP-57 FOR THE PERIOD 1961-63

The uncontrolled section of Canal 111 (fig. 1) will be seaward of the salt-barrier line legally established in 1960 by the Board of County Commissioners of Dade County. (See fig. 1.) The intention of the salt-barrier line is to prevent further salt-water encroachment by limiting the digging of uncontrolled canals. According to the ordinance, any canal that extends inland beyond the salt-barrier line must be controlled at that line. The principal criteria used by the County officials to establish the coastal position of the salt-barrier line were: (1) Salinity of the ground water in the coastal areas; (2) the land-surface elevations; and, (3) the locations of existing and proposed flood-control and water-control works.

The salt-barrier line was alined 3 to 5 miles seaward of the inland position of water containing 1,000 ppm (parts per million) of chloride at the bottom of the aquifer in 1951 (Klein, 1957, fig. 2) to provide a buffer zone between fresh and salt water and to minimize intrusion caused by additional uncontrolled canals. Dade County officials presumed that because the land surface elevations seaward of the salt-barrier line were less than 2 feet above msl, occasional storm inundations by sea water would contaminate the underlying sections of the aquifer regardless of other control measures.

A program of exploratory drilling and water sampling in the Everglades National Park during 1961-63, in cooperation with the U. S. National Park Service, furnished additional data on the quality of the ground water south and southwest of Florida City. Those data show that ground water is fresh an appreciable distance seaward of the legally established salt-barrier line. (Compare 1,000 ppm chloride line on figure 4 with position of 1,000 ppm chloride and salt-barrier lines on figure 1.)

Owing to its concern as to the effects of Canal 111 on the fresh-water resources and ecology of the adjacent Everglades National Park, the National Park Service requested the Geological Survey to make a hydrologic analysis of the situation. This report documents the findings of that study. It describes briefly the major elements of hydrologic conditions before construction of the canal and the hydrologic changes which probably will result from the canal, both with and without a control structure near the coastal end.

HYDROLOGIC SITUATION BEFORE CONSTRUCTION OF CANAL 111

Except for the northern part where oolitic limestone is at the surface, the industrial area is blanketed by a fresh-water marl that ranges in thickness from a few inches to 2 feet and has a relatively low permeability. The marl is underlain by peat whose maximum thickness is about 4 feet. The peat layer immediately overlies the highly permeable Miami Oolite of Pleistocene age, the uppermost limestone unit of the Biscayne aquifer, which is about 60 feet thick. A marine marl covers the coastal fringes of the mainland. The marine marl increases in thickness offshore and forms the bottom sediments of Florida Bay and the lower arm of Biscayne Bay. The increased thickness of the marine marl forms a relatively impermeable bay floor which retards not only the discharge of ground water from the aquifer along the coast when ground-water levels are high, but also the encroachment of sea water inland into the aquifer when ground-water levels are low.

Water levels fluctuate seasonally, ranging from a maximum of about 6 feet above msl to a minimum of 1 foot below msl in the northern part of the industrial area, and about 3 feet above msl to 1.5 feet below msl in the southern part near the boundary of the Everglades National Park. For example, at the end of December 1962, water levels in southern Florida were about half a foot below average for that time of the year (fig. 3). At this time, shallow

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Figure 3. -- Map of Everglades National Park and vicinity showing the contours of the water levels on December 31, 1962. (Adapted from Hartwell and others, 1963).

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ponding prevailed a few miles south of the conservation areas, but in most of the rest of the area the water level was below the land surface. Within the industrial area the water level ranged from about 2.5 feet below the land surface inthe north to about 0.5 foot below in the south. The pattern of the contours in figure 3 shows that water was moving from the conservation areas, where the water level was high, through the aquifer toward Biscayne Bay, Florida Bay, and the Gulf of Mexico.

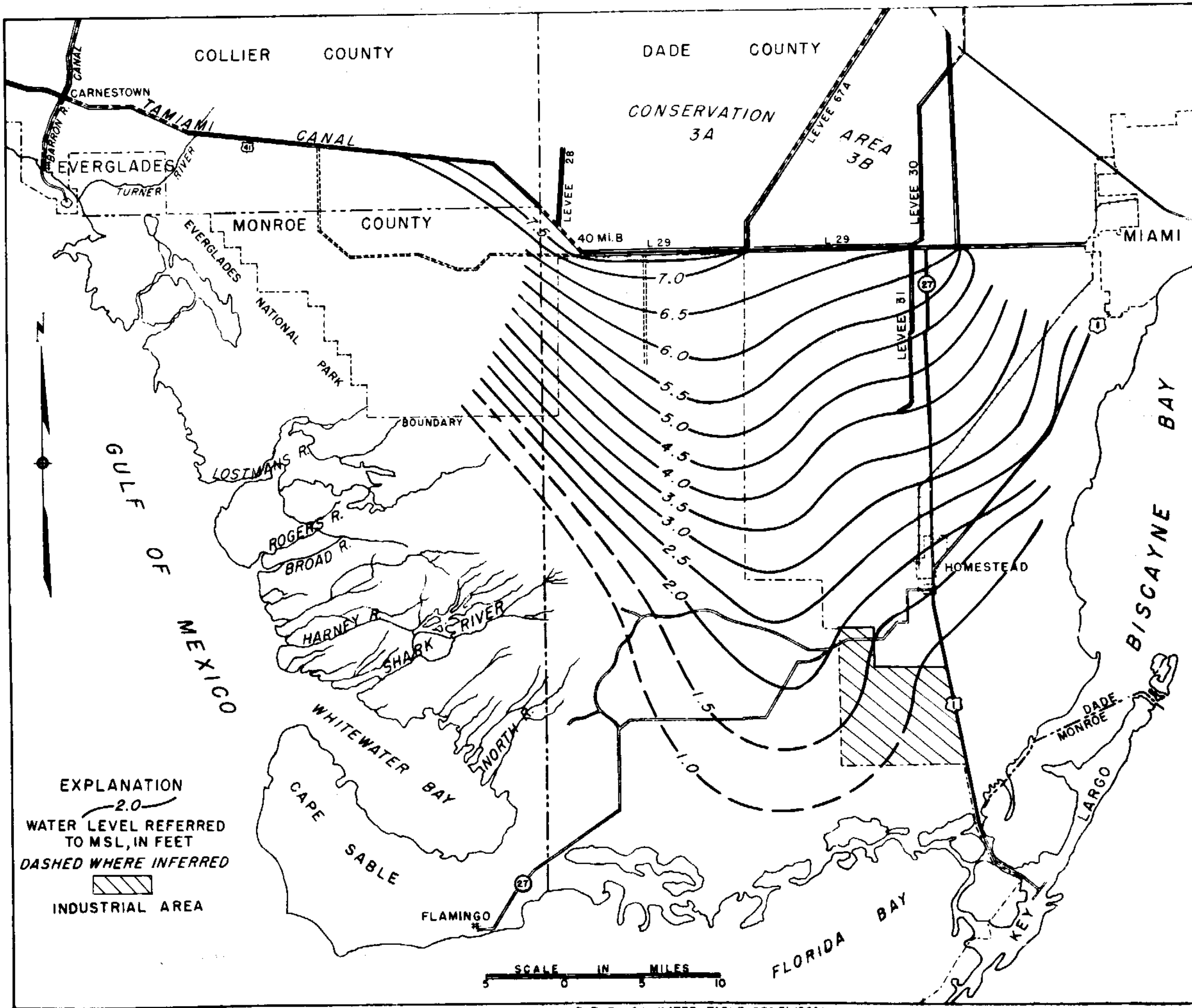

FIG.3 - MAP OF EVERGLADES NATIONAL PARK AND VICINITY SHOWING CONTOURS OF THE LOW WATER TABLE, DEC. 31, 1962 (Adapted from Hartwell and others, 1963)

The configuration of the contours was considerably different in May 1962, after about 7 months of drought (fig. 4). The water

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Figure 4.--Map of Everglades National Park and vicinity showing contours of the low water table, May 1962. (Adapted from Hartwell and others, 1963).

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levels in May 1962 were the lowest levels of record since water-control practices were established in 1946. The most striking feature of the water-level contour pattern of May 1962 was near the southern tip of the mainland, where a massive cone of depression developed as a result of the long antecedent rainless period and the high rate of evapotranspiration (Hartwell and others, 1963). The contour pattern shows that fresh ground water from the north was moving southward toward the center of the cone of depression and that salt water was moving toward the center of the cone of depression from the directions of lower Biscayne Bay, Florida Bay, and Whitewater Bay.

The cone of depression developed because the flow of fresh and salty ground water toward the center of the cone was not sufficient to balance the evapotranspirative losses in the area. The magnitude of the water lost by evapotranspiration from the area within the -0.5 foot contour (more than 275 square miles) was estimated by Hartwell and others (1963, p. 7) to be about 1,580 acre-feet per day (790 cubic feet per second).

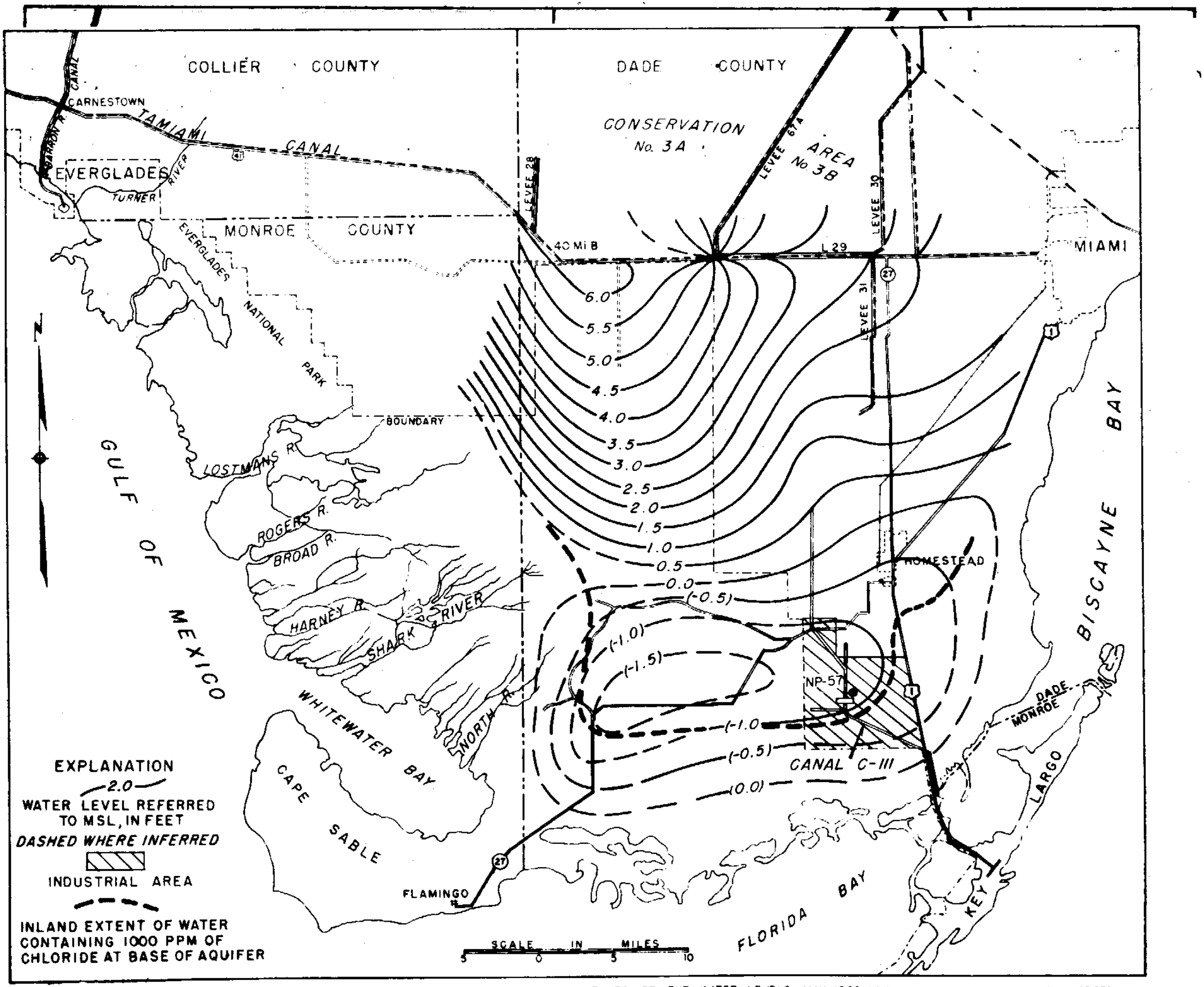

FIG 4 – MAP OF EVERGLADES NATIONAL PARK AND VICINITY SHOWING THE CONTOURS OF THE WATER LEVELS, MAY 1962 (Adapted from Hartwell and others, 1963)

The industrial area is entirely within the extent of the May 1962 cone of depression and includes a part of the line which marks the inland extent of water containing 1000 ppm of chloride at the base of the Biscayne aquifer. Although the inland edge of the salt front at the base of the aquifer undoubtedly moves toward the center of the cone of depression, it did not reach as far as the site of observation well NP-57 in 1962. Water samples collected from a depth of 54 feet in that well in May 1962 contained only 19 ppm of chloride.

A cone of depression to below sea level apparently develops whenever a drought is sufficiently extended. An earlier indication that water levels in southern Dade County declined below sea level during a drought was shown in a water-level contour map for May 19, 1945 (Parker and others, 1955, p. 210-211). The 1945 map showed only the northeastern part of the cone of depression, but otherwise was similar to the cone of May 1962. 1/

1/ Because of a typographical error on the map on page 211 (Parker and others, 1955) the water-table contours in the depressed area in the southwestern corner of the map are shown without the minus (-) sign to indicate they are below mean sea level.

The extent of salt-water encroachment in southern Dade County during the drought of 1945, as described by Parker and others (1955, p. 679-82), is shown in figure 5. According to Parker, all the canals,

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Figure 5.--Map of southern part of Dade County showing chloride concentrations in canals, June and July 1945 (adapted from fig. 188 Parker and others, 1955).

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whether controlled or not (only the North and Florida City Canals were controlled), in the area east and southeast of Florida City became contaminated. Chloride concentration of sea water is about 19,350 ppm, but many recorded chloride concentrations in 1945 exceeded that of sea water, some by as much as 30 percent. Salt water extended inland along the North and Florida City Canals to Florida City and the outskirts of Homestead and along the canal adjacent to the Old U. S. Highway No. 1 nearly to Florida City.

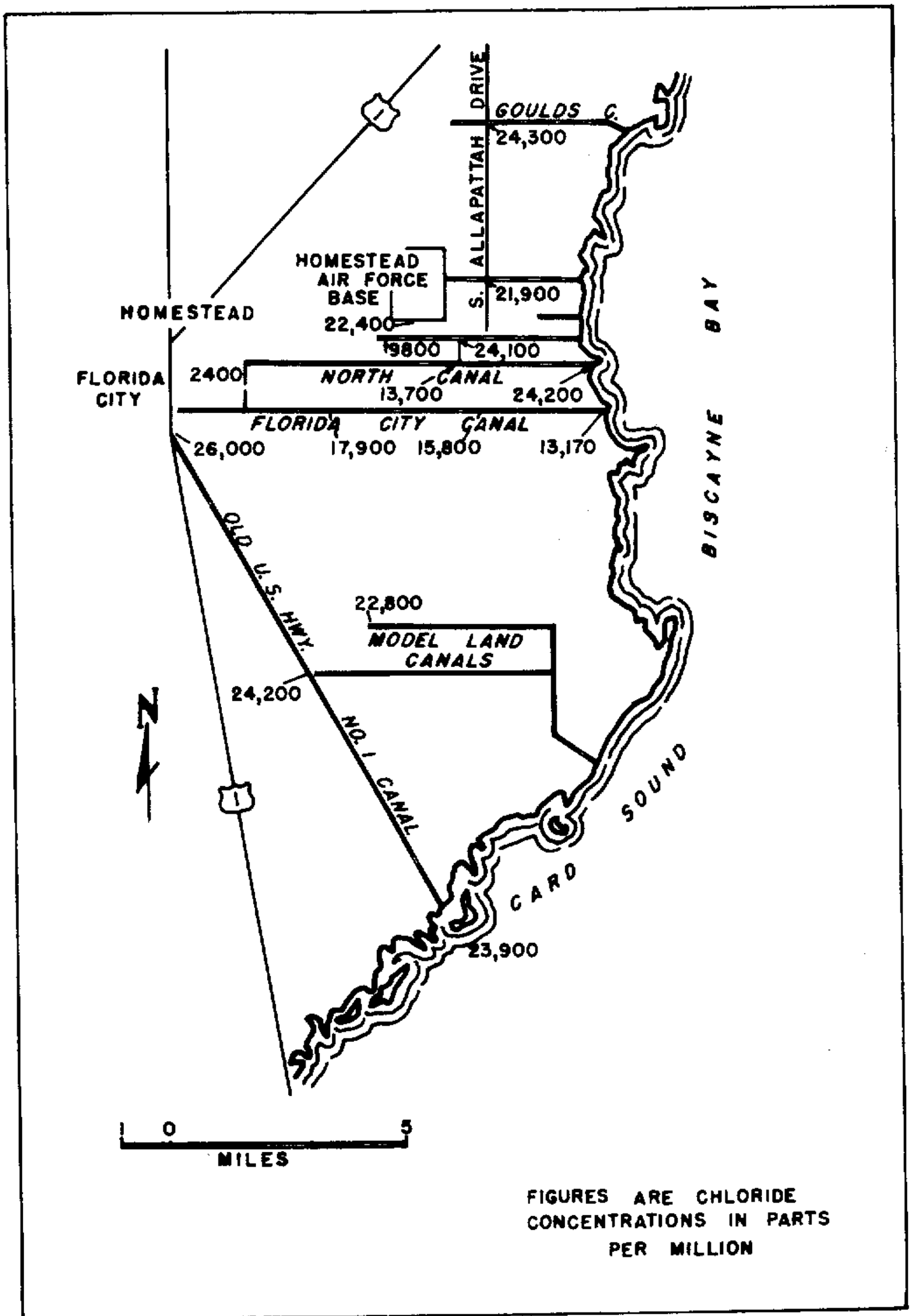

FIG. 5—MAP OF SOUTHERN PART OF DADE COUNTY SHOWING CHLORIDE CONCENTRATIONS IN CANALS, JUNE AND JULY 1945 (Adapted from fig. 188 Parker and others, 1955)

EFFECTS OF UNCONTROLLED REACH OF CANAL 111

Ground water containing 1,000 ppm of chloride at the base of the Biscayne aquifer at the southern tip of the mainland in 1962 extended inland to about the position shown in figure 4. Its position in 1965 is presumed to be about the same. The uncontrolled reach of Canal 111, as shown superposed on the 1962 map shown in figure 4, will extend from the coast, where the entire thickness of the aquifer contains salt water, to structure S-18C, about 8 miles inland, where the entire thickness of the aquifer, as indicated by periodic sampling of well NP-57, contains fresh water. The $2\frac{1}{2}$-mile uncontrolled spur canal also will traverse an area where the aquifer contains only fresh water. Analyses of canal-water samples collected in March 1965, during construction of Canal 111, showed that the upper part of the aquifer contained fresh water as far as 4.5 miles downstream from structure S-18C. A sample collected at that point at a depth of 10 feet contained 80 ppm of chloride.

The canal will cut through the marl blanket and into the permeable limestone of the Biscayne aquifer. It therefore will accelerate the runoff of fresh water during rainy seasons and periods of flood, and induce the encroachment and recharge of sea water into the aquifer at times when water levels are low. If an uncontrolled canal is completed when conditions are similar to those of May 1962, the fresh water - salt water contact will move to a position inland from that shown in figure 4 because the water level in the canal would generally be above that in the Biscayne aquifer. The uncontrolled reach of Canal 111 will contain salt water except possibly for short periods when the discharge of flood waters would temporarily freshen the water in its upper reach. During normal dry seasons no fresh water will be discharged, and saline water will extend as far upstream as the control structure and throughout the spur canal west of the structure. The new position would adjust as though an arm of Biscayne Bay were extended 8 miles inland.

The rate of the encroachment of salt water into the aquifer is low and it will vary to some extent with the amount and distribution of rainfall. Periods of more rapid encroachment of salt water will be those of prolonged drought when ground-water levels to the west decline. As shown in figure 4, during periods of drought the hydraulic gradient in the aquifer within the area of Canal 111 is inland, and water moves slowly toward that area of depressed water levels. During periods of drought an uncontrolled canal would in effect provide a long, narrow channel through which sea water could infiltrate toward the center of the depression. Because the water level of the canal will approximate that of Biscayne Bay, the hydraulic gradients between the canal and the center of the depression will be appreciably greater than those shown in figure 4 and the rates of ground-water movement will be increased accordingly. The size of the area of depressed water levels would be reduced by infiltration from the canal during periods of low water levels, but the replenishment to the aquifer would be largely sea water from the canal. Although the rate of salt-water encroachment will be slow, all previous experience indicates that during droughts an uncontrolled canal such as Canal 111 will permit an increase in the extent and amounts of salt-water encroachment over that which existed before the canal was built.

The areas adjacent to and south of the canal would be the first to be affected by its construction and completion. When water levels would be high, the canal would intercept part of the water that moves to the eastern part of the Everglades National Park (immediately south of the industrial area) and discharge it to the ocean. When water levels would be about average or low, salt water would move into the canal and infiltrate the Biscayne aquifer laterally and downward to form a wedge-shaped lobe that narrowed upstream. Experience along earlier uncontrolled canals indicates that with time this lobe might coalesce with the salt-water lobe extending northward along U.S. Highway No. 1 (fig. 4), thereby enlarging the extent of contamination beneath the industrial area.

Water levels in the vicinity of the industrial area and to the north are periodically high in response to rainfall and other seasonal controls, as shown by the hydrograph of well G-613 (fig. 6). However, the frequency

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Figure 6.--Hydrograph of Well G-613.

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and maximum elevation of the annual high water levels may be expected to be reduced as a result of major flood-control works proposed north of the industrial area and of Canal 111. The general lowering of the water levels, which may be attributed to the rapid removal of flood waters and drainage of ground water in storage, may tend to increase by a small increment the inland movement of salt water on a broad front.

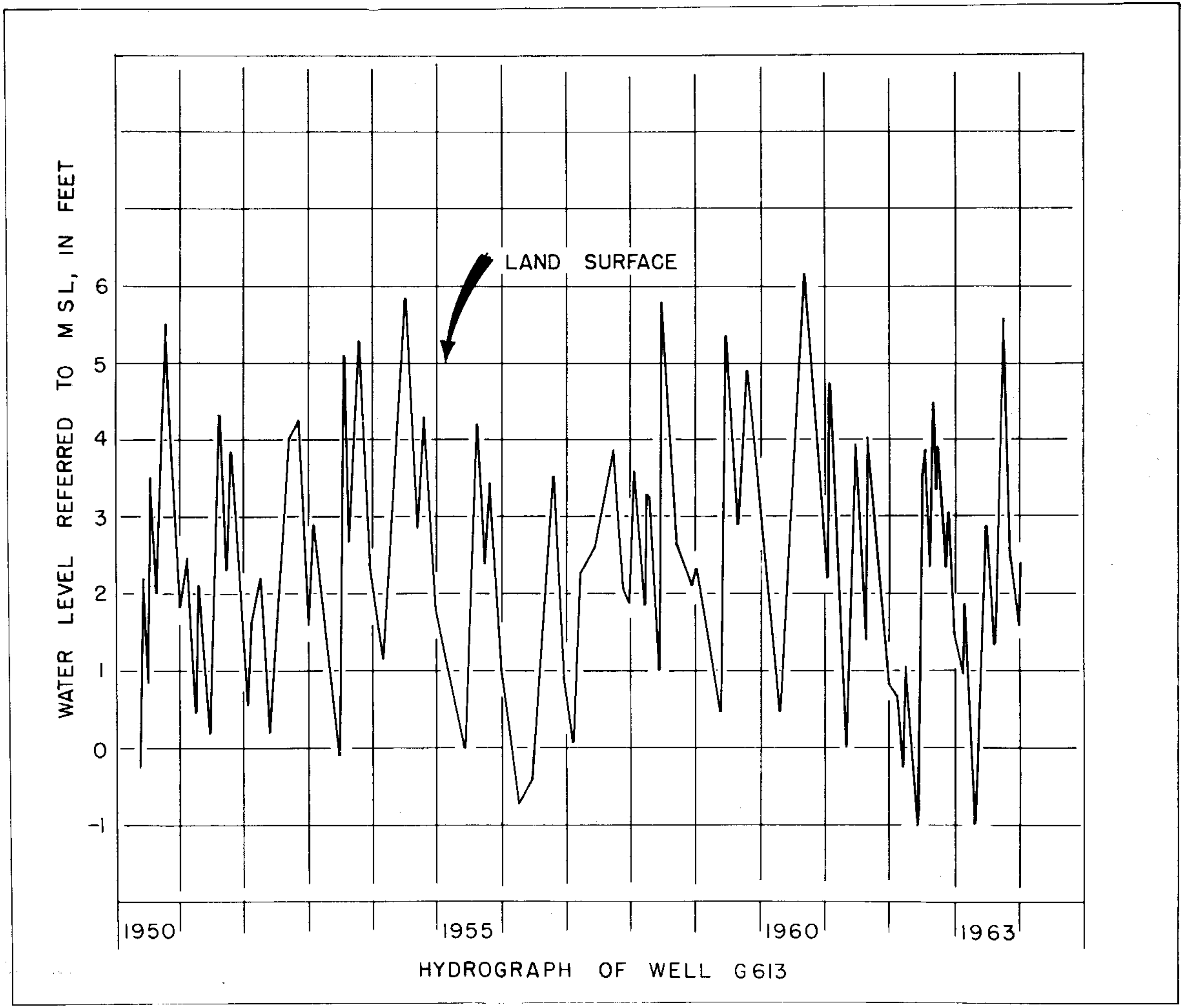

FIG. 6 – HYDROGRAPH OF WELL G-613

Another aspect of Canal 111 is that construction plans call for a continuous levee on the north and northeast bank of the canal as far downstream as U.S. Highway No. 1, and a discontinuous levee, with 100-foot openings at about ground level at 400-foot intervals, along the south and west bank. The purpose of the openings is to permit a part of the flood water discharged through structure S-18C to disperse overland from the canal southward. The openings in the levee, however, also will act to disperse salt water at certain times when sea level is above the land surface. During spring tides, when levels of 2 feet above mean sea level are not uncommon, and during storm tides, when levels of several feet above mean sea level may be reached, the uncontrolled reach of the canal would form a direct avenue through which sea water could move inland and spill overland through the levee openings to innundate the area south of the canal.

Inundation by salty waters spilled southward through the levee openings may also affect the biota of the area. The Everglades National Park south from Canal 111 to Florida Bay for the most part contains much vegetation that grows only in a fresh-water environment. With time, these sea-water inundations could change the biota there to types that can tolerate only salt water because the sea water flooding the area could not drain away rapidly. The change might be affected by ponding of the salty water and by its evaporation. A low marly ridge near Florida Bay forms a barrier (oral communication from Dr. Frank C. Craighead, ecologist, 1965) which will retard overland runoff, and downward percolation of the salty water will be retarded by the marl blanket overlying the aquifer. The resulting ponding will accelerate biotic changes, and evaporation and intermittent sea-water inundations may result in a build-up of salts in the soil despite periodic dilution during fresh-water floods.

POSSIBLE ALLEVIATION MEASURES

The effects of Canal 111 on salt-water encroachment could be alleviated by the construction of a salinity-control structure on the canal, and by providing sufficient fresh water to retard the inland migration of the salt-water front. A salinity-control structure near the bay would reduce wastage of fresh water to the sea, but it alone probably would not prevent salt water from moving farther inland during dry seasons.

To prevent or reduce the inland extension of salt water to the uncontrolled reach of the canal a supply of fresh water would have to be furnished. The quantity of fresh water required would be that amount necessary to maintain water levels above mean sea level. The quantity of water would have to be made available by a canal or canals from areas where water levels were higher than in the vicinity of Canal 111.

The nearest source of fresh water for replenishment to Canal 111 would be water in aquifer storage in upgradient areas more than 6 miles north of Homestead, where water levels are above sea level during prolonged drought (fig. 4). If a controlled feeder canal were extended an appreciable distance northward to intercept fresh water, it would transect the eastern sector of the cone of depression, and outseepage from the canal would reduce the size of the depression. Replenishment to the cone of depression would raise water levels in the critical southern part of the area and thus reduce the threat of salt-water encroachment; but at the same time the drain of water from storage in the north would lower water levels there.

Future water-control plans in southern Dade County include an extension of Canal 111 to connect with the Levee 31 Canal to the north (fig. 1). The northern reach of proposed Levee 31 Canal would intercept ground water whose head is relatively high even during prolonged droughts, and fresh water would flow to the lower controlled reach of Levee 31 Canal and from there to Canal 111.

The proposed Levee 31 Canal also will supply water to a system of controlled major canals which extend eastward to Biscayne Bay. In southern Dade County, the proposed system will move water eastward and southward from the interior. The effect of the proposed system under most conditions will be to decrease the hydraulic gradient in the aquifer--that is, to raise water levels along the coast while lowering them in the interior. Another probable effect will be to reduce the size of, but not eliminate, the cone of depression in southern Dade County. The cone will be reduced due to infiltration of water from the proposed canals as the water moves from the interior to the coast; but probably will not be eliminated because the rate of replenishment from the canal system to the area of depressed water levels will be less than the overall loss from that area by evapotranspiration (Hartwell and others, 1963). In view of the probable periodic recurrence of low water levels in the area, and the probable decline in hydraulic gradient between the interior and the coast, no major permanent seaward recession of the new salt front established through the construction of the canals can be expected after they are completed, unless the water supply of southern Dade County can be supplemented by additional water from the north.

Hydrologically, then, water from the north moving south through the proposed Levee 31 Canal into Canal 111 might alleviate and retard the encroachment of salt water moving northward and westward along Canal 111. However, it cannot be expected to restore the fresh water-salt water interface to the position had before Canal 111 affected the hydrologic system. Whether as much water from the north as will be needed to retard the inland movement of the salt-water front can be made available is not known.

Water-control and management agencies have indicated that no external source of water (other than natural flow of ground water) will be introduced from the north to the canal system in southern Dade County. The area must then rely on (1) flow of ground water southward from the conservation areas (figs. 3 and 4); (2) water stored locally in the aquifer at the end of each rainy season; and (3) replenishment by rainfall during the normally dry season. Under these conditions, it is probable that the salt-water front will move inland by increments until it reaches a new balance.

SUMMARY AND CONCLUSIONS

Canal 111 in the southeastern tip of Florida will extend 10 miles inland from the coast and at least one mile, and possibly as much as 4 miles, inland of the present salt-water front. Canal 111 will also extend to an area where the water tables have declined down to or below mean sea level for periods ranging from a few days to a few months in 7 years out of the 14 during the interval 1950-64.

The effect of an uncontrolled sea-level canal such as Canal 111 will be to accelerate runoff of fresh water and to lower adjacent water levels when water levels are high. When water levels are low, the sea water that moves into the canal will recharge the Biscayne aquifer into which the canal is incised. Inland movement of the salt front also may limit the development of water-supply facilities in the vicinity.

Spring and storm tides will inundate the area south of the canal and may affect the biota in that part of the Everglades National Park.

A salinity-control structure on the canal near its mouth would reduce but not necessarily prevent wastage of fresh water to the sea and would reduce but not prevent salt water from moving inland.

Inland extension of the salt-water front could be reduced by a supply of fresh water sufficient to maintain water levels above mean sea level. The only possible source of fresh water is from areas of high water levels to the north. However, the probable periodic recurrence of low water levels in the vicinity of Canal 111 and the probable decrease in hydraulic gradient between the inland areas and the coast, in part the effect of Canal 111, preclude the likelihood of restoring the salt-water front to the position it had before Canal 111 is constructed.

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