Prepared in cooperation with
DADE COUNTY, MIAMI-DADE WATER AND SEWER AUTHORITY, SOUTH FLORIDA WATER MANAGEMENT DISTRICT, FLORIDA KEYS AQUEDUCT AUTHORITY, and the HOMESTEAD AIR FORCE BASE

INTRODUCTION

Early hydrologic descriptions by Munroe (1930, p. 188, 218) and Sewell (1933) indicated that pristine conditions in Dade County, Fla., were marked by high ground-water levels near the coast and in The Everglades, freshwater springs welling up through the floor of Biscayne Bay, and 50-foot deep wells yielding potable water by flow near the mouth of the Miami River. Conditions began to change with the dredging of the Miami River and the inland extension of the Miami Canal which was cut into permeable zones of the underlying limestone of the Biscayne aquifer. Drainage by the canal lowered ground-water levels in adjacent areas, disturbed the natural balance between the fresh ground water and the saltwater of Biscayne Bay, and permitted saltwater to locally intrude the limestone. In addition to the Miami Canal, several other canals were dug which also contributed to lowered water levels, causing saltwater intrusion to advance along a broad front in coastal Dade County. Intrusion remains a major problem facing local and regional water management agencies.

The investigation of saltwater intrusion in Dade County by the U.S. Geological Survey began in the late 1930's and continues in cooperation with Dade County, the Miami-Dade Water and Sewer Authority, the South Florida Water Management District, the Florida Keys Aqueduct Authority, and the Homestead Air Force Base. It is through this continuing long-term study of the extent and causes of saltwater movement that assessments can be made of methods and criteria for controlling saltwater intrusion in the highly permeable Biscayne aquifer in Dade County--the sole source of drinking water for the area. The purpose of this report is to summarize the effects that major hydrologic changes--brought about by land reclamation, flood control, and water management by local and regional agencies--have had on saltwater intrusion in Dade County over the years and to delineate the inland extent of intrusion as of 1984.

Saltwater intrusion is particularly dynamic in coastal Dade County because of the high permeability of the limestone composing the Biscayne aquifer, because of the good interconnection between canals and the aquifer, and because of the seasonal and year-to-year variability of rainfall. The problem is accentuated because urban growth continues to encroach on inland wetland areas which results in lowered inland water levels. This lowering reduces the seaward freshwater hydraulic gradient and the freshwater head at the coast, both of which govern the intrusion of saltwater. In addition, Dade County is at the south terminus of the South Florida Water Management District where water levels are influenced by upgradient water-management practices. Also, Dade is one of the most distant counties south of Lake Okeechobee--the source of much of the dry-season replenishment by canals to the east coastal areas.

SALTWATER INTRUSION BEFORE 1946

Saltwater intrusion gained strong impetus after the construction of primary drainage canals that extended from Lake Okeechobee, across The Everglades, and through the coastal ridge to the coast (fig. 1; Leach and others, 1972, fig. 7). The canals were virtually uncontrolled during the 1920's and 1930's, and caused a continuous diversion to the ocean of large quantities of fresh surface water from The Everglades and drainage of ground water from the Biscayne aquifer and other surficial aquifers of southeast Florida. This caused water levels to decline excessively, triggering the inland movement of saltwater into the lower zones of the surficial aquifers adjacent to the coast in southeast Florida. In the 1920's, an expanded network of drainage canals in Dade County brought about further discharge of large quantities of freshwater to tidewater. By the end of the dry seasons of 1945 and 1946, saltwater intrusion had advanced along a broad front as shown by the inland position of the saltwater-freshwater interface in figure 2 (Parker and others, 1955, fig. 200).

Saltwater intruded landward along each major canal, but the areas of pronounced intrusion were the coastal areas of the Miami and Tamiami Canals, the Coral Gables area, and south Dade County. The inland intrusion of saltwater along canals during 1945 is shown in figure 3 (Parker and others, 1955, figs. 184 and 188). In Miami and vicinity, saltwater moved several miles upstream in most canals, but particularly critical was the Hialeah-Miami Springs area where some supply wells in the municipal well field had to be shut down because the water contained excess chloride. At the end of a prolonged period of below normal rainfall, canals in south Dade County contained saltwater as far inland as Homestead and Florida City. This intrusion in the south was due chiefly to record low, below sea level, ground-water levels shown on the generalized water-table contour map in figure 4 (Parker and others, 1955, fig. 45).

SALTWATER INTRUSION DURING 1946-62

After the record low water levels of 1945, water-supply agencies responded to the threat of further saltwater intrusion in Dade County by installing (in 1946) sheet-steel piling, salinity-control structures in all primary canals as far seaward as possible. The installation and operation of controls in primary canals were designed so that timely releases of water could be made for flood reduction, but the controls could be closed to conserve water for dry-season use to prevent overdrainage. The interval 1946-62 could then be considered one of elemental water control, although major flooding occurred during 1947 because canals were not adequately designed to handle the record rainfalls from two consecutive tropical storms. The salinity-control structures and practices successfully halted saltwater intrusion by blocking saltwater from moving upchannel beyond the control structures in the canals and by sustaining high water levels near the coast during dry seasons.

In some instances, after the installation of salinity-control structures, the tongues of intruding saltwater along canals retreated seaward as shown by Parker and others (1955, fig. 169) (compare 1953 map with 1946 map, fig. 5). The seaward retreat was especially important along the Miami Canal, as the salinity-control structure--installed after 1945 at N.W. 36th Street--permitted full production again from Miami's well field adjacent to the Miami Canal. As shown in figure 5, the pattern of intrusion changed only slightly from 1953 to 1962 despite an increase in well-field pumping from 52 to 80 Mgal/d. The map of 1962 in figure 5 shows the inland extent of saltwater at the base of the Biscayne aquifer in Miami and vicinity at the end of the severe and prolonged dry season of 1962 after more than 15 years of elemental water control and water conservation. The 15-year period included the following events:

1. Record flooding, 1947-48.
2. The creation in 1949 of the Central and Southern Florida Flood Control District (renamed South Florida Water Management District in 1971). Construction and operation of a system of canals, control structures, levees, pumping stations, and water-storage areas whose functions were flood protection and water conservation.
3. Prolonged dry seasons, 1951-52, 1955-56.
4. High water levels, 1958-60, extensive flooding in south Dade County after Hurricane Donna and Tropical Storm Florence, 1960.
5. Near record low water levels, 1961-62.
6. The beginning in 1961 of an extensive drainage canal network in south Dade County.

Included also during the period 1946-62 was the completion in 1953 of the eastern levee system (Levees 30 and 31 in Dade County, fig. 6) of the then Central and Southern Florida Flood Control District (now South Florida Water Management District) and, later in 1962, the completion of the southern levee (Levee 29) to enclose Water Conservation Areas 3A and 3B. The levee system separating Conservation Areas 3A and 3B diverted (southward) part of the water that had previously flowed from The Everglades eastward to the ocean. The enclosure of Water Conservations Areas 3A and 3B enabled the impoundment of water in Dade County for replenishing the aquifer in coastal urban areas during dry seasons. The enclosure also marked the change from elemental to comprehensive water management within the region.

EFFECT OF SOUTH DADE COUNTY CANAL SYSTEM ON SALTWATER INTRUSION, 1963-80

Of major significance in south Dade County was the beginning in 1961 of construction of the extensive drainage canal system which was designed to prevent recurrence of flood damages of the magnitude of those caused by Hurricane Donna in 1960. The canal system in south Dade County (Canals 1, 100, 102, 103, and the inland (northward) extension of Canal 111, fig. 6) was virtually completed by 1967. Unlike the canals constructed earlier, canals in southeast Dade County were equipped with flow-regulation structures near the coast and at sites inland (fig. 6) to step up water levels to reduce overdrainage. As designed, the canal drainage system lowered water levels during most of the 1960's and early 1970's, as shown by the long-term hydrographs of wells G-596, G-614, and S-182 in figure 7 (well locations in fig. 6). The frequency with which water levels in south Dade County approached or declined below sea level is shown in the hydrograph of well G-614. In general, annual peak water levels were lowered, and annual low levels declined further, as compared to pre-1962 levels. Although withdrawals of ground water at the major well fields during the 1960's and 1970's were increasing annually, water levels at the three observation wells were not directly affected by those withdrawals because the wells are remote from areas of municipal withdrawals.

The inland movement of saltwater during 1970-71 (fig. 6) represented a readvance of saltwater intrusion--a result of the first prolonged, near record dry season in southeast Florida since completion of the south Dade County canal network. Between 1970 and 1971, the inland movement of saltwater at the base of the aquifer was nearly 1 mile in the Canal 111 area and exceeded 0.5 mile in the Canal 103 and Canal 1 basins. Saltwater intrusion also occurred near the Miami well field adjacent to the Tamiami-Miami Canal basin.

Concern about the recurrent low water levels in south Dade County provided impetus for the South Florida Water Management District and the U.S. Army Corps of Engineers to implement remedial measures. These measures consisted of methods to increase the quantities of water from Water Conservation Areas 3A and 3B into south Dade County through an improved conveyance canal system. Implementation began in 1976 and was completed before 1982. The result was a rise of nearly 1 foot in the average of the yearly lowest water levels in coastal areas (hydrograph of well S-182) and rises of 1 foot in areas farther inland (hydrographs of wells G-614, G-596, fig. 7) since 1976. A permanent 1-foot rise in low water levels could be highly important in preventing further saltwater intrusion in south Dade County. The adjusted annual low water levels after 1976 were approaching the annual low levels that preceded the installation of canals (pre-1962) in much of south Dade County.

STATUS OF SALTWATER INTRUSION, 1980-84

The approximate inland extent of saltwater containing 1,000 mg/L (milligrams per liter) of chloride at or near the base of the Biscayne aquifer in coastal Dade County in May 1984 is shown in figure 8. The base of the permeable limestones in southeast Dade County ranges from about 60 to 100 feet below land surface and in northeast Dade County about 110 to 150 feet below. Some of the wells did not fully penetrate to the base of the highly permeable limestone; therefore, the position of the 1,000-mg/L line in figure 8 was estimated through a series of interpolations of chloride concentrations which were related to the measured concentrations of the samples at each of the observation wells obtained in May 1983 and 1984. That is, the chloride concentrations at the expected base of the aquifer were interpolated as greater than the concentration in the sample from the observation well. An adjustment was then required to delineate the seaward or landward position of the line with reference to each observation well.

Also, data obtained by Kohout (1960, fig. 3) and Kohout and Klein (1967, figs. 3-8), describing chloride distribution within the zone of diffusion between freshwater and seawater in the Biscayne aquifer of the Silver Bluff area of Miami and the Cutler area of southeast Dade County, were used in estimating chloride concentrations for positioning the line seaward or landward of observation wells. At Silver Bluff, where the zone of diffusion extended inland nearly 12,000 feet, the distance between water containing 200 mg/L of chloride and 1,000 mg/L of chloride along the floor of the aquifer was about 600 feet in 1954. At Cutler, where the zone of diffusion extended inland about 600 feet, the distance between water containing 500 mg/L of chloride and 1,000 mg/L of chloride along the floor of the aquifer was less than 200 feet in 1958. Additional data obtained from multidepth wells at the inland edge of the zone of diffusion indicated that the chloride concentration increased from less than 200 mg/L at a depth of 80 feet below sea level to greater than 4,000 mg/L at a depth of 95 feet below sea level. These data also provided the means by which chloride interpolations were made at several observation wells.

A comparison of the inland patterns of saltwater intrusion in 1984 (fig. 8) and 1971 (fig. 6) shows little inland saltwater migration during the intervening period, but rather it shows a local freshening (seaward movement) in the lower part of the aquifer in the Tamiami-Miami Canal area as a result of the 3-mile downstream relocation of the flow-regulation structure on the Tamiami Canal. This improvement (freshening) occurred despite the increase in municipal withdrawals at the Miami-Hialeah well field from 90 Mgal/d in 1971 to about 130 Mgal/d in 1983. Another effect of water management is that no further inland migration of saltwater has occurred since the early 1960's in the Canal 2 basin where municipal withdrawal has increased from 70 Mgal/d in 1962 to nearly 130 Mgal/d in 1983.

The position of the 1,000-mg/L chloride line in Dade County in 1984 is the result of the combined effects of natural hydrologic events and man's alterations and management practices on the hydrologic system of southeast Florida. If saltwater intrusion is to be controlled and future freshwater demands of urban growth are to be met, continuation of adequate ground-water levels near the coast and inland will have to be sustained during prolonged dry periods by means of water-management practices.

Increased withdrawals from the large municipal well fields (which represent most of the ground-water pumpage in the county) have caused only local declines in water level and relatively minor effects on the inland movement of saltwater. To satisfy future demands in Dade County, the Miami-Dade Water and Sewer Authority has selected the option of locating new well fields in inland wetlands, remote (upgradient) from existing well fields and from heavily urbanized areas.

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Copies of this map may be purchased from:

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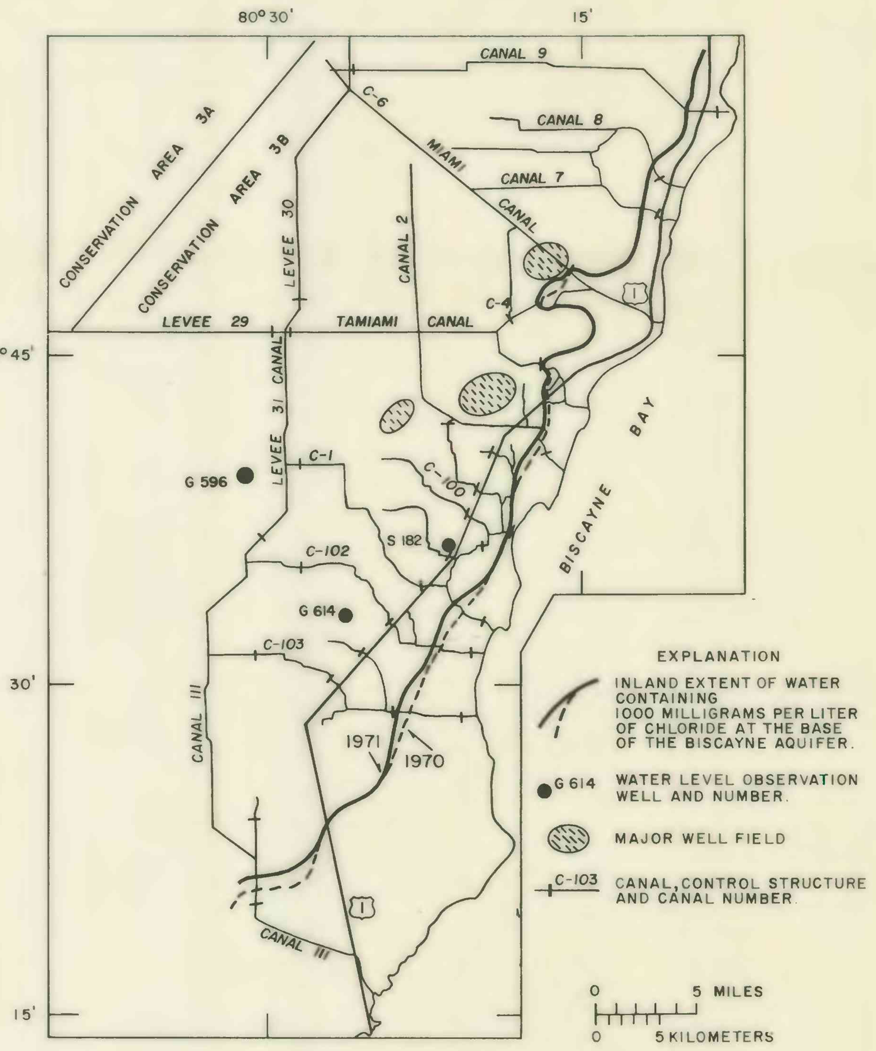

Figure 6.--East Dade County showing the inland extent of saltwater intrusion during 1970 and 1971.

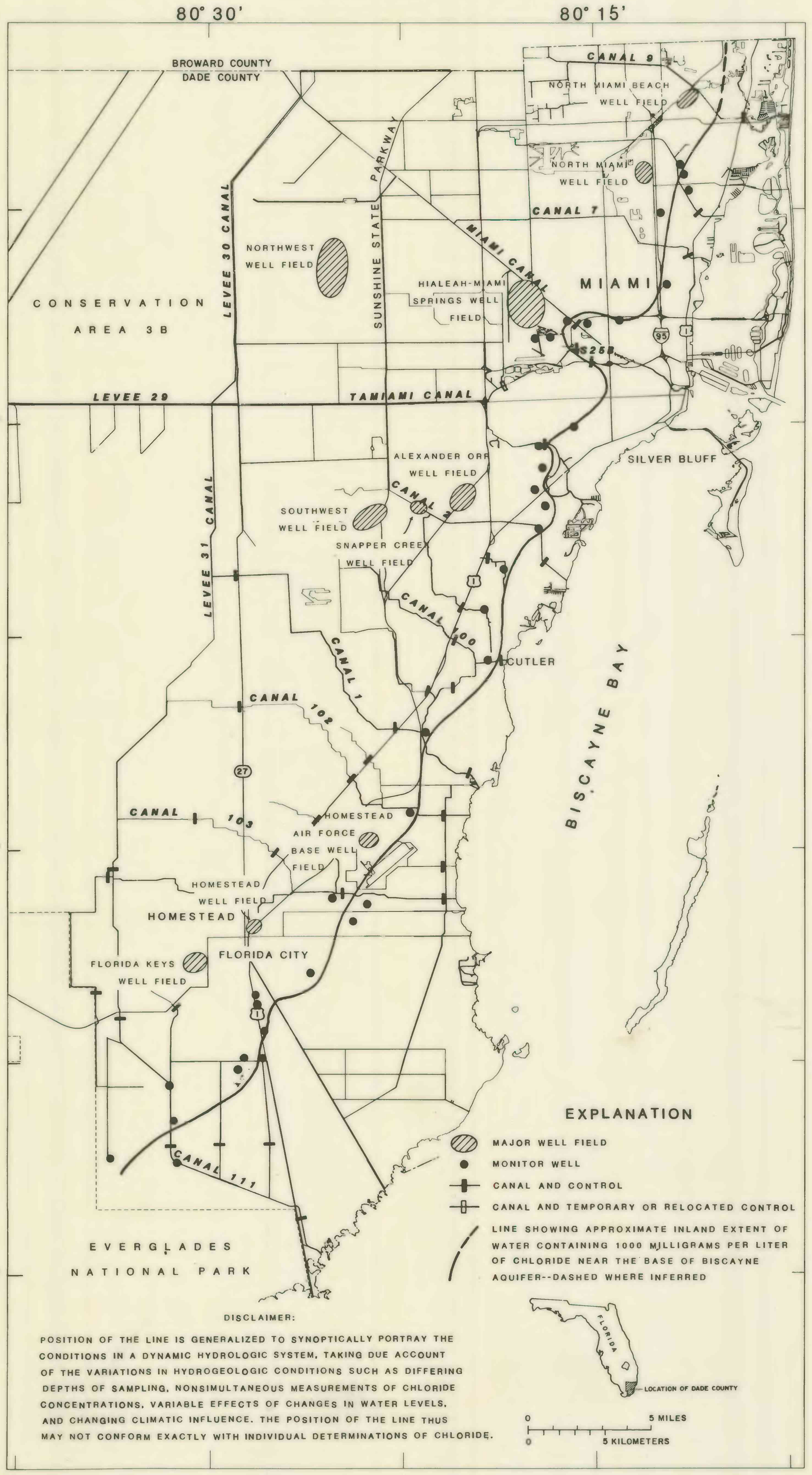

Figure 8.--Dade County showing approximate inland extent of water containing 1,000 milligrams per liter of chloride near the base of Biscayne aquifer, May 1984.

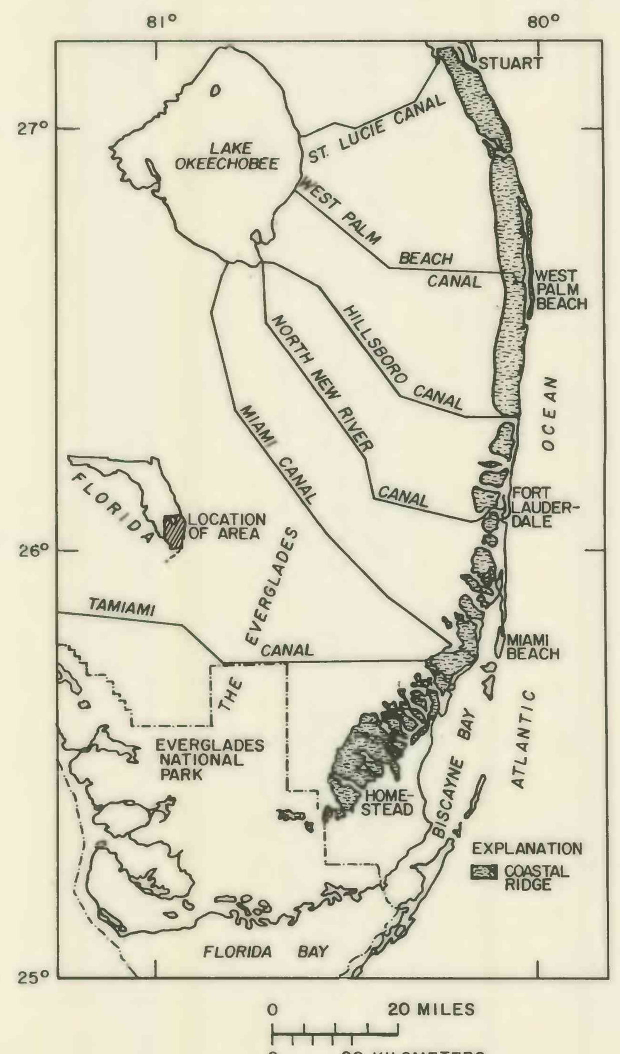

Figure 1.--Southeast Florida showing the major canals that cross the Everglades to the coast.

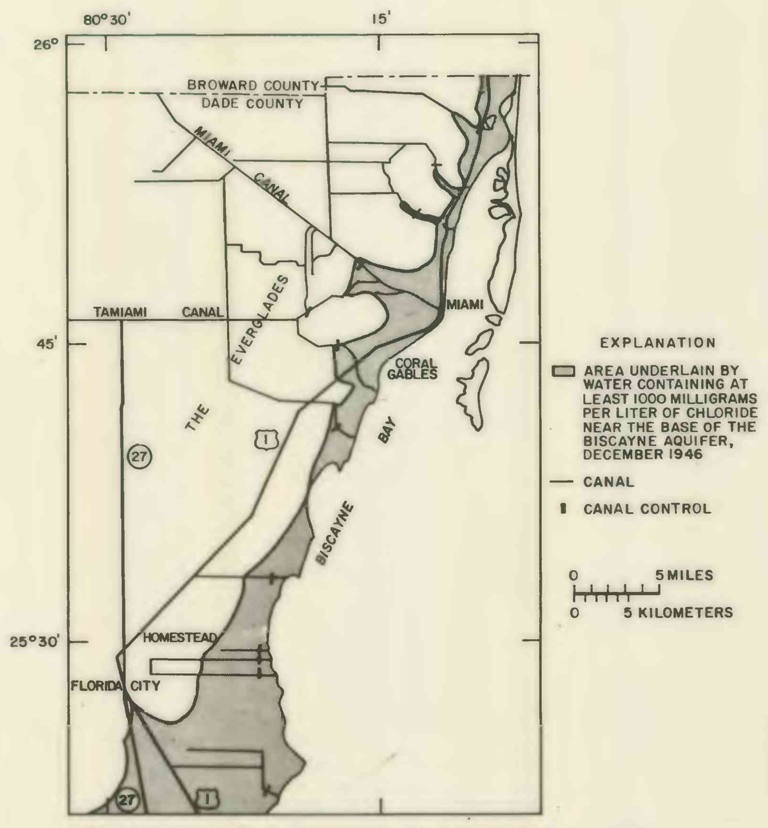

Figure 2.--East Dade County showing the inland extent of water containing 1,000 milligrams per liter of chloride at and near the base of the Biscayne aquifer, December 1946 (from Parker and others, 1955).

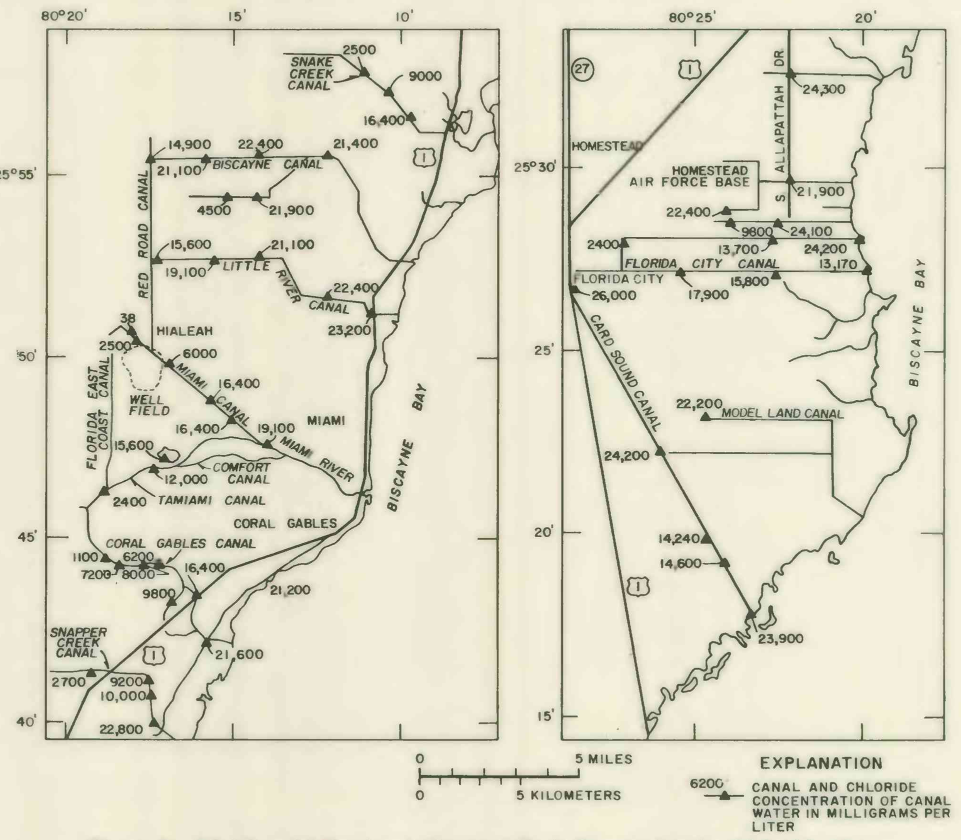

Figure 3.--Vicinity of Miami and of coastal Dade County showing high chloride concentrations in canal water during 1945 (from Parker and others, 1955).

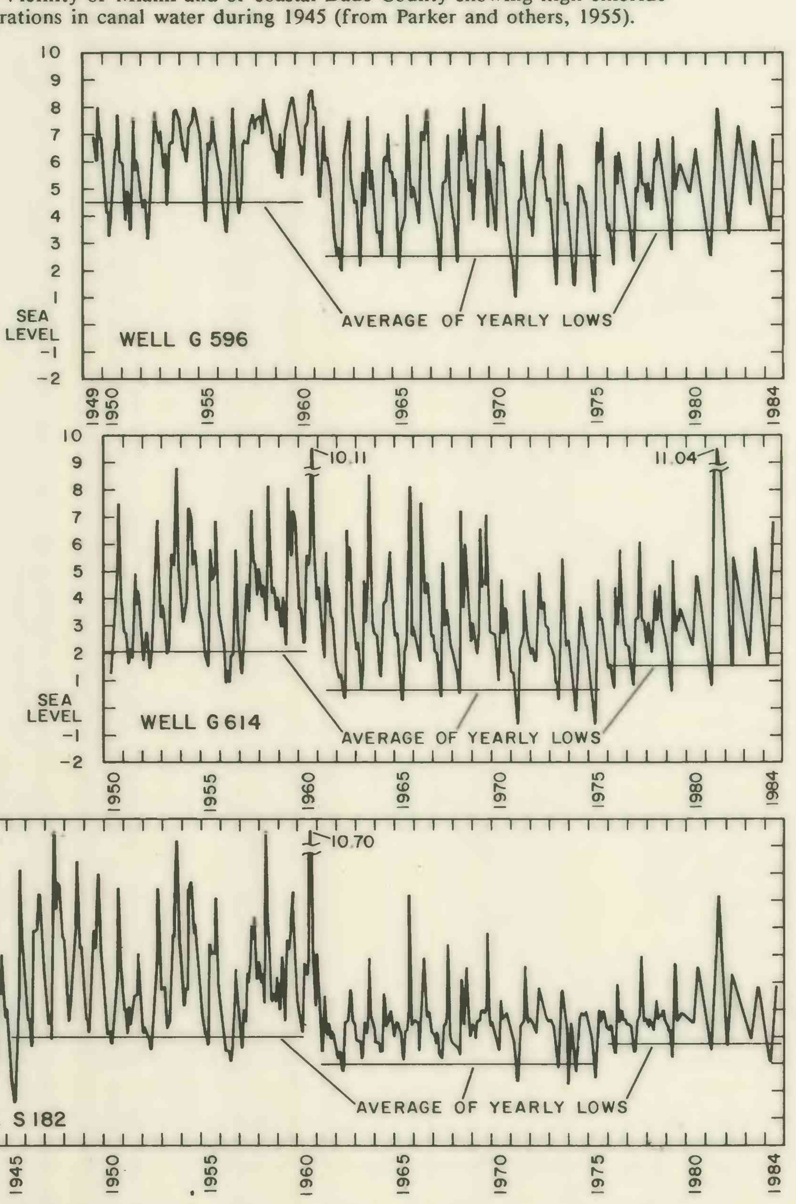

Figure 7.--Wells G-596, G-614, and S-182 in south Dade County, 1945-83.

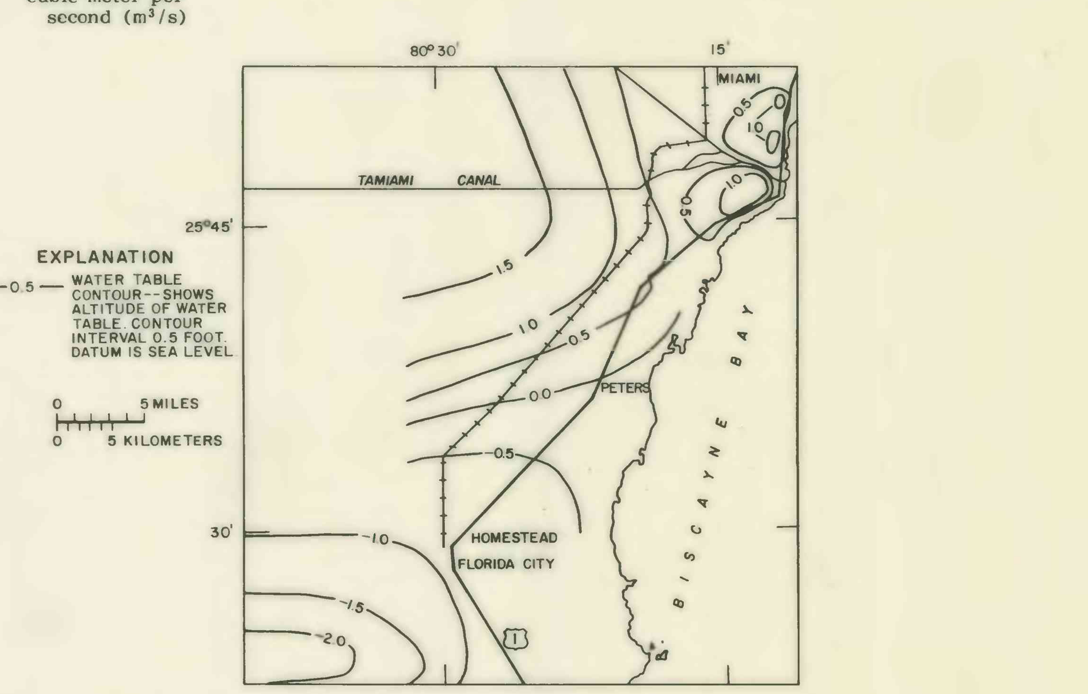

Figure 4.--Southeast Dade County showing the general configuration of the water table, May 19, 1945 (from Parker and others, 1955).

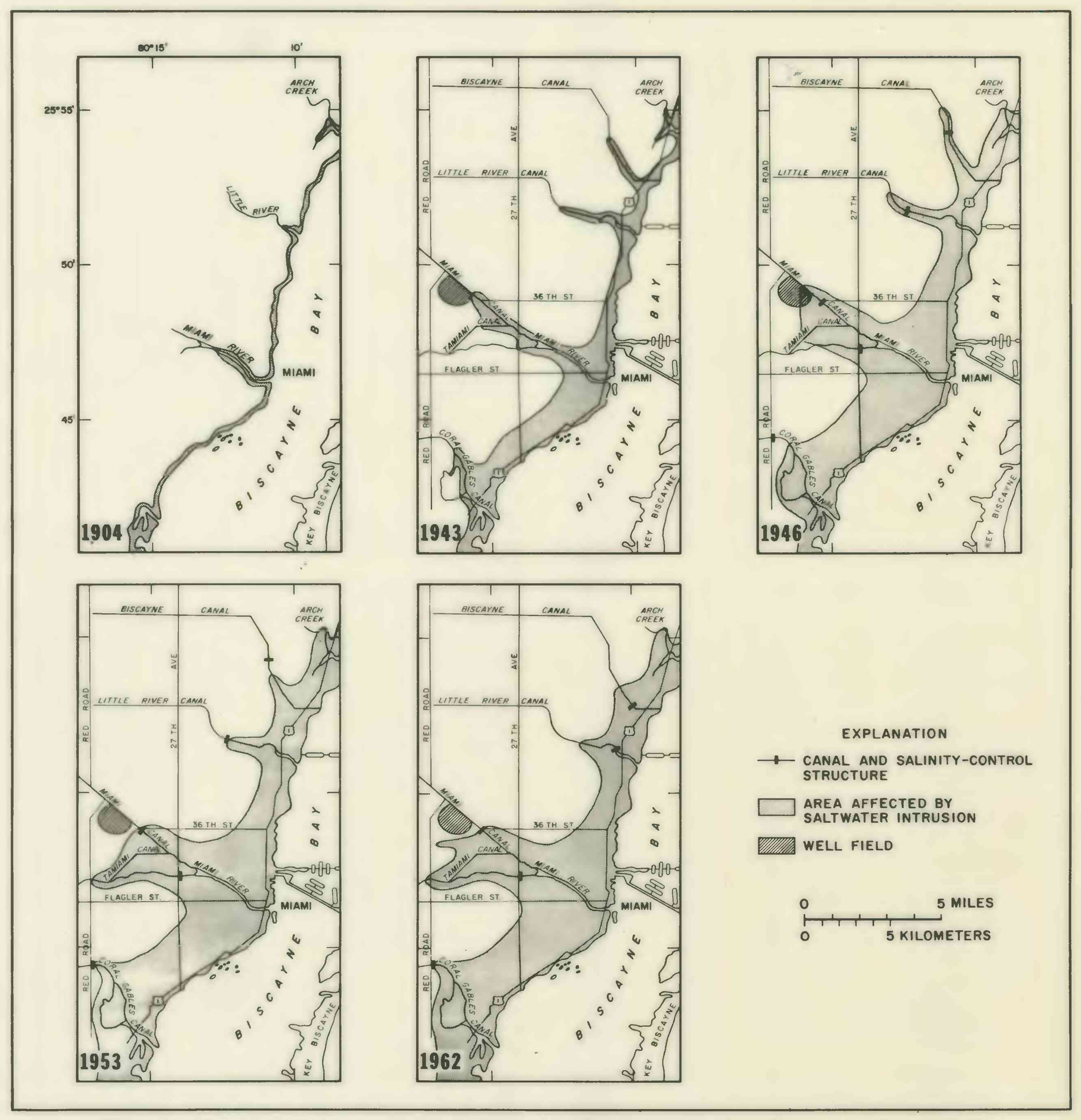

Figure 5.--Miami area showing progressive saltwater intrusion at the base of the Biscayne aquifer, 1904-62 (modified from Parker and others, 1955, p. 289; Kohout, 1961; Leach and Grantham, 1966).

SYNOPSIS OF SALTWATER INTRUSION IN DADE COUNTY, FLORIDA, THROUGH 1984

By
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1985