SOUTHWEST BROWARD COUNTY STUDY

OCTOBER, 1982

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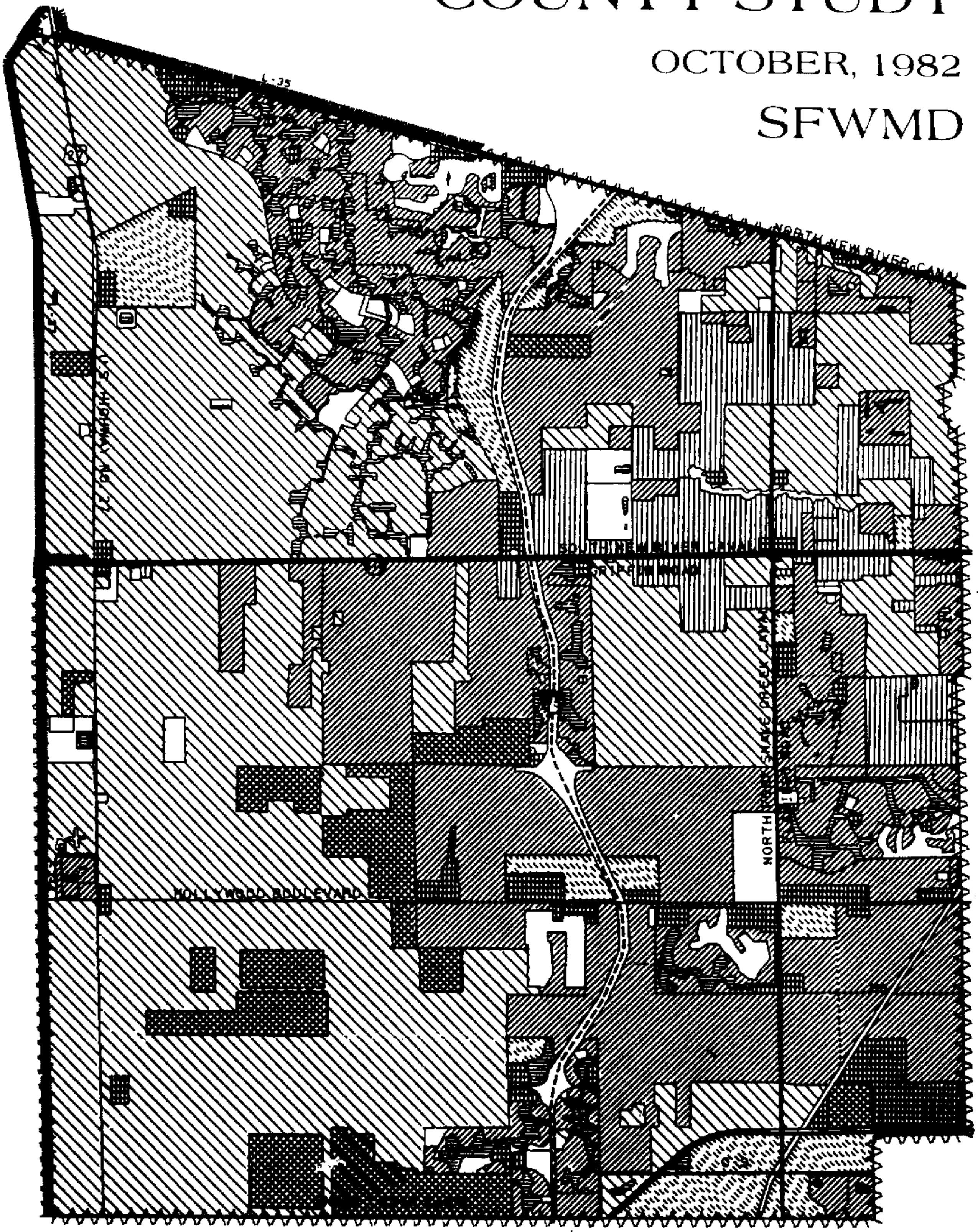

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October 1982

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The staff of Land Resources Division provided the computerized mapping support for this study. Without their helpful assistance this analysis would not have been possible.

The United States Geological Survey provided the majority of the water resource data presented in this report. Analysis of these data was conducted in cooperation with Aaron Higer, Brad Waller, and Dr. John Fish.

Land use information and coordination was supplied in a cooperative manner by Tom Walker, Mary Johnson and Susan Philp of the Broward County Planning Council and by Kelly Carpenter of the Broward County Office of Planning.

INTRODUCTION

In order to address concerns relating to proposed development as it may affect surface and groundwater quality in the Southwest Broward County area, the Broward County Commission actively sought assistance from federal, state and regional agencies. Two agencies offered help in response to this appeal: the United States Geological Survey (USGS) and the South Florida Water Management District (WMD).

The WMD agreed to conduct this preliminary study in cooperation with the USGS and the staff members of the Broward County Planning Council and the Office of Planning. Broward County and the WMD shared the cost of obtaining data on this area from the USGS. The WMD also provided matching funds to enable the Section 208 Director to act as the lead county coordinator for the duration of the study.

The data to be supplied by the USGS included data collected in the area in conjunction with past and present programs of that agency. These data were augmented by data available at the WMD. It should be noted that no new data were to be collected and analysed; only existing, available data were used, primarily because of time constraints.

Broward County was responsible for supplying the land use information needed to conduct several analyses in conjunction with the study. Upon receipt of all the land use information required, the WMD then had ninety days to develop conclusions and recommendations.

CHAPTER 1. LAND USE

INTRODUCTION

The Southwest Broward County Study area is adjacent on the west to Water Conservation Areas 3A and 3B, bordered on the north by the North New River Canal, the Dade County line on the south and on the east by 100th Avenue. The area includes portions of the cities of Miramar, Pembroke Pines, Davie and Cooper City, with the remainder in unincorporated Broward County. The United States Geological Survey Quadrangles of "Andytown," "Cooper City NE," "Cooper City SW," "Cooper City," "Pennsuco" and "Opa-Locka" constitute the study area.

According to population estimates provided by the Broward County Office of Planning, the current population of the study area is approximately 35,330. The population of this area when fully developed is estimated to be 330,000 people.

Data

The first objective of the study was to develop baseline land use information to attempt to identify potential land use and water quality changes and trends in the area. Three maps were developed, exhibiting; existing, committed, and proposed land use. The fourth map was a combination of the first three; created to represent a picture of the study area completely developed at some undetermined point in the future. Land uses are depicted on these maps in basic general categories; agricultural, industrial, commercial, borrow pits, and urban lakes. Residential land uses are divided into two categories; two dwelling units per acre or less and greater than two dwelling units per acre. For purposes of this study it was assumed that residential developments at densities of three dwelling units per acre or greater could be economically and feasibly served by central water and sewer systems. Below that density, individual wells and septic tanks were assumed to be the means of potable water supply and waste treatment.

The surface water bodies are divided into three categories, the first being the primary canal system which serves the area. Secondly, borrow pits are specifically identified on the study area land use maps. They are distinct from retention/detention lakes which are integral parts of a drainage system serving either an existing or proposed urban devlopment and are depicted on the land use maps as such, if that information was available.

The South Florida Water Management District's Land Resources Division has the responsibility of obtaining and updating the land use for the area within the District's boundaries and to store that information in a computerized geographic data base system. To accomplish this, the District is divided into six planning areas. The Lower East Coast is one of these planning areas and includes Palm Beach, Broward, Dade and Monroe Counties. In 1981 the update of the Lower East Coast was started.

The updating program involves mapping, land use/land cover surveys, field checking, editing, with final storage in the Computervision system. For this study, the boundary lines were delineated on the six individual USGS quadrangle sheets by Broward County planners. Upon receipt of this information, these lines were digitized. Using the system capabilities, this boundary was inserted and used to delineate those portions of the USGS quadrangles that fell within the project limits. This produced the Existing Land Use map of the area (see Plate 1).

At the initiation of the Southwest Broward County study, existing land use information was being updated for Broward County; therefore, current existing land use information was available in the District's system. Agricultural land uses were verified with the assistance of the District Conservationist, USDA Soil Conservation Service. This map was then examined for accuracy by the Broward County staff. After additions and corrections were made, a final map was developed and stored for use

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PAGES.

(Plates 1,2,3, and 4)

(Pages 3 - 6 in previous publishing.)

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SFWMD

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At present, approximately 27 percent of the study area is in agricultural land use with improved pasture being the predominant type of agricultural activity. Another 29 percent of the land is grassland or brushland which is used for seasonal pasture at a low animal density during the winter or dry months of the year. Urban land uses total 24 percent of the area; low density single family residential being the major land use within the urban category. The remaining 20 percent includes wetlands, and various open vegetated areas, as well as borrow pits and water areas. Currently, borrow pits involve only .6 percent of the area.

Land use information for the Committed Land Use Map was provided by the Broward County planners. This map depicts committed but as yet undeveloped tracts of land within the study area, such as plats, subdivisions and developments of regional impact approved by the Broward County Commission (see Plate 2). All of these developments are primarily residential in nature with 14,600 acres dedicated to four large planned unit developments; Weston, 84 South, Chapel Trails and Ivanhoe. The conceptual site development plans were provided and used in developing this map because of the greater accuracy and detail they offered. It should be noted that when the acreage of these proposed developments is added to the existing urban land use acreage, the sum constitutes 42 percent of the total area.

Proposed borrow pit excavation is also represented on this map. These borrow pits are depicted as being fully excavated to the limits established by Broward County regulations. Based on this information, borrow pits are expected to involve 5 percent of the study area when it is fully developed.

Broward County planners also provided information for the Proposed Land Use Map (see Plate 3). This map represents the Broward County Land Use Plan as adopted and is also representative of the Land Use Element of the Broward

County Comprehensive Plan. The various land use types are depicted in generalized manner with emphasis on low density residential land use.

The land use category "agriculture" has been applied to much of the area on the Land Use Plan; however, the actual land use interpretation is more accurately termed "rural residential." It is doubtful that successful agricultural activities could take place in the western half of the study area because it is marginal for intensive farming due to poor drainage. Rural residential densities, therefore, more accurately and realistically reflect future land use trends.

For comparative, analytical and modeling purposes, a map representing the study area completely developed at some point in the future was necessary. The levels of land use information, existing, committed and proposed, were combined to create what is called the Composite Land Use Map (see Plate 4).

Significant land use changes and trends can be identified when comparing the Composite with the Existing Land Use Map. The trend in the area is away from agricultural and towards urban land uses. Specifically, agriculture will represent only 5 percent of the total land area; while 35 percent will be committed to low density single family residential development. Notably commercial and industrial land use acreage will increase to represent 3 percent and 4 percent, respectively.

In summary, existing land use information was provided by the WMD for this study. Broward County supplied the WMD with detailed information on committed and proposed land use plans affecting the Southwest Broward Study area.

Planning and Regulation

There are several existing regulatory and planning processes which either seek to improve the quality of surface water from land uses or provide the basis for the implementation of various methods for the protection of surface and groundwater quality. The South Florida Water Management District has a rule which applies specifically to the western C-9 basin. Basically, the purpose of this rule is to prevent fill encroachment by development from adversely impacting the flood protection characteristics of the eastern C-9 basin. Additionally, the appropriate water quality control measures for the protection of the water resources is an inherent part of this rule.

The District has identified areas where water quality considerations are extremely important. These areas include canals backpumped to Lake Okeechobee or to the Water Conservation Areas, or proposed for backpumping. This condition applies to the western C-11 basin in the study area because backpumping occurs through the S-9 structure into Water Conservation Area 3A.

Best Management Practices (BMP's) are required to be incorporated into surface water management systems to reduce pollutant loadings to receiving waters. These BMP's are water quality enhancement measures which can be used separately or in combination to improve the stormwater runoff from development prior to off-site discharge.

Broward County has developed several levels of planning and regulatory processes which address land use impacts on surface and groundwater quality and quantity.

The Potable Water Subelement of the Broward County Comprehensive Plan recommendations provide the policy framework for the implementation of various methods for the protection of the water resources of Broward County. These include:

1. Regionalization of wellfields; and
2. Protection of the Biscayne Aquifer and future wellfields.

The subelement also recommends the establishment of ordinances or regulations protecting the cones of influence of existing wellfields and in areas where new wellfields may be developed.

In the Coastal Zone Protection/Conservation Element the flooding potential of western C-9 and C-11 basins is recognized as a development constraint. The water quality impacts are more directly addressed in a policy guideline concerning septic tank development in the area. The monitoring and regulation of septic tanks is considered essential to prevent or minimize contamination of surface and groundwaters due to tank overflow during flooding.

Associated with the policy guidelines of the Comprehensive Plan as they affect land development and water management are several studies either proposed or being conducted by county staff. The Broward County Planning Council proposes a study of the impact of septic tanks on the study area. The Office of Planning through the County Administrator's office recently submitted a report to the County Commissioners which provides recommendations regarding the organization of staff resources and advisory committees for the purpose of local water resource management, pertaining to the development of recommendations on future wellfield location and wholesale water distribution.

In addition to the County Comprehensive Plan, Broward County also has a Land Development Code. According to the information provided, all new development within the unincorporated area of Broward, and all development which requires the platting of land within municipalities of Broward County must meet minimum standards, one of which is adequacy of water management.

The Broward County Zoning Ordinance establishes the different types of uses permissable within each zoning category. It is an extensive regulatory document designed to "accomplish the aims and purposes" of the Comprehensive Plan.

These major planning regulatory processes all serve to provide some measure of protection to the water resources of the area. Progress is being made to strengthen and improve these courses of action in the future.

CHAPTER 2. GROUNDWATER

INTRODUCTION

The western regions of the C-9 and C-11 basins are largely undeveloped; however the inception of the I-75 extension combined with urban sprawl are acting to modify the region. Based on current projections, this growth rate will result in a 934% increase in population for the study area alone. Residential, commercial and industrial land uses are incorporated in the development plan which is destined to modify existing conditions of the Biscayne aquifer within the study area. Of primary concern is the effect development will have on quantity and quality of water within the aquifer. The quantity of water available to development is affected by geologic conditions, saltwater influences, and modification of recharge patterns. Water quality will be mainly influenced by byproducts of development such as waste management, industrial contamination and runoff loads. The result of previous studies combined with local ambient conditions were used to assess possible impacts of the composite land use plan (Plate 4).

Data used in this study were provided in part by the USGS with special assistance from John Fish and Brad Waller. Additional information was obtained through the Broward County Water Management Division and the Broward County Planning Council. The scope of this study did not allow for the development of original data but is based on the evaluation of existing information. Conclusions are based on projections of existing average conditions on future land use plans and in many cases require additional investigations. Major gaps in the current data records are noted and additional investigations, when warranted, are listed under the recommendation section. Data stations are shown on Plate 2-1.

TOPOGRAPHY

Land elevations for the study area are presented in the Water Management Study of the Western C-11 Canal Basin and the Water Management Plan for the

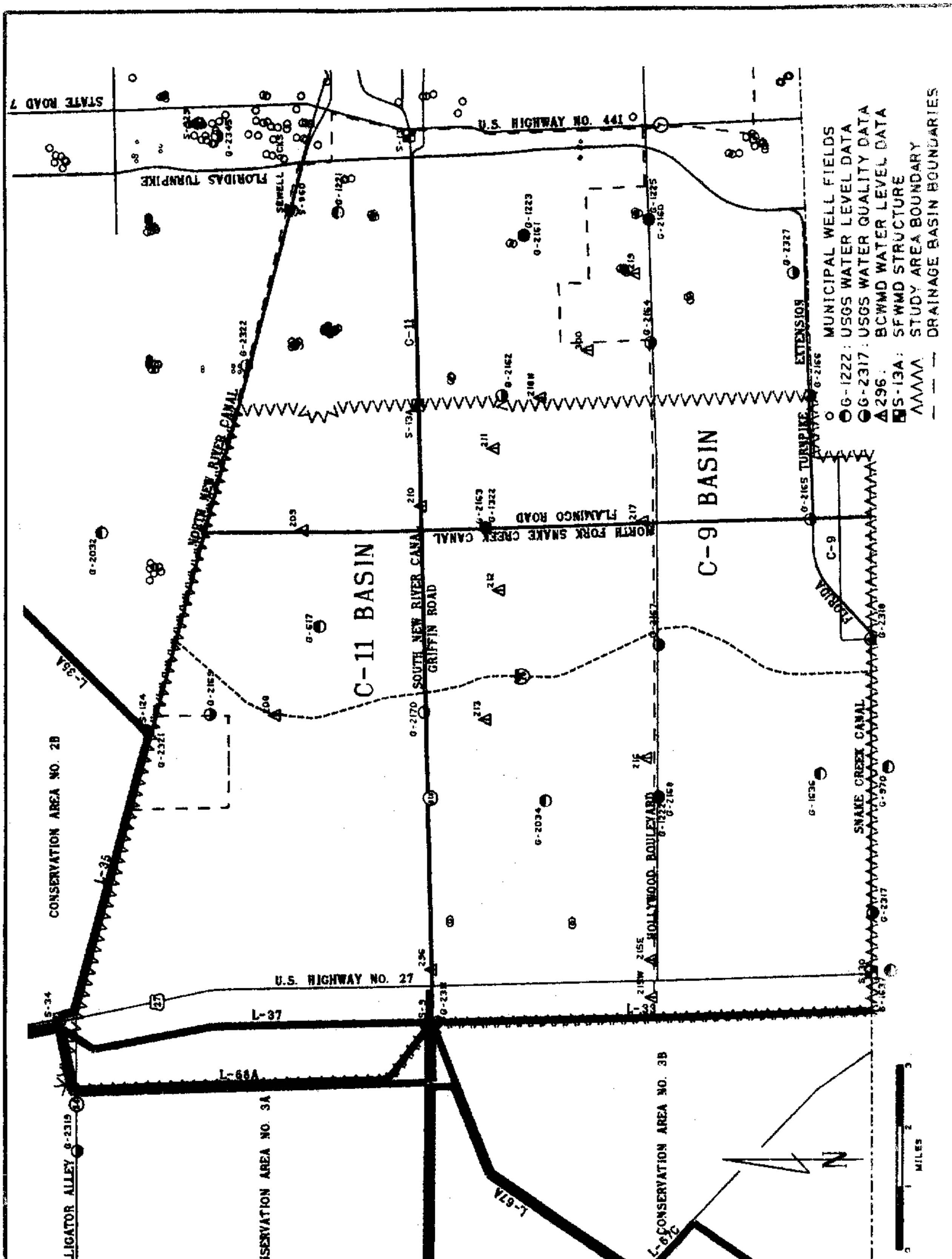


PLATE 2-1 DATA BASE MAP FOR THE S.W. BROWARD STUDY AREA

C-9 Basin (SFWMD, 1976 and 1980). Topographic surveys in both basins were conducted by running elevation lines in a north-south direction along section lines. Data points were collected every .1 mile and are accurate to .1 of a foot, all elevations are referenced to NGVD (National Geodetic Vertical Datum of 1929). Contour intervals of 1 foot were use to illustrate the relief within the study area (Plate 2-2). The data are characteristic of average existing surface elevations and do not represent topographic highs or lows such as levees, proposed surface elevations for development or borrow pit areas. In general, surficial drainage in both basins is towards the southeast.

The C-11 basin is located in central Broward County, about 12 miles west of Fort Lauderdale. Sections of Cooper City, the Town of Davie, and the City of Pembroke Pines are in the basin. The remainder of the basin is in unincorporated Broward County, east of Water Conservation Areas 3A and 3B.

The majority of land surface elevations range between 4-7 feet NGVD within the C-11 basin. A comparison of the topographic map with groundwater elevations show that large areas are prone to flooding and may be inundated for long periods, especially in the western areas of the basin. The 100 year flood elevation for the western C-11 basin based on existing land use can be as high as 7.8 feet NGVD (SFWMD, 1980). However, existing required residential floor pad elevations appear to be sufficient to prevent flood damage from most storm events. Lawns, driveways and unimproved roads will be under water frequently, as is documented by historical events. Depending on the accessibility to the secondary or primary drainage system, inundation of certain areas may be quite lengthy.

The C-9 basin lies on both sides of the Broward - Dade County line from the Intracoastal Waterway on the east to Water Conservation Area 3B on the west. The basin can be evenly divided into east and west sub-basins. The

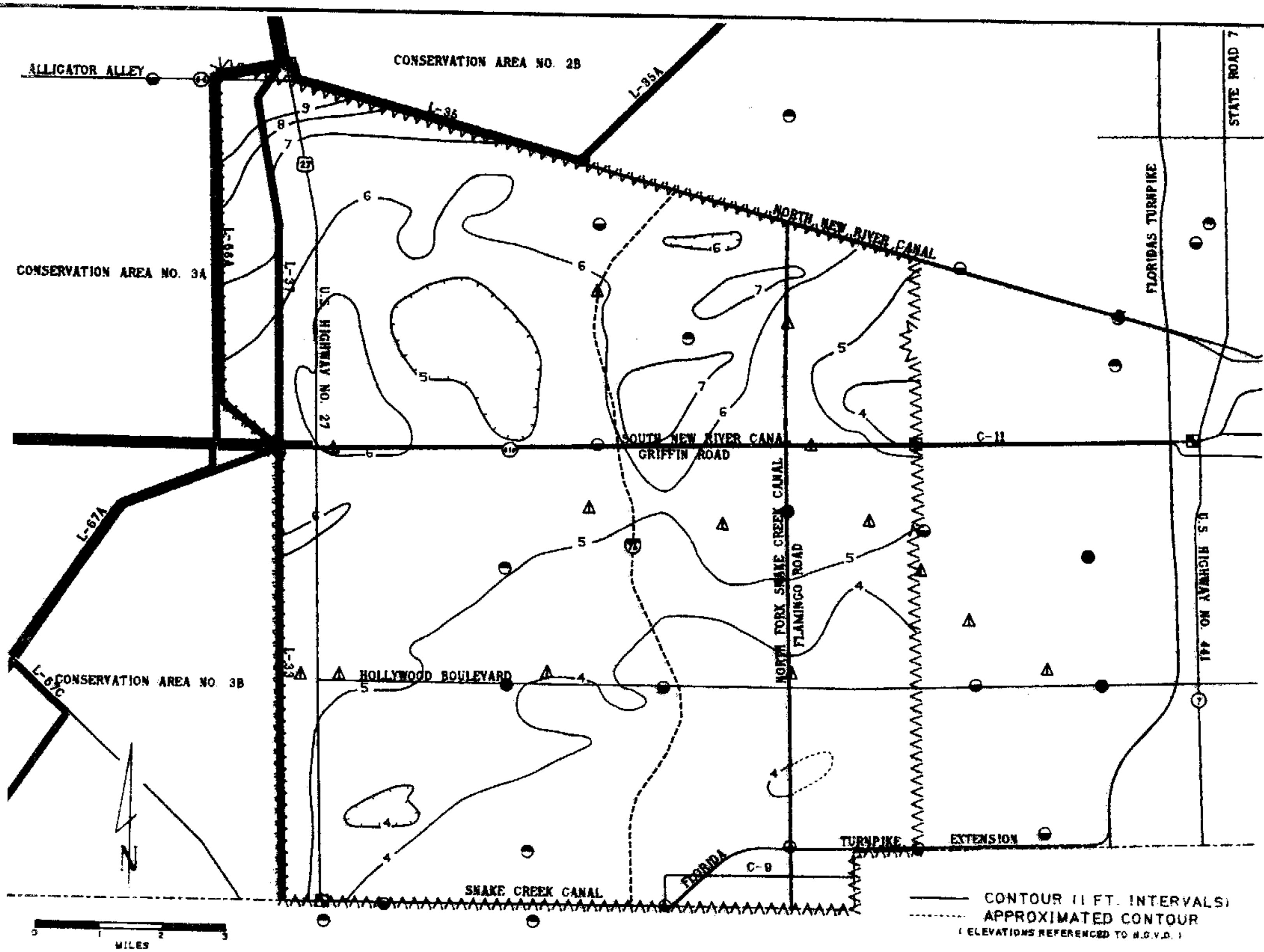


PLATE 2-2 TOPOGRAPHY OF S.W. BROWARD STUDY AREA

eastern sub-basin, bordered to the west by Flamingo Road, is defined on the east by the coastal ridge. Land elevations of the ridge area are commonly 10-15 feet at its western end. The western sub-basin is west of Flamingo Road and east of the Water Conservation levee L-33. The topography of the western sub-basin shows little relief, with an average land surface elevation of approximately 4 feet. Variations in land elevations within this area are not expected to be much more than 1 foot. Low elevations and lack of slope prevent much of the runoff from leaving the basin during normal rainfall. High groundwater levels prevent the downward percolation of water and in many areas water accumulates in ponds for several weeks. Consequently, the western sub-basin acts as a detention area which holds storm water while the eastern sub-basin is draining. Fill encroachment in the area would displace flood water storage, creating higher ponding stages which may force water eastward resulting in higher stages in the east. Therefore, the amount of fill in the west has been limited so as to prevent additional flooding in the eastern sub-basin and retain the storage capability of the western sub-basin while minimizing an increase in stage rise. Existing building elevations within the western sub-basin has greater than 100 year flood protection. The 100 year flood elevation for much of the basin would exceed 7 feet NGVD. Broward County fill criteria for all residential floor pad elevations is at least 8 feet which will provide sufficient protection during the 100 year flood stage. Local flooding will probably occur, however, in parts of the eastern sub-basin even though the primary drainage system appears more than adequate. Flooding would be caused by the inability of the secondary and tertiary drainage systems to deliver storm runoff to C-9 after rainfall events (SFWMD, 1976).

HYDROLOGIC REGIME

The Biscayne aquifer is comprised of carbonate and clastic sediments ranging in age from late Pliocene to Holocene. It is one of the most productive aquifers in the world with transmissivities ranging from 15 mgd/ft to 0.4 mgd/ft. The aquifer is generally wedge shaped ranging in thickness from over 240 feet in coastal Broward County, thinning to the west where it pinches out 35 to 40 miles inland in the Everglades. The aquifer is unconfined with groundwater levels responding dynamically to recharge and discharge. Surficial recharge is strongly influenced by top soil which range from sand in the east to low permeable muck to the west. Rainfall provides the major source of freshwater recharge with additional inflow from adjacent areas either through controlled canals or from groundwater flow. Outflow to the sea and evapotranspiration accounts for the major portion of discharge from the aquifer along with losses through discharge to canals during high water levels, and by public and private wellfield withdrawals. Flow directions generally trend from the northwest to the southeast with maximum groundwater elevation occurring in the Water Conservation Areas and decrease to sea level near the coast.

Soils

The distribution of the various soils association in western Broward County is shown on Plate 2-3. Two basic categories are present, the organic peat or muck characteristic of the Water Conservation Areas and the sandy soils which are representative of the Coastal Ridge.

Covering a relatively small area in the east and just south of the North New River Canal is the Paola - Urban land - St. Lucie Association. This association consists of low knolls and ridges that are part of the Coastal Ridge. Typically they have a thin surface layer of gray fine sand and a subsurface layer of white and yellow sand to a depth of approximately 80 inches. The soils are excessively drained and have severe limitations for structures designed to hold water (Pendleton, et al., 1976).

Adjacent to the Florida Turnpike is the Immokalee - Urban land - Pompano Association. Within the area low ridges are interspersed with broad flats.

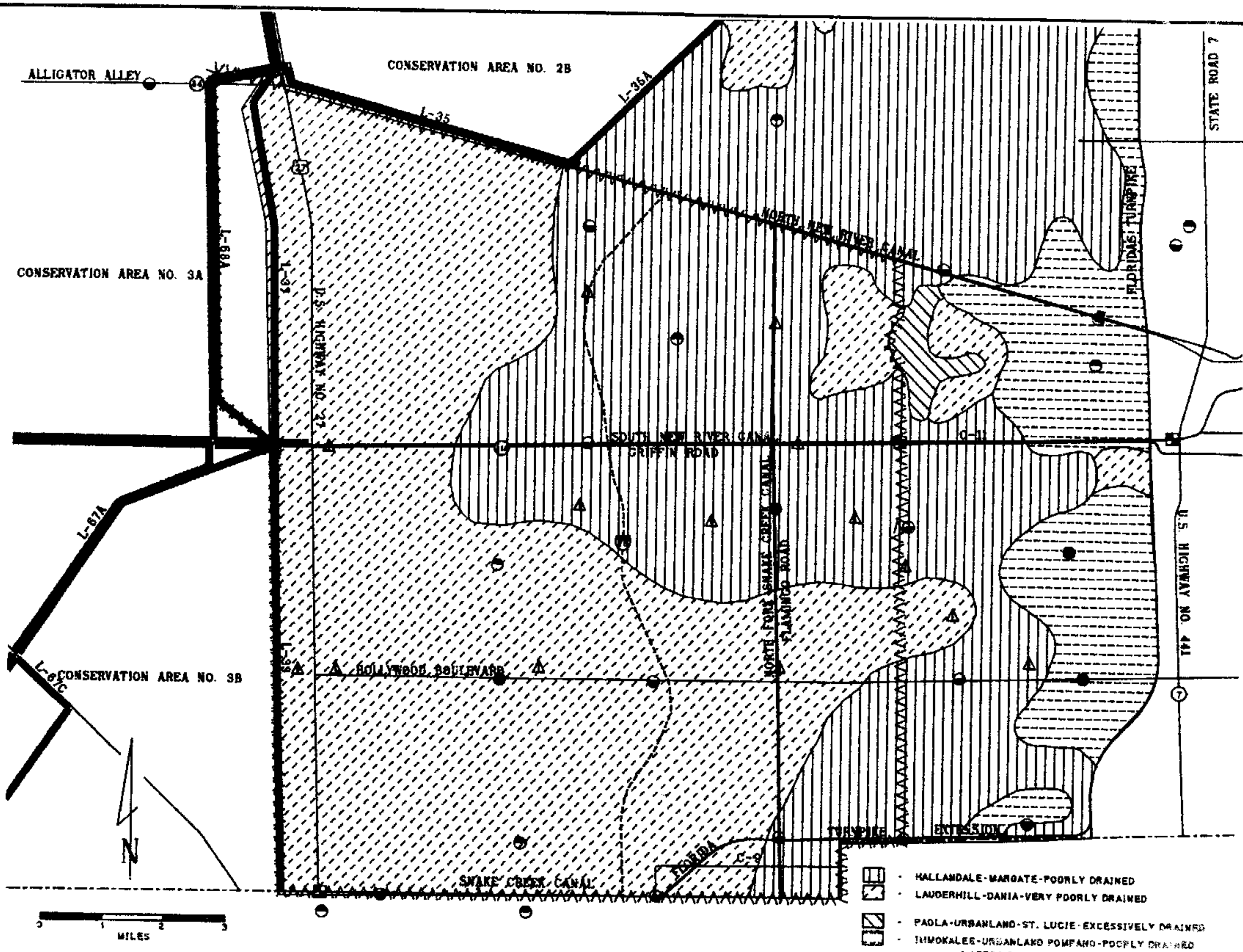


PLATE 2-3 GENERAL SOILS MAP OF S.W. BROWARD STUDY AREA

The soils are comprised of a dark sand combined with organic matter that are approximately 80 inches deep. Although the soils are poorly drained, drainage and water control have been established over most of the association. Flooding is a hazard in undeveloped areas that are without adequate water control (Pendleton, et al., 1976).

The northeast section of the study area is generally composed of the Hallandale - Margate Association. Broad flats, drainageways and ponds are typical of the area. Soils consist of a dark fine sand which increase in clay content with depth. The soil layer is between 7 and 40 inches deep. The soils of this association are poorly drained and have necessitated the establishment of water control and drainage.

The remainder of the study area consist of the Lauderhill - Dania Association which is made up of broad flats. Soils within the area are composed of black and dark reddish brown sapric material or muck that range between 14 and 40 inches deep. These soils are very poorly drained because of their high muck content. With adequate drainage these soils have good farming potential. Community developments, however, would require that the soils be removed and replaced by fill because of their low strength.

In general, the soil cover within the study area does not allow water to percolate downward readily. Poor drainage coupled with lack of slope results in standing water over much of the area. Such characteristics are unfavorable for septic tanks, sewage lagoons or sanitary landfills unless intensive reclamation is undertaken (Pendleton, et al., 1976).

Geology and Hydrogeology of the Biscayne Aquifer

Geologic data analyzed in this study were in part provided by John Fish (USGS) as a result of a study currently being completed on the Biscayne Aquifer of Broward County. Those readers wishing a more detailed dissertation on the geology and stratigraphy of the aquifer are directed to the upcoming report by Fish and Causaras.

The Biscayne aquifer is composed of both freshwater and marine limestones, sandstones and sands ranging in age from Pliocene to Holocene. It is areally extensive, supplying Dade, Broward, and southeast Palm Beach County with potable water. The upper portion of the aquifer is composed of highly permeable solutioned biogenic limestones, sands, and shell beds in Dade County with increasing percentages of fine grained sands to the north. The basal portion of the aquifer consists of fine grained sandstones and sandy lime muds of lower permeability. The unit is confined below by impermeable silts and clay size sediments of the lower Tamiami and Hawthorn Formations. The thickness of the Biscayne ranges from over 240 feet in coastal Broward County and thins to the west where it pinches out adjacent to the Broward - Collier, Dade-Monroe county line. Porosity varies with sediment type and includes intergranular, moldic, primary and secondary solution piping. Transmissivities are highest in east Dade with values ranging from 4 to 15 million gallons per day per foot (MGD/ft). Transmissivities decrease to the north with increased amounts of fine grained sands filling solution cavities. Values here range from 4 MGD/ft in south central Broward to 0.4 MGD/ft in northeastern Broward (Sherwood, et al., 1973).

<u>Geology and Hydrogeology of the Southwest Broward Area</u>

The sediments which constitute the Biscayne aquifer within the study area are consistent with those described above with increasing percentages of sand. Plate 2-4 depicts the surficial geology which lies directly beneath the recent soils. The formations identified in the study area include the Pamlico Sand, Miami Oolite, and Ft. Thompson Formations. Below these units is the Lake Flirt Marl, Anastasia Formation, Caloosahatchee Marl, and the Tamiami Formation have been identified (BCPC, 1980). Figures 2 through 4 (Appendix A) indicate the lithology and relative permeability of the sediments along cross sections A-A', B-B', C-C' shown on Figure 1. Qualitative permeability

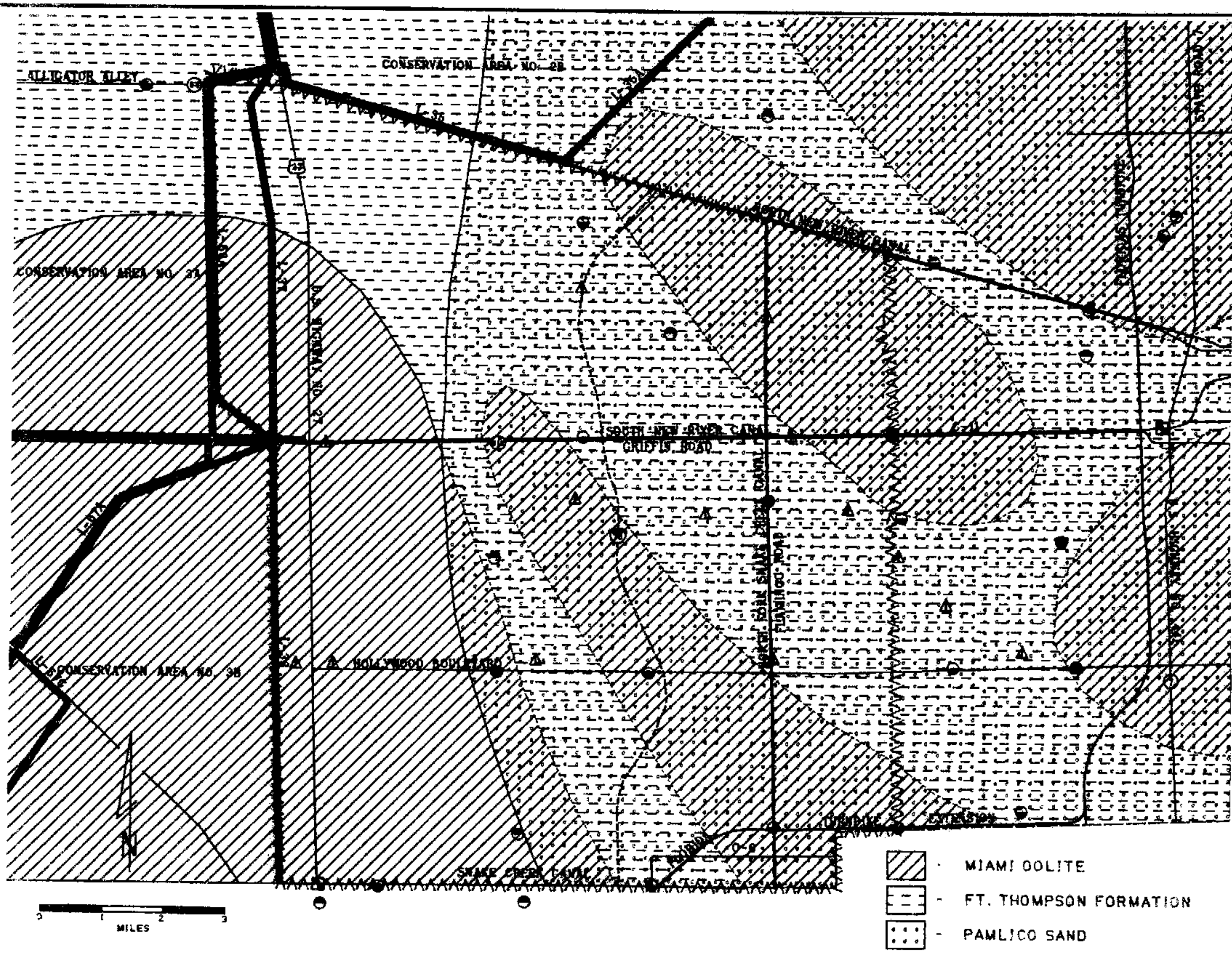


PLATE 2-4 GEOLOGICAL MAP OF THE S.W. BROWARD STUDY AREA (AFTER PARKER 1955)

assessments are based on grain size and lithology determined from core samples courtesy of John Fish. A quantitative study on permeabilities through aquifer testing is being undertaken by the USGS and is expected to be completed by 1983.

The aquifer is generally divided into an upper and lower region by a bed of fine sands and micrites of moderate to low permeability located between -10 to -50 feet NGVD. The limestones and sands which overlie this bed comprise the Miami Oolite and Pamlico sands in this area and have moderate to high permeability. The limestones beneath the less permeable zone productive region are very permeable and represents the Ft. Thompson and Anastasia Formations. These limestones offer the best prospect for municipal wellfield development.

The thickness of the Biscayne aquifer in the study area ranges from 60 feet in the northwest corner to over 160 feet along the eastern border as shown in Plate 2-5. The base of the aquifer is defined by hydraulic conductivity and is often independent of formation boundaries. Klein and Causaras (1982) picked the base of the aquifer below the contact between the Tamiami and Ft. Thompson Formations noting that the upper portion of the Tamiami often contained permeable sediments which are hydraulically connected to the Biscayne. This moderate to low permeability region is shown on Figures 2 through 4 towards the bottom of each section. The Tamiami Formation is assumed to correspond to the top of this region and the base of the aquifer is assumed to be defined by the basal silts. The basal region of moderate to low permeability along the western border of the study area and out into the Water Conservation Areas contains connate brackish water which could affect wellfield development (see Water Quality).

Transmissivity is the product of hydraulic conductivity and the saturated thickness of a unit. Hydraulic conductivity is dependent on grain size,

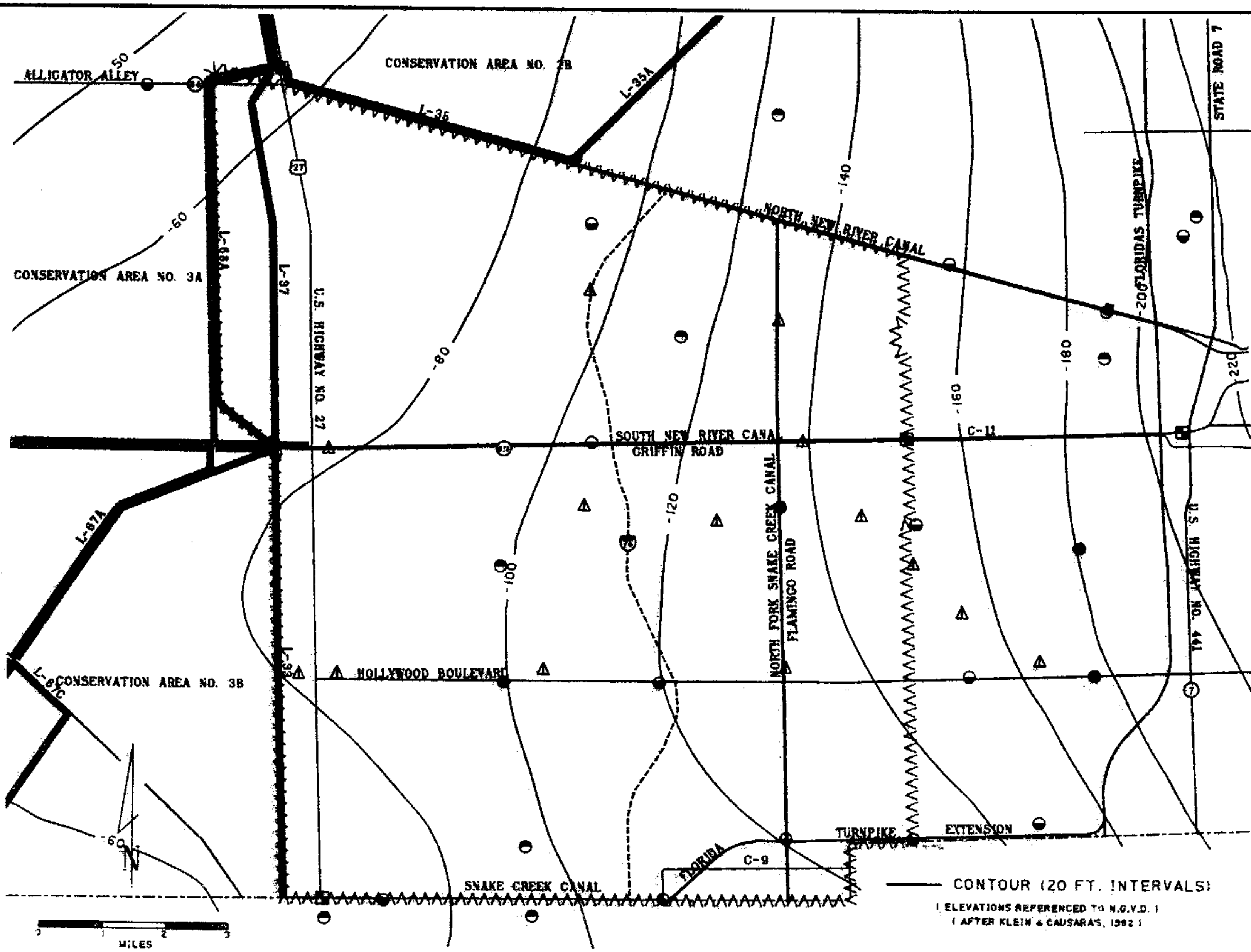


PLATE 2-5 BASE OF THE BISCAYNE AQUIFER OF THE S.W. BROWARD STUDY AREA

sorting and the distribution of fracture and solution openings (permeability). It is both thickness and grain size which most directly influence the range of transmissivities in the study area. As previously discussed the aquifer is thin to the west while permeability decreases to the north and east with increasing concentration of sand. The result is a decreasing trend in transmissivities in the north and western regions of the study area. Data on well hydraulics are scarce for the study area. Appel (1973) indicates transmissivities range from 3 to over 4 mgd/ft. However, more recent data indicate lower values for the area. Bearden (1974) calculated a value of 2 mgd/ft for the Hallandale wellfield area while a value of 1 mgd/ft was calculated using corrected specific capacity data from South Broward Utilities well number 5W near C-11 and Flamingo Road (verbal communication, John Massey-Norton, 1982). Values ranging from 0.6 to 2.98 mgd/ft were calculated from production wells in the Dixie Wellfield (Camp, Dresser and McKee, 1980).

Recharge-Discharge

Groundwater levels of the Biscayne aquifer are the result of dynamic responses to recharge and discharge. Rainfall provides the major source of freshwater recharge with additional inflow from adjacent areas either through controlled canals or by means of groundwater inflow. Outflow to the sea and evapotranspiration accounts for the major portion of discharge from the aquifer along with losses through discharge to canals during periods of high groundwater elevations, and by public and private wellfield activities.

An average of 60 inches of rain falls annually on Broward County with greater than average rainfall occurring along the coast and slightly less to the west. Long term rainfall data were analyzed for three stations in the study area and are summarized on Figures 5 through 7, Appendix A. Rainfall for the seven year period from 1974 to 1980 was compared with the average taken from 1969-80. Average annual rainfall for all three stations from 1974 to 1980 was 45.95 inches. At S-9 there was little deviation between the 1969-1980 average and the 1974-1980 average, however data from S-34 and Sewell's Lock indicates a 15.1 and 17.4 percent decrease in rain respectively over the last seven years. Data from the Ft. Lauderdale field station are available from 1971 to 1981. Interpolation of these data suggests a 15 percent decline in rainfall during 1974 to 1980 at this station. As a result of this recharge deficiency groundwater levels on Plates 2-6 and 2-7 may be below average. This may be a short term decline in rainfall and should not be considered a long term or permanent change.

In addition to rainfall, groundwater levels in the study area are influenced by three major east-west canals; the North New River, the South New River (C-11), the Snake Creek Canal (C-9), and by one north-south canal extension; the North Fork Snake Creek Canal. Water levels are maintained in these canals through structures S-34, S-9, and S-30 located along the western boundary of the study area, and to the east by Sewell's Lock, S-13A, and S-29 (Plate 2-1). Generally, stage levels in the canals are regulated by releasing water from the C-9 and C-11 basins to the coast. During periods of drought water is released eastward from the conservation areas and is held in the basins to elevate groundwater levels. During periods of surplus water, S-9 has backpumping capabilities to pump excess water from the basin into the Water Conservation Areas for storage.

Exchange rates between canal and groundwater bodies depend upon several factors including permeability of the aquifer, permeability of the canal bottom sediments and the hydraulic difference between the canal stage and the aquifer. The quantitative relationship between canal stage levels and groundwater elevations has not been examined within the study area. Waller (1978) notes that most of the water entering the C-11 canal during backpumping at S-9 is due to induced groundwater inflow but he did not measure volumes or rates of exchange between groundwater and the canal. In studying the effects of infiltration from the Miami Canal in the Miami Springs - Hialeah

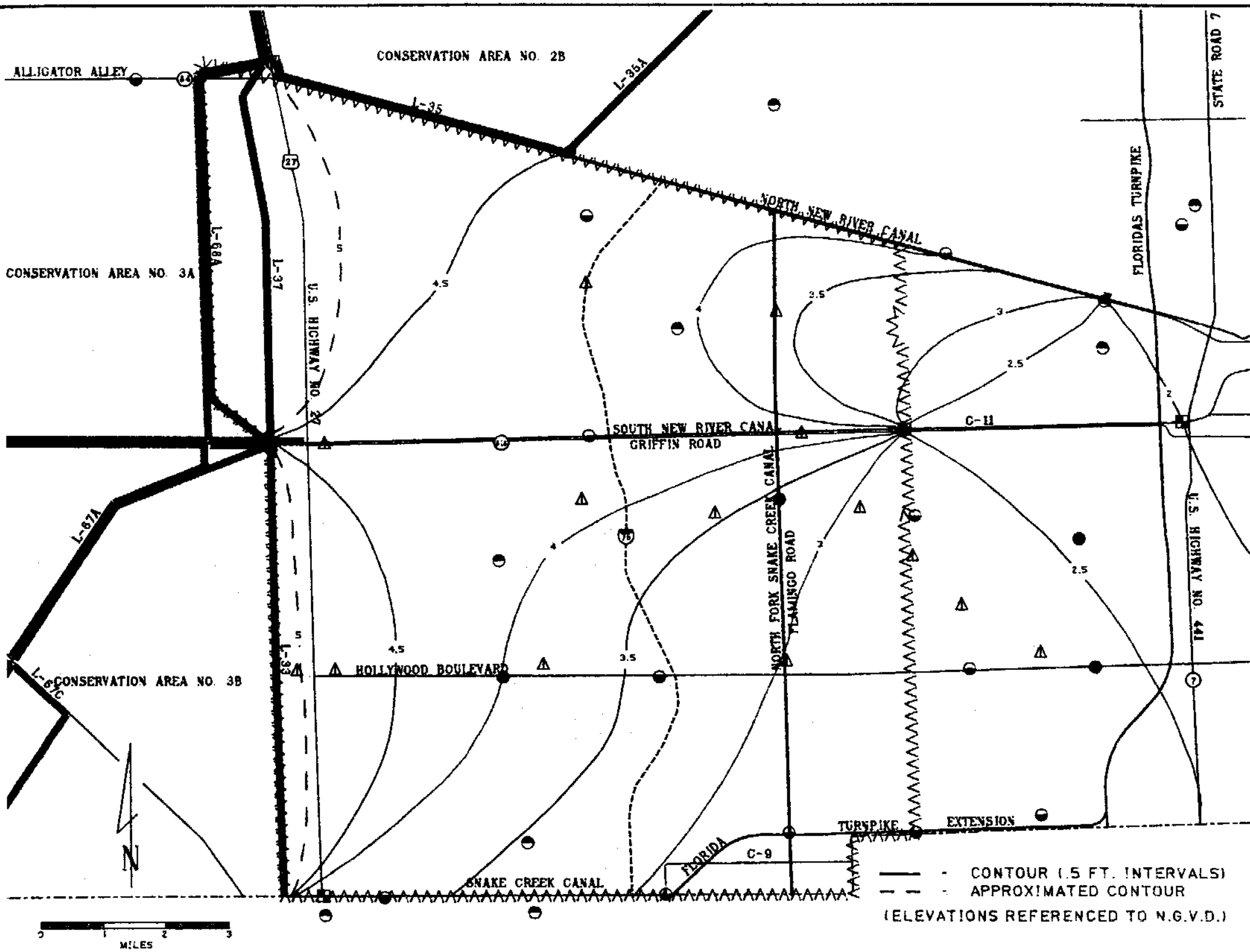


PLATE 2-6 MEAN HIGH GROUNDWATER LEVELS, JULY — SEPT., 1974-80
OF THE S.W. BROWARD STUDY AREA

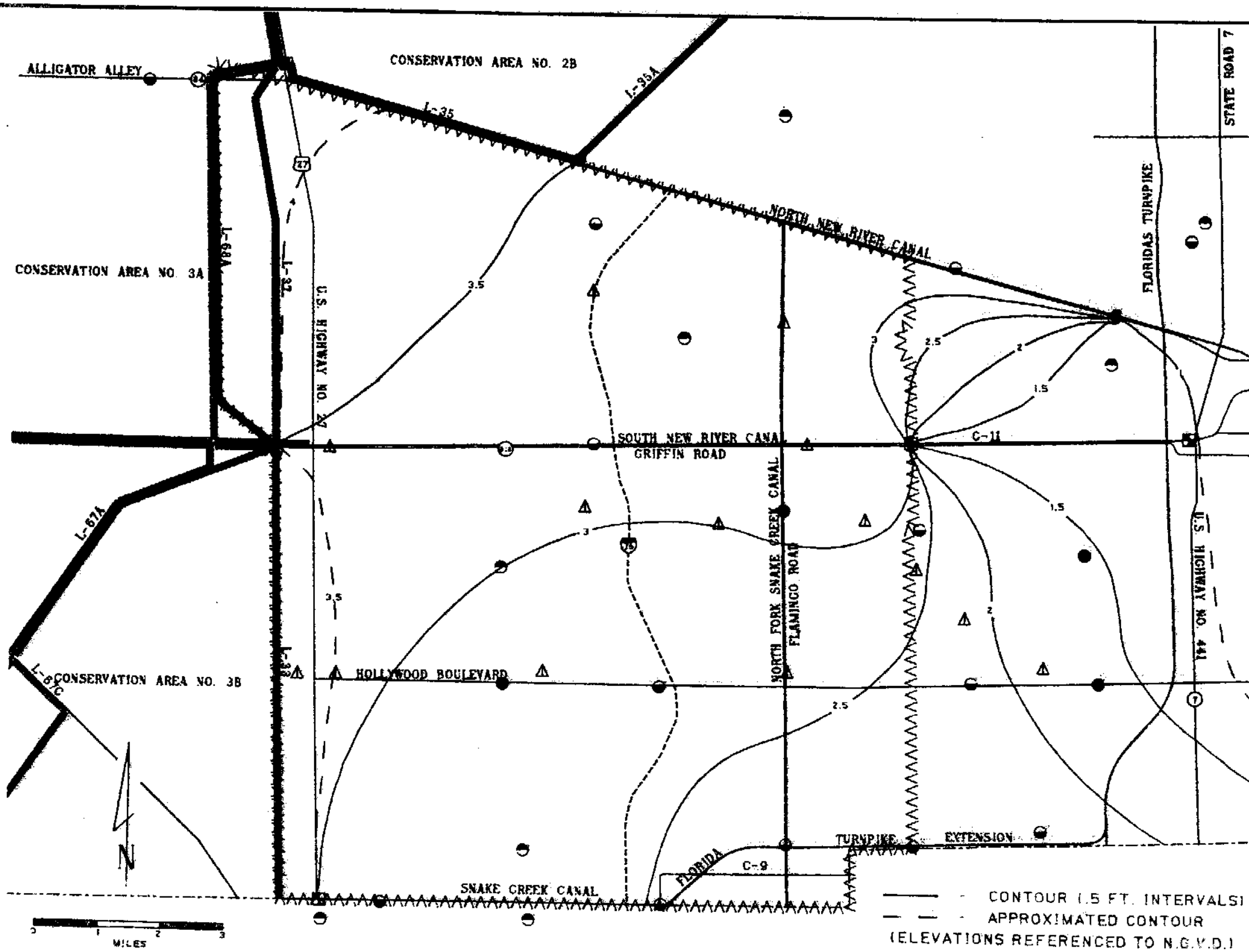


PLATE 2-7 MEAN LOW GROUNDWATER LEVELS, FEB.-APR., 1974-80: Of The S.W. BROWARD STUDY AREA

wellfield, Miller (1978) found that 50 percent of the 120 mgd yield in May 1973 was attributed to recharge by the canal.

The qualitative relationship between canals and groundwater elevations for a period from 1974 to 1981 is shown on Plate 9. The three dimensional surface was made by combining average groundwater elevations for the wet season (see water table elevations) and combining them with average canal stages from 1974 to 1981. Ridges indicate high water levels within the regions Water Conservation Areas which provide recharge to the aquifer. Troughs denote areas of groundwater discharge which are mainly associated with controlled canals. The irregular surface along the North New River Canal is the result of limitations in the program used in the simulation. The greater the relief between the ridge or trough to the adjacent groundwater surface the greater the hydraulic gradient between the canal and aquifer. By assuming homogeneity of the aquifer and the canal sediments, these areas of high relief indicate the highest rates of exchange. The importance of maintaining high groundwater elevations has been established, and therefore further investigations and monitoring of the canal groundwater relationship within the study area should be considered.

Additional recharge enters the western border of the study area as seepage through levees L-33 and L-37. Waller (1978) reports the rate of leakage into the C-11 basin through a 9.5 mile length of L-33 and L-37 is 58.16 mgd. Although there are no groundwater level monitoring wells in the northwestern region of the study area to verify this, the effect of this seepage can be assumed to elevate groundwater levels adjacent to the levees. Data on seepage across the L-37 levee into the C-9 basin are not available at this time.

Of the 60 inches of average annual rainfall about 22 inches returns to the atmosphere as evaporation from surface water, 20 inches returns to the

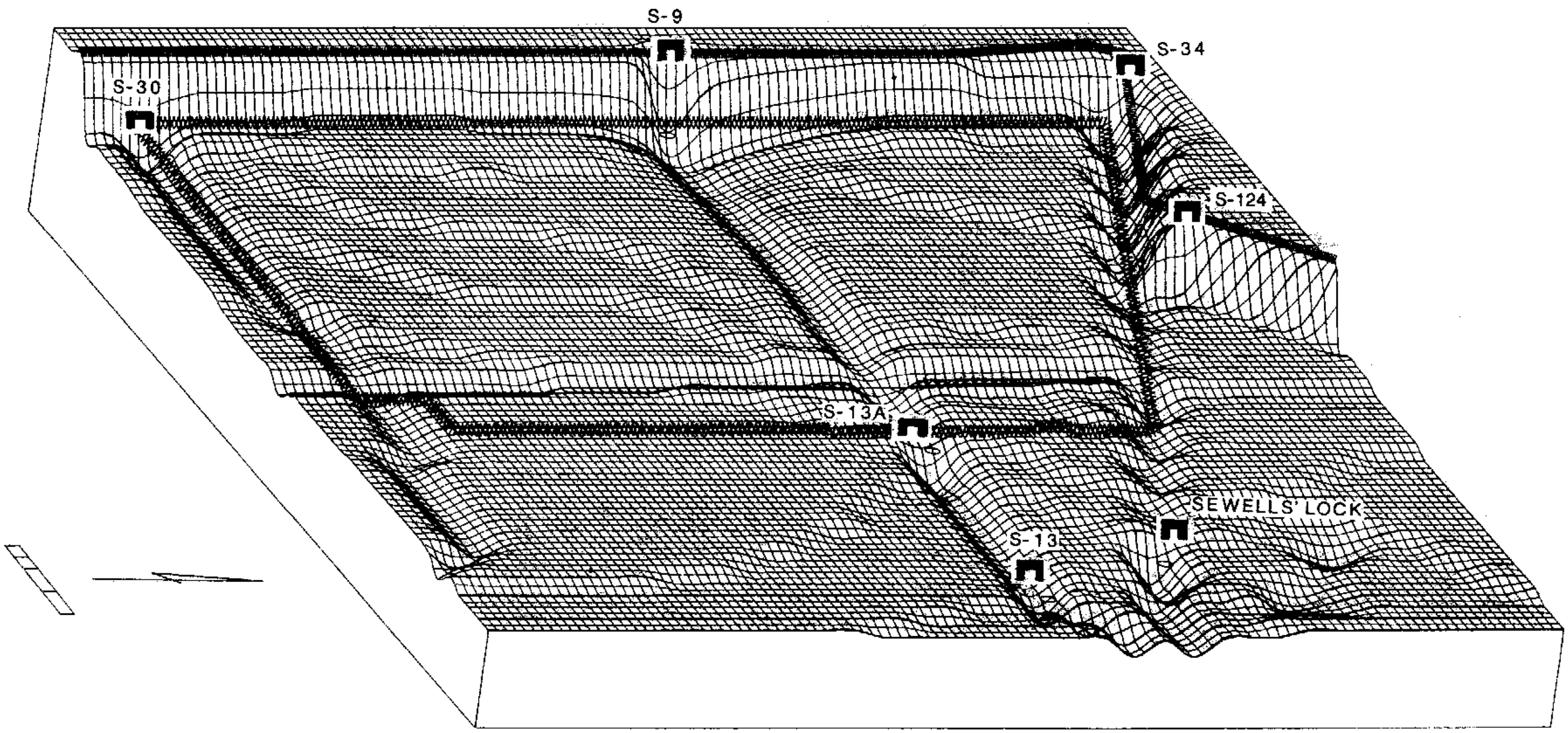


PLATE 2-8 MEAN HIGH GROUNDWATER LEVELS, S.W. BROWARD CO., JULY-SEPT., 1974-1980: (vertical exaggeration 1000x)

atmosphere as evapotranspiration 1 inch flows to the canals as surface runoff, 2.5 inches is used by wellfields and the remaining 14.5 inches flows to the sea by canals or by groundwater flow (Sherwood, et al., 1973). Aside from estimates of evapotranspiration withdrawals related to wellfield activities are probably the least accurate. The population of Broward County has grown significantly since 1973 as indicated by the increase in water use. Currently approximately 160 mgd is being withdrawn from the aquifer for municipal supply. This demand is reflected by water levels in well S-329 located near the Ft. Lauderdale wellfield (Plate 2-8). The Ft. Lauderdale wellfield is currently pumping between 38 and 45 mgd with a potentiometric head in the vicinity of the wellfield of up to 1.5 feet below sea level (Plate 2-15). As evidenced by the westward migration of the saltwater front, continued reduction of groundwater levels could result in further progression of the front into the wellfield.

Groundwater Surface

The water table of the Biscayne aquifer is a fairly smooth surface which gently dips from the northwest to the southeast (Plates 2-6 and 2-7). This surface is strongly influenced by levees, canals, and drainage structures used for flood and drought control. Rainfall enters the aquifer directly through unsaturated sediments at various rates depending on the overburden, and this in turn results in fluctuations in the water table. Near the coast, groundwater and seawater meet in a dynamic interface, the location of which is a function of the freshwater head and differential densities between fresh and salt water.

In southwest Broward County the highest groundwater elevations, in excess of eight feet above sea level are located in the Water Conservation Areas where water levels are above land surface for much of the year. East of the Water Conservation Area, groundwater levels are reduced to less than six feet by levees L-33, L-35 and L-37 and by drainage structures S-34, S-30 and S-9 to prevent flooding. From the levees the water table generally dips to the southeast with low gradients ranging from 0.2 ft per mile during the wet season to 0.1 ft per mile during the dry season. Steeper gradients occur along the canals and adjacent to wellfields with maximum gradients occurring near the major structures S-9, S-34, S-13A and Sewell's Lock.

Groundwater levels can fluctuate by several feet in short periods of time in response to rainfall. The relationship between rainfall and short term water level changes has not been studied in detail in the south Broward area. Parker (1955), studying the effects of rainfall and the water table in muck soils at the Dade-Broward county line east of State Highway 25, measured a 0.82 ft rise in the water table following a 2.7 inch rain and calculated the ratio of recharge to water level rise as 0.27. The raingage station used to measure the rainfall was located 1.5 miles south of the test well. Parker suggests that because the study involved an intense short term storm more rain may have fallen at the test site which would result in a higher recharge ratio. In comparison, Parker noted a higher recharge rate in oolitic limestones where a 6.95 inch rainfall resulted in a 2.54 ft rise in the water table. After estimating 1 inch of rain would be held by the 4.5 ft of unsaturated overburden, the ratio of recharge to water level rise was 0.19. This would indicate that in regions covered by muck soils much of the rainfall is lost as surface runoff. Thus, in regions where development requires the replacement of muck soils by borrow fill (mostly oolitic limestones for the study area) groundwater levels could rise more dynamically during storm events.

Because groundwater elevations are capable of rising several feet in a day, short term water level maps are not always representative of the average water table. The USGS publishes wet and dry season maps for Broward County based on data taken over a several day period in May and October. However, in order to provide a basis for future comparison, long term average elevations are presented in this report. The wet and dry season water level maps of the study area are shown on Plates 2-6 and 2-7. Water level data analyzed in the production of these maps were based on daily observations taken from February through April and July through September from 1974 to 1981. Contour lines are generalized and do not reflect influences by secondary canals from which there is little available data. Water level contours in the northwestern quadrant of the C-11 basin are approximate due to the lack of data in the region.

Historical data from six wells within the study area are shown in figures 10 through 14 (Appendix A). Average water levels are shown along with maximum and minimum values for each year. Land surface elevations shown on the figures indicate local ambient topographic elevations in the vicinity of each well based on survey data and do not represent the elevation of the well itself. Data from G-2034, G-1637 and G-1222 indicates at least one flooding event every year. All three of these wells are located in the southwestern quadrant of the study area which is characterized by low topography and high groundwater levels. The relationship between topography and average groundwater elevations is shown on Plates 2-9 and 2-10 as isopachs of the unsaturated zone. These maps were produced by combining the long term average water levels with the topographic surface map. The stippled areas are prone to flooding especially during the wet season. Although there are no data on groundwater levels in the northwestern quadrant of the C-11 basin, inspection of the area indicates frequent flooding along SR 27 during the wet season. It is not known whether the standing water is due to poor infiltration capabilities of thick low permeable soils or high groundwater levels.

The extent in which canals affect groundwater levels is reflected in the mean water levels between 1974 and 1981. During this period, there was a 15%

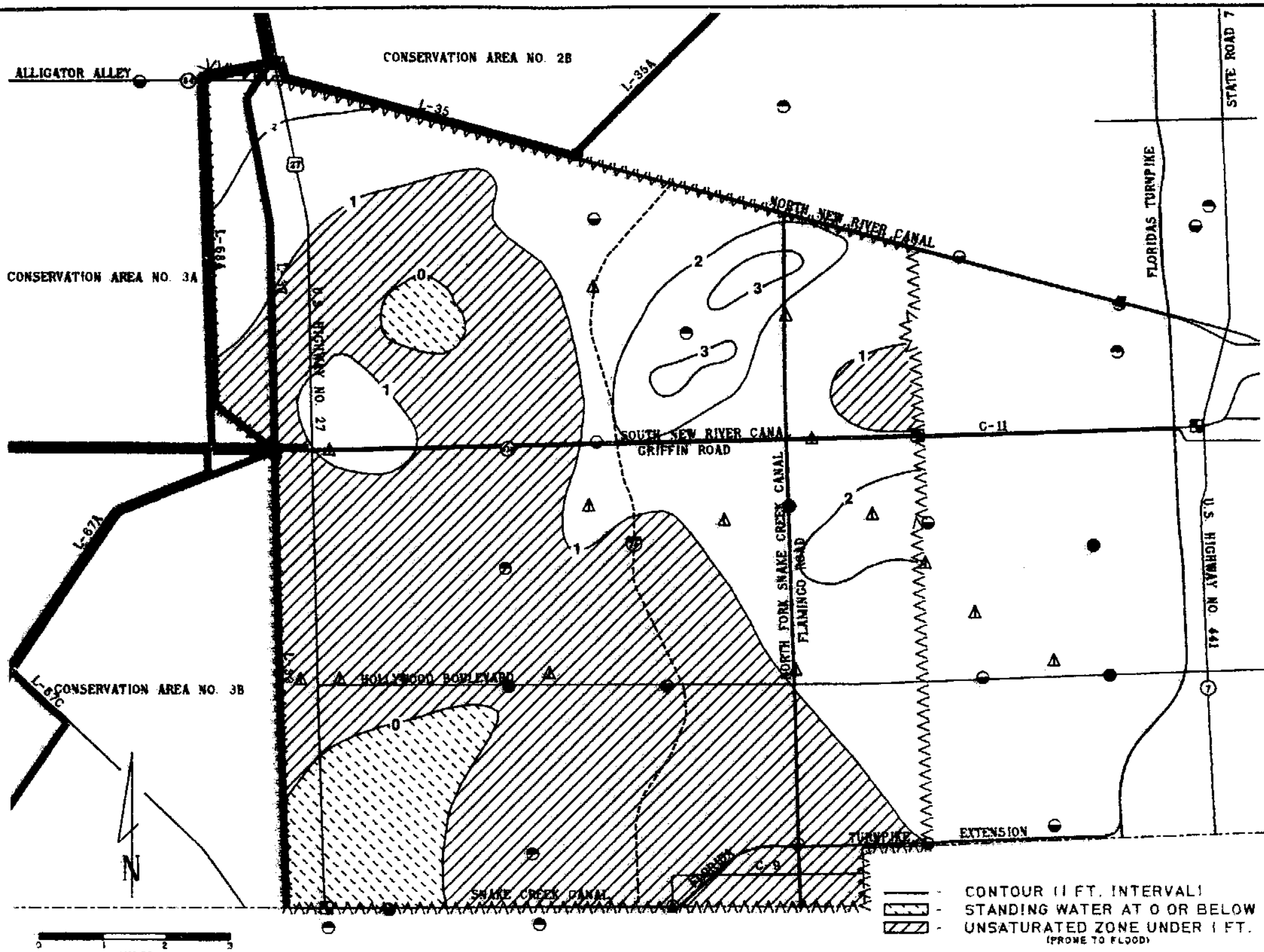


PLATE 2-9 MEAN THICKNESS OF UNSATURATED ZONE, DURING WET SEASON, 1974-1980: Of The S.W. BROWARD STUDY AREA

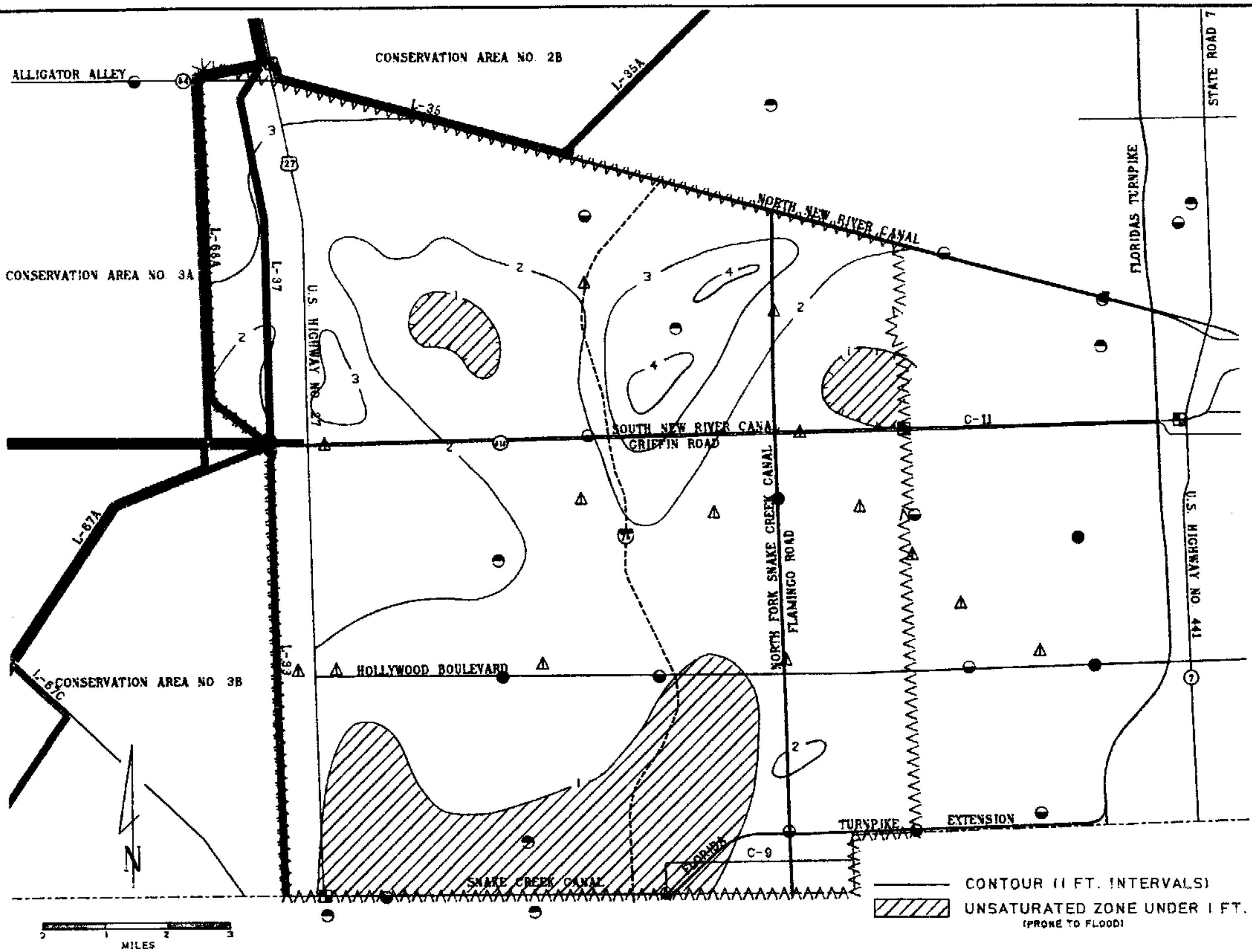


PLATE 2-10 MEAN THICKNESS OF UNSATURATED ZONE, DURING DRY SEASON, 1974-1980: Of The S.W. BROWARD STUDY AREA

deficiency in rainfall which peaked in 1981 when rainfall was approximately 20% below average. During periods of drought, water is discharged by gravity from the Water Conservation Area into the C-9 basin to elevate groundwater levels. As a result, mean water levels in the study area do not always reflect the lack of rain. Two stations, G-2034 and G-617 show a decline in mean water levels. These two stations are both removed from any primary control canals and do not receive large amounts of canal recharge. Of the remaining wells which show no relationship to the decline in rainfall, two wells, G-1637, located just south of C-9 at S-20 and G-1225 actually show an increase in groundwater levels during the 1981 drought.

The relationship between freshwater and seawater was originally quantified in the Gyben-Herzberg Principle. This theory is based on the difference in specific gravity between fresh and sea water where a 41 feet column of freshwater is needed to balance 40 feet of seawater. This relationship has been used to estimate the location the saltwater interface based on freshwater elevations. Originally postulated for small islands and atolls of uniform permeability, the theory has only limited application on large land masses. However, the general principle that reduced freshwater heads in coastal regions provide the mechanism for landward migration of the saltwater front has been well documented (see Parker et al, 1955). This effect is seen in southern Broward County on Plate 2-15. During the 1981 drought, the location of the saltwater interface was measured by the saltwater intrusion monitoring network. Groundwater elevations shown were taken on May 11 through 15 (Hull, 1981). Due to depressed groundwater levels throughout south Broward, seawater had moved inland far enough to affect water quality of the Hallandale Wellfield and was encroaching on the Hollywood and Dixie Wellfields. Although direct seawater influx does not pose a likely threat to the study area, increased pumpage from wellfields needed to provide water for increasing populations combined with similar drought conditions of 1971 or 1981 could pose a substantial threat to the easternmost wellfields.

WATER QUALITY

The groundwater quality of the Biscayne aquifer is chiefly influenced by the solution of limestone and calcareous sand. Generally, the water is classified as a calcium bicarbonate type containing significant amounts of dissolved iron. The groundwater is hardest in north Broward and iron concentrations increase southwest and also with depth. Low concentrations of potassium and sulfate have been found where agriculture and residential lawn care requires the use of fertilizers (Klein, 1978). Nitrogen concentrations are also characterized as being low. At depth the total dissolved solid content and chloride concentrations increase which indicates less circulation from infiltration of rainfall and canal water. Concentrations of chlorides increase northwest where the aquifer is recharged with connate water from the North New River Canal. A major problem of municipal supplies is color. This is due to the thick organic peat soils in the Everglades and western Broward County.

Chlorides

The groundwater quality of the Biscayne aquifer has been monitored by the USGS at 19 different well locations within or in proximity to the study area. Water samples were analyzed at 11 well sites in 1974 located east of the Water Conservation Areas between the North New River and Snake Creek Canals. The remaining 8 sites were sampled in 1981 and are adjacent to the boundary of the study area. Wells prefaced with a 2100 series number represent data obtained in 1974. These wells have not been monitored continuously. Wells of the 2300 series indicate water quality data from 1981. Well locations and designation are shown on Plate 2-1.

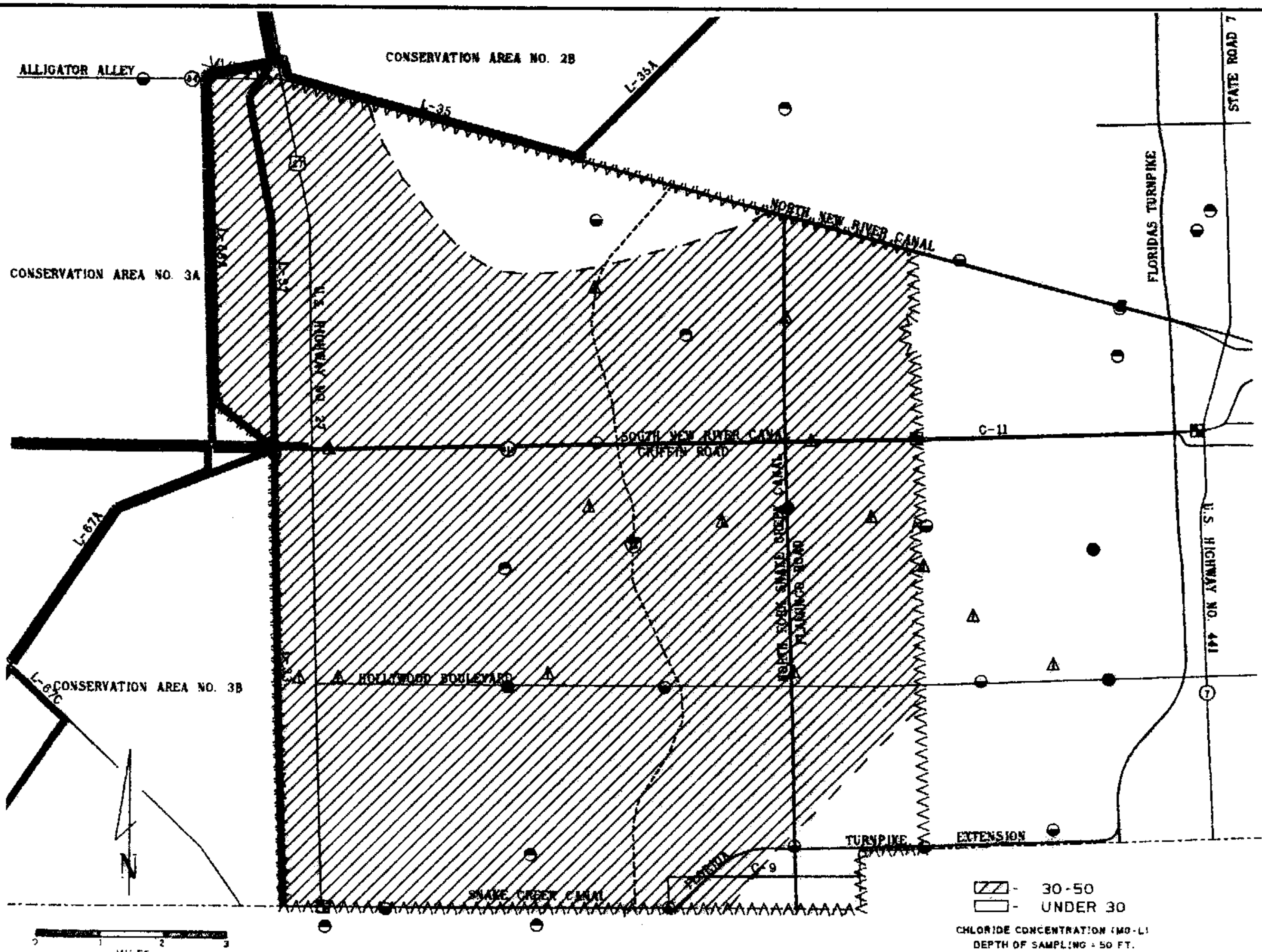


PLATE 2-11 CHLORIDE CONCENTRATION OF THE BISCAYNE AQUIFER, JULY-SEPT., 1974 Of The S.W. BROWARD STUDY AREA

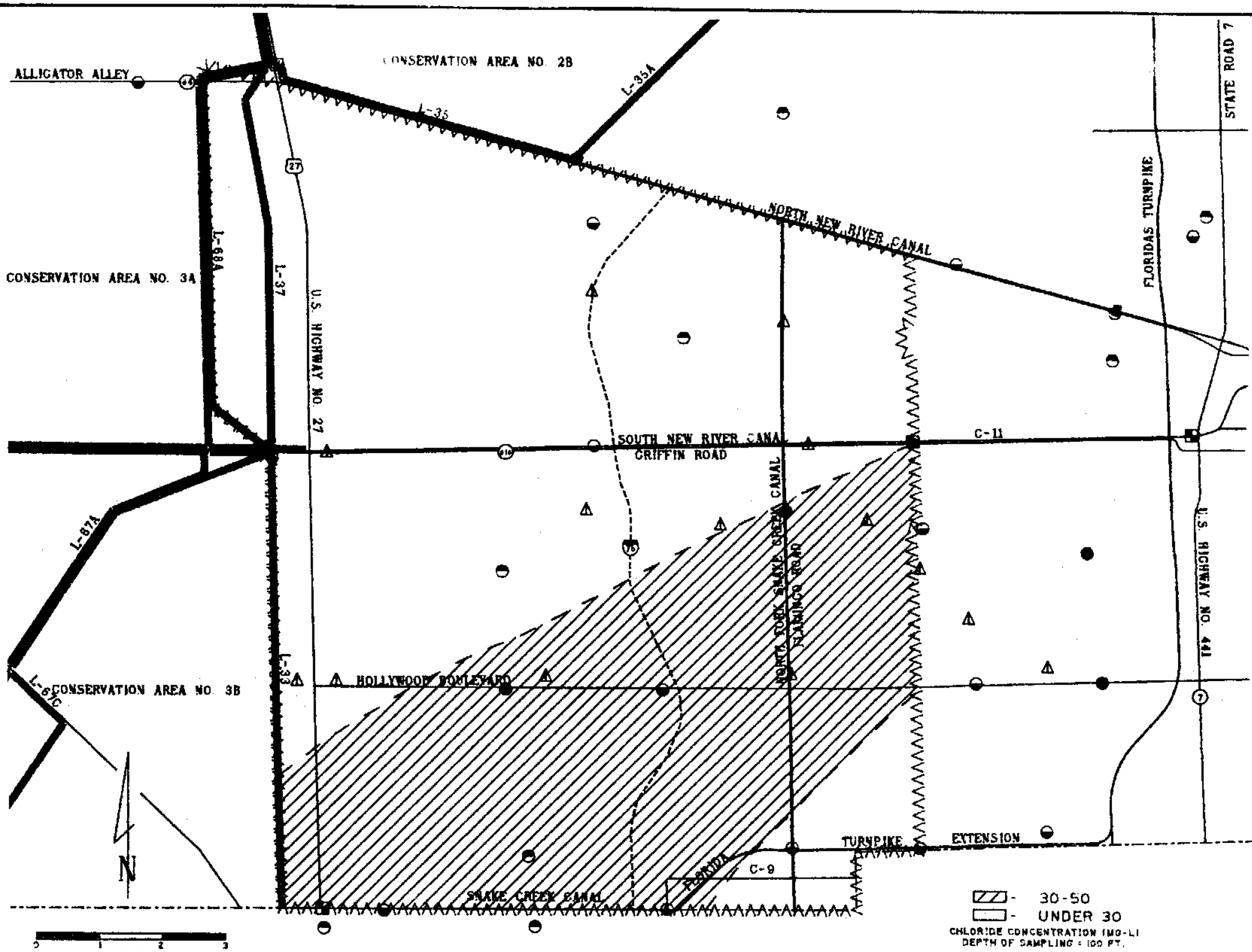


PLATE 2-12 CHLORIDE CONCENTRATION OF THE BISCAYNE AQUIFER, JULY-SEPT., 1974
Of The S.W. BROWARD STUDY AREA

Chloride concentrations are found in almost all natural waters. They may be derived from 1) natural mineral origin, 2) water that has been trapped in sediments during deposition or connate water, 3) sea water intrusion, 4) salts for agricultural purposes, 5) human and animal sewage, or 6) from industrial effluent. The acceptable chloride content for potable water is 250 mg/l. Measurements of chloride concentration (mg/l) were collected for all wells.

Illustrated in Figures 15 to 22, are the chloride concentrations and specific conductance for the 2300 series wells with depth. Values were obtained at 10 feet intervals and generally, both parameters increase with depth. High salinity values are associated with basal sediment zones of low permeability which are mostly composed of fine sands and silt. Zones of low permeability impede circulation and thus mineralized water is not easily flushed from the aquifer. Such zones are found intermittently throughout the aquifer; however, it is the basal sediments that most consistently contain the highly mineralized water. Permeable beds are associated with good circulation and generally result in low chloride concentration. Areas of high permeability are associated with the solution riddled limestone and sandstone lithologies. Figures 15, 16 and 17 depict chloride content for wells G-2327, G-2311 and G-2319 respectively. Concentrations at total depth within these wells approach values representative of the salt water interface (1000 mg/l, see Plate 2-15). However, the source of these high chlorides are associated with connate or mineralized water of the moderate to low permeable basal sediments of the aquifer rather than intruding salt water from the ocean.

Plates 2-11 and 2-12 illustrate the 1974 chloride concentrations of the 2100 series wells at depths of 50 and 100 ft respectively. Water quality is very good at both depths, however, concentrations at the 50 ft depth are slightly higher than at 100 ft. This small increase may be due to salts percolating from agricultural areas. Greater concentrations from this source

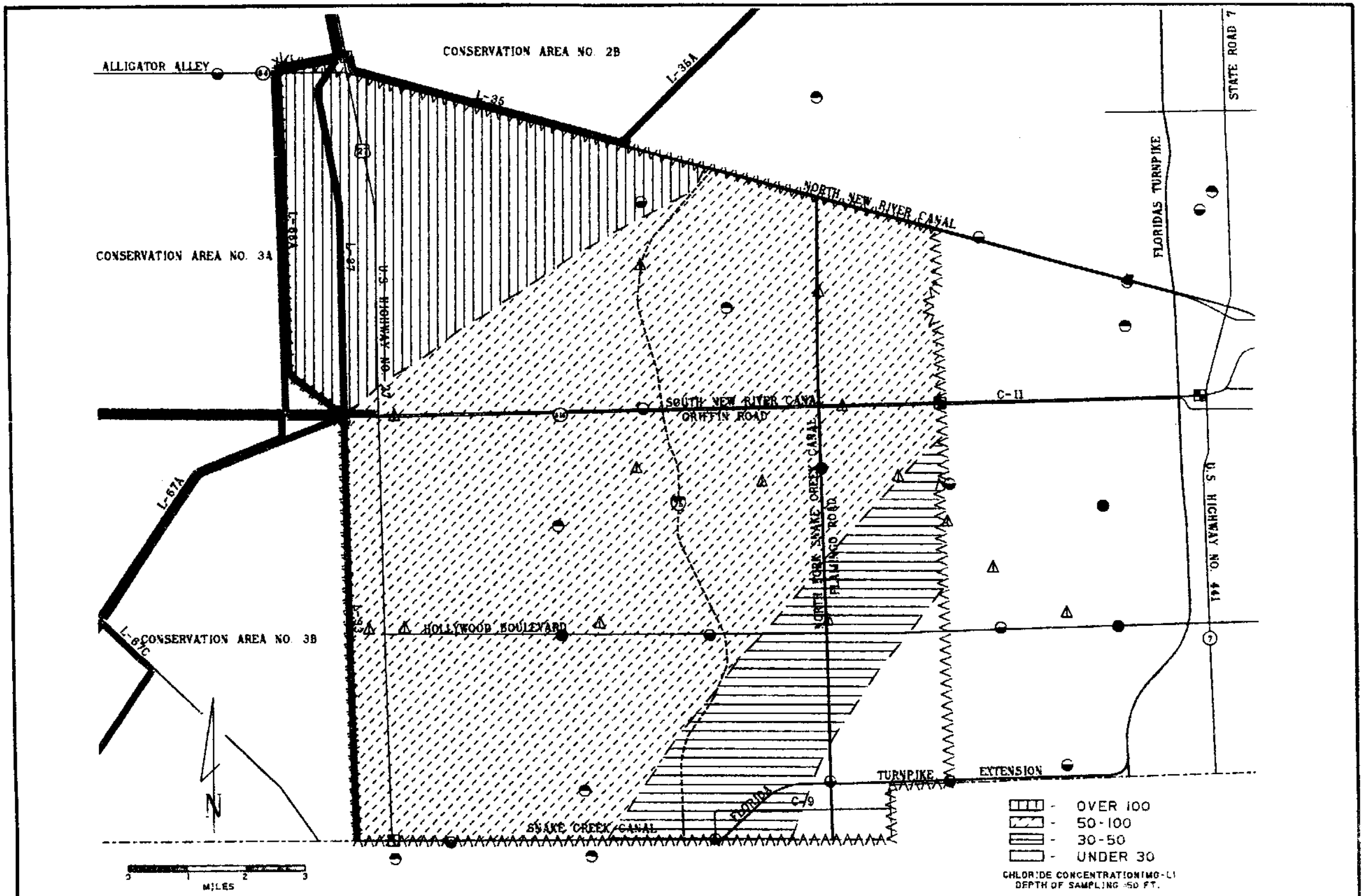


PLATE 2-13 CHLORIDE CONCENTRATION OF THE BISCAYNE AQUIFER, MAY-JULY, 1981 Of The S.W. BROWARD STUDY AREA

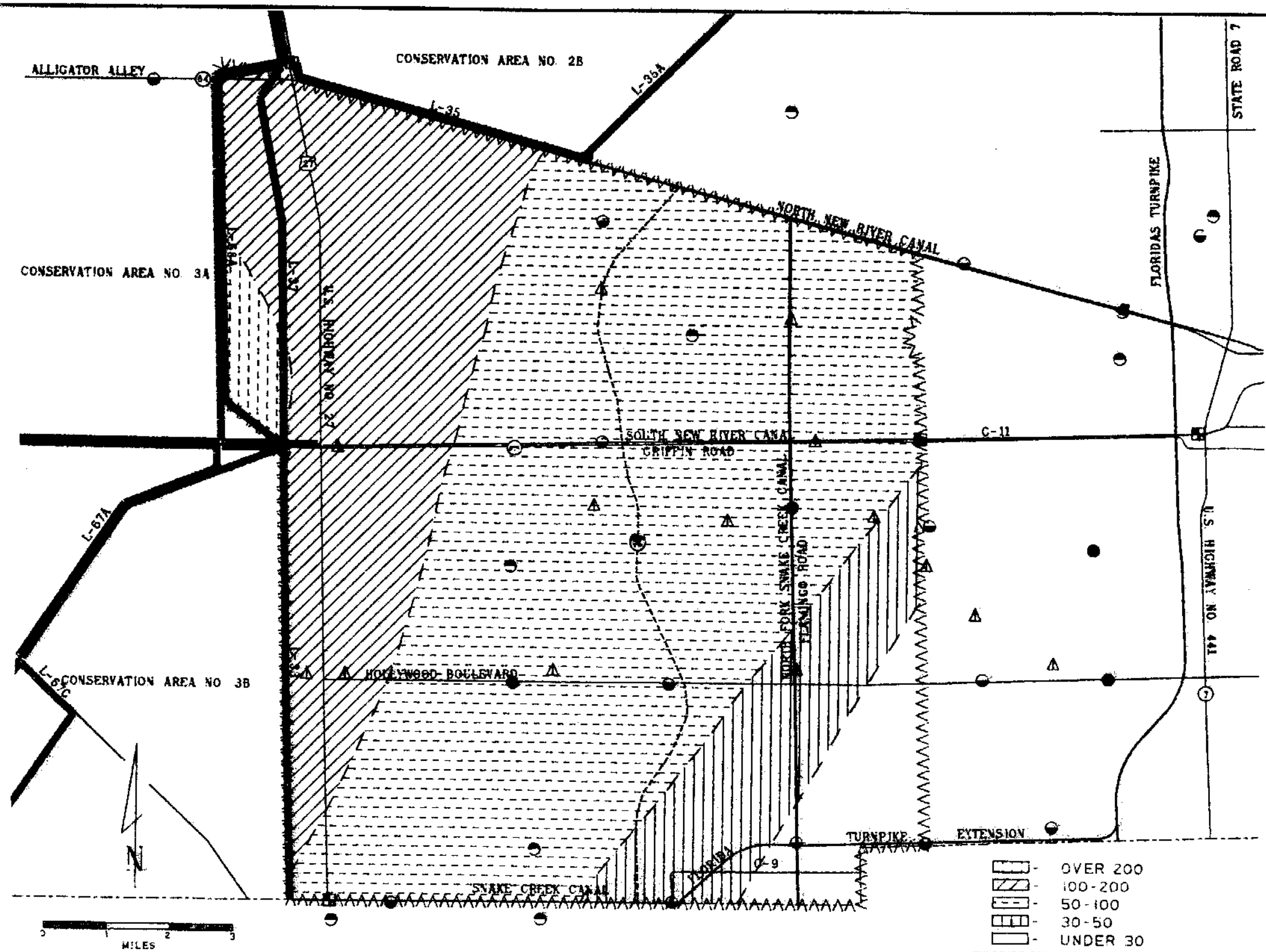


PLATE 2-14 CHLORIDE CONCENTRATION OF THE BISCAYNE AQUIFER, MAY-JULY, 1981 Of The S.W. BROWARD STUDY AREA

would occur at shallower depths since there would be less dilution. Concentrations shown on either map do not exceed 50 mg/l which is well below the recommended limit set for drinking water standards.

The 1981 chloride data was obtained from the 2300 series wells and is shown in Plates 2-13 and 2-14 for depths of 50 feet and 100 feet respectively. The average salinity value for the 100 foot depth is approximately twice as high as the chloride concentrations found at the 50 foot interval. Chloride concentrations at either depth are consistently higher than the concentrations for 1974. At the 100 feet depth the average salinity value for the 2300 series wells is 5 times higher than the average value of the 2100 series.

In part, location and sample depth of several 2300 series wells is responsible for the apparent increase in salinity to the west. At a depth of 100 feet wells G-2321, G-2319 and G-2311 penetrate the basal region of the aquifer. Hence, high salinity is due to the connate mineralized water of the moderate to low permeable beds near the base of the aquifer. Plate 2-14 illustrates that chloride concentrations increase to the west at the 100 foot interval. The increase is associated with the thinning of the aquifer in this direction. At a depth of 50 feet, these same wells are within the permeable regions of the aquifer and salinity values are lower. At depths less than 50 feet a significant decrease in chloride concentration is not observed (see Figure 15 to 22, Appendix A). An increase in salinity to the west is also observed at the 50 foot interval.

Hydrologic conditions from 1974 to 1981 may have caused several sources of saline water to be actively recharging the aquifer. Over a period of 8 years rainfall was less than average for the study area and as a result, groundwater levels declined in those areas not influenced by canal recharge. Figure 13 (Appendix A) shows a drop in the mean water level for well G-617 from 1974 to present. A corresponding increase in chloride concentrations for

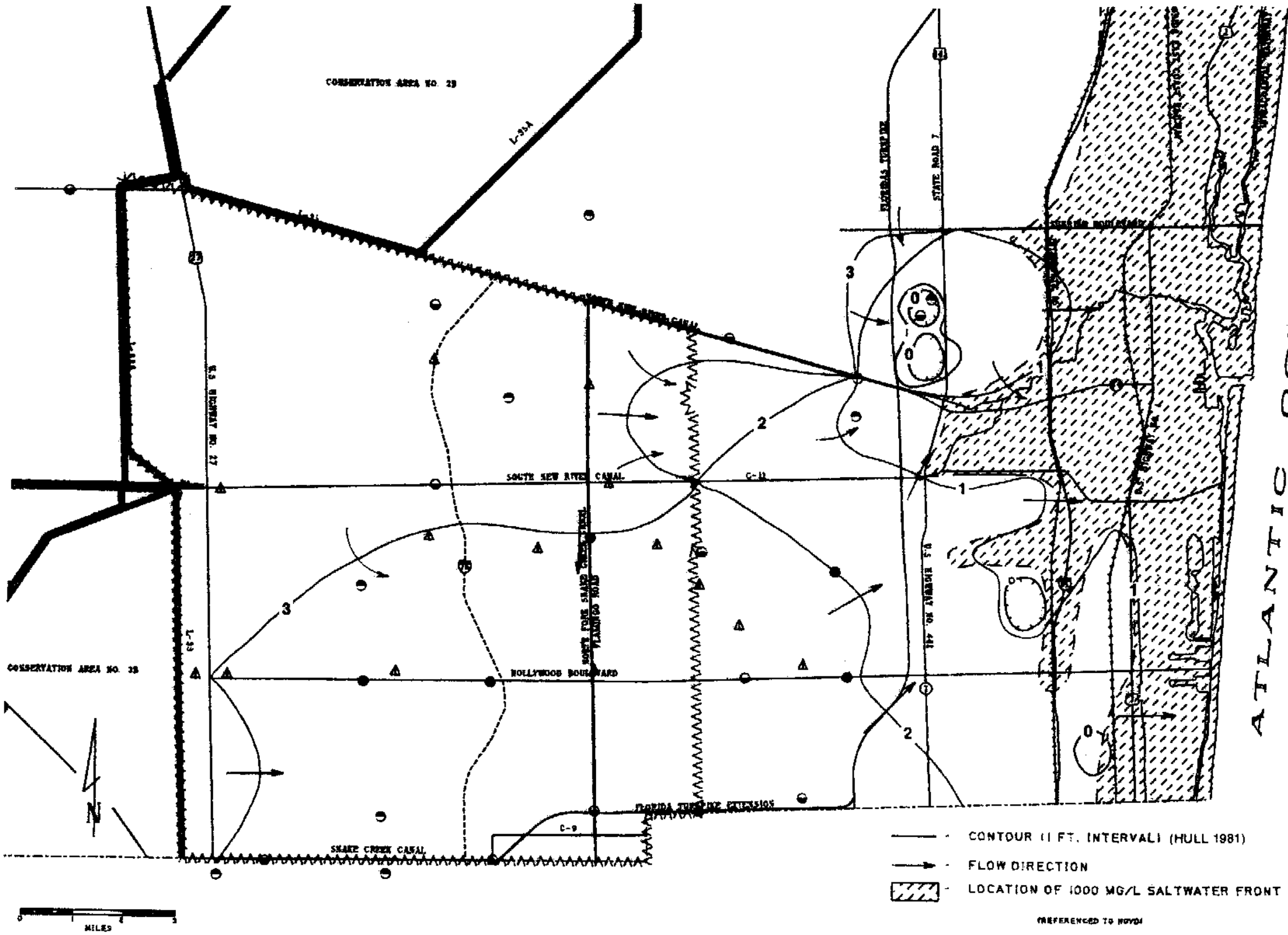


PLATE 2-15 LOCATION OF SALTWATER INTERFACE WITH RELATION TO GROUNDWATER LEVELS FOR MAY 11-15, 1981 Of The S.W. BROWARD STUDY AREA

this same period is shown in Figure 23 (Appendix A). However, elsewhere in the study area groundwater levels showed little change during the drought due to the influences of controlled canals which supplied major recharge to the basin. Klein (1978) notes that during low groundwater levels the North New River Canal receives recharge from connate water within its upper reaches. Millar (1981) studying water quality in the Water Conservation Areas noted elevated chloride concentrations in the southern portion of 2-A and the eastern portion of 3-A. The average chloride values taken from S-34 located on the North New River Canal near US 27 during 1981 was 102 mg/l. An average of 92 mg/l was measured at S-9 during the same period. Water quality data for the upper 50 feet of wells 2319 and 2311 located near S-34 and S-9 respectively compare closely to the chlorides measured in the canals suggesting that a portion of the increase in chloride concentrations between 1974 and 1981 can be attributed to recharge from canal water.

An analysis of groundwater quality data suggests that an increase in chloride concentrations originate from the west. Mineralized water from the New North River Canal and possible upward migration of connate water due to lower freshwater heads appear to be responsible for this increase. A comprehensive knowledge of groundwater levels and quality as the area developes necessitates a continuous network of monitoring wells in order to identify both long and short term fluctuations or trends. This is especially true for the western C-11 basin where groundwater data are scant.

Nutrients

Nutrients examined in the study area were limited to nitrogen and phosphorus species. While both nutrients are essential to aquatic life, an overabundance will result in eutrophic conditions. High concentrations are associated with sewage effluent, runoff from fertilized areas and organic soils.

The composition of nitrogen is dependent upon the availability of water. Waller (1978) explains that when the water table is artificially maintained several feet below ground surface, an oxidizing environment is provided and much of the nitrogen is in the form of nitrate. In groundwater, the nitrogen composition near the Rolling Hills development differ from that found near the Water Conservation Areas. The developed area had a higher concentration of nitrate which is attributed to a low water table and the use of lawn fertilizers. In contrast, the Water Conservation Areas are wet during much of the year such that a reducing environment is present. Organic soils decompose slowly which results in a total nitrogen content composed of primarily organic nitrogen and ammonium.

Within the study area concentrations of the nitrogen species have remained fairly constant, indicating no significant point source (Waller, 1978). In both the C-9 and C-11 basins, nitrogen concentrations are characterized as low.

In south and central Florida 80 percent of the total phosphorous loading is in the form of inorganic orthophosphate (Goolsby, 1976). In the western C-11 basin the average orthophosphate concentration was 0.01 mg/l and a high of 0.03 mg/l at S-13A (Waller, 1978), the higher concentrations were associated with agricultural areas. Concentrations in groundwater are low because of the contact with limestone. Waller (1978) explains that most of the orthophosphate is complexed with calcium ions that chemically bind the phosphate in the limestone, thus stabilizing its level in groundwater.

Synthetic Organic Chemicals

Of the many synthetic organic chemicals (SOC) investigated in previous studies, only a few have been detected. Pesticides can be classified as being soluble or insoluble in water. Soluble pesticides include 2-4-D, silvex and methyl parathion and are relatively mobile in groundwater. Insoluble pesticides include DDD, DDE, DDT, dieldrim, chlordane, and PCB. Previous investigations note insoluble pesticides concentrate in lake and canal bottom sediments.

Pesticides in groundwater at the Davie landfill consisted of silvex at a concentration of 0.3 ug/l and lindane at 0.2 ug/l (BCEQB, 1981b), trace amounts of 2, 4-D were rarely found at the landfill (Mattraw, 1976). Concentrations of these pesticides were within EPA drinking water standards.

Pesticides were rarely found in groundwater throughout the study area and when detected were in concentration well below the EPA standards.

Heavy Metals

In south Florida trace metals tend to remain in close proximity to their source. The general physical-chemical characteristics of trace metals tend to limit their solubility in waters having a high pH. The geology of the Biscayne aquifer ensures a high pH because of it calcium carbonate content (Goolsby, 1976). Arsenic, Cadmium, Chromium and Lead were found to have concentrations in groundwater less than NIPDWS (National Interium Primary Drinking Water Standards) from sources at the following distance and depth from the respective sites: the Davie landfill at a distance of 50 feet and a depth of 10 feet (Mattraw, 1976); the NE Broward County site at 60 feet and a depth of 26 feet (Pitt, 1975); at a 50 foot distance from the I-95 and SR-836 interchange and a depth of 20 feet (Beaven and McPherson, 1978); and, less than 20 feet from septic tanks at a depth of 10 feet. In addition, adsorption to organic material, dispersion and dilution further reduce trace metal concentrations below drinking water standards.

WATER RESOURCE AVAILABILITY

Despite restrictive zoning which limits development to 1.7 dwelling units per acre (BCPC, 1981) build out populations within the study area will account for 42 percent of the total population increase projected for all of Broward

County from 1980 to the year 2000. The 1980 population figure of 35,330 for the study area is expected to increase to 330,080 upon build out for an increase of 934 percent (Kelly Carpenter BCOP; written communication, 1982). Currently there are six utilities that service the study area; Pembroke Pines, Miramar, Davie, and Sunrise Systems 1, 2, and 3. At an estimated consumptive use of 135 gallons per capita day (based on mean current per capita usage), water requirements for the built out population will exceed 44.5 mgd for the study area alone. This represents an increase of 39 mgd over current use. In addition, growth outside the study area will continue to tax existing facilities to the east resulting in the necessity to develop new wellfields to the west away from the influences of seawater encroachment.

The availability of groundwater needed to supply these increased demands is somewhat limited in the study area due to geologic constraints. Development of wellfields in the western regions of the C-9 and C-11 basins is restricted by both the thinness of the aquifer and by the presence of brackish connate water in the underlying basal sediments. The resulting transmissivities are low and moderate pumpage could result in upconing of saltwater from the west. Although the aquifer is thicker in the northeast, increased percentages of fine sands reduce transmissivities to less than 1 mgd/ft and large scale development would result in large cones of influence. Additionally, industrial land use is proposed primarily along the I-75 corrider. Some industrial land uses generate pollutants which can jeopardize potable water supplies, especially if located within the cone of influence of a wellfield.

Perhaps the most favorable area for freshwater production is in the southern region of the study area, east of I-75. The aquifer is both thick and transmissive and readily recharged by the wetlands of the C-9 basin and the Snake Creek Canal. It is recommended that the studies required for the placement of future wellfields commence prior to further development in order to prevent additional limitations on those regions best suited for freshwater supply. Additionally, a cone of influence ordinance, and revised industrial use zoning categories can be undertaken. These and other means of wellfield protection are necessary to ensure adequate water supplies for the residents of Broward County.

As development progresses, water quality within the study area will be subjected to the influences of waste disposal, surface runoff loadings, and industrial contaminants. These influences will result in increased amounts of diversified contaminants reaching the Biscayne aquifer. Natural processes within the aquifer result in the elimination of many pollutants by means of dispersion, dilution, filtering, and chemical modification. The results of these effects have been noted in several studies in Broward and Dade Counties where high density regions have maintained groundwater integrity (with the exception of saltwater intrusion). Specific sources and types of contaminants which may develop in the study area cannot be predicted; however, comprehensive monitoring programs in addition to appropriate restrictions, will be necessary to protect water quality.

Currently, virtually all the solid waste generated in south Broward and parts of Dade County is processed at the 180 acre Davie landfill which is owned and operated by Broward County. At current usage the landfill is expected to reach capacity by early 1984 and as a result, Broward County is currently evaluating possible sites within the study area to provide for future solid waste disposal. The impact the new site has on groundwater depends primarily on the design and construction of the landfill, thickness of unsaturated sediments between the aquifer and the landfill, vertical and horizontal permeability of the aquifer, type and volume of waste, duration of disposal, absorbant properties of the geologic formation, and the local hydraulic gradients (Klein, 1978).

Political, geologic, and hydrologic conditions within the study area limit the possible locations for extensive landfill development. The average thickness of the unsaturated sediments is shown on Plates 9 and 10. The zone of unsaturated sediments provide some degree of filtering action against contaminants prior to entering groundwater. The region of thickest sediments occurs in the northeastern quadrant of the C-11 basin north of the existing Davie landfill. Major portions of the C-9 basin, while not influenced by large scale development, are prone to frequent flooding due to high groundwater levels. This, combined with the high density of borrow pits which provides direct recharge to the Biscayne aquifer, could result in overland distribution of pollutants and a direct contamination of the aquifer. While the western boundary of the study area has the lowest potential for wellfield development, only the northern reaches of the C-11 has a significant amount of unsaturated overburden to provide filtering. While it is advantageous to select a site with significant amounts of unsaturated overburden, impermeable lined pits built on several feet of unsaturated borrow fill could allow for safe development in wet areas when accompanied by facilities to collect leachate with subsequent treatment.

Average water level elevations are shown on Plates 2-6 and 2-7. The most obvious restriction that the water table surface places on waste disposal is in those areas where public water supply wells exist or are planned. The enactment of a Cone of Influence Ordinance however would limit potentially harmful development in these regions. Regions immediately north of the South New River Canal near S-9 are strongly influenced by hydraulic gradients initiated by backpumping at S-9. For this reason landfill development in this region should be restricted. If pumpage of the backpumping facility at S-34 were to be increased, a reverse in existing gradients in the northwest portion of the C-11 basin would further restrict landfill development in this region.

In addition to careful site location, design and construction, the physical characteristics of the aquifer affect the development of leachate plumes. The mobility of trace metals within the aquifer is restricted by high pH values which in turn are maintained through the presence of calcium. Phosphates associated with sludge and fertilizers form complexes with calcium and are not mobile for great distances. The most widespread pollutants are those which remain mobile in groundwater such as chloride, sodium, sulfate, and TDS; however, rapid groundwater flow plus recharge dilutes and disperses these complexes. The existence of a moderate to low permeable unit located between 30 to 50 ft below surface throughout the study area, may help to restrict the vertical migration of leachate. Low rainfall infiltration rates attributed to soil types currently may affect dilution and dispersion of leachate.

Due to efforts to regionalize wastewater treatment systems, the use of septic tanks will be restricted to those areas of very low density (2.0 dwelling units per acre or less) where it is financially infeasible to provide sewer systems. The extent to which low density septic systems affect groundwater quality within the study area is being investigated by the BCPC. Pitt (1975) in a study on septic tank effluent in Dade County, attributed dispersion, solution and chemical processes in restricting effluent to a maximum depth of 20 feet for 65 water quality parameters. Despite the limited impact of effluent noted in Pitt's study the use of septic tanks within the cones of influence of major wellfields should be restricted as a precautionary measure.

The impact of stormwater runoff on the quality of groundwater represents a potential threat to those regions where on site water retention lakes are required. The quality of stormwater runoff varies widely with land use. Due to the lack of filtering effects by surficial soils such water directly recharges the aquifer. Weinberg, et al., 1980, in a study in north Broward noted that runoff water quality in urban areas is typically high in Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nutrient loads (from lawn and garden fertilizers) heavy metals, Cl^-, TDS, and petroleum based pollutants. An increase in most of these parameters was noted downgradient from the lake as compared to groundwater upgradient however the extent of the contaminants could only be identified in the immediate vicinity of the lake. There was "no indisputable evidence" that the lake was degrading groundwater quality for a significant distance downgradient. Weinberg (1980) found that lead was being concentrated in the bottom sediments of the lake but the study did not examine other metals. Miller (1978) studying the effects of bottom sediments in the Miami Canal found the sediments contained concentrations of metals, organic and inorganic carbon, nitrogen species, strontium, arsenic. However, traces of these compounds were not filtered out and were measured in the groundwater. Bottom sediments were most effective in removing insoluable pesticides such as DDD, DDE, DDT, dieldrim, chlordane, and PCB while only partially eliminating water soluble 2-4-D, silvex, and methyl parathion.

Currently the Broward County 208 Program is investigating potential groundwater quality impacts associated with stormwater runoff however actual impacts will probably not be clearly defined until development proceeds. Therefore the establishment of a comprehensive water quality network should be undertaken in order to identify and delineate contamination effects in and adjacent to residential and industrial developments.

CONCLUSIONS

Hydrogeologic data identified within the study area included lithologic descriptions, groundwater levels, water quality, soils and topography. The proposed land use plans prepared by the Broward County Planning Council were compared with the results of this analysis so as to identify the potential effects that development may have on the Biscayne aquifer.

The topographic relief in the C-11 basin ranges from 4-7 feet NGVD. Within the C-9 basin the average land elevation is 4 feet NGVD. Lack of slope coupled with the poor drainage capabilities of the soils results in standing water for much of the area. Groundwater levels for the period of 1974 to 1980 were averaged for both wet and dry seasons. The data represents the mean hydrologic conditions which can be expected to reoccur. A comparison of the topography and groundwater elevations indicate that large areas are prone to flooding in the south western area of the study.

The Biscayne aquifer consists of highly permeable carbonate and clastic sediments. Adjacent to the Water Conservation Areas the aquifer is approximately 60 feet thick and therefore its transmissivity is limited. The thickness of the aquifer ranges from 140-160 feet along the eastern border. To the north the transmissivity is approximately 1 mgd and increases to the south to over 3 mgd.

The basal portion of the aquifer consists of moderately low permeable sediments which contain brackish water. A comparison of the 1981 groundwater quality data with that of the 1974 indicates an overall increase in chloride concentrations which originate from the west. Brackish water from the upper reaches of the North New River Canal and upward migration of connate water during low groundwater levels may be responsible for this increase.

The bulk of the recharge received by the aquifer is provided by rainfall, inflow from major canals, and seepage across L-33 and L-37. Over the period of 1974 to 1981 rainfall has been approximately 15% less than average. The deficiency in rainfall may have lowered groundwater elevations in areas not readily recharged by the major canal systems. Water levels in the canals are maintained by structures S-34, S-9, and S-30 on the west and to the east by Sewell's Lock, S-13A and S-29. During drought conditions water is released from the Water Conservation Areas and held in the basin to elevate groundwater levels and to prevent saltwater intrusion. Backpumping facilities exist at S-9 which pump excess water to the Water Conservation Areas for storage during periods of surplus water.

Physical and chemical characteristics of the aquifer limit the mobility of many contaminants. Examination of the water quality data available showed nutrients and trace metals to be generally below EPA drinking water standards. Color and dissolved iron frequently exceeded EPA standards for much of the study area. The effect of increased loading associated with development can not be quantified.

The projected potable water requirements for the study area will exceed 44.5 mgd. Water will be provided by either private or municipal systems. Hydrogeologic conditions within the study area limit the location of large wellfield withdrawals. However, the southern region east of the I-75 corrider appears favorable for freshwater production. The aquifer is both thick and transmissive within this area and can be readily recharged by the Snake Creek and North Fork Snake Creek Canals.

RECOMMENDATIONS

1. The existing groundwater quality and groundwater elevation monitoring network should be reevaluated and expanded to provide data in those areas where development will impact groundwater. The existing groundwater quality network should be sampled on a regular basis and expanded into those regions where data are currently unavailable. Specific monitoring programs should be designed to monitor the effects of retention lakes, borrow pits, landfill and inudstrial waste sites on the aquifer. Such data would be useful in evaluating the efficiency of best management practices.

2. Specific planning to protect the groundwater resources of the study area should be undertaken prior to further development. Concepts which should be evaluated include:

   a. Broward County should initiate a program to evaluate those regions in the study area with potential for wellfield development. Such studies should include more detailed assessments of both water quality and population to be served by the system as well as site location. Consideration of a diverse system consisting of several small wellfields versus one large regional facility should also be examined.

   b. In order to maintain the integrity of the aquifer in the vicinity of new and existing wellfields a Cone of Influence ordinance should be developed and implemented. This ordinance would act to restrict those types of developments which adversely effect the quality of water in those areas influenced by wellfield development.

   c. The design of storm water retention lakes, borrow pits or any other drainage system which exposes the Biscayne aquifer to direct surface water recharge should incorporate best management practices in order to restrict the amounts of contaminants entering the groundwater system.

d. Current industrial zoning categories contained in the zoning code should be reevaluated based on water resource impacts.

e. Landfill sites should be evaluated with consideration to the thickness of unsaturated sediments. Landfill design should incorporate impermeable liners with leachate collection and treatment facilities to prevent contamination of the aquifer.

f. The County's proposed study should be undertaken to determine the effect of septic tanks on the study area.

3. Specific data on aquifer hydraulic characteristics should be developed through aquifer tests. An evaluation of potential upward movement of connate water from the base of the aquifer should be incorporated in this study. A mathematical model utilizing these data would provide the basis for wellfield designs and permit evaluation.

CHAPTER 3. QUANTITATIVE HYDROLOGICAL EVALUATION

INTRODUCTION

The principal objective of this computer simulation was to quantitatively evaluate the hydrological effects that the future land use patterns of the composite map would have on the southwest Broward region. This was a preliminary analysis to detect pre- and post-development impacts on the surface and groundwater system of the area. An integrated surface-groundwater model was applied to this region using a time step of one day and a spatial resolution of one-half mile. Three sets of computer runs were generated simulating past (1969-1971), present (1981), and future (maximum build out) land use conditions. Actual rainfall data from the years 1969 to 1971 were used because this period included a full spectrum of rainfall conditions ranging from the heavy rains of 1969 to the severe drought of 1971. Wellfield pumpage values were collected from the utilities in the south Broward region for the historical and present simulations, while future simulations were based on projected 1990 pumpage values. This study does not include the effects of new wellfield development that may occur.

Model Area

The designated Southwest Broward County Study area was expanded eastward to the coastline so that the effects the proposed development may have on eastern regions could be evaluated. Plate 3-1 depicts the locations of major discharge structures, groundwater gauges, the proposed Weston development, and one of the proposed borrow pits. Either stage or discharge hydrographs are available for all of these locations in Appendix B.

Data

In addition to the rainfall and wellfield pumpages, the initial water conditions and time invariant data defining the physical properties of the study area were input into the model. Average values for soil type, land use,

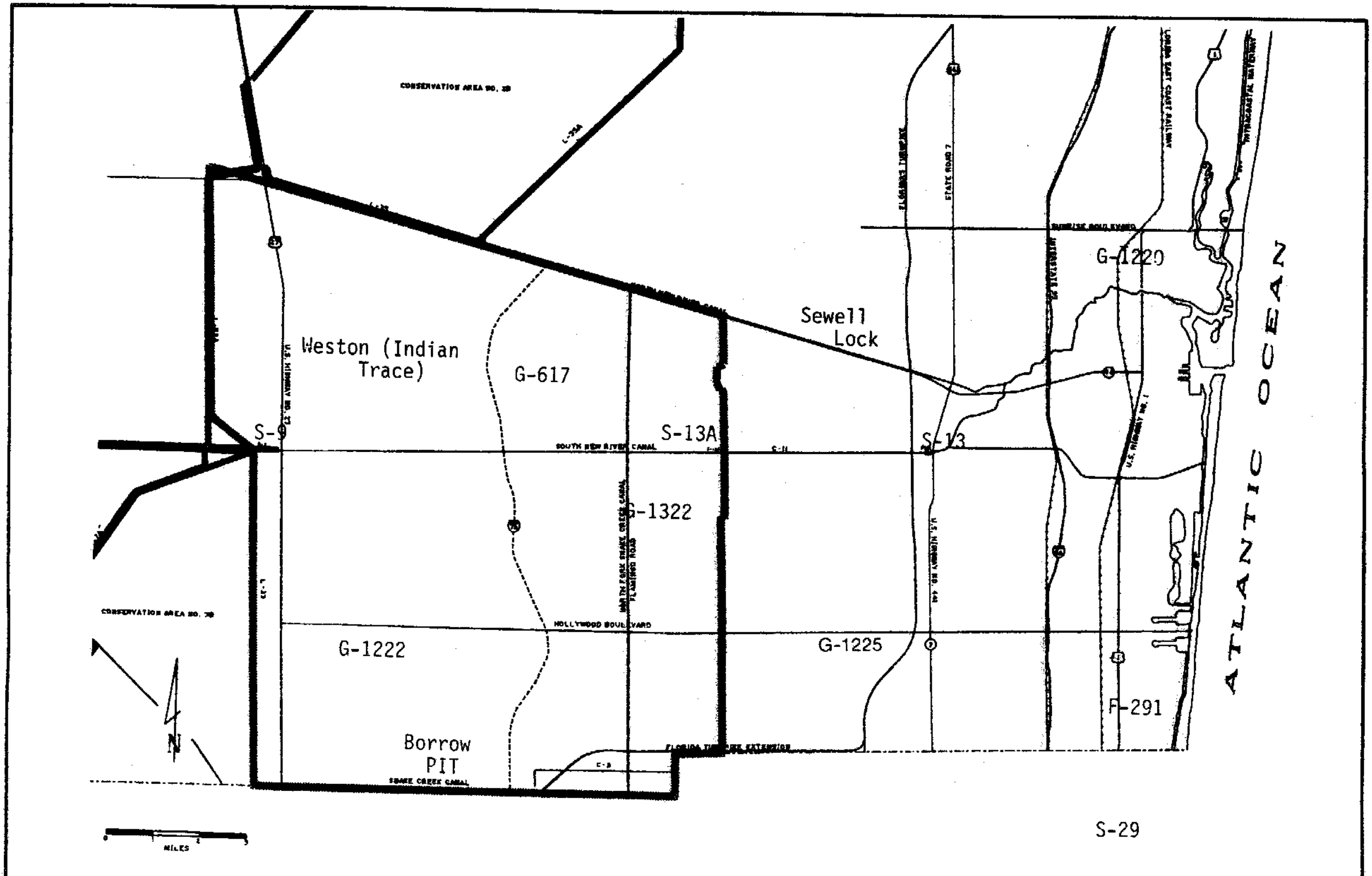


PLATE NO. 3-1 MODEL AREA

aquifer depth, permeability and topography were estimated for each quarter of a square mile area in the study area for each period simulated. Canal and levee locations were also digitized for each computer run. Finally, general regulation policies for each canal reach were incorporated to determine when discharges must be made throughout the canal network.

METHODOLOGY

1. Surface Water Computation

Initially, rainfall was added to the ponded depth at the beginning of each day. Infiltration to the groundwater system was then estimated based on the hydraulic conductivity of the soil. Infiltration amounts were limited by the amount of surface water ponded and the storage available in the subsurface system at each node. Finally, overland flow was computed using Manning's equation. This flow was assumed to act similarly to flow in a wide channel so that the hydraulic radius may be approximated by the average ponded depth. The roughness coefficient was considered a function of land use and average depth of flow. The equation used to compute the overland flow between nodes, is:

$$VOF = \frac{(1.49)}{(NL^{1/2})} H^{5/3} \quad (Hu-HD)^{1/2} \; DT/2$$

Where,

W = width of the calculated flow

n = Manning's coefficient and is a function of the use and of the flow depth

L = distance between nodes

H = depth of flow

Hu = average upstream stage above sea level

HD = average downstream stage above sea level

VOF = overland flow volume

Computations were made twice in each time step, in the north-south direction and in the east-west direction.

2. Evapotranspiration

The ET losses were estimated from potential ET (PET) and were a function of depth to water table. PET varies with land use and the time of year. The model uses 12 monthly PET values for each of four land use types: urban, agricultural, swamp, and vacant. Each land use has a shallow root zone (SRZ), and a deep root zone (DRZ) that are used to determine the actual amount of ET in the following way:

ET = PET when the water table is at or above the shallow root zone.

ET = zero when the water table is below the deep root zone.

ET = PET *(DRZ - DPH) (DRZ - SRZ) when the water table is between the shallow and the deep root zones where DPH is the distance from the land surface to the water table.

PET values along with the shallow and deep root zones values for each land use are shown in Table 1, Appendix B. ET quantities were subtracted from surface ponding if surface water was available, otherwise they were accounted for from the groundwater system.

3. Channel Flow Computations

The computations were made using an iterative, implicit scheme which determines the stage in the channel that will give a mass balance between upstream inflows and calculated outflows for each channel reach. The flow processes included in the model are:

a. Structure discharges which were calculated using a simple weir formula. The weir heights are adjusted seasonally in the model to simulate changes in regulation schedules during the wet and dry season.

b. Groundwater seepages into and out of the canal that were based on the hydraulic gradient between the canal and the groundwater system at each node of the canal.

c. Overland flows into and out of a canal which were based on the head between the canal system and the surface water system at each node.

4. Groundwater Computations

Groundwater flow rates were based on the finite difference approximation of the two dimensional transient equation for unconfined aquifers:

Where,

Tx = transmissivity values in the x direction.

Ty = transmissivity values in the y direction.

S = storage coefficient.

h = hydraulic head.

RCHG = net groundwater recharge due to wellfield pumpage, canal seepage, infiltration from surface ponding, and ET.

Model Results

Model results include areal contour maps of water levels in feet above sea level at the end of the wet season (October 31) and dry season (April 30) for the rainfall conditions corresponding to the period 1969-1971. These results appear in Appendix B for the past, present, and proposed future land use conditions.

Figures 1B, 2B, and 3B illustrate the regional view of the water table for past, present, and future land use conditions respectively, immediately after a heavy rainfall event. The coastal regions are practically at the same levels for all three conditions. This indicates future development of southwest Broward will not increase the potential for flooding along already developed coastal regions. Interior regions have lower water tables near the locations of the detention/retention areas and borrow pits. These areas provide additional storage for excess rainfall during storm events.

Figures 1E, 2E and 3E represent the regional views of the water table for the same sequence of land configurations after drought conditions have been prevalent for several months. The proposed future land use conditions show a greater drawdown near the coast because of the larger future well pumpage needs projected for the region. Water levels in the southwest region of Broward County are actually higher because of the presence of the borrow pits and detention/retention areas.

Stage hydrographs for present and proposed future land use configurations appear in Appendix B. Figures 4G and 4H illustrate that the water levels in future proposed borrow pits and retention areas respectively will be generally lower than those in the present groundwater system. Only during severe drought situations will water levels be higher in the future case.

Appendix B contains the discharge hydrographs for present and future conditions. Urbanization of southwest Broward County will cause a 15% to 20% increase in annual total runoff into the western C-9 and C-11 canals. In the C-9 basin, the increase in runoff is practically offset by the reduction of groundwater seepage so that only 1% - 2% increase in the annual total outflow occurs. However, in the C-11 basin, the increase in the hydraulic gradient induced by the proposed Weston development will increase groundwater flow from the Water Conservation Areas and the North New River Canal. A 10% increase in the amount of outflow occurs for the western C-11 basin.

Comparisons of discharge from the C-11 and C-9 basins for the present and proposed land use patterns are presented in Figures 5A and 5B, respectively.

CONCLUSIONS

Four major conclusions can be made from the results of this report:

1. Proposed detention/retention areas and borrow pits in southwestern Broward County will minimize the peaks and valleys in the stage

hydrographs of this region by providing additional storage in these locations to store excess water during the wet periods for use during the dry periods.

2. The Weston (Indian Trace) development will cause additional seepage from the Water Conservation Areas because of the lower control elevation planned for the proposed retention areas during the wet periods. This will cause an additional amount of water to be backpumped through S-9 into the Water Conservation Areas.

3. During dry periods, in spite of the additional storage provided by borrow pits and surface water management systems resulting from develoment in the study area, increased well pumpage along the coast will lower the groundwater table in the coastal region.

4. Proposed changes in southwest Broward County do not significantly influence water levels along the coastal region during periods of heavy rainfall; therefore, they will not contribute to additional flooding.

CHAPTER 4. SURFACE WATER QUALITY

INTRODUCTION

As part of the South Florida Water Management District's overall analysis of the impact of development in southwest Broward County, the Division of Water Chemistry assessed present surface water quality within the area. This evaluation of current water quality in the basins will be used as a baseline data set to compare estimates of future quality.

The primary objective of this analysis was to compare the water quality in this drainage basin with respective data for other south Florida canals and with existing water quality standards. In order to insure the validity of this comparison the data set had to first be examined for any areal or temporal differences which would preclude the use of single means for comparative analysis.

The ultimate concern is not only how the changes in land use and drainage patterns brought about by development will affect the surface water quality in southwest Broward but also, what impact these changes will have on Water Conservation Area 3A (WCA-3A) due to the projected increases in area runoff to be pumped into WCA-3A by the S9 (see Chapter 3).

Method of Analysis

The initial step taken by the Division of Water Chemistry was to assemble and tabulate all available water quality data within the predescribed boundaries for the period 1968 to present. Three agencies supplied data: the United States Geological Survey (USGS), the Broward County Environmental Quality Control Board (BCEQCB) and this agency - the South Florida Water Managment District (SFWMD). All water quality monitoring sites were located on, or in close promixity to, the two major canals which presently drain the area; the South New River (C-11) and Snake Creek (C-9) canals. Plate 4-1 provides a general base map for the area including surface water quality monitoring sites.

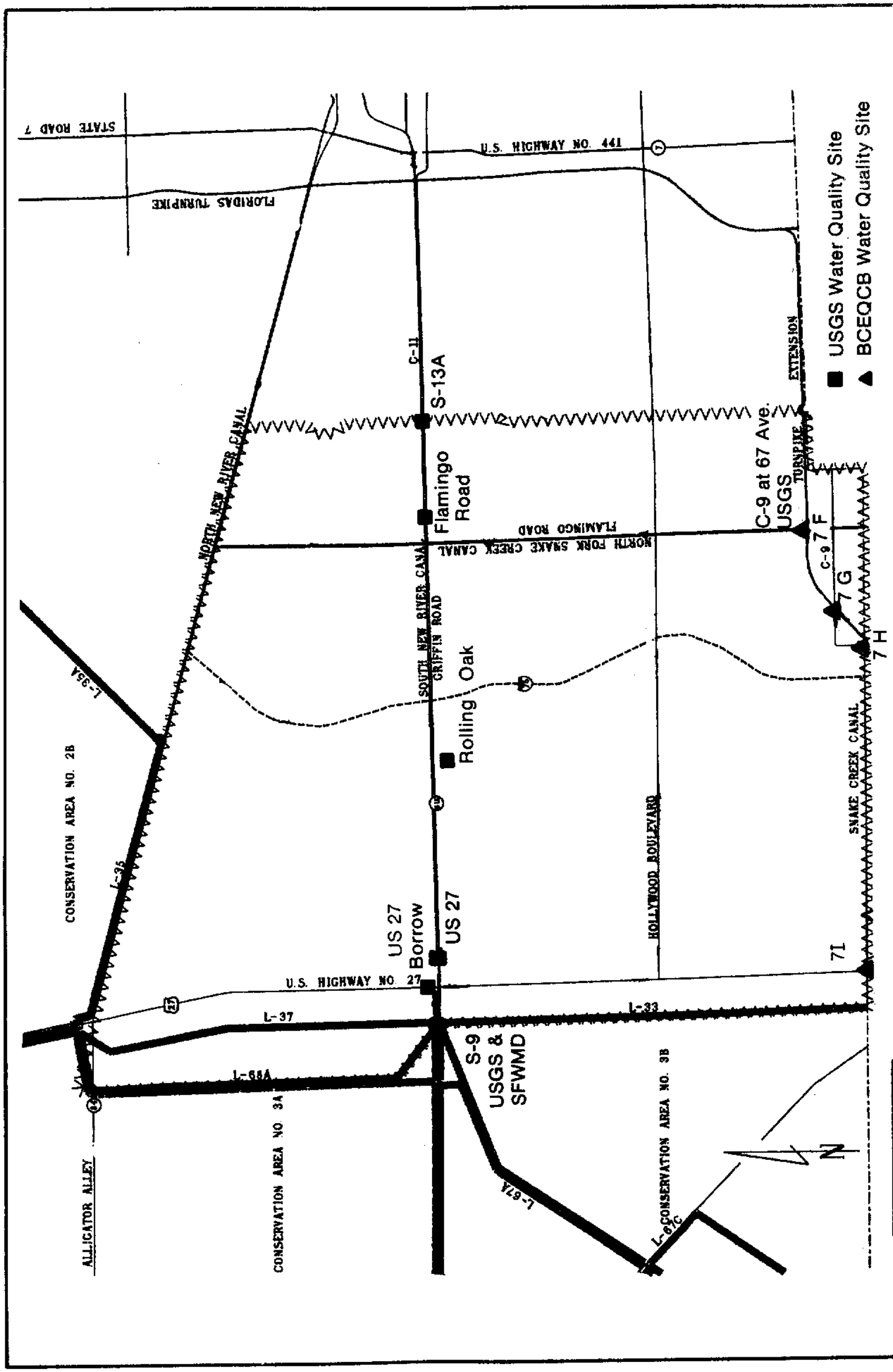


Plate 4-1 MAP OF SURFACE WATER QUALITY SAMPLING STATIONS

Since three different agencies were responsible for historical data collection under a variety of programs; the parameters measured, frequency of sampling and period of record differ considerably among the three agencies. Additionally, it must be pointed out that historical data was used for this analysis and, therefore, the data was not a product of a program designed specifically to answer the needs of this particular study.

Table 4-1 provides a summary of the southwest Broward water quality data. The USGS provided data for six stations along the South New River (S-9, US-27, US-27 Borrow, Rolling Oak, Flamingo Road, and S-13A), and for one station on the Snake Creek (C-11 at 67th Avenue). The other four stations taken into consideration on the C-11 were provided by the BCEQCB. The SFWMD's own data at S-9 were also incorporated into the C-11 analysis.

From S-9 east along C-11 to the S-13A structure is a distance of approximately 13 miles. Along this transect both the land use and the characteristics which make up the hydrogeological profile (i.e. water table, soil type, seepage) of the adjacent land change considerably. Using a Pinkham and Pearson Biotic Similarity Index, coefficients of association were calculated for the seven stations along the South New River in order to highlight any possible areal differences in general surface water quality. The means for the period of record for five major water chemistry parameters dissolved oxygen, specific conductance, total nitrogen, total phosphorus and chlorides for the seven C-11 stations, were utilized in the statistical analysis of association. The resultant dendrogram provides an opportunity not so much to differentiate between "good" and "bad" water quality stations, but rather to analyze for similarities or differences among sites. The utilization of this technique requires two important assumptions, 1) the period of record means are an accurate estimate of canal quality; and 2) the five selected parmeters are of equal importance in the assessment of general

Table 4-1 AVERAGE NUMBER OF OBSERVATIONS

CANAL SYSTEM	STATIONS	SOURCE	PHYSICAL	NUTRIENTS	IONS	METALS	PESTICIDES	PERIOD OF RECORD
C-11 (SOUTH NEW RIVER)	S-9	SFWMD	120	125	95	7	0	1978-82
	S-9	USGS	90	90	45	16	13	1969-80
	US 27	USGS	18	18	4	1	0	1975
	US 27 BORROW	USGS	24	24	4	1	0	1974-75
	ROLLING OAK	USGS	18	17	4	1	0	1975
	FLAMINGO	USGS	20	17	4	1	0	1975-77
	S-13A	USGS	50	40	27	3	10	1970-80
C-9 (SNAKE CREEK)	7I	BCEQCB	72	72	0	0	0	1975-80
	7H	BCEQCB	72	72	0	0	0	1975-80
	7G	BCEQCB	72	72	0	0	0	1975-80
	7F	BCEQCB	72	72	0	0	0	1975-80
	AT 67th AVE.	USGS	50	40	36	24	11	1968-80

water quality. A coefficient of association of 62% or less is considered a statistically significant difference in association. This cut-off point is related to the variance of individual parameter values which make up the mean.

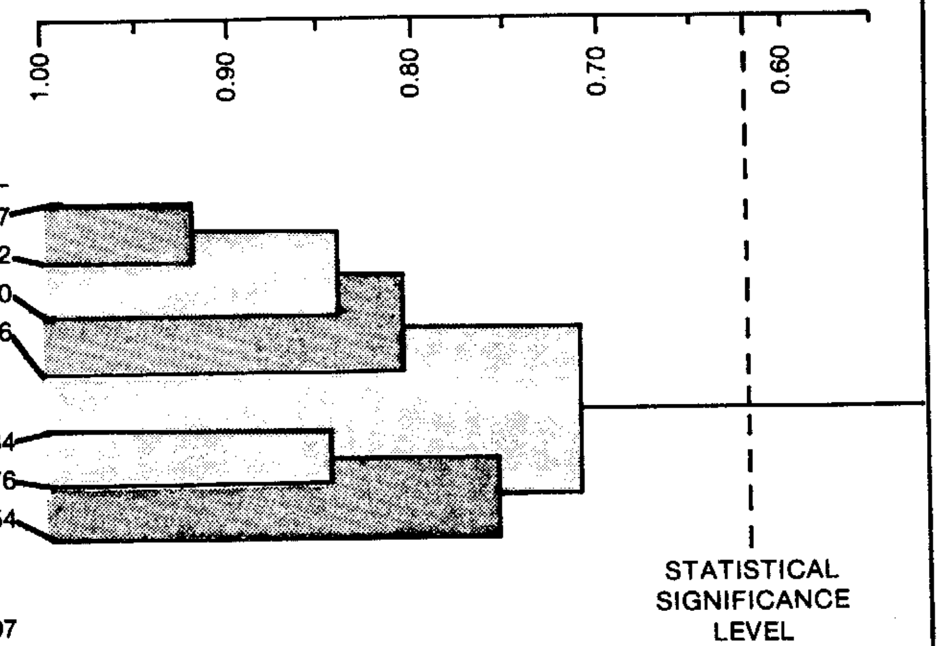
The resultant dendogram is depicted on Plate 4-2. As would be expected geographic location plays an important role in station similarity. The US-27 Borrow Canal and C-11 at US-27 demonstrate the highest level of similarity due most probably to their close proximity to each other. Similarly S-13A at the eastern end of the canal is most similar to its closest neighbor - Flamingo Road. Unfortunately, this high correlation does not exist for two different agencies at the same sampling site. The USGS and SFWMD data at S-9 were only moderately similar due perhaps to differences in sampling frequency, sample handling, and/or analytical techniques.

Although there were no statistically significant differences among stations, two distinct groups did emerge. The four stations at the western end of C-11; S-9 (USGS), S-9 (SFWMD), US-27, and US-27 Borrow Canal did, as a group, exhibit lower dissolved oxygen and phosphorus concentrations and higher levels of nitrogen, conductance, and chlorides than those three stations in the eastern end.

In general, with the important exception of phosphorus, the water in the western end of the C-11 canal could be termed "relatively poorer" in overall quality. It must be stressed that phosphorus, an important indicator of water quality problems, demonstrated the reverse trend - higher concentrations in the eastern more urbanized half. As previously mentioned, these areal differences in water quality may be as much a function of the hydrological and geological characteristics of the drainage basin as they are of local land use. Specifically, regional soil type, permeability and subsurface groundwater movement may significantly affect the water chemistry within a canal.

PLATE 4-2   A COMPARISON OF WATER QUALITY STATIONS ALONG THE SOUTH NEW RIVER

Group	Station	D.O.	COND.	TN	TP	CL
1	C-11 at US 27	2.5	810	1.77	0.016	87
1	US 27 BORROW	2.9	874	1.71	0.016	102
1	S-9 (USGS)	1.7	749	1.77	0.021	90
1	S-9 (SFWMD)	1.6	855	2.29	0.013	106
2	C-11 at FLAMINGO	4.1	721	1.70	0.031	84
2	S-13A	5.3	692	1.80	0.048	76
2	ROLLING OAK FEEDER	4.5	605	1.75	0.015	54
	GROUP 1 MEANS	2.2	822	1.89	0.017	97
	GROUP 2 MEANS	4.6	673	1.75	0.031	71



PINKMAN & PEARSON COEFFICIENT OF ASSOCIATION

The presence of any strong seasonal trends would also render our usage of a single canal mean unsuitable. Dry season (November - April) versus wet season (May - October) means for three USGS stations within the study area are summarized, compared and presented in Table 4-2. Parameters compared include: specific conductance, dissolved oxygen, total nitrogen, total organic nitrogen, ammonia, nitrate, ortho and total phosphorus.

The results of this wet/dry season analysis indicate typical south Florida seasonal trends in surface water quality. The majority of nutrient concentrations displayed slightly increased wet season values when compared to dry season means. This trend would most likely reflect a nutrient enrichment of canal systems by local surface runoff. Conductance demonstrated the reverse trend, i.e. mean values declined during the wet season, most probably as a direct result of dilution by relatively low conductance rainwater. Similar seasonal analysis of SFWMD's data at S-9 also support this finding.

Due to the results of this first two analyses, it can be assumed that since there are no significant areal or seasonal differences in water chemistry data in the C-11 and C-9 canals, canal averages will be a valid means of characterizing the general water quality within these canals. One way to evaluate the general water quality within a canal is to compare it to other canal systems within the same general area. Therefore, water chemistry data was summarized and tabulated for other drainage basins in south Florida using SFWMD historical data for the same time period (where available). The other canals used in this comparison include the Tamiami and North New River canals, which like the C-11 and C-9 canals drain the western edge of the populated areas of the Gold Coast. Also included are the heavily urbanized C-15 and C-16 canals in the Delray area and the L-3 data, representing the low intensity agriculture of Hendry County. Water Conservation Area 3A was also included since this will be the receiving body for projected increase

Table 4-2 DRY/WET SEASON MEANS, 1968-80

		COND.	D.O.	TN	TOrgN	NH4	NO3	OPO4	TPO4
SNR @ S-9	DRY	781	1.39	1.74	1.19	0.48	0.04	0.008	0.020
	WET	715	1.99	1.82	1.35	0.32	0.13	0.009	0.024
SNAKE CREEK @ 67th AVE.	DRY	706	3.5	1.49	1.11	0.16	0.15	0.010	0.012
	WET	637	2.6	1.83	1.20	0.34	0.18	0.009	0.016
SNR @ S-13A	DRY	728	5.8	1.73	1.12	0.11	0.21	0.017	0.018
	WET	652	4.9	1.86	1.56	0.25	0.16	0.053[4]	0.072

1. BRAD WALLER, USGS, 8/12/82
2. TYPICAL WET SEASON - MAY 1 - OCTOBER 1
3. ALL VALUES IN (mg/L)
4. UNFILTERED ALIQUOT

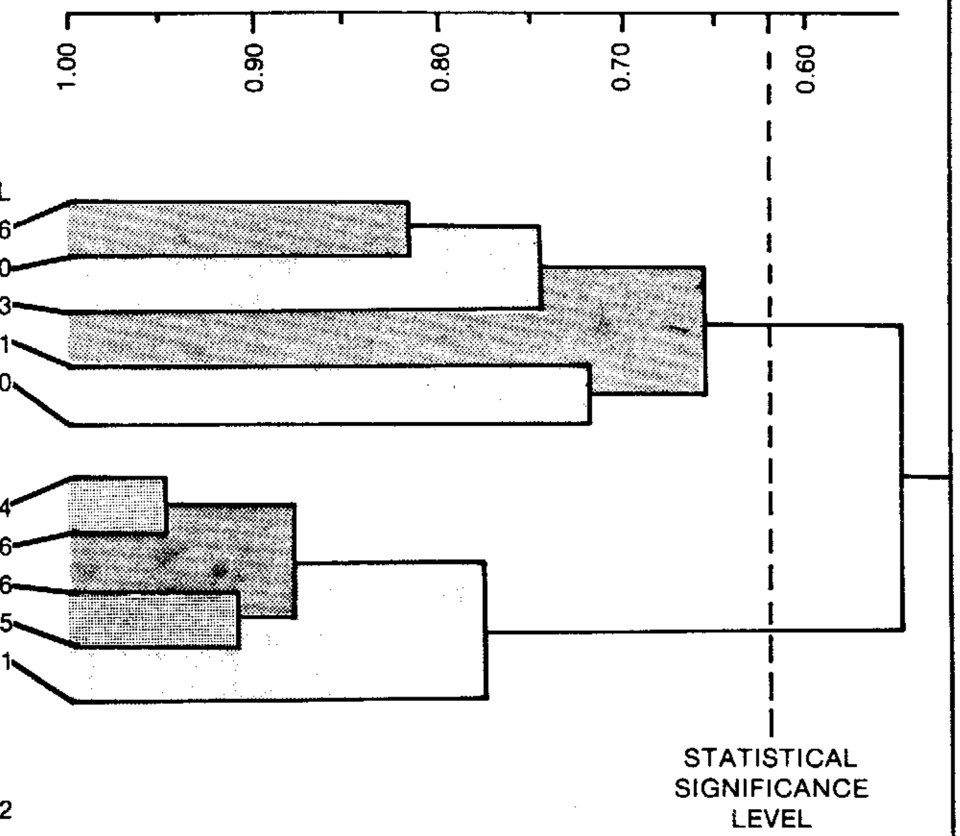
discharges by S-9 resulting from proposed changes in land use in the western C-11 basin. Again, the same five water chemistry parameters were averaged and input into the Pinkham and Pearson statistical package to calculate coefficient of association.

Plate 4-3 represents the results of this cluster analysis. Again, geographic location was responsible for some high levels of association (i.e. C-15 and C-16). This time two groups of canals do establish statistically significant differences in general water quality. The North New River, C-11, C-9, Tamiami Canals and WCA-3A interior were as a group lower in dissolved oxygen and total phosphrous and higher in chlorides, specific conductance and total nitrogen than the Group 2. Four of the five canals in Group 2 represent heavily urbanized drainage basins which demonstrate better general water quality than some less developed basins. Again the important exception here is total phosphrous which demonstrates a ten-fold increase in urbanized basins as compared to less developed basins. The inclusion of WCA-3A interior water quality in the "poorer" quality group is somewhat of an anomaly. The general water quality in WCA-3A is relatively good, but because of very low levels of total phosphorus, it was grouped in with the C-11 and C-9 canals in the cluster analysis.

Since the amount of water pumped by the S-9 pumping station will most probably experience substantial increases, a comprehensive analysis of the SFWMD's biweekly S-9 data (1978-82) was performed using a SPSS (Statistical Package for the Social Sciences) frequency distribution. The resultant curves were compared to both the Class III State Water Quality Standards - Chapter 17-3 and the Everglades National Park (ENP) Standards as outlined in the Memorandum of Agreement signed by the ENP, SFWMD, and the Army Corps of Engineers. The ENP standards, which specifically pertain to water delivered to the Park from WCA-3A, were included in this comparison for two reasons. Surface water pumped into WCA-3A by S-9 may significantly impact the quality

PLATE 4-3 A COMPARISON OF C-9 AND C-11 WATER QUALITY TO SEVERAL OTHER CANALS IN SOUTH FLORIDA

Group	Canal	D.O.	COND	TN	TP	CL
1	SOUTH NEW RIVER	3.3	758	1.83	0.023	86
1	TAMIAMI	3.3	611	1.41	0.021	50
1	WATER CONS. AREA 3A	4.5	517	2.09	0.015	53
1	SNAKE CREEK	1.1	785	2.29	0.012	111
1	NORTH NEW RIVER	3.6	790	2.06	0.005	110
2	C-15 (WEST	6.9	495	2.08	0.193	44
2	C-15 (EAST)	6.7	490	1.83	0.202	46
2	C-16 (WEST)	6.2	561	1.92	0.253	56
2	C-16 (EAST)	5.7	533	2.00	0.192	55
2	HENDRY COUNTY (L-3)	6.0	438	2.04	0.073	41
	GROUP 1 MEANS	3.2	692	1.94	0.015	82
	GROUP 2 MEANS	6.3	503	1.97	0.183	48



PINKMAN & PEARSON COEFFICIENT OF ASSOCIATION of water discharged to the Park. Also, these standards were selected as they represent some of the most comprehensive in the nation. Table 4-3 provides a summary of parameters, standards, number of observations and percent frequency of observations in excess of standards.

Two parameters at S-9 were found to be in frequent transgression of State Standards; dissolved oxygen, and ammonia. This must be tempered somewhat by the observation that virtually all surface waters in south Florida occasionally exhibit dissolved oxygen levels of less than the State Standard of 5.0 mg/L. Additionally, most of the data were collected when S-9 had to drawdown C-11 excessively due to its inadequate section. Zinc and cadmium values also exceeded State Standards for some observations, however, since the total number of observations was relatively few, it is difficult to ascertain if these values are a significant indication of a water quality problem.

Since the ENP standards are more comprehensive, several discrete values did exceed ENP limits for dissolved oxygen, ammonia, total nitrogen, calcium, alkalinity, and iron.

Findings

1. Statistical analysis indicated no significant areal differences in general water quality along the South New River.
2. Wet/dry seasonal differences in general water chemistry are slight and typical of south Florida surface waters.
3. Water quality in the C-11 and C-9 canals is similiar to that of the Tamiami and North New River canals. Generally, it is of relatively poorer quality than some heavily urbanized canals. The important exception is phosphorus, a major indicator of degradation, which exhibits substantial increases in urbanized canals.
4. Present water quality discharged by S-9 into WCA-3A does not presently meet all water quality standards. Increases in discharge may further impact the interior water quality of WCA-3A.

Table 4-3 SUMMARY OF S-9 WATER QUALITY DATA, 1978-82[1]

PARAMETER	ENP STANDARD	% OF OBS. GREATER THAN ENP STANDARD	CHAPTER 17-3 CLASS III STANDARD	% OF OBS. GREATER THAN STATE STANDARD	TOTAL # OF OBSERVATIONS
TEMPERATURE (C°)	-	-	-	-	123
DISSOLVED OXYGEN (mg/L)	4.5	99%	5.05	100%	123
CONDUCTIVITY (micromhos/cm)	647.	98%	100% increase over background	0%	121
pH	7.6-8.0	20%	6.0-8.5	0%	121
TURBIDITY (JTU)	11.	4%	50	0%	96
COLOR	124.	1%	-	-	83
TOTAL NITROGEN (mg/l)	2.9	32%	-	-	125
NH4 (mg/L)	0.24	88%	0.20[2]	93%	125
TOTAL PHOSPHORUS (mg/L)	0.24	0%	-	-	125
ORTHO PHOSPHORUS (mg/L)	0.02	0%	-	-	125
Na(mg/L)	93.	0%	-	-	35
K(mg/l)	5.0	0%	-	-	35
Ca (Mg/L)	86.	50%	-	-	98
Mg (mg/L)	25.	1%	-	-	97
CHLORIDE (mg/L)	143.	0%	-	-	125
ALKALINITY (as $CaCO_3$)	269 (NTE)[3]	87%	20 (NLT)[4]	0%	98
Fe (mg/L)	0.27	33%	1.00	0%	3
Cd (microg/L)	10.	0%	1.2	42%	7
Cu (microg/L)	8.	0%	30	0%	7
Pb (microg/L)	13.	0%	30	0%	7
Zn (Microg/L)	72.	0%	30	20%	5

1 SFWMD unpublished data

2 ionized form

3 NTE - not to exceed

4 NLT - not less than

CHAPTER 5. FUTURE NUTRIENT LOADINGS

INTRODUCTION

The purpose of this investigation is to determine future changes in yearly stormwater nutrient loadings for the Broward County study area. The basis for this determination of potential impacts of land use changes on surface water quality is a comparison of the Existing Land Use Map of the study area with the Composite Land Use Map developed for purposes of this study.

The parameters chosen for comparison in the study were suspended solids, total phosphorus, and total nitrogen as the stormwater data from these are the most readily available. Due to the limited amount of data on land use loading rates in the literature, many assumptions had to be made in comparing the land use plans and as such this report should only be used as a preliminary analysis.

Assumptions

Table 1 lists the different land use classifications for the existing and composite land use maps.

Dairy lands were not included in the analysis since the areas are approximately equal in the existing and composite land uses, and therefore no changes would be expected in nutrient loadings.

Data were unavailable for ornamentals, levees, institutional areas, transportation modes (excluding highways), cemeteries, parks, golf courses, recreational facilities, and horse training/stable areas. However, only a minor change in acreage occurs in most of these land uses, and since they are relatively small areas they were considered insignificant. Although a large change occurred in golf course areas, this land use was considered to have no impact on surface waters as it was assumed for the purpose of this study, that much of the water percolates on-site.

No data were available for mines, quarries, and spoil areas. Nutrients from these areas most likely will be contained on-site. Data were also unavailable for the 'open under development' and 'open and undeveloped' land use classifications. Nutrient loadings from undeveloped land areas probably will be low as they are usually covered with vegetation. However, the areas that are under development have been known to cause water quality problems during major storm events.

Lakes and canals were not considered as this portion of the study only investigated surface loading rates.

It should be noted that the effects of best management practices were not taken into account in this analysis. Surface water quality probably could be improved under the composite land use map by incorporating best management practices into new drainage systems as they develop in the area.

Results

Overall the percentage increase in pollutant loadings for those areas that were studied are as follows:

1. Suspended Solids - 20 percent
2. Total Nitrogen - 10 percent
3. Total Phosphorus - 30 percent

Table 2 lists the nutrient loadings used in the study. The highest total annual phosphorus loadings are associated with single family-dense residential land uses. Commercial land use generates the highest suspended solids load on an annual basis. Industrial and commercial land uses generate the highest yearly total nitrogen loadings.

For use of comparison, Table 3 indicates those land uses grouped under the same general heading.

Tables 4 and 5 contain the nutrient loading tabulations for the land uses in the existing and composite land use maps, respectively.

RECOMMENDATIONS

The results indicate that there probably will be a decrease in surface water quality in the study area when the composite land use map is achieved. As previously stated, surface water quality could be improved under the composite land use map by incorporating best management practices into new drainage systems as they develop in the area. Some best management practices are:

1. Retention ponds.
2. Exfiltration systems.
3. Swales
4. Detention ponds.
5. Street cleaning.
6. Street and catch basin flushing.
7. Porous paving.

Retention and exfiltration systems are by far the most effective best management practices in the above list and their use is encouraged throughout the District. Use of retention ponds, exfiltration systems, and detention ponds in the study area would virtually guarantee an improvement in surface water quality under the composite land use map. Properly designed swale systems can also act as effective best management practices but their storage capabilities are usually limited. While methods 5, 6, and 7 are worthwhile best management practices, their use singularly would not necessarily guarantee an improvement in surface water quality. They should be used in conjunction with methods 1, 2, 3, and/or 4.

The listing of the above best management practices is not intended to preclude the utilization of other state-of-the-art methods or innovative design concepts to improve water quality.

Due to the preliminary nature of this investigation, a comprehensive study needs to be conducted to more closely assess the shifts in water quality brought about by the urban and industrial development of this area.

TABLE 5-1- Land Use Data

Land Use	SFWMD Classification	Area(acres±) Existing	Composite
Dairy farms	AFDF	1751	1752
Horse training/Stables	AFHT	149	125
Citrus	AMCT	2876	1993
Ornamentals	AMOR	193	113
Improved pasture	APIM	16083	478
Levees	BL	84	84
Mines/Quarries	BP	494	3881
Spoil area	BS	619	80
Pine flatwoods	FEPF	784	0
Cabbage palms/Oaks	FMCO	31	30
Old fields, forested	FMOF	1280	0
Pine oak	FMPC	590	0
Brazilian pepper	FOBP	97	58
Water	H	1446	2615
Grassland	RG	20012	0
Brushland	RSSB	2673	0
Cultural/Entertainment	UCCE	107	107
Hotel/Motel	UCHM	19	21
Sales/Services	UCSS	60	104
Industrial	UI	75	3324
Cemeteries	UOCM	39	39
Golf courses	UOGC	692	1050
Park	UOPK	15	798
Recreational facility	UORC	11	46
Open, under development	UOUD	4949	0
Open, undeveloped within urban area	UOUN	633	0
Multi-family building	URMF	483	4424
Mobile homes	URMH	690	700
Single-family, high density	URSH	1265	2508
Single-family, low density	URSL	5105	27540
Single-family, medium density	URSM	4690	15025
Correctional	USCF	76	76
Educational	USED	66	229
Religious	USRL	2	2
Electrical power facilities	UTEP	34	34

TABLE 5-1 (continued)

Land Use	SFWMD Classification	Area(acres±) Existing	Composite
Major highways and right-of-ways	UTHW	114	1102
Solid waste disposal	UTSW	6	201
Major transmission lines	UTTL	136	136
Water supply plants	UTWS	7	7
Cypress	WFCY	84	84
Melaleuca	WFME	3249	608
Sawgrass	WNSG	2192	1924
Non-forested fresh	WN	4441	4509
Other recreational areas	UO	0	81
Other institutional areas	US	0	168
Other transportation areas	UT	0	192
Other commercial areas	UC	0	2182

TABLE 5-2

Yearly Nutrient Loadings (lbs/acre/yr)

Land Use	SS[a]	TN[b]	TP[c]	Reference
Single family-low density	69	1.2	0.2	Broward County Planning Council (1978)
Single family-dense residential	170[d]	6.0	1.8	Wanielista et. al. (1982)
Multiple family	260	9.7	0.7	Broward County Planning Council (1978)
Commercial	788	11.2	1.0	"
Industrial	362	11.4	0.7	"
Flatwoods	24	2.0	0.1	Black, Crow, and Eidsness, Inc. (1977 a,b,c)
Pasture	306[e]	6.5	1.2	Wanielista et. al. (1982)
Citrus	250[e]	4.0	0.2	"
Rangeland[f]	24	2.0	0.1	
Swamps	25	4.9	0.2	Black, Crow, and Eidsness, Inc. (1977 a,b,c)
Highway[g]	18	1.1	0.1	Mattraw and Miller (1981)

a - suspended solids
b - total nitrogen
c - total phosphorus
d - estimated using low density and multiple family data; should not be used as a reference
e - from Wanielista (1979); Note: These are not from the same site as the TN and TP data and should not be treated as such. They were only used due to lack of SS data for these two land uses.
f - assumed same values as flatwoods
g - estimated

TABLE 5-3

Listing of Land Use Areas Which Were Grouped Under a General Heading (See Tables 4 and 5)

Land Use (general)	Sub-classification
1. Forested uplands	a. Pine flatwoods
	b. Brazilian pepper
	c. Cabbage palms/Oaks
	d. Old fields forested
	e. Pine/Cabbage palms
2. Rangeland	a. Grassland
	b. Brushland
3. Commercial	a. Shopping center
	b. Sales and services
	c. Cultural and entertainment
4. Open areas	a. Recreational facility
	b. Golf courses
	c. Parks
	d. Cemeteries
5. Institutional	a. Educational
	b. Religious
	c. Correctional
6. Other transportation modes	a. Major transmission lines
	b. Water supply plants
	c. Sewage treatment plants
	d. Solid waste disposal
7. Wetlands	a. Cypress
	b. Melaleuca
	c. Non-forested fresh
	c. Sawgrass (division of non-forested fresh)

TABLE 5-4

Existing Land Use Loadings

Land Use	Area (acres)	Loadings(10^3 lbs/yr) SS[a]	TN[b]	TP[c]
Dairy	1751			
Horse training/Stables	149			
Citrus	2876	719	12	0.6
Ornamentals	193			
Improved pasture	16083	4921	105	19.3
Levees	84			
Mines/Quarries	494			
Spoil areas	619			
Forested uplands(5 sub-classes)	2783	67	6	0.3
Water	1446			
Rangeland (2 sub-classes)	22685	544	45	2.3
Commercial (3 sub-classes)	186	147	2	0.1
Industrial	75	27	1	0.1
Open areas (4 sub-classes)	753			
Open under development	4949			
Open undeveloped within urban area	633			
Multi family building	483	126	5	0.3
Single family-low density	5105	352	6	1.0
Single family-medium, high, and mobile homes	6645	1130	40	12.0
Institutional (3 sub-classes)	144			
Major highways and right-of-ways	114	2	Negligible	Negligible
Other transportation modes (4 sub-classes)	183			
Wetlands (4 sub-classes)	9965	250	49	2.0
TOTAL	78398[d]	8285	271	38.0

a. Suspended solids

b. Total nitrogen

c. Total phosphorus

d. Pollutant loading area = 67000 acres

TABLE 5-5

Composite Land Use Loadings

Land Use	Area (acres)	Loadings (10^3 lbs/yr) SS[a]	TN[b]	TP[c]
Dairy	1752			
Horse training/Stables	125			
Citrus	1993	498	8	0.4
Ornamentals	113			
Improved pasture	478	146	3	0.6
Levees	84			
Mines/Quarries	3881			
Spoil areas	80			
Forested uplands (2 sub-classes)	88	2	Negligible	Negligible
Water	2615			
Commercial (3 sub-classes)	2414	1902	27	2.4
Industrial	3324	1203	38	2.3
Open areas (4 sub-classes)	2014			
Multi family building	4424	1150	43	3.1
Single family-low density	27540	1900	33	5.5
Single family-medium, high, and mobile homes	18233	3100	109	32.8
Institutional (3 sub-classes)	475			
Major highways and right-of-ways	1102	20	1	0.1
Other transportation modes (4 sub-classes)	570			
Wetlands (4 sub-classes)	7125	178	35	1.4
TOTAL	78430[d]	10009	297	48.6

a. Suspended solids

b. Total nitrogen

c. Total phosphorus

d. Pollutant loading area = 66721 acres

CHAPTER 6. RECOMMENDATIONS

Summary

It was the objective of this study to provide preliminary analysis of the impacts of land use on surface and groundwater quality in the Southwest Broward County Area. This was accomplished by several methods of investigation in order to:

1. Describe the present and future land use patterns of the area;
2. Characterize the surface water quality of the primary canals serving the study area;
3. Identify the groundwater quality and quantity characteristics within the area studied;
4. Predict the potential effects of future land use patterns on the surface and groundwater systems; and
5. Predict the potential nutrient loadings which may occur as a result of future land development.

Additionally, the major planning and regulatory processes affecting water quality were identified.

Conclusions

1. Existing land use within the study area is predominantly agricultural or is used seasonally for agricultural purposes. Future land use patterns will be urban in nature, primarily low density residential.
2. The land uses approved by Broward County Commission action through the Land Use Plan and through the DRI process and platting appear to be reasonable based on evaluation of the existing water resources data for the study area.
3. A comparison of the topography and groundwater elevations indicate that large areas are prone to flooding in the southwestern portion of the study area.

4. The Biscayne aquifer consists of highly permeable carbonate and clastic sediments. Adjacent to the Water Conservation Areas the aquifer is approximately 60 feet thick and therefore its transmissivity is limited.
5. A comparison of the 1981 water quality data with that of the 1974 indicates an overall increase in chloride concentrations which originate. Brackish water from the western reaches of the North New River Canal and upward migration of connate water during low groundwater level conditions may be responsible for this increase.
6. Physical and chemical characterstics of the aquifer limit the mobility of many contaminants. Examination of the groundwater quality data available showed nutrients and trace metals to be generally below EPA standards. Color and dissolved iron frequently exceeded EPA standards for much of the study area. The effect on groundwater quality of increased loading associated with development cannot be quantified.
7. The projected potable water requirements for the study area will exceed 44.5 mgd. Hydrogeologic conditions within the study area limit the location of large wellfield withdrawals. The aquifer is both thick and transmissive in the southern region east of the I-75 corrider, and can be readily recharged by the Snake Creek and North Fork Snake Creek Canals.
8. Information is lacking on the impact of septic tanks on water quality within the study area.
9. Hydrogeological information is scant regarding the northwestern portion of the study area.
10. Proposed detention/retention areas and borrow pits in southwestern Broward County will minimize the peaks and valleys in the stage hydrographs of this region by providing additional storage in these locations to store excess water during the wet periods for use during the dry periods.

11. The Weston (Indian Trace) development will cause additional seepage from the Water Conservation Areas because of the lower control elevation planned for the proposed retention areas during the wet periods. This will cause an additional amount of water to be backpumped through S-9 into the Water Conservation Areas.

12. During dry periods, in spite of the additional storage provided by borrow pits and surface water management systems resulting from development in the study area, modeling analysis indicates that increased well pumpage along the coast would lower the groundwater table in the coastal region.

13. Proposed changes in southwest Broward County do not significantly influence water levels along the coastal region during periods of heavy rainfall; therefore, they will not contribute to additional flooding.

14. Statistical analysis indicated no significant areal differences in general water quality along the South New River.

15. Wet/dry seasonal differences in general water chemistry are slight and typical of south Florida surface waters.

16. Water quality in the C-11 and C-9 canals is similar to that of the Tamiami and North New River canals. Generally, it is of relatively poorer quality than some heavily urbanized canals. The important exception is phosphorus, a major indicator of degradation, which exhibits substantial increases in urbanized canals.

17. Present water quality discharged by S-9 into WCA-3A does not presently meet all water quality standards. Increases in discharge may further impact the interior water quality of WCA-3A.

18. An increase in nutrient loadings may occur as a result of development. However, if proposed land uses coupled with existing commitments are developed in accordance with the current Land Use Plan and with the incorporation of best management practices in their drainage systems,

then the general water quality characteristics of the study area should not degrade.

Recommendations

1. The industrial zoning categories contained in the zoning code should be reevaluated based on potential adverse water resource impacts.
2. The existing groundwater quality and groundwater elevation monitoring network should be reevaluated and expanded to provide data in those areas where development will impact groundwater. The existing groundwater quality network should be sampled on a regular basis and expanded into those regions where data are currently unavailable. Specific monitoring programs should be designed to monitor the effects of retention lakes, borrow pits, landfill and industrial waste sites on the aquifer. Such data would be useful in evaluating the efficiency of best management practices.
3. Broward County should initiate a program to evaluate those regions in the study area with potential for wellfield development. Such studies should include more detailed assessments of both water quality and population to be served by the system as well as site location. Consideration of a diverse system consisting of several small wellfields versus one large regional facility should also be examined.
4. In order to maintain the integrity of the aquifer in the vicinity of new and existing wellfields a Cone of Influence ordinance should be developed and implemented. This ordinance would act to restrict those types of developments which adversely effect the quality of water in those areas influenced by wellfield development.
5. Landfill sites should be evaluated with consideration to the thickness of unsaturated sediments. Landfill design should incorporate impermeable

liners with leachate collection and treatment facilities to prevent contamination of the aquifer.

6. The County's proposed study should be undertaken to determine the effect of septic tanks on the study area.

7. Specific data on aquifer hydraulic characteristics should be developed through pump tests. An evaluation of potential upward movement of connate water from the base of the aquifer should be incorporated in this study. A mathematical model utilizing this data would provide the basis for wellfield designs and permit evaluation.

8. A vigorous program at the local level requiring the incorporation of best management practices into new drainage systems is necessary to protect the surface water quality of the area.

9. Due to the preliminary nature of this investigation, a comprehensive monitoring program needs to be conducted to more closely assess the shifts in water quality brought about by the urban development within the study area.

BIBLIOGRAPHY

American Iron and Steel Institute, 1980. Modern Sewer Design: American Iron and Steel Institute, Washington, D.C.

Appel, C. A., 1973. Electrical-Analog Model Study of a Hydrologic System in Southeast Florida: U. S. Geological Survey Open-File Report.

Bearden, H. W., 1974. Groundwater Resources of the Hollywood Area, Florida: Florida Department of Natural Resources, Report of Investigations No. 77.

Beaven, T. R. and B. F. McPherson, 1978. Quality of the Water in Borrow Ponds Near a Major Highway Interchange, Dade County, Florida, October-November 1977: U. S. Geological Survey Open-File Report 78-1029.

Black, Crow, and Eidsness, Inc., 1977. Technical Memorandum on Water Quality Data submitted to the East Central Florida Regional Planning Council (3 Volumes).

Broward County Environmental Quality Control Board, 1981b. Results of Ground Water Quality Monitoring for 1979 and 1980 at Broward County's Solid Waste Disposal Facility, Davie, Florida, 45 pp.

Broward County Office of Planning. The Coastal Zone Protection/Conservation Element of the Broward County Comprehensive Plan, March 1981.

Broward County Planning Council. Areawide Clean Water Management Plan for Broward County, Florida, 1978.

Broward County Planning Council, Environmental Planning Section. The Potable Water Element of the Broward County Comprehensive Plan, June 1980.

Broward County Planning Council, 1981a. The Impact on the Quality of Groundwater from Secondary Development Along the I-75 Corridor in Southwest Broward County, Florida: An Assessment of Existing Information, 94 pp. (Written Communication.)

Camp, Dresser and McKee, 1980. Dixie Well Field Stress Analysis.

Carpenter, K., 1982. Written Communication to Ms. Pat Walker, June 14, 1982: Broward County, Florida.

Cassagnol, Claude L., 1981. Filtration of Detained Stormwater Through Sand and Alum Sludge for Water Quality Control: Master's Thesis Report, University of Central Florida, Orlando, Florida.

Florida Department of Transportation. Reevaluation of Interstate 75 at NW 186th Street - Miramar Parkway - Nova Drive, Dade and Broward Counties, April 1982.

Goolsby, D. A., H. C. Mattraw, A. G. Lamonds, D. V. Maddy and J. R. Rollo, 1976. Analysis of Historical Water-Quality Data and Description of Plan for a Sampling Network in Central and Southern Florida: U. S. Geological Survey Water-Resources Investigations 76-52.

Hull, J. E., 1981. Altitude of Water Table of the Biscayne Aquifer in Broward County, May 11-15, 1981: U. S. Geological Survey Open-File.

Klein, H. and J. E. Hull, 1978. Biscayne Aquifer, Southeast Florida: U. S. Geological Survey Water-Resources Investigations 79-112.

Klein, H., and Causarás, C. R., 1982. Biscayne Aquifer, Southeast Florida, and the Contiguous Surficial Aquifer to the North, Principal Aquifer in Florida: U. S. Geological Survey Water-Resources Investigations Open File Report 82-255.

Leach, S. D., Klein, H., and Hampton, E. R., 1972. Hydrologic Effects of Water Control and Management of Southeast Florida: U. S. Geological Survey, Report of Investigations No. 60.

Mattraw, H. C., Jr., 1976. Ground-Water Quality in the Davie Landfill, Broward County, Florida: U. S. Geological Survey Water-Resources Investigations 76-56.

Mattraw, H. C., Jr., J. E. Hull, and H. Klein, 1978. Ground-Water quality near the Northwest 58th Street Solid Waste Disposal Facility Dade County, Florida: U. S. Geological Survey Water-Resources Investigations 78-45.

Mattraw, H. C., Jr., and R. A. Miller, 1981. Stormwater Quality Processes for Three Land-Use Areas in Broward County, Florida: U. S. Geological Survey Water-Resources Investigations 81-23.

Massey-Norton, J., 1982. Verbal Communication: South Florida Water Management District.

McCuen, R. H. Water Quality Trap Efficiency of Storm Water Management Basins: Journal of the American Water Works Association 16, No. 1 (February 1980), 15-21.

Millar, Paul, S., 1981. Water Quality Analysis in the Water Conservation Areas 1978 and 1979: Technical Memorandum, South Florida Water Management District.

Miller, W. L., 1978. Effects of Bottom Sediments on Infiltration from the Miami and Tributary Canals to the Biscayne Aquifer, Dade County, Florida: U. S. Geological Survey Water-Resources Investigations No. 78-36.

Parker, G. G., G. E. Ferguson, and S. K. Love, 1955. Water Resources of Southeastern Florida: U. S. Geological Survey Water Supply Paper 1255.

Pendleton, R. E., et al., 1976. Soil Survey of Broward County Area, Florida: U. S. Geological Survey Water-Resources Investigations No. 78-36.

Pitt, W. A. J., Jr., 1975. Effects of a Landfill Operation on Ground-Water Quality in North Broward County, Florida, U. S. Geological Survey Open-File Report 75-405.

Pitt, W. A. J., Jr., H. C. Mattraw, and H. Klein, 1975. Ground-Water Quality in Selected Areas Serviced by Septic Tanks, Dade County, Florida: U. S. Geological Survey Open-File Report 75-607.

Sager, A. Vacuum Sweeper Solves Multiple Problems: Public Works, 108 (April 1977), 90-91.

Sherwood, C. B., H. J. McCoy and C. F. Galliher, 1973. Water Resources of Broward County, Florida: Florida Department of Natural Resources, Bureau of Geology Report of Investigations No. 65.

South Florida Water Management District, 1976. Water Management Plan for the Western C-9 Basin.

South Florida Water Management District, 1981. Water Management Study of the Western C-11 Canal Basin, 41 pp.

Waller, B. G., 1978. Effects of Land Use and Water Management on Water Quality in the Western South New River Canal Basin, Southeast Florida, 1974-75: U. S. Geological Survey Water-Resources Investigations No. 78-30.

Wanielista, M. P. Stormwater Management: Quantity and Quality: Ann Arbor, Michigan, Ann Arbor Science, 1979.

Wanielista, M. P., et al., 1981: Stormwater Management Manual.

Wanielista, M. P., et al., 1982. Stormwater Management for Lake Togopekaliga Watersheds: University of Central Florida, Orlando, Florida.

Weinberg, M., D. Reece and D. Allman, 1980. Effect of Urban Stormwater Runoff to a Man-Made Lake on Groundwater Quality: South Florida Water Management District Technical Publication No. 80-4.

Whipple, W., Jr. Dual Purpose Detention Basins: Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers 105 (September 1979), 403-412.

APPENDIX A

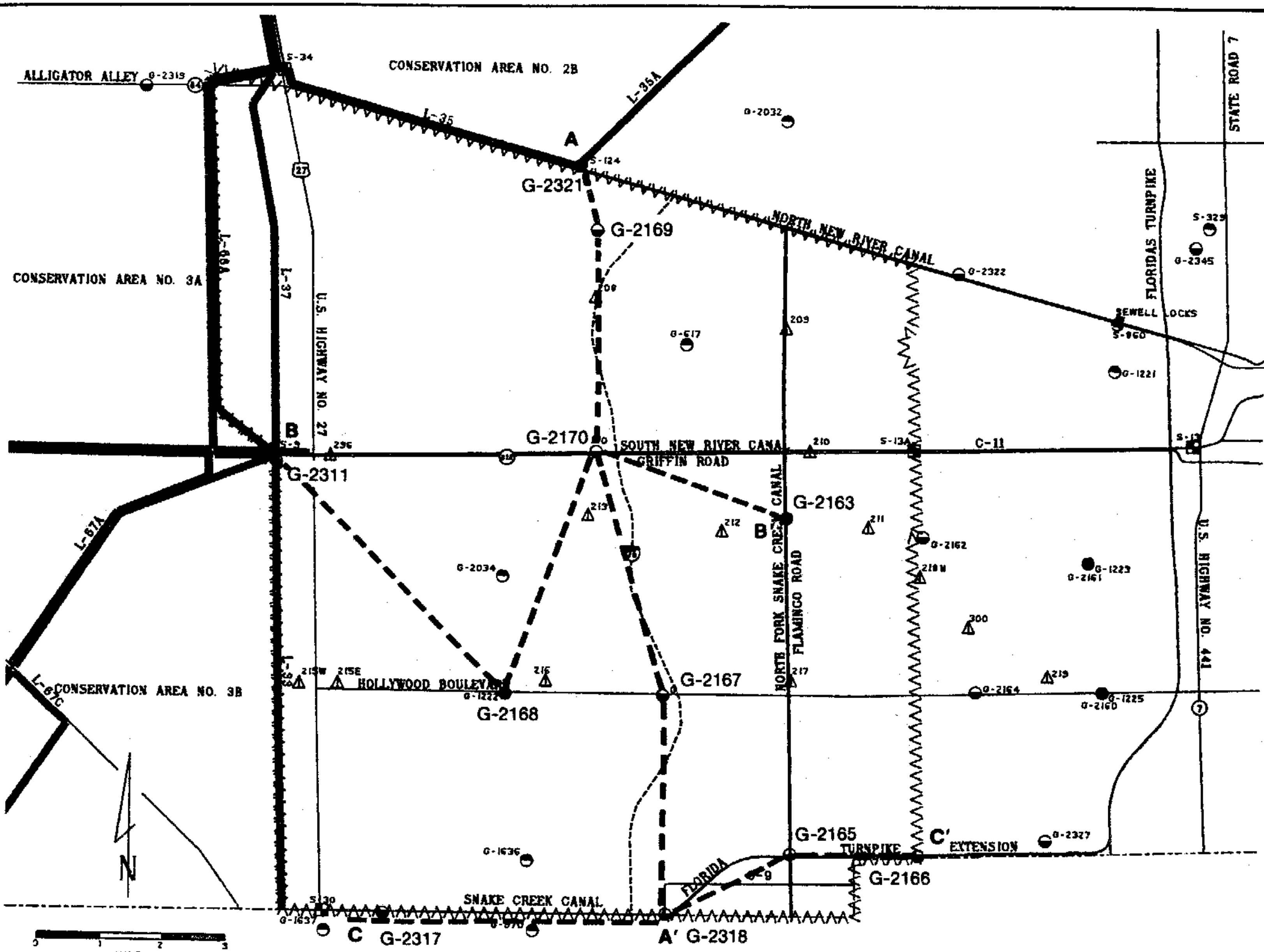


Figure 1 LOCATION OF CROSS SECTION A-A' B-B' C-C'

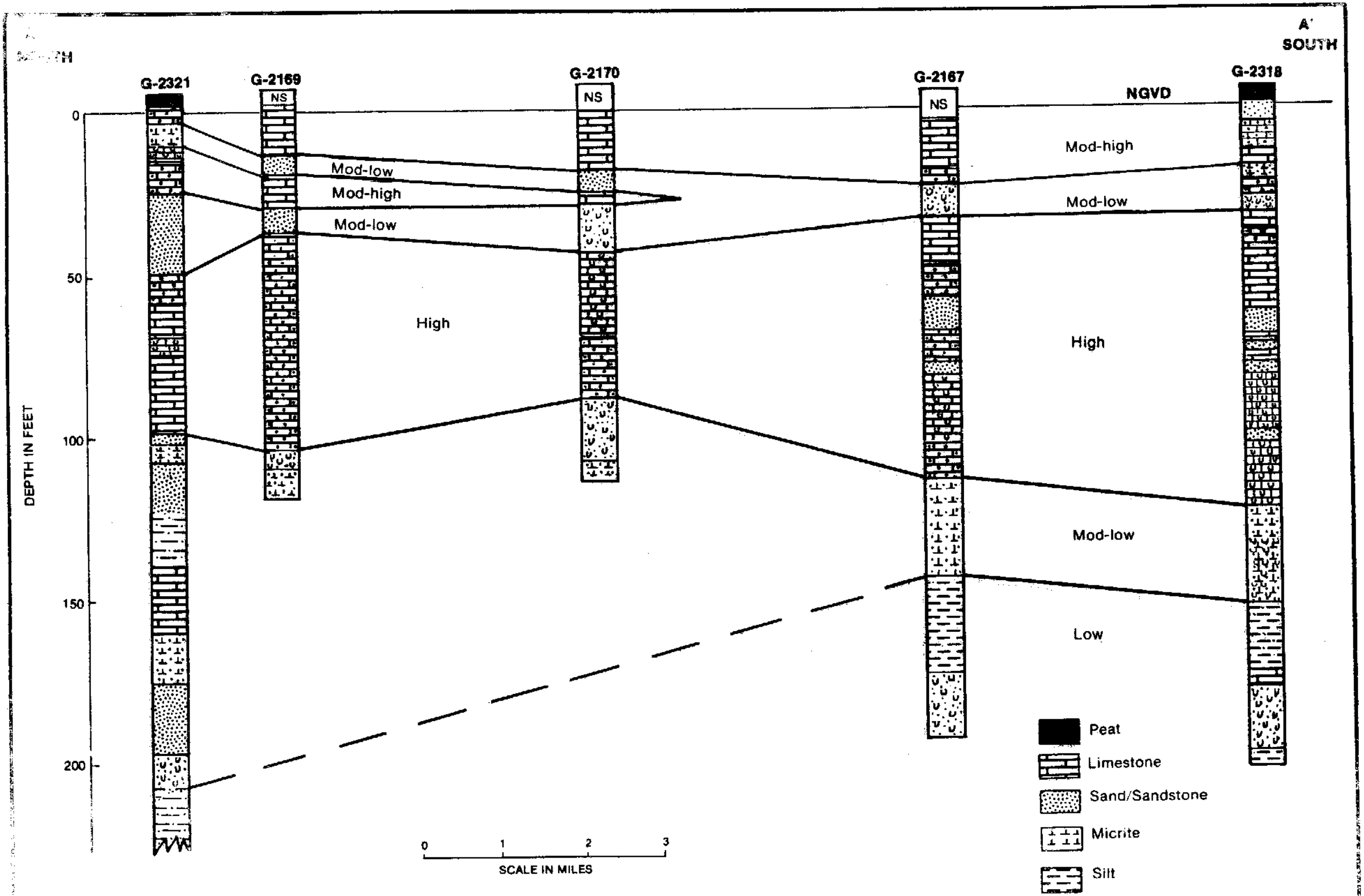


Figure 2 North-South lithology/permeability cross section (A-A[1])

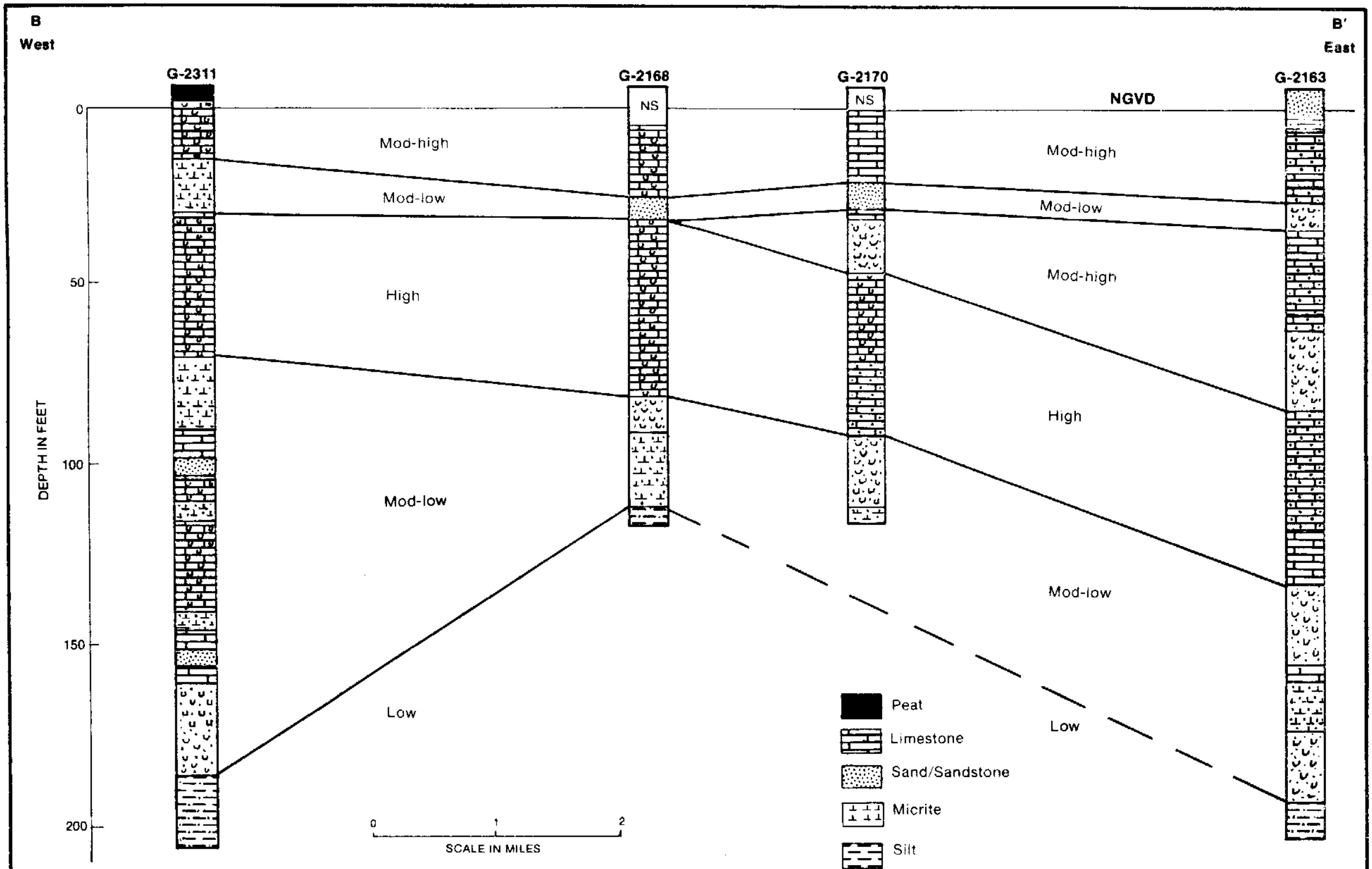


Figure 3 West-East lithology/permeability cross section (B-B')

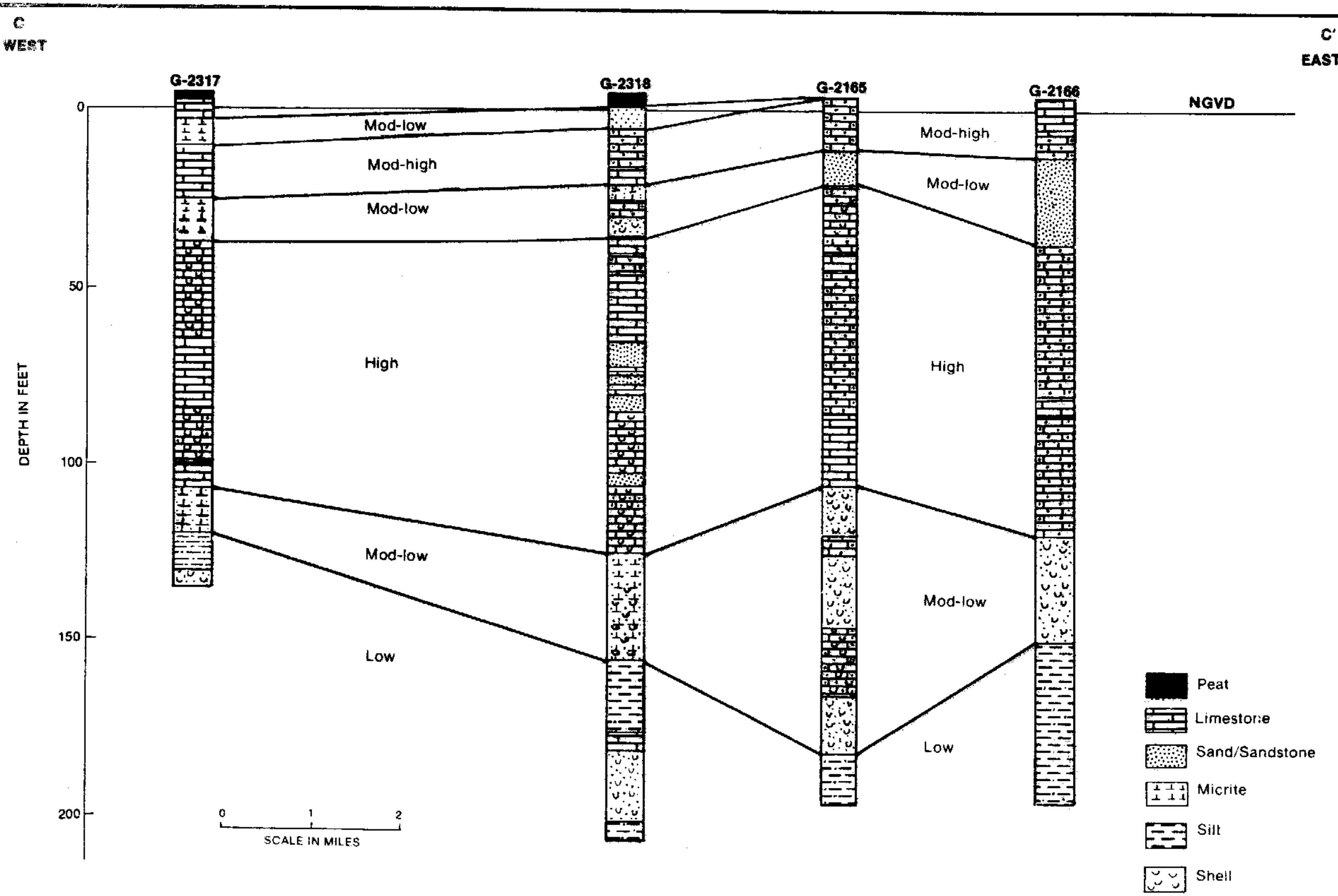


Figure 4 West-East lithology/permeability cross section (C-C')

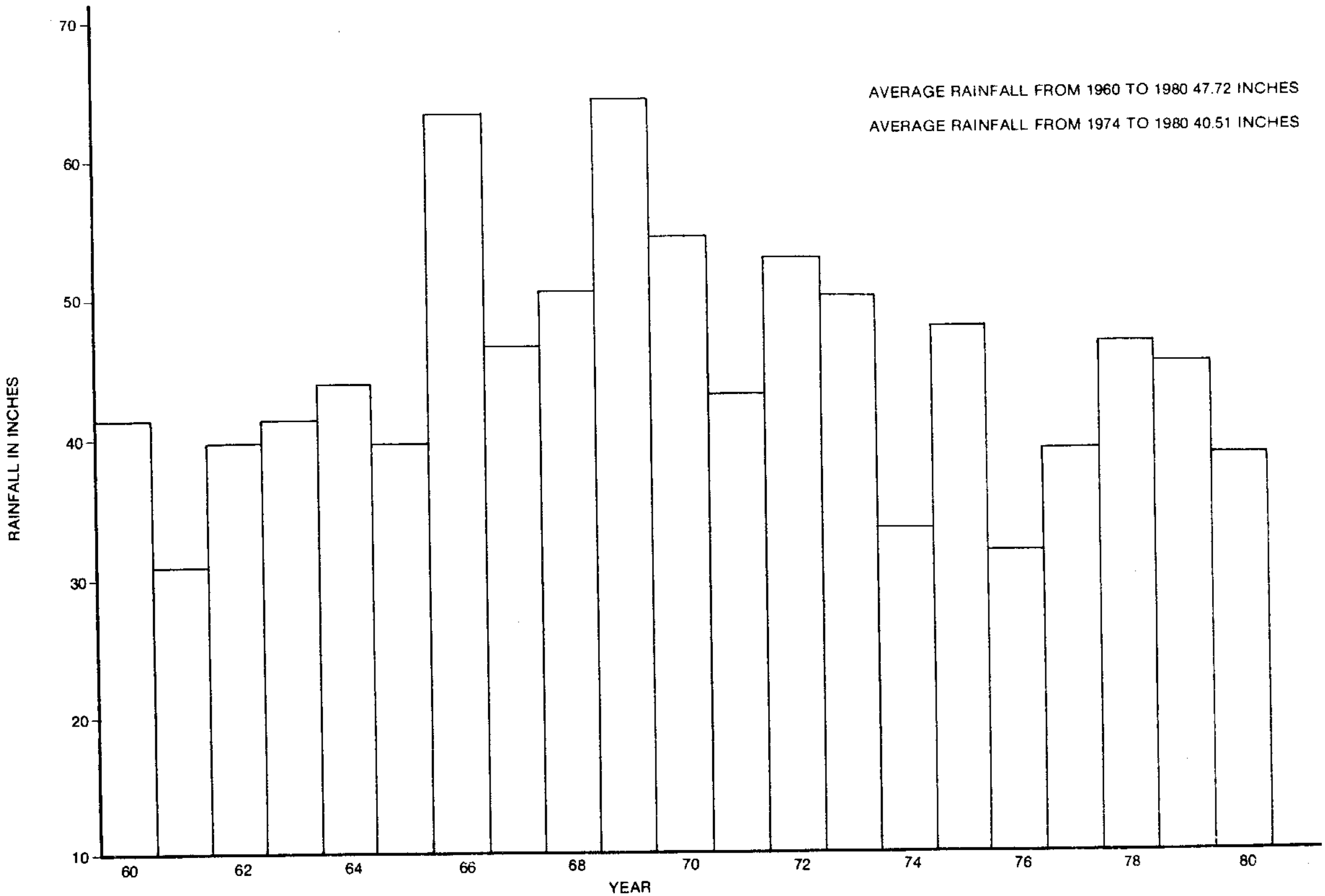


Figure 5 YEARLY RAINFALL TOTALS FOR STATION WA-106; NEAR S-34

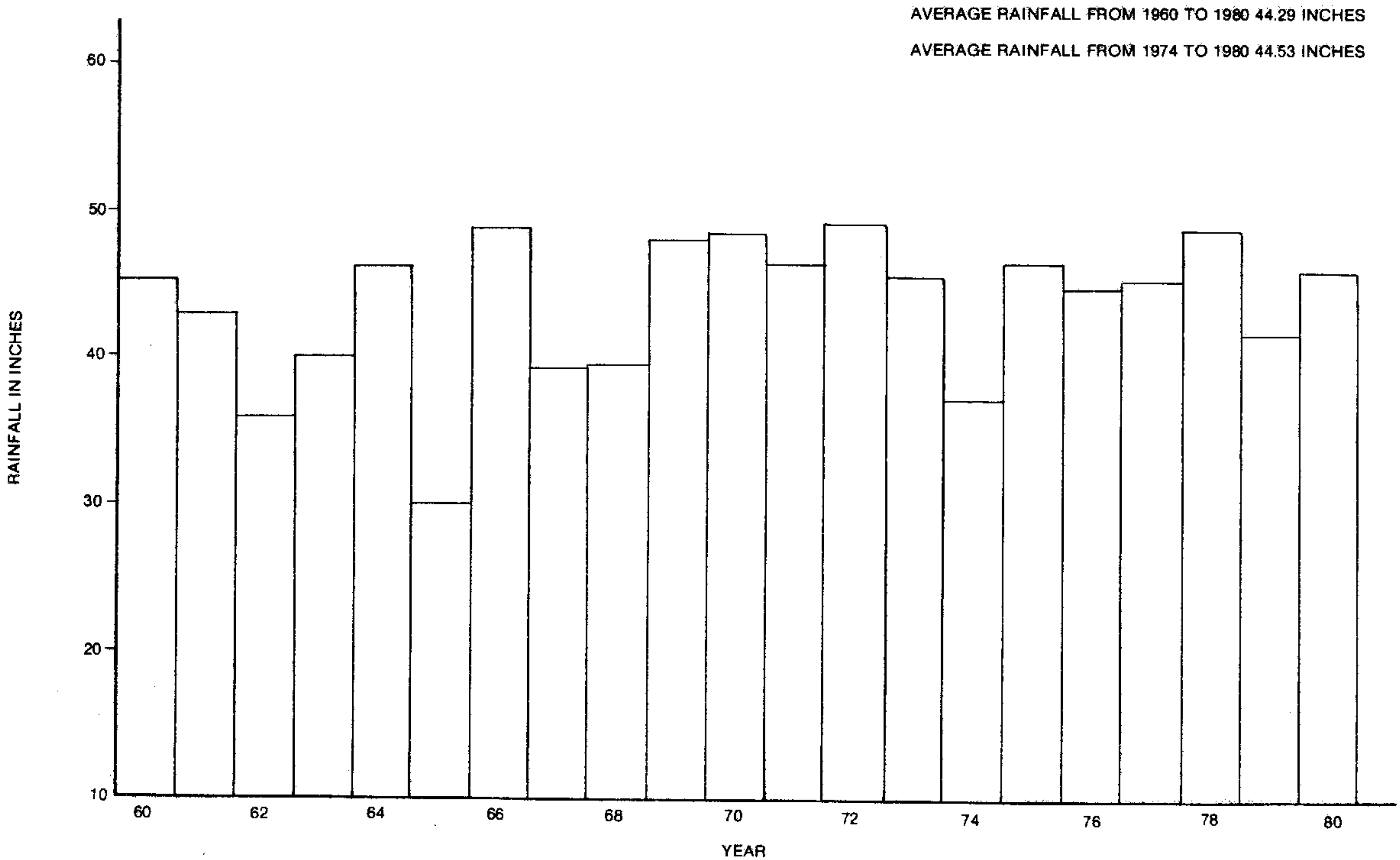


Figure 6 YEARLY RAINFALL TOTALS FOR STATION WM-115; S-9

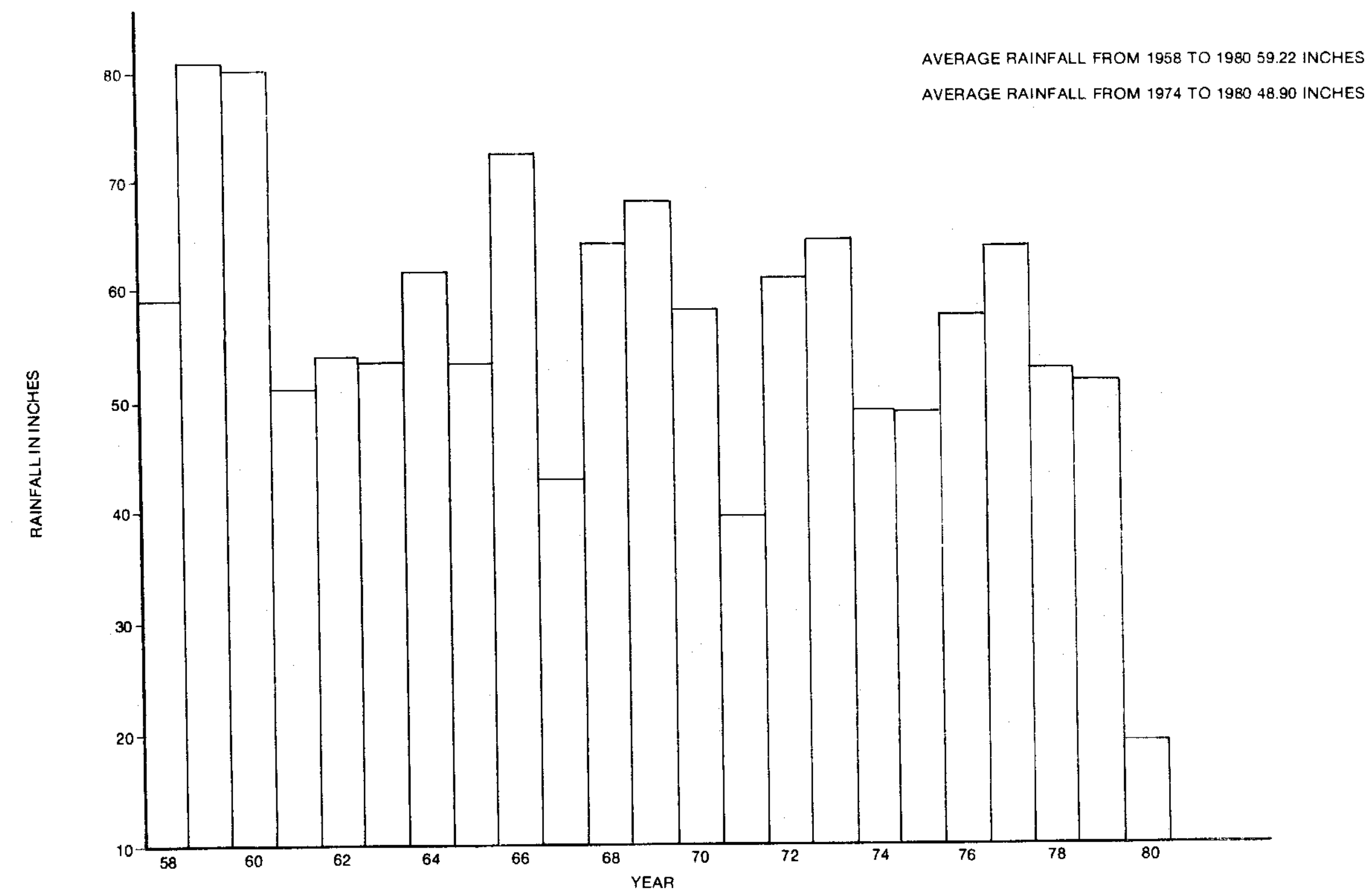


Figure 7 YEARLY RAINFALL TOTALS FOR STATION WM-109; SEWELLS LOCK

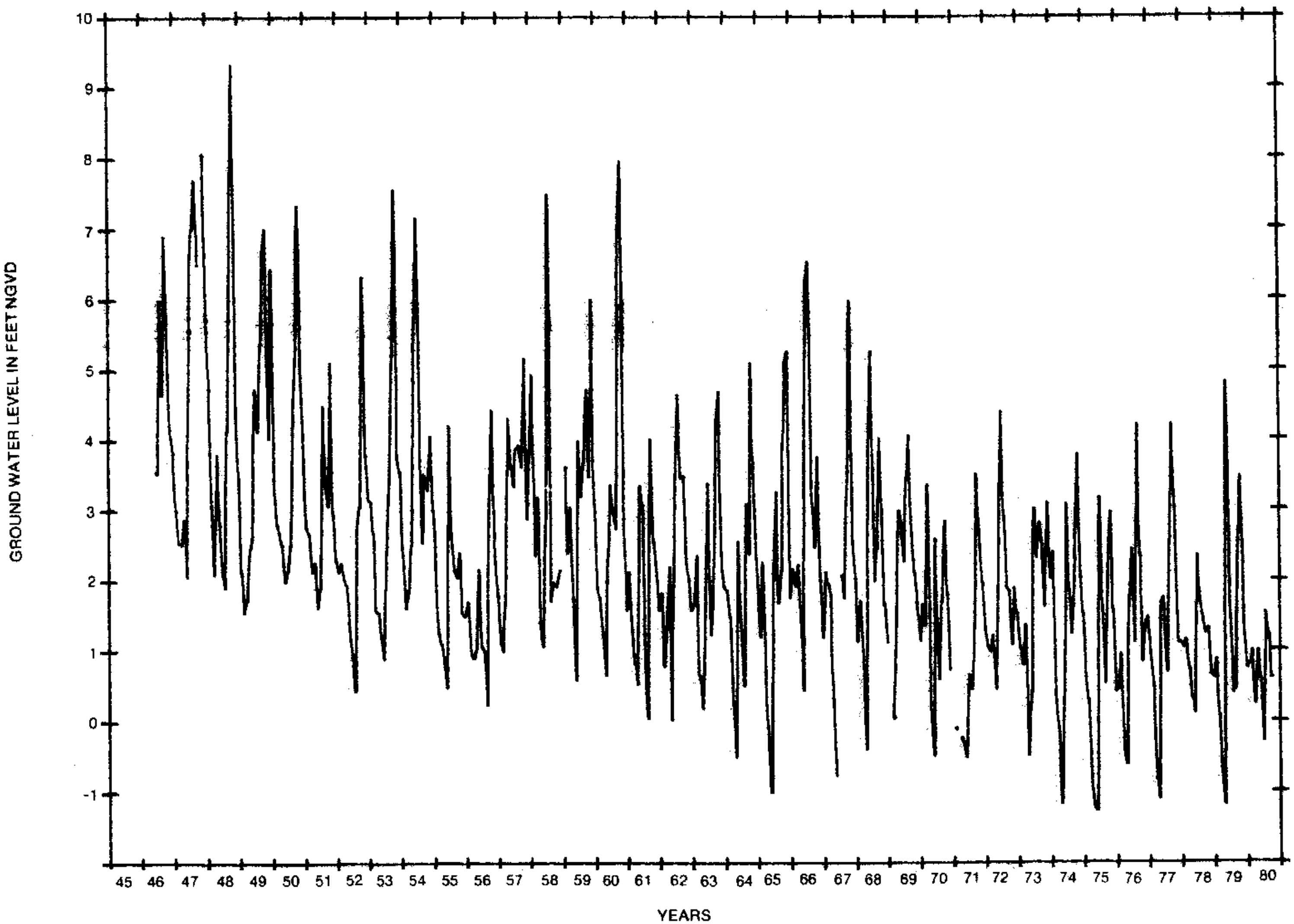


Figure 8 LONG TERM HYDROGRAPH FOR WELL S-329 (COURTESY U.S.G.S.)

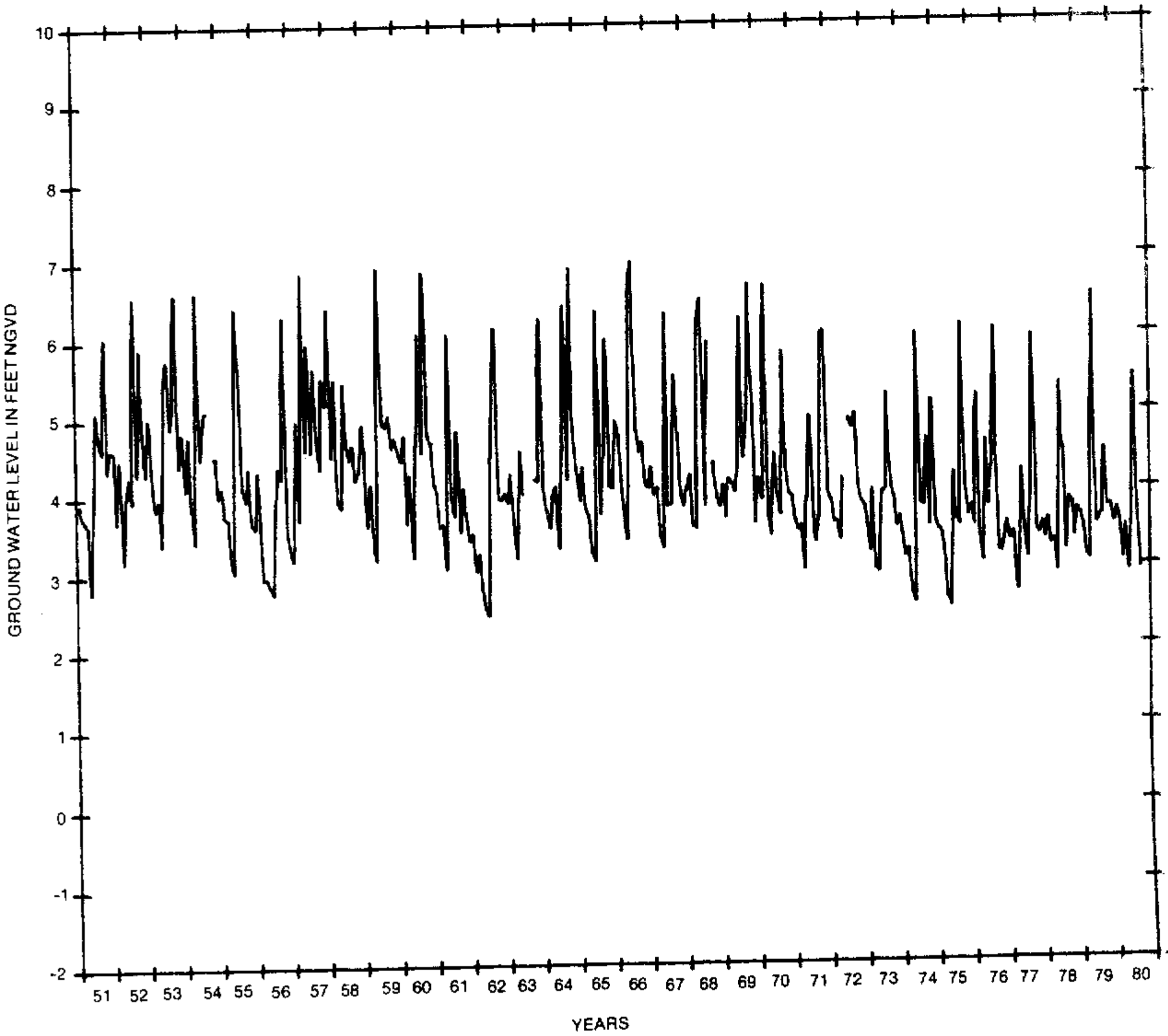


Figure 9 LONG TERM HYDROGRAPH FOR WELL G-617 (COURTESY U.S.G.S.)

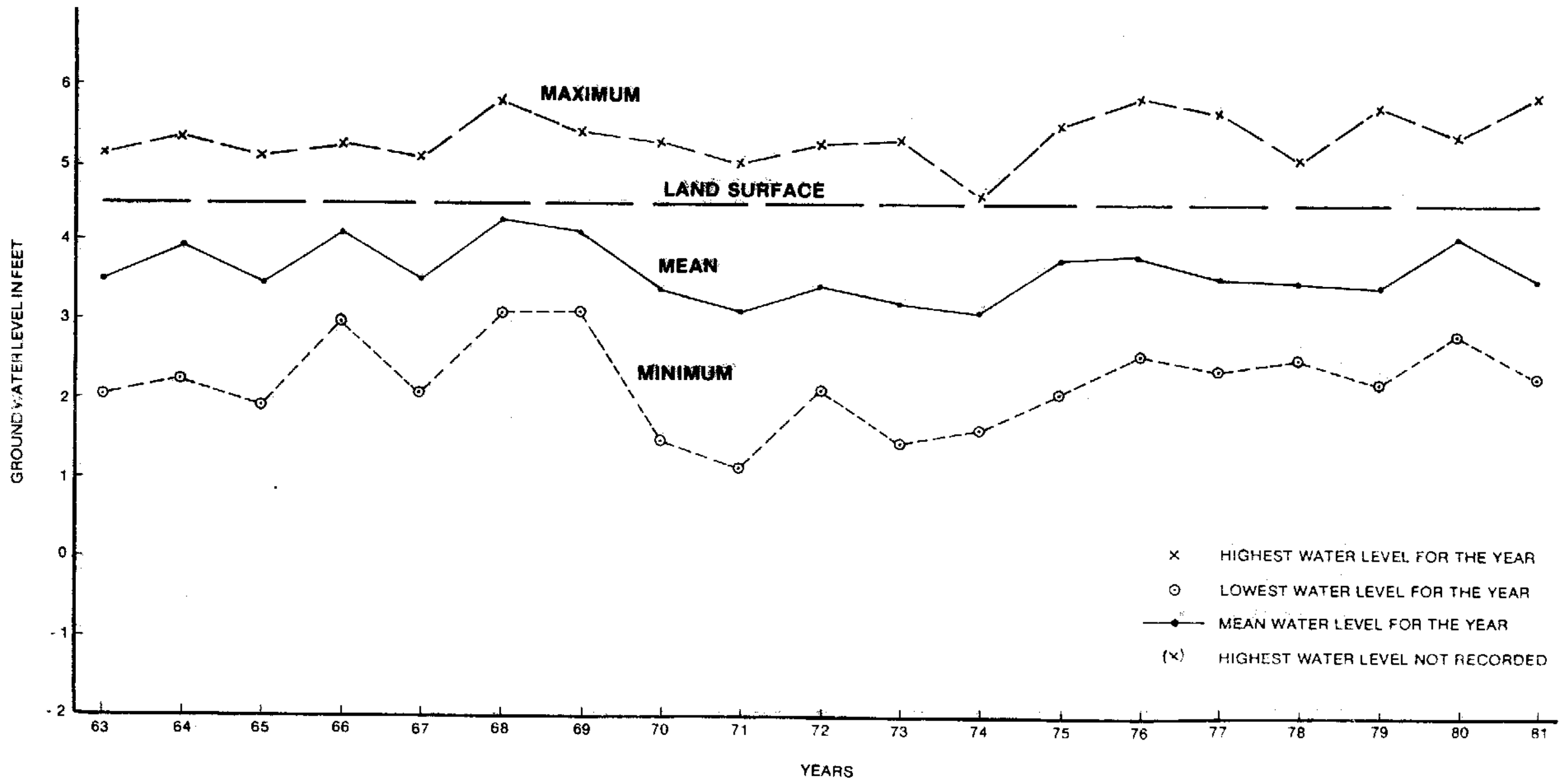


Figure 10 LONG TERM MAXIMUM MINIMUM AND MEAN WATER LEVELS FOR WELL G-1222

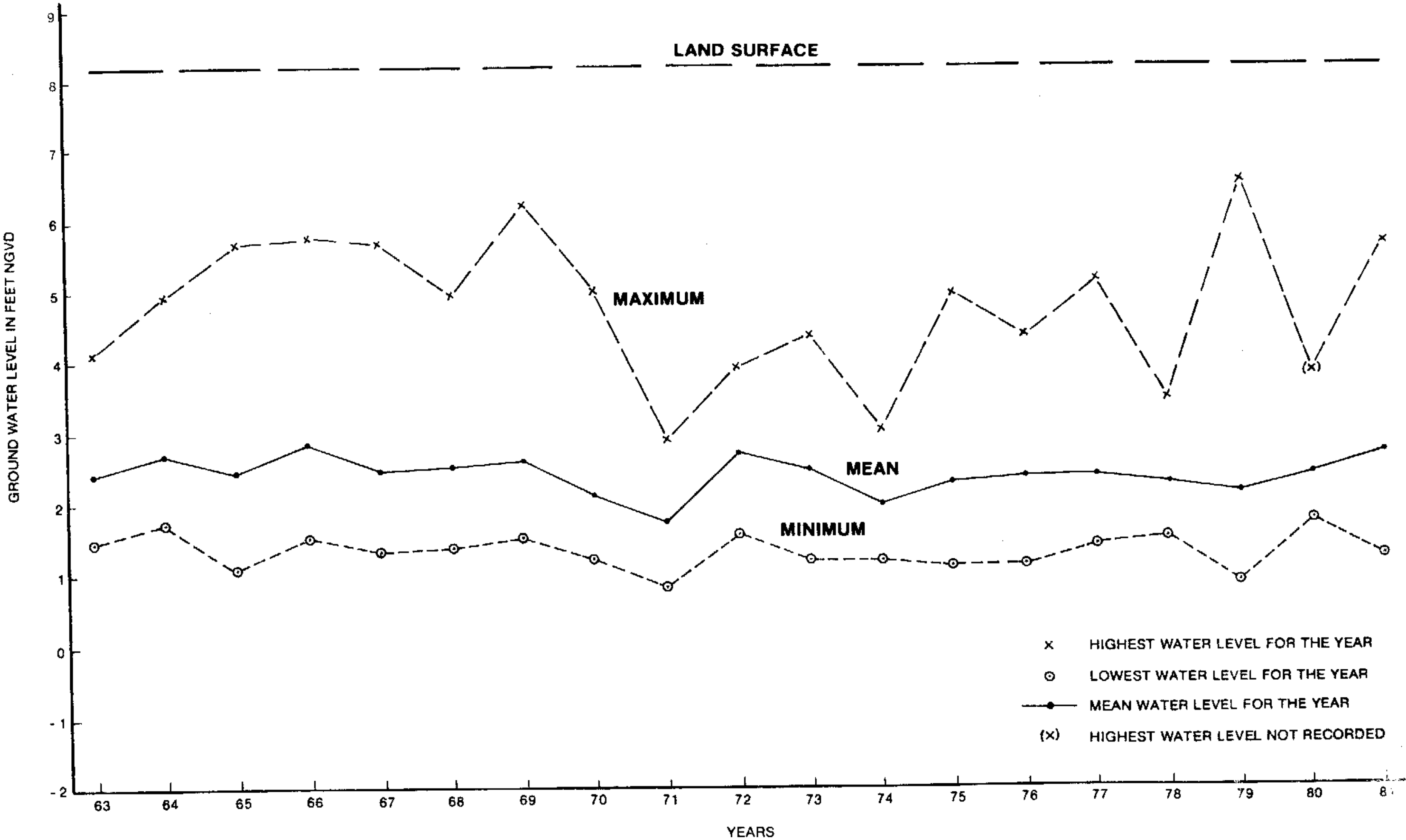


Figure 11 LONG TERM MAXIMUM MINIMUM AND MEAN WATER LEVELS FOR WELL G-1225

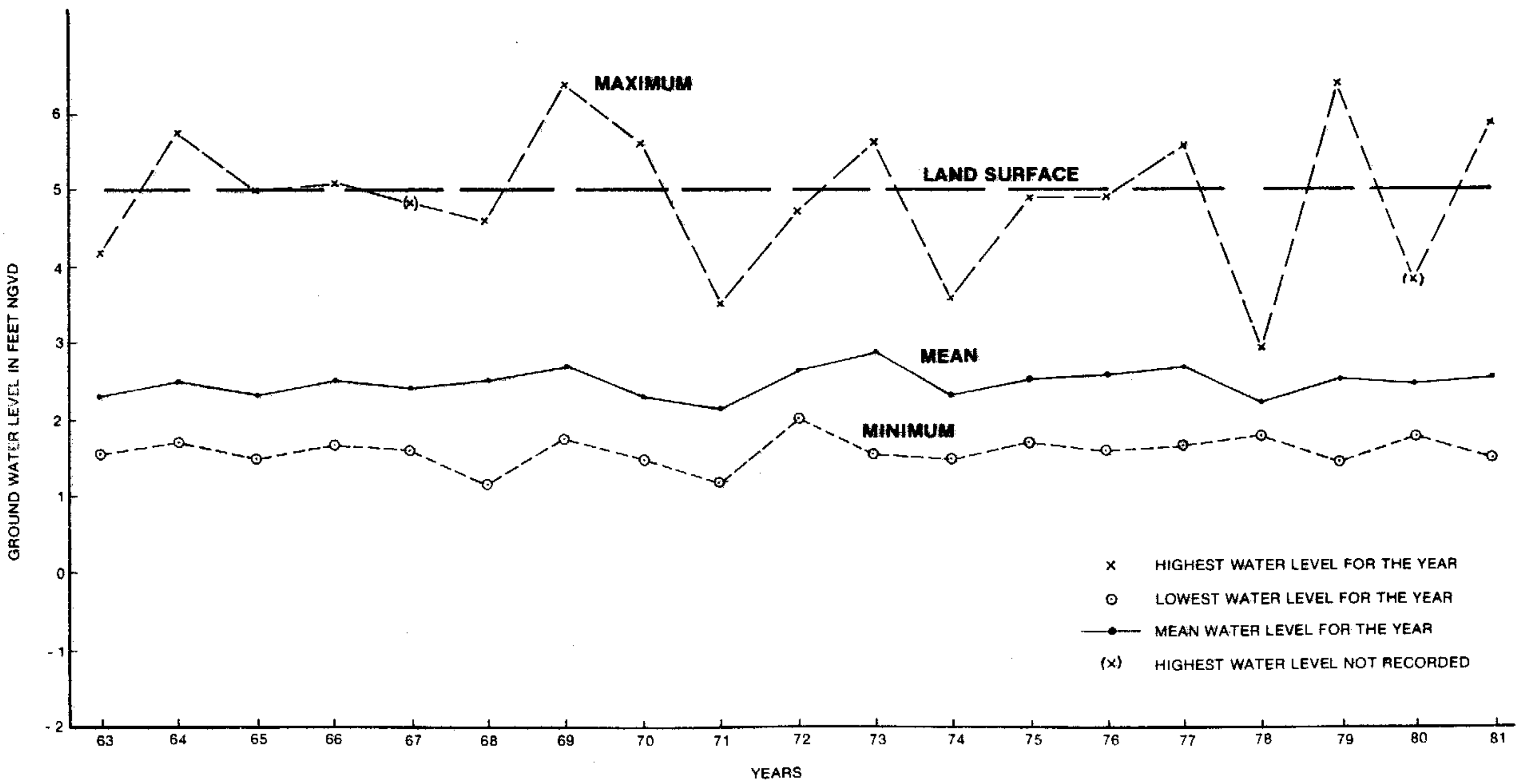


Figure 12 LONG TERM MAXIMUM MINIMUM AND MEAN WATER LEVELS FOR WELL G-1223

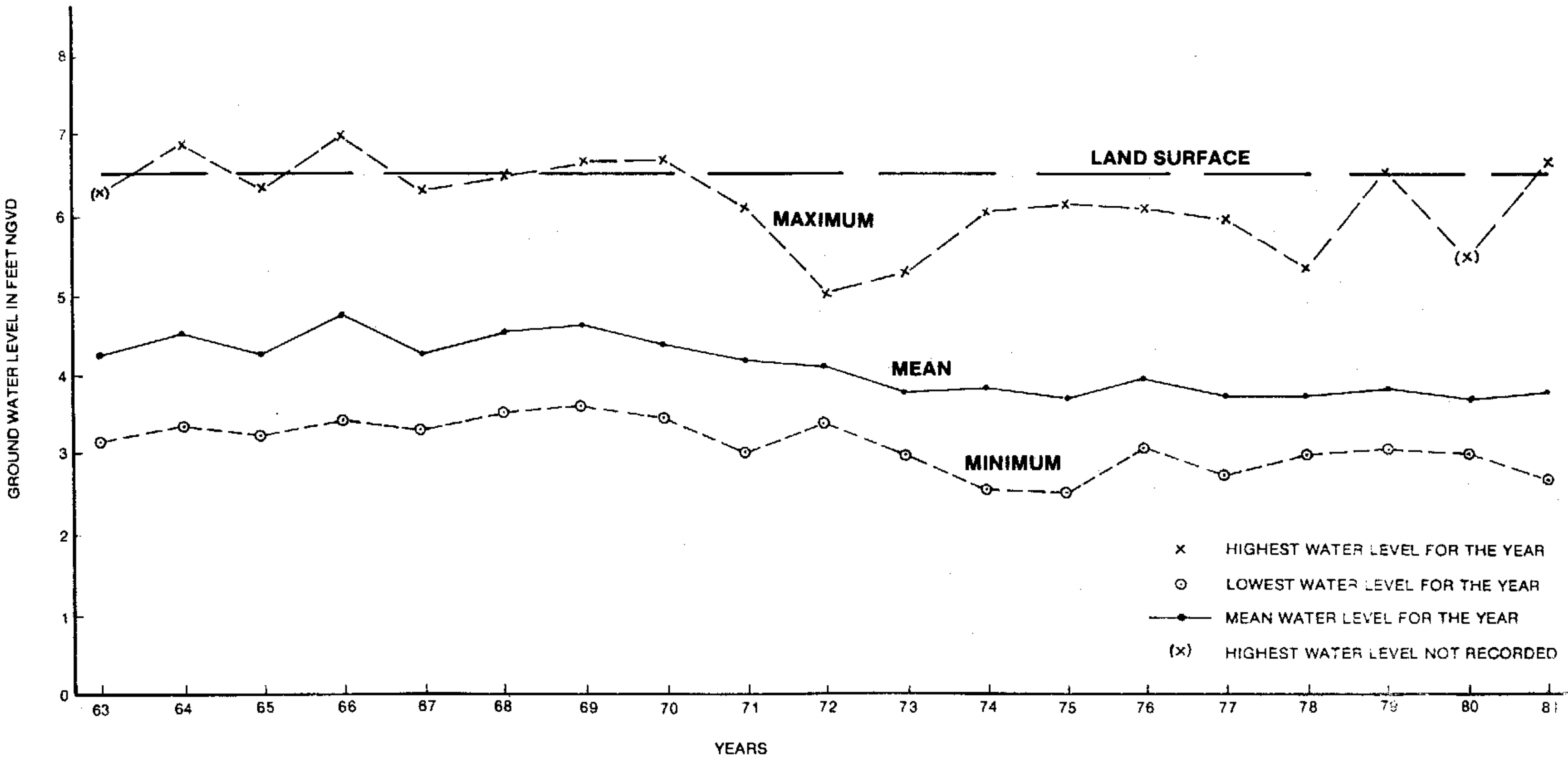


Figure 13 LONG TERM MAXIMUM MINIMUM AND MEAN WATER LEVELS FOR WELL G-617

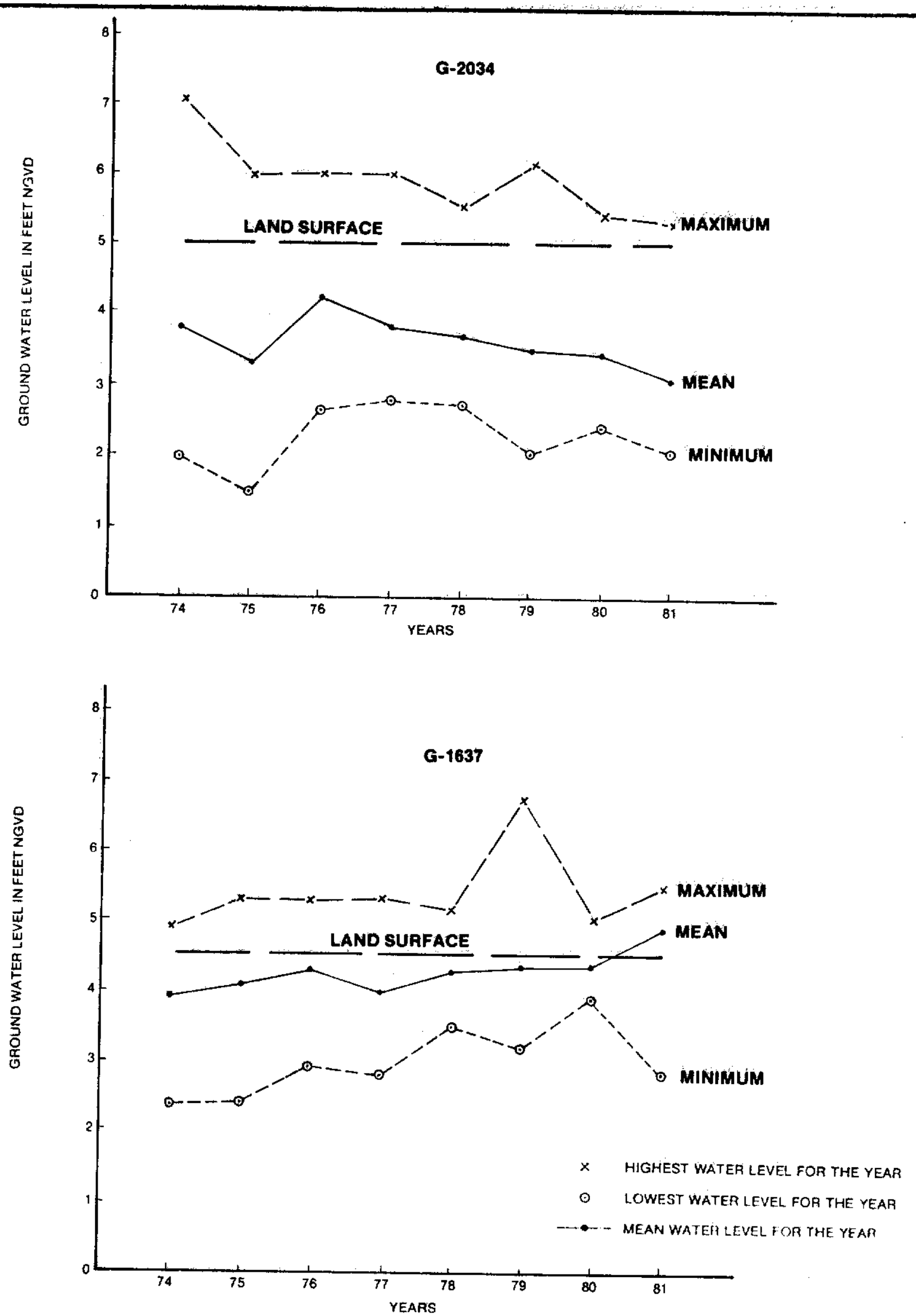


Figure 14 LONG TERM MAXIMUM MINIMUM AND MEAN WATER LEVELS FOR WELLS G-2034 & G-1637

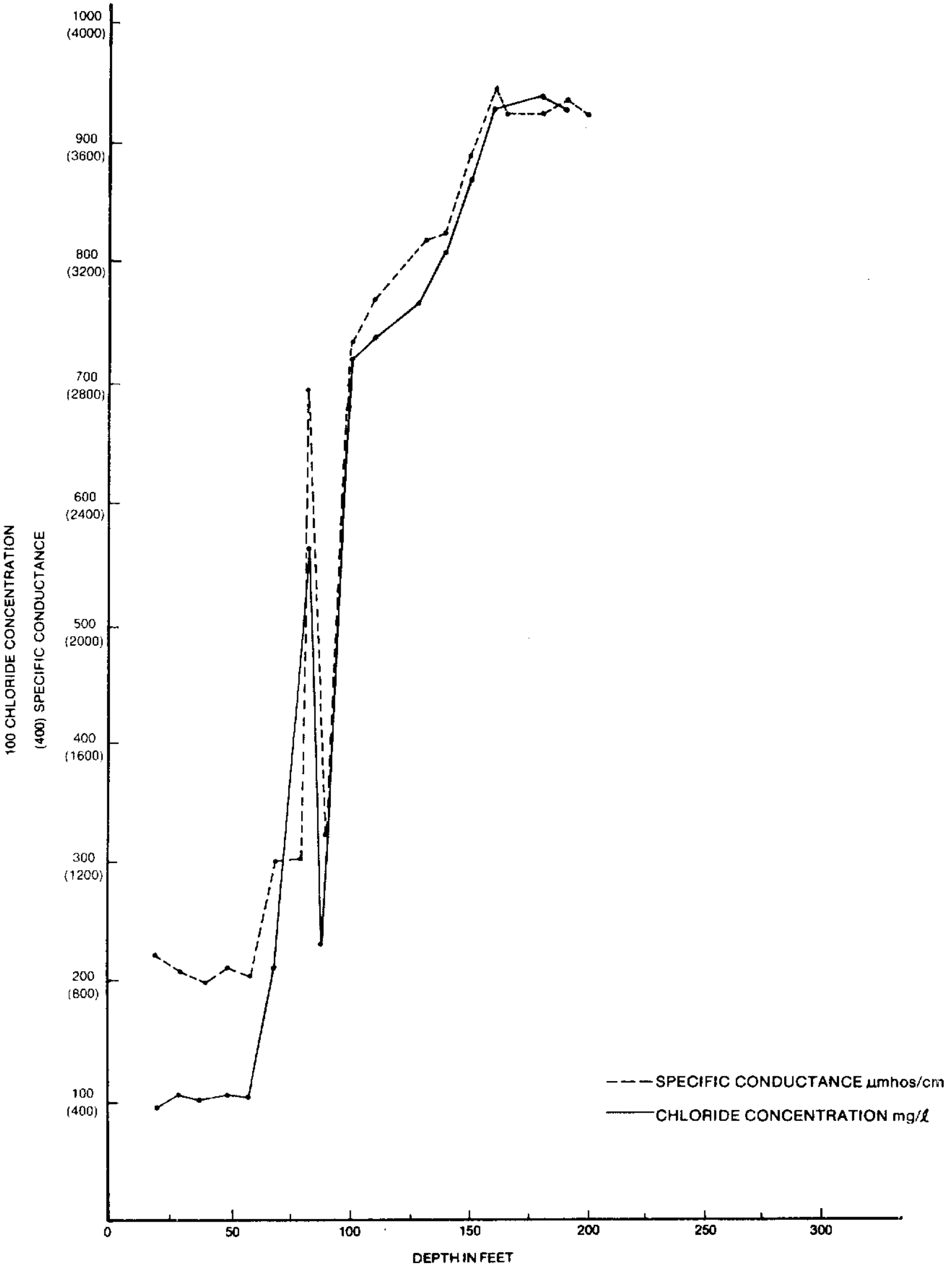


Figure 15 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2311 SAMPLED 1981 (COURTESY U.S.G.S.)

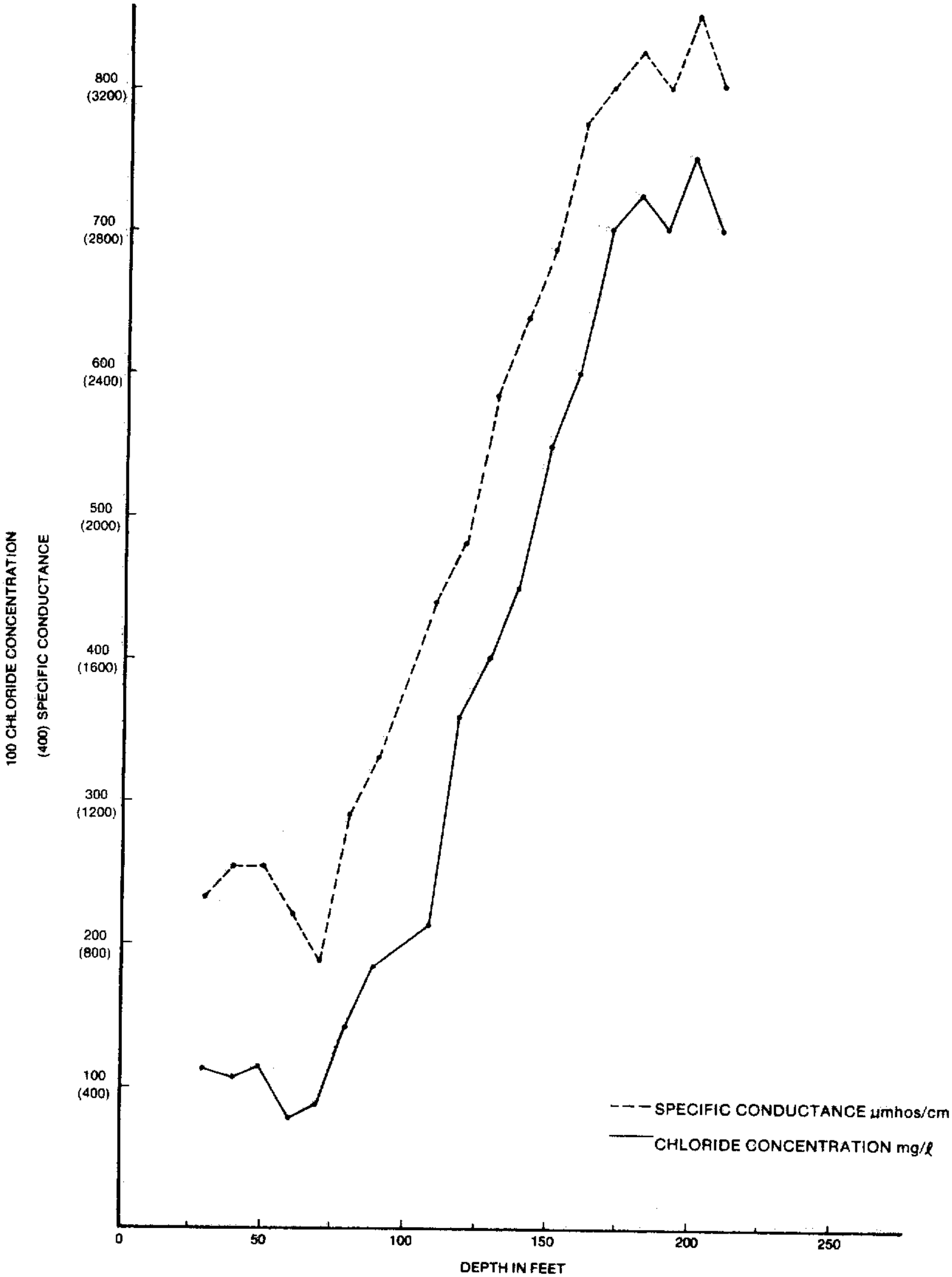


Figure 16 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2319 SAMPLED 1981 (COURTESY U.S.G.S.)

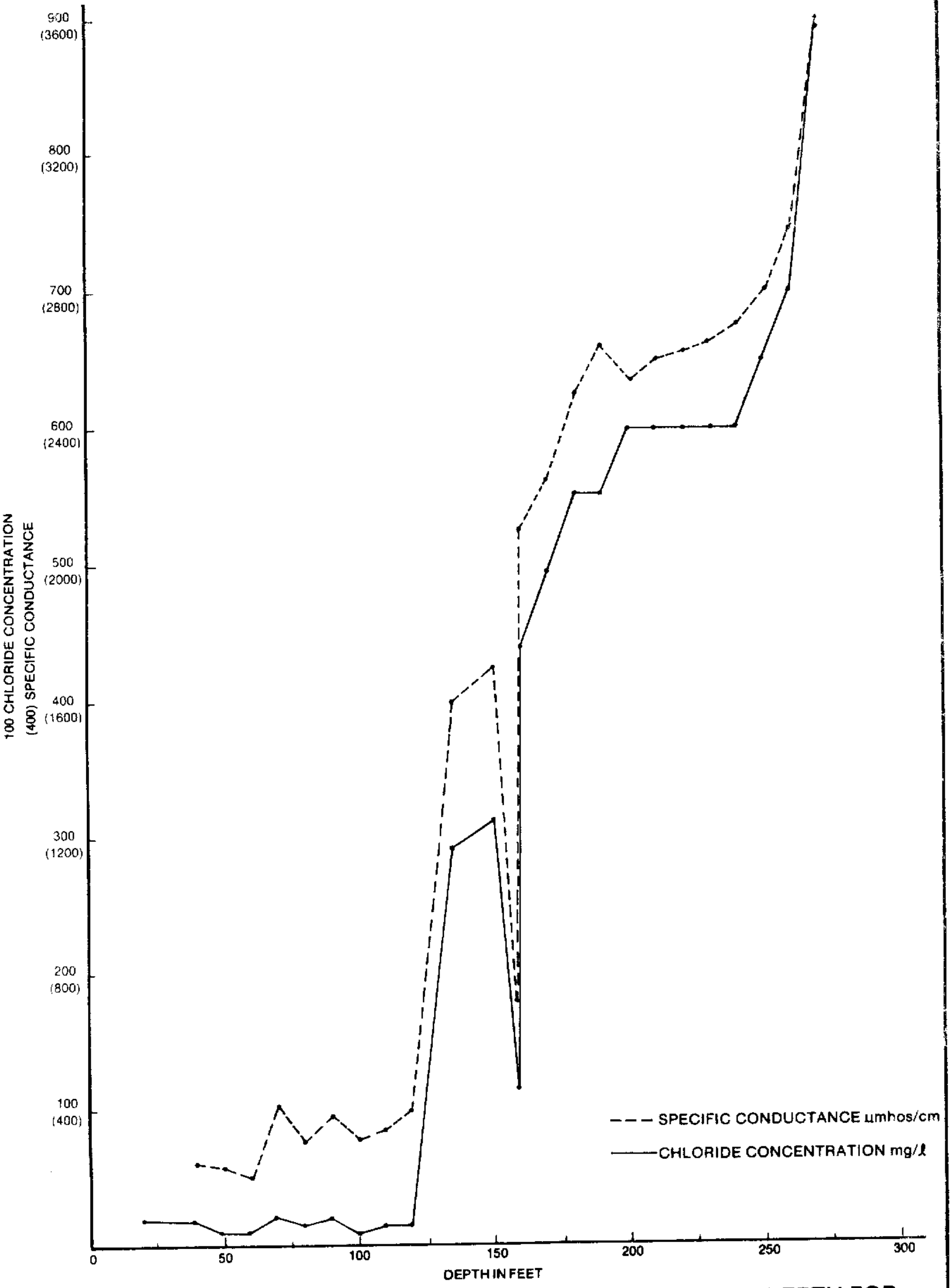


Figure 17 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2327 SAMPLED 1981 (COURTESY U.S.G.S.)

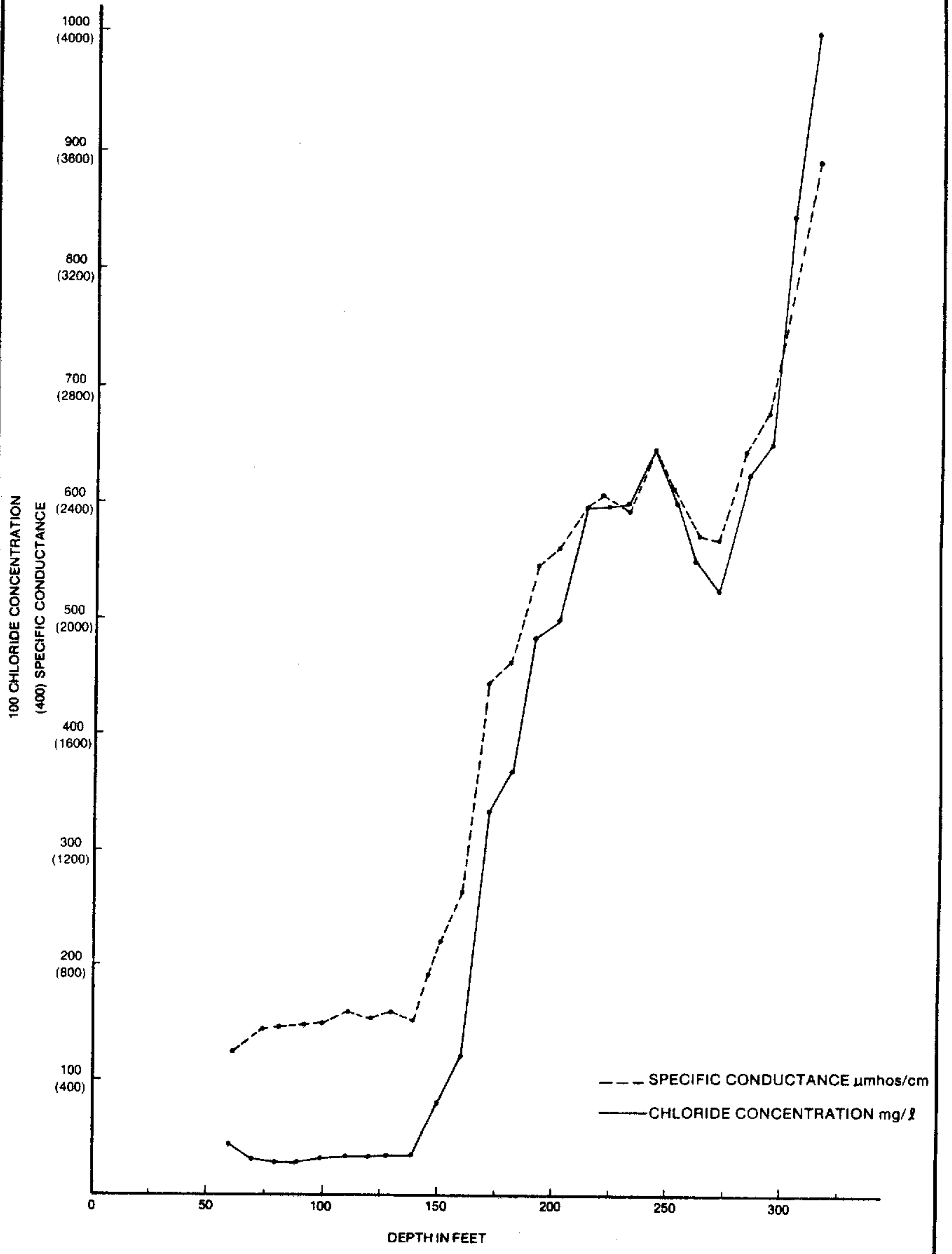


Figure 18 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2345 SAMPLED 1981 (COURTESY U.S.G.S.)

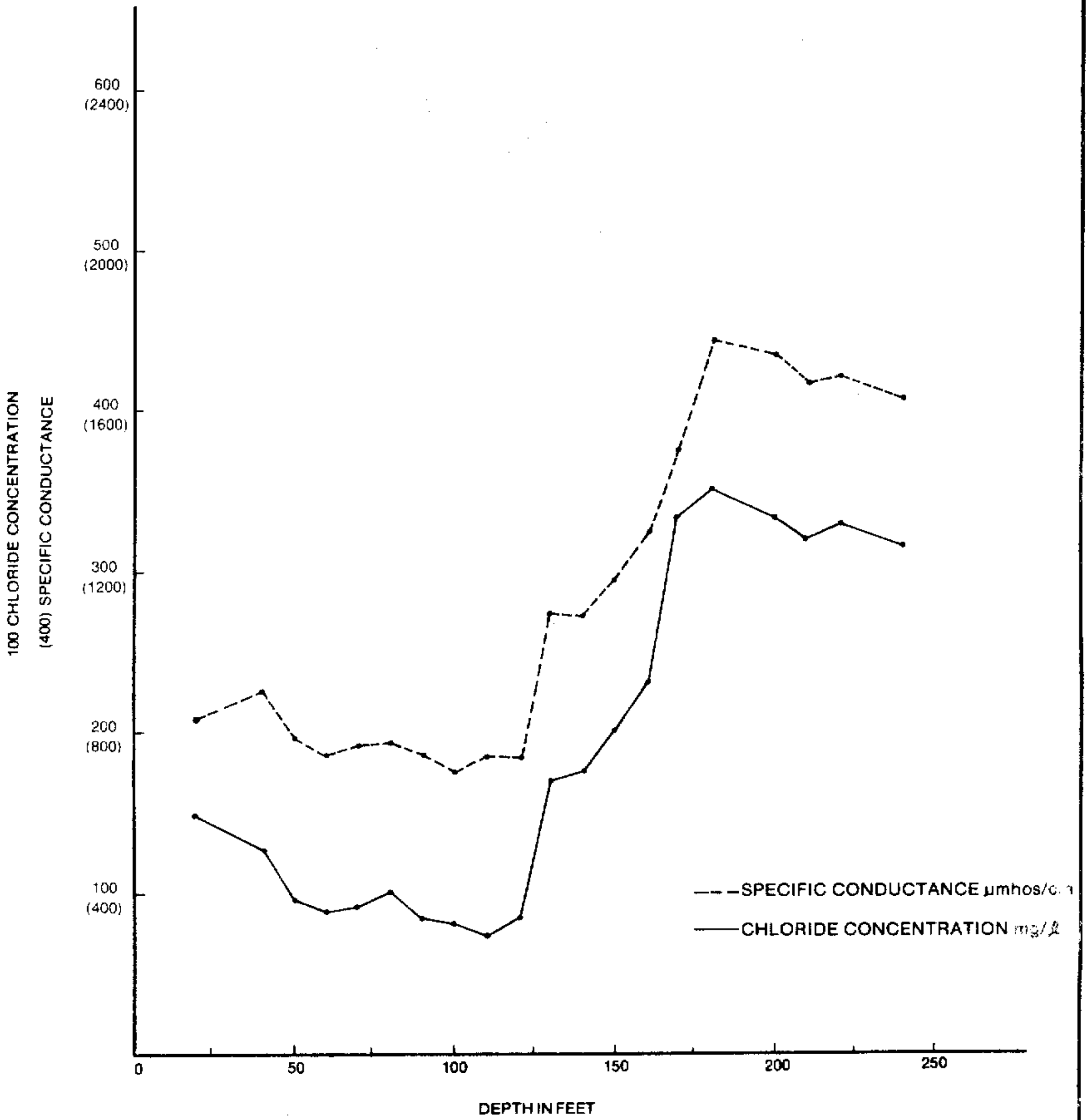


Figure 19 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2322 SAMPLED 1981 (COURTESY U.S.G.S.)

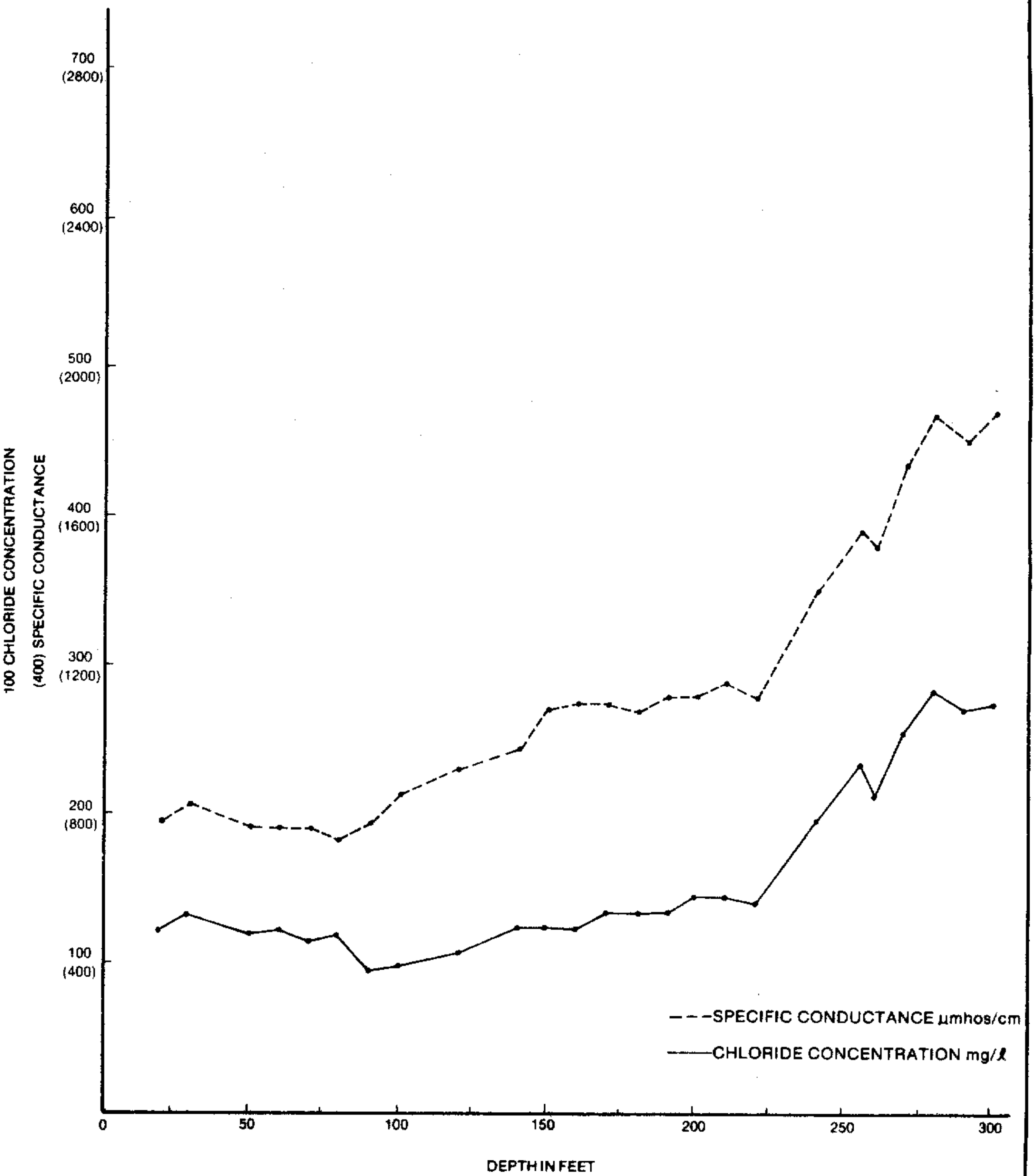


Figure 20 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2321 SAMPLED 1981 (COURTESY U.S.G.S.)

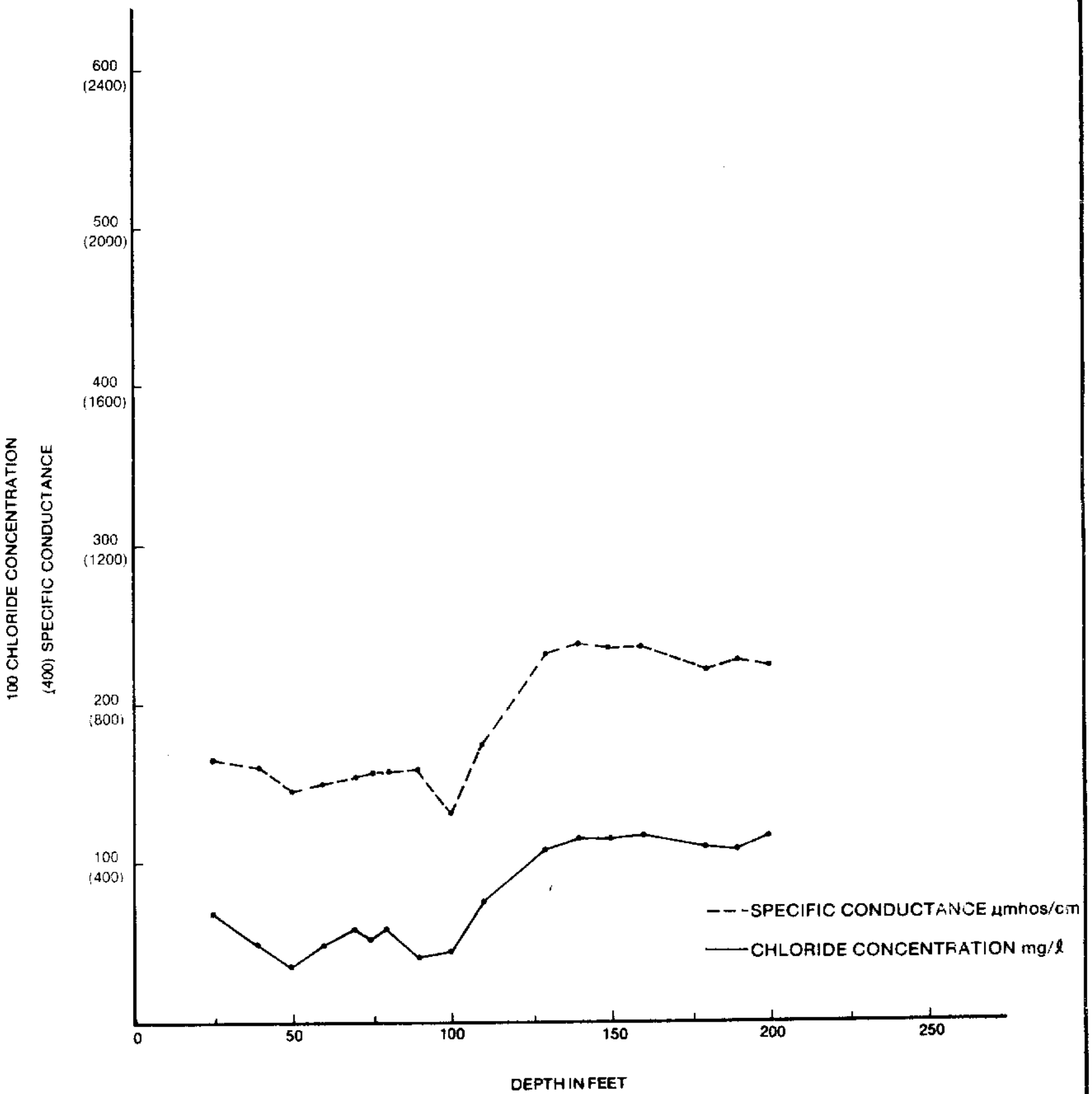


Figure 21 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2318 SAMPLED 1981 (COURTESY U.S.G.S.)

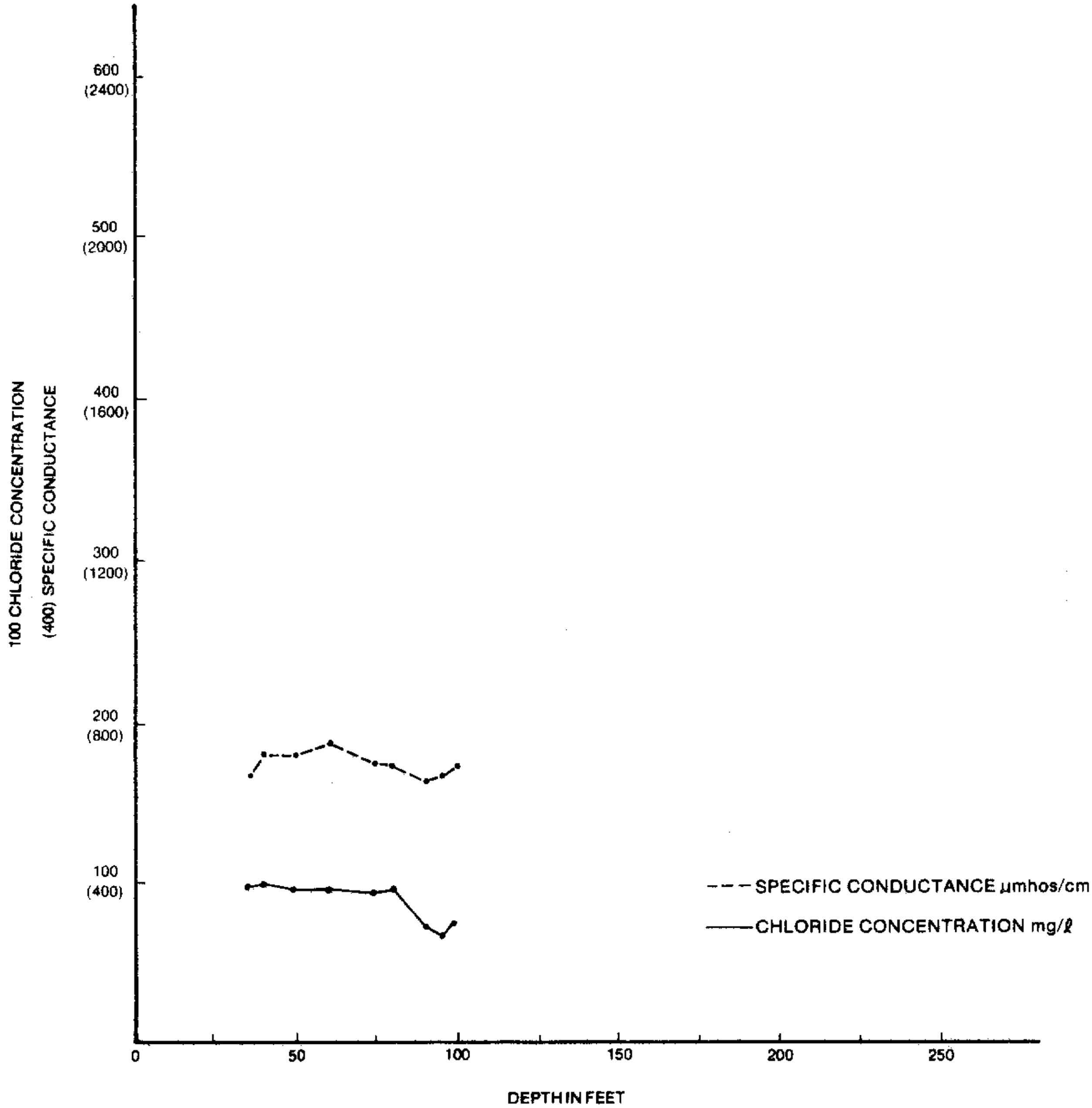
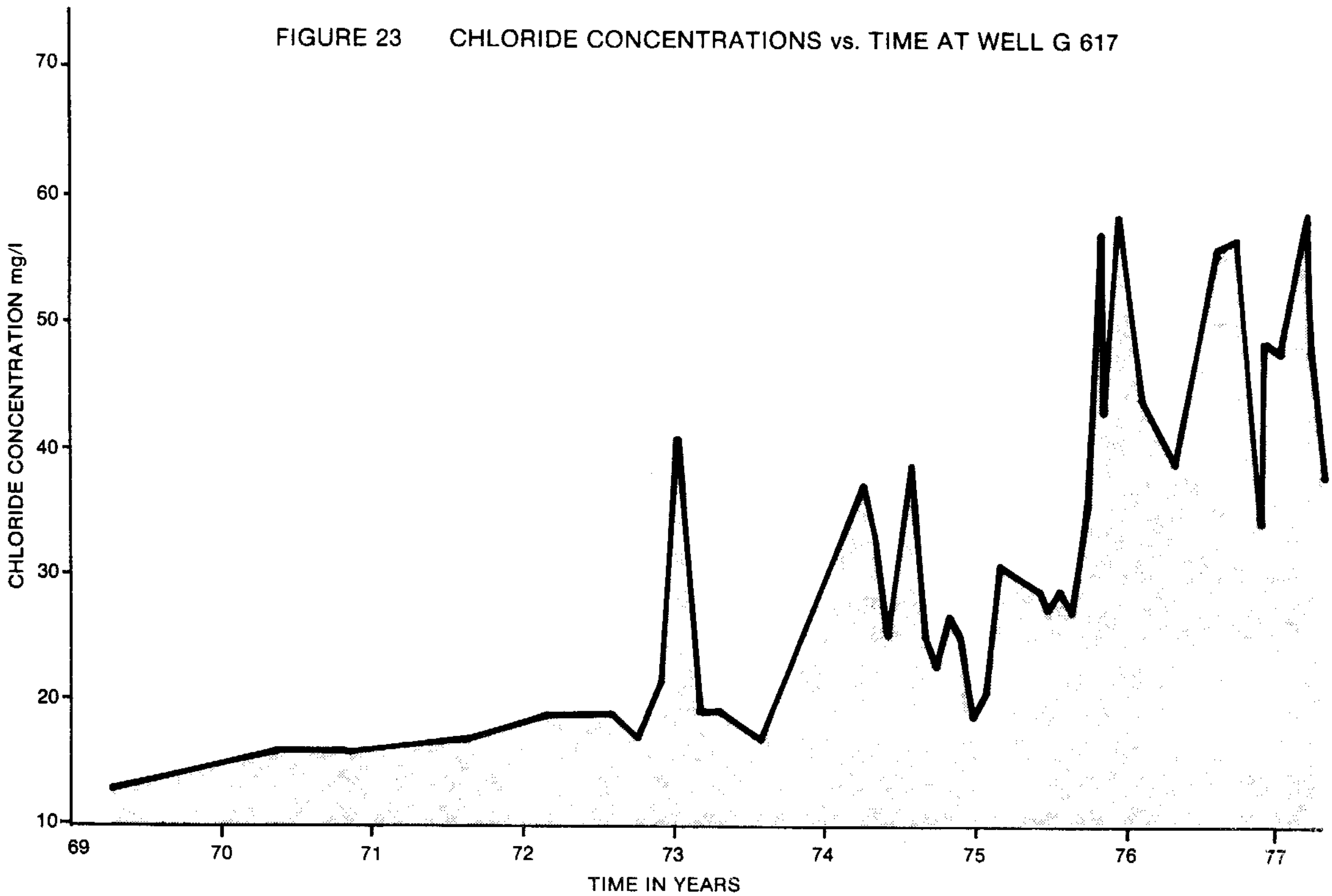


Figure 22 CHLORIDE CONCENTRATION / CONDUCTIVITY VS DEPTH FOR WELL G-2317 SAMPLED 1981 (COURTESY U.S.G.S.)

FIGURE 23 CHLORIDE CONCENTRATIONS vs. TIME AT WELL G 617



APPENDIX B

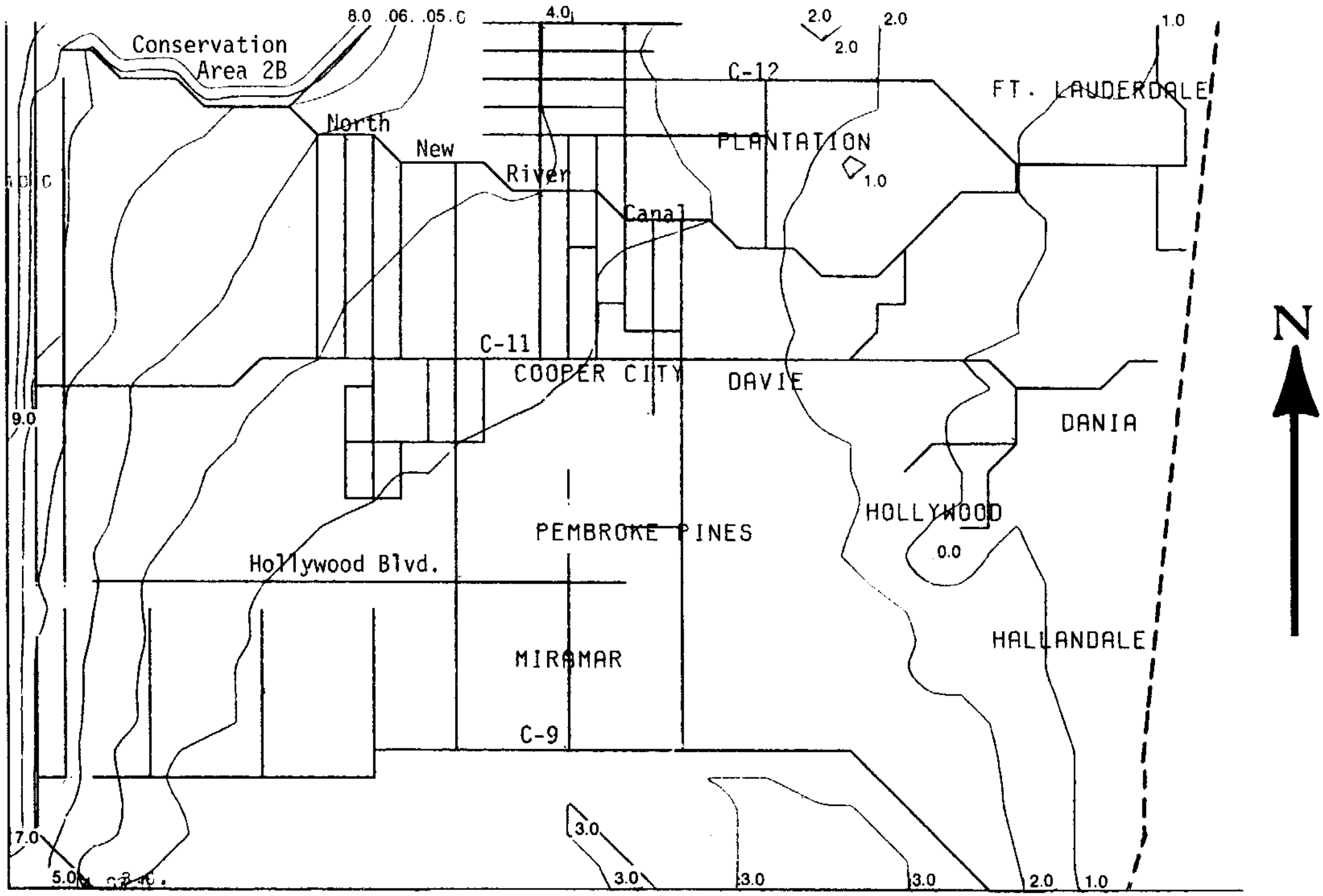


FIGURE 1A: GROUNDWATER TABLE FOR END OF APRIL 1969 — SIMULATION

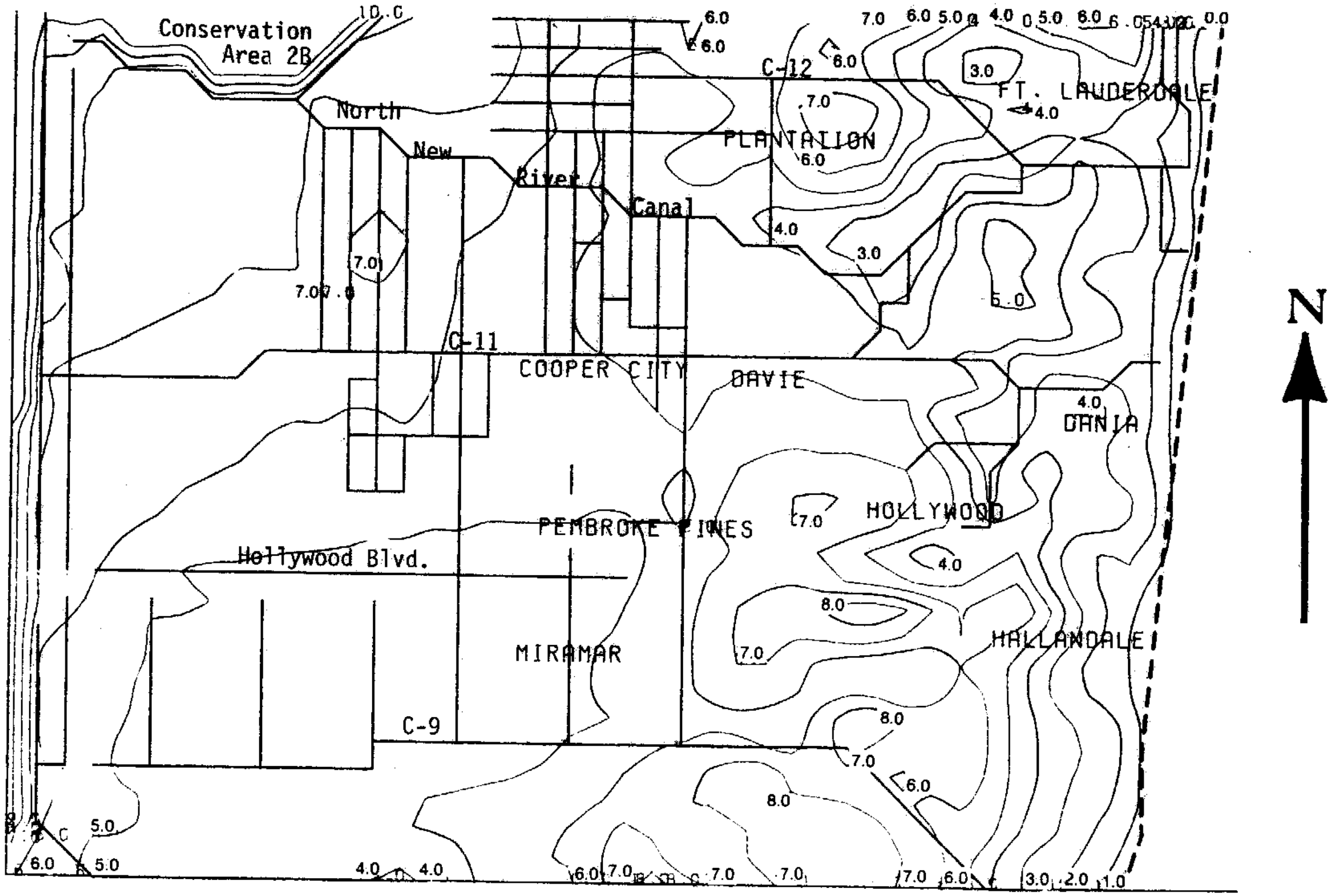


FIGURE 1B: GROUNDWATER TABLE FOR END OF OCTOBER 1969 — SIMULATION

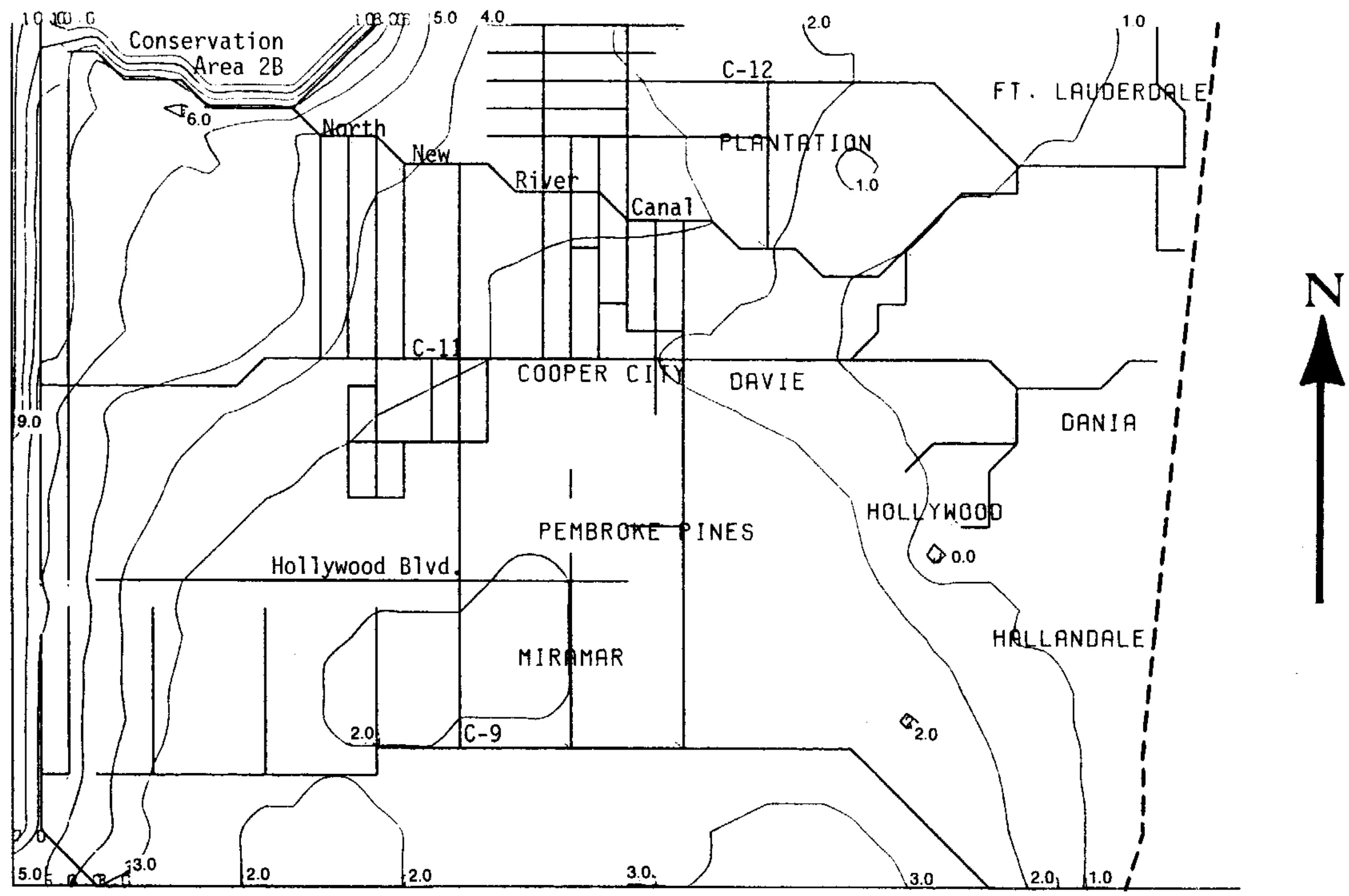


FIGURE 1C: GROUNDWATER TABLE FOR END OF APRIL 1970 — SIMULATION

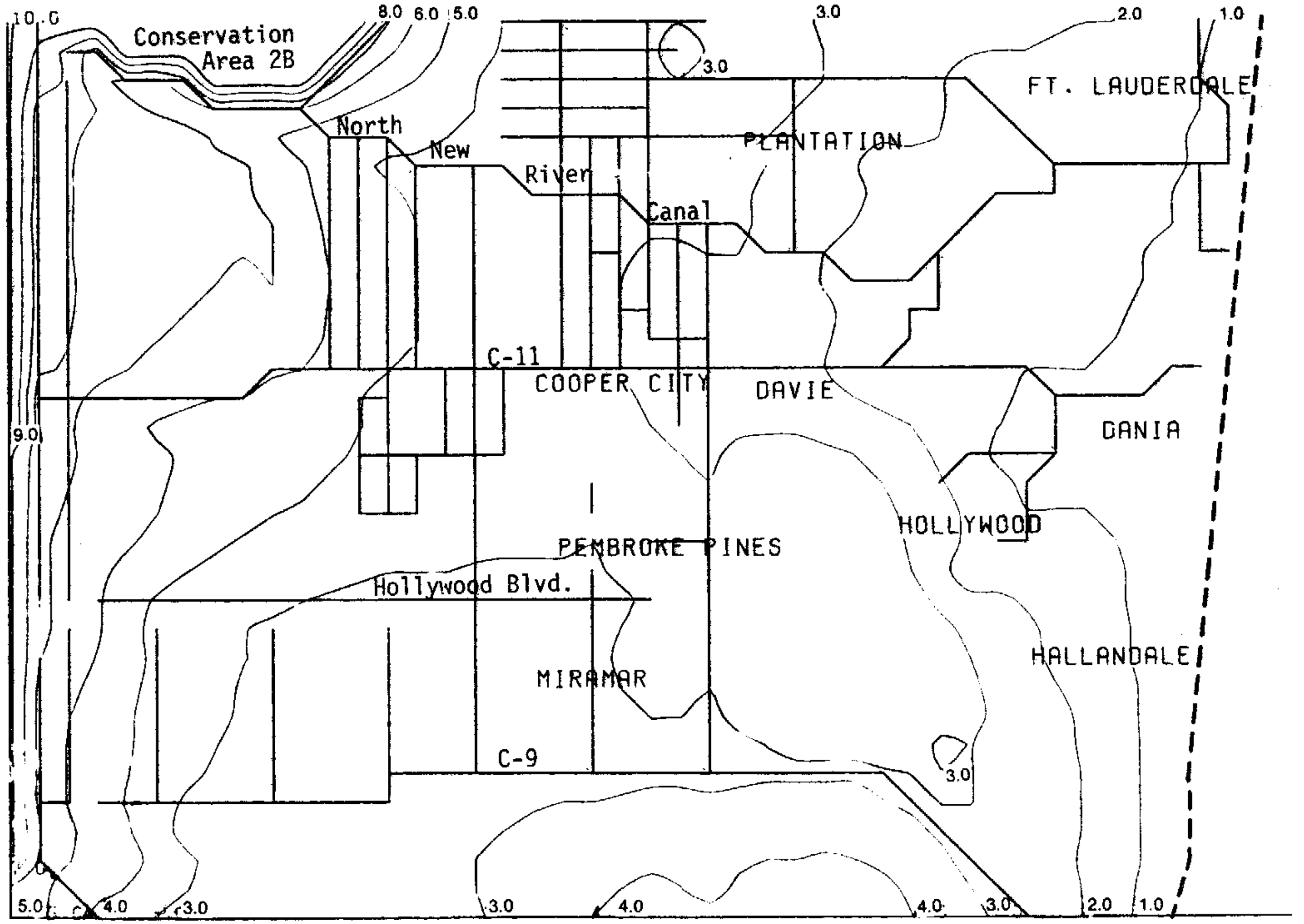


FIGURE 1D: GROUNDWATER TABLE FOR END OF OCTOBER 1970 — SIMULATION

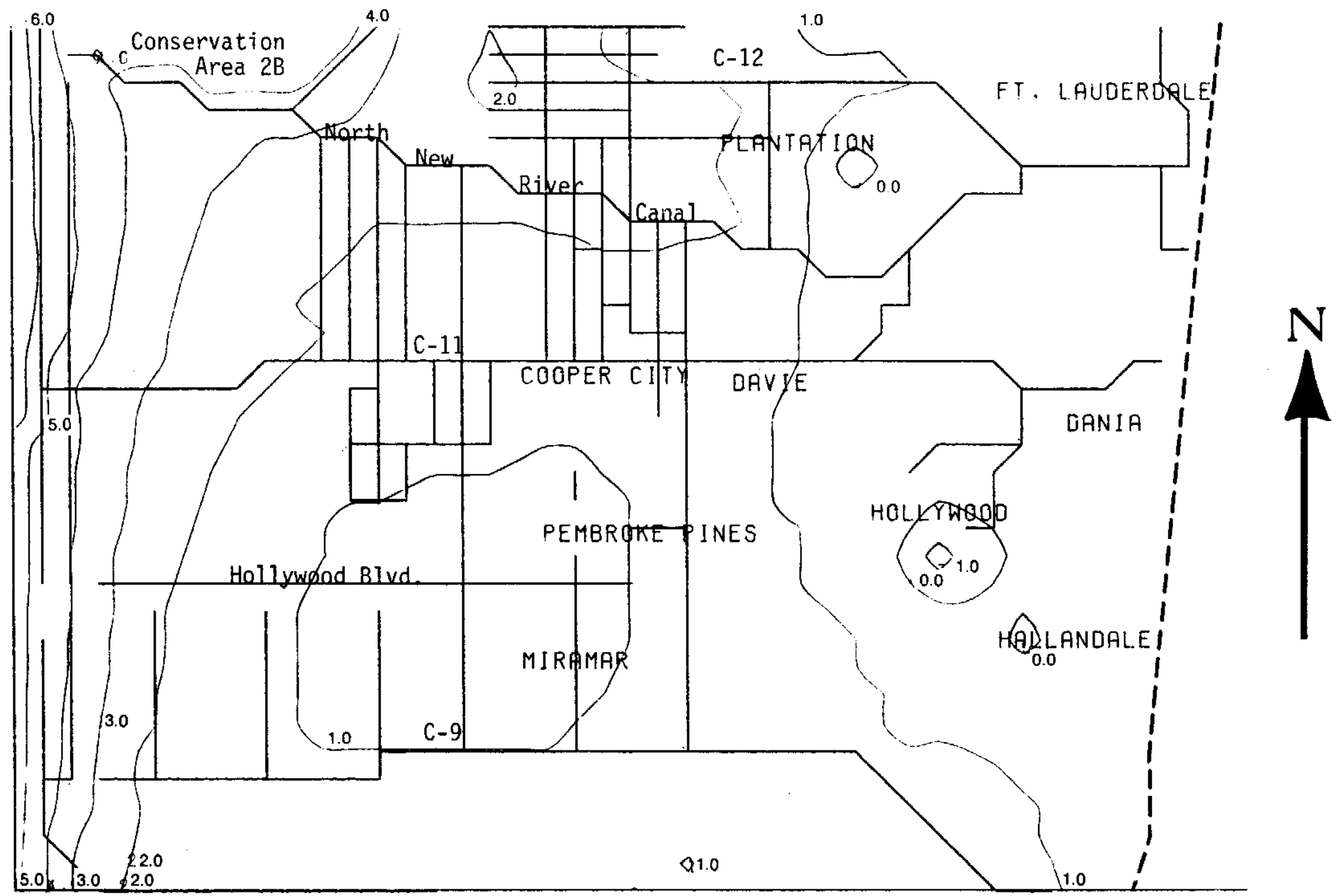


FIGURE 1E: GROUNDWATER TABLE FOR END OF APRIL 1971 — SIMULATION

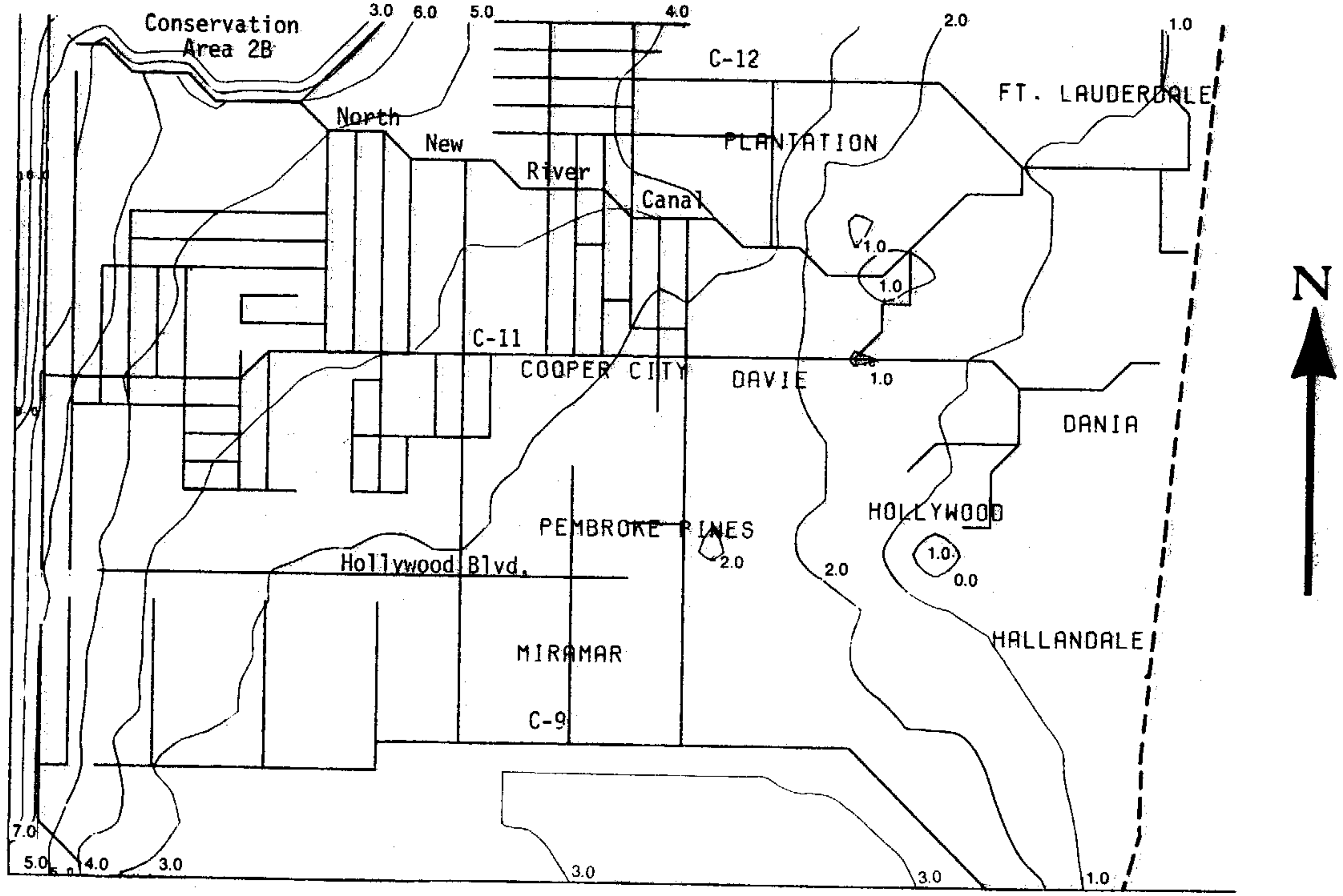


FIGURE 2A: GROUNDWATER TABLE FOR END OF APRIL 1969 — PRESENT CONDITIONS

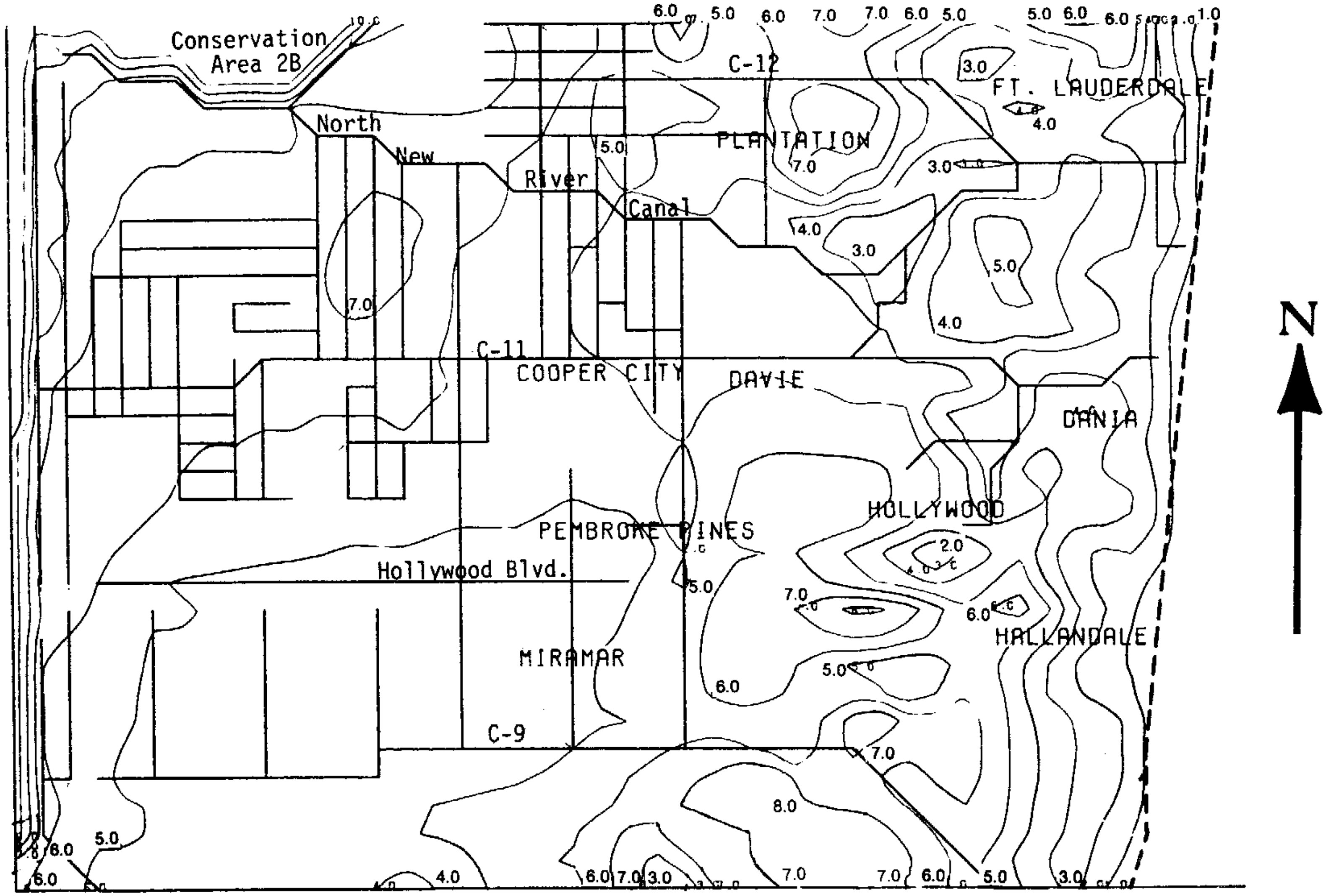


FIGURE 2B: GROUNDWATER TABLE FOR END OF OCTOBER 1969 — PRESENT CONDITIONS

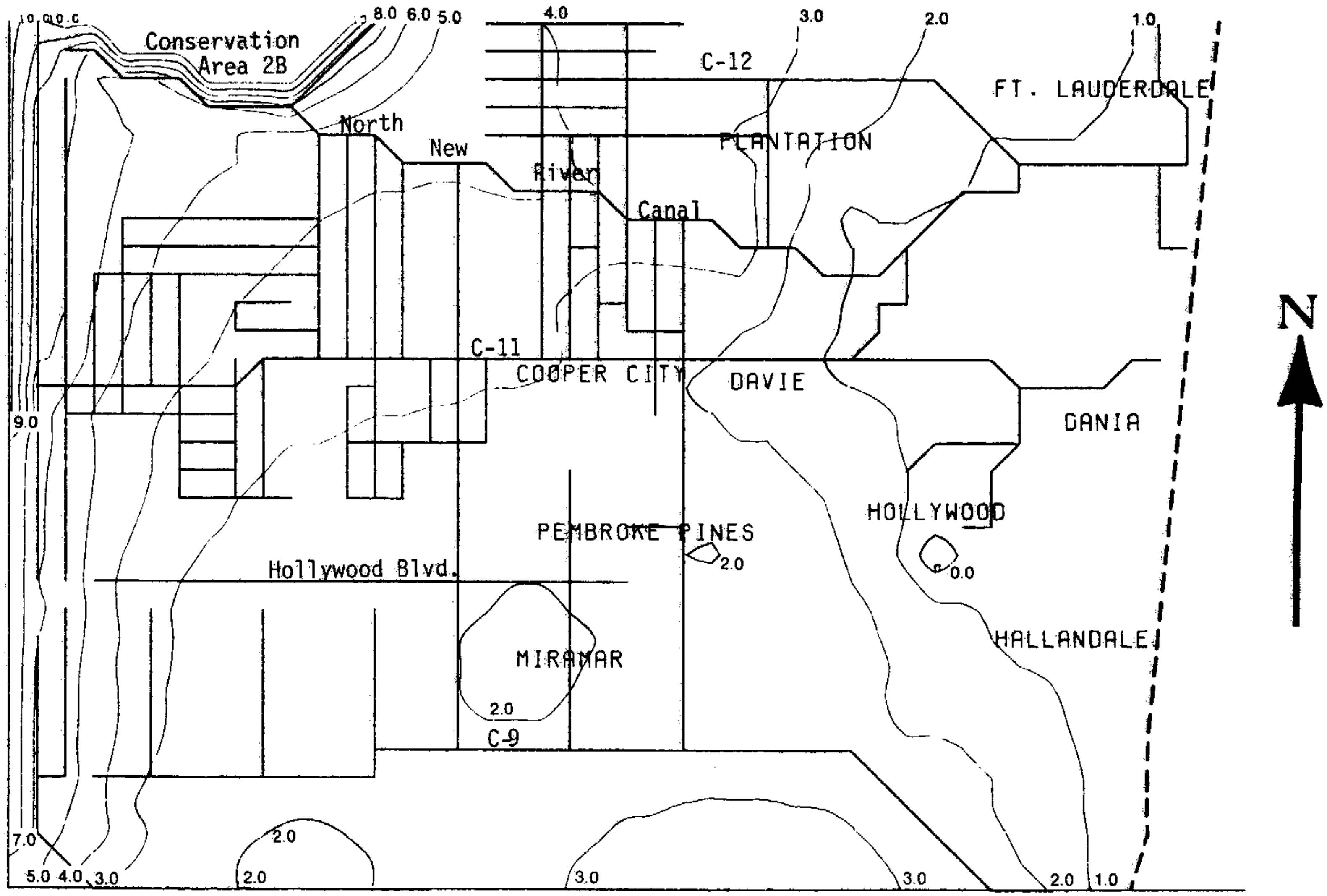


FIGURE 2C: GROUNDWATER TABLE FOR END OF APRIL 1970 — PRESENT CONDITIONS

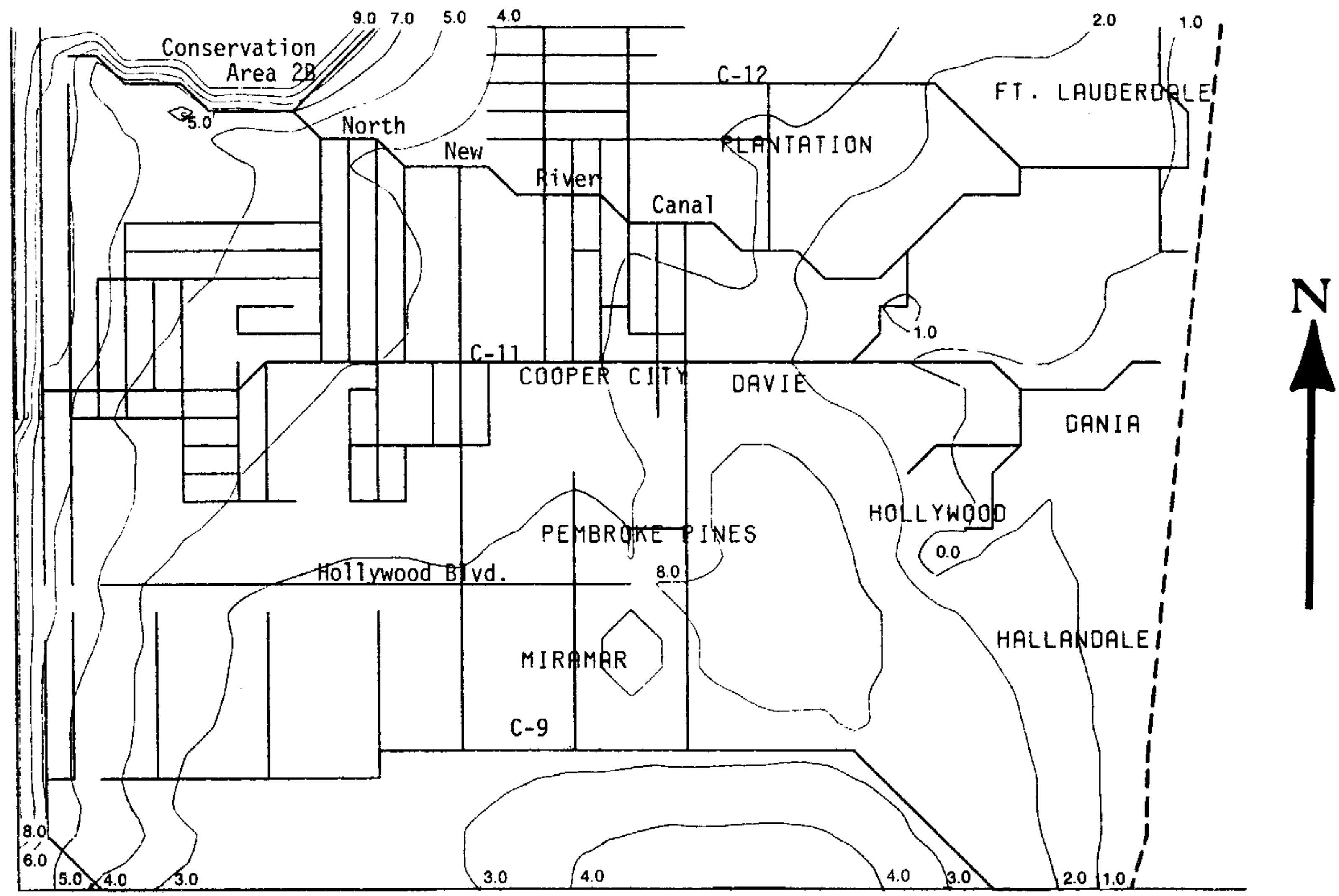


FIGURE 2D: GROUNDWATER TABLE FOR END OF OCTOBER 1970 — PRESENT CONDITIONS

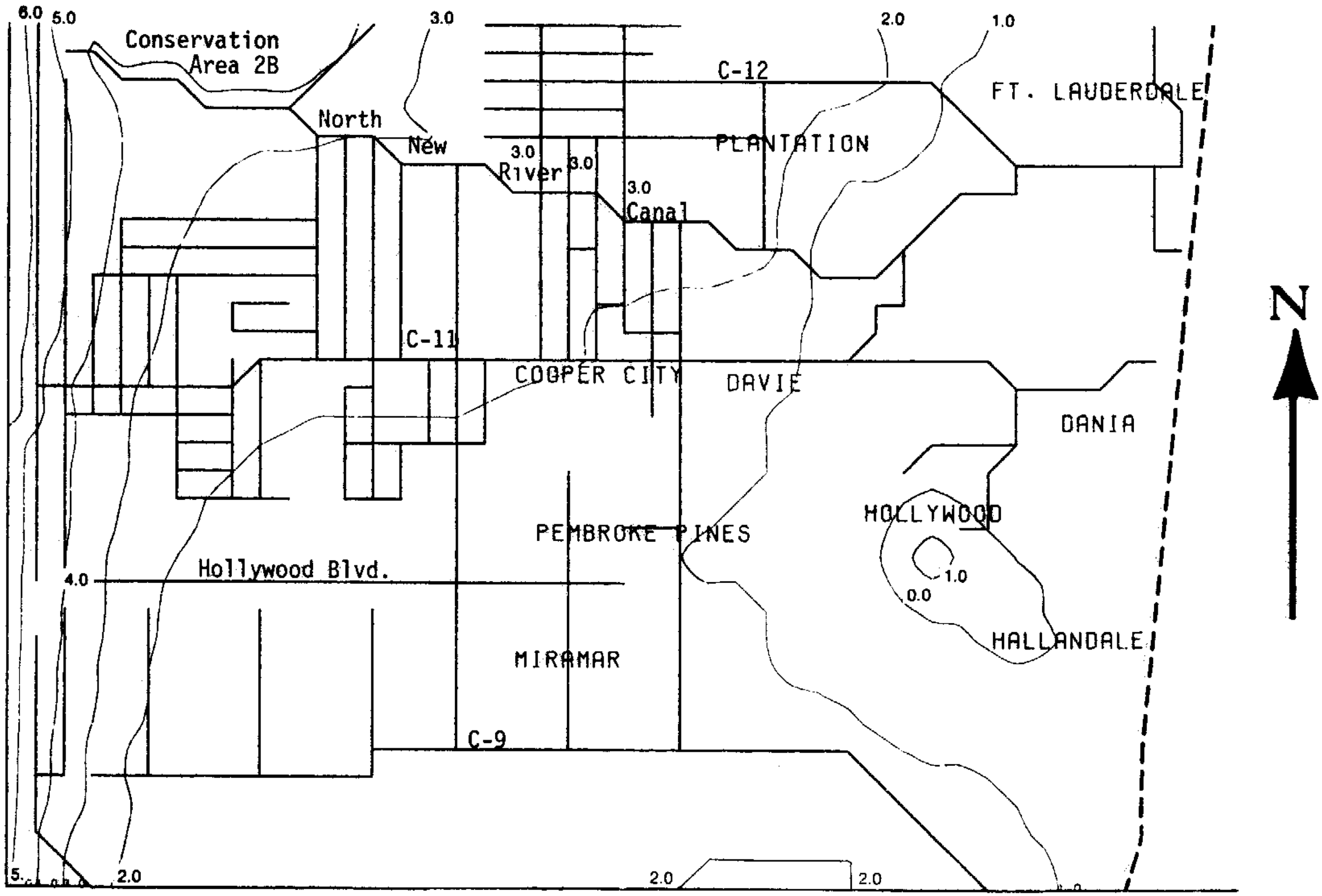


FIGURE 2E: GROUNDWATER TABLE FOR END OF APRIL 1971 — PRESENT CONDITIONS

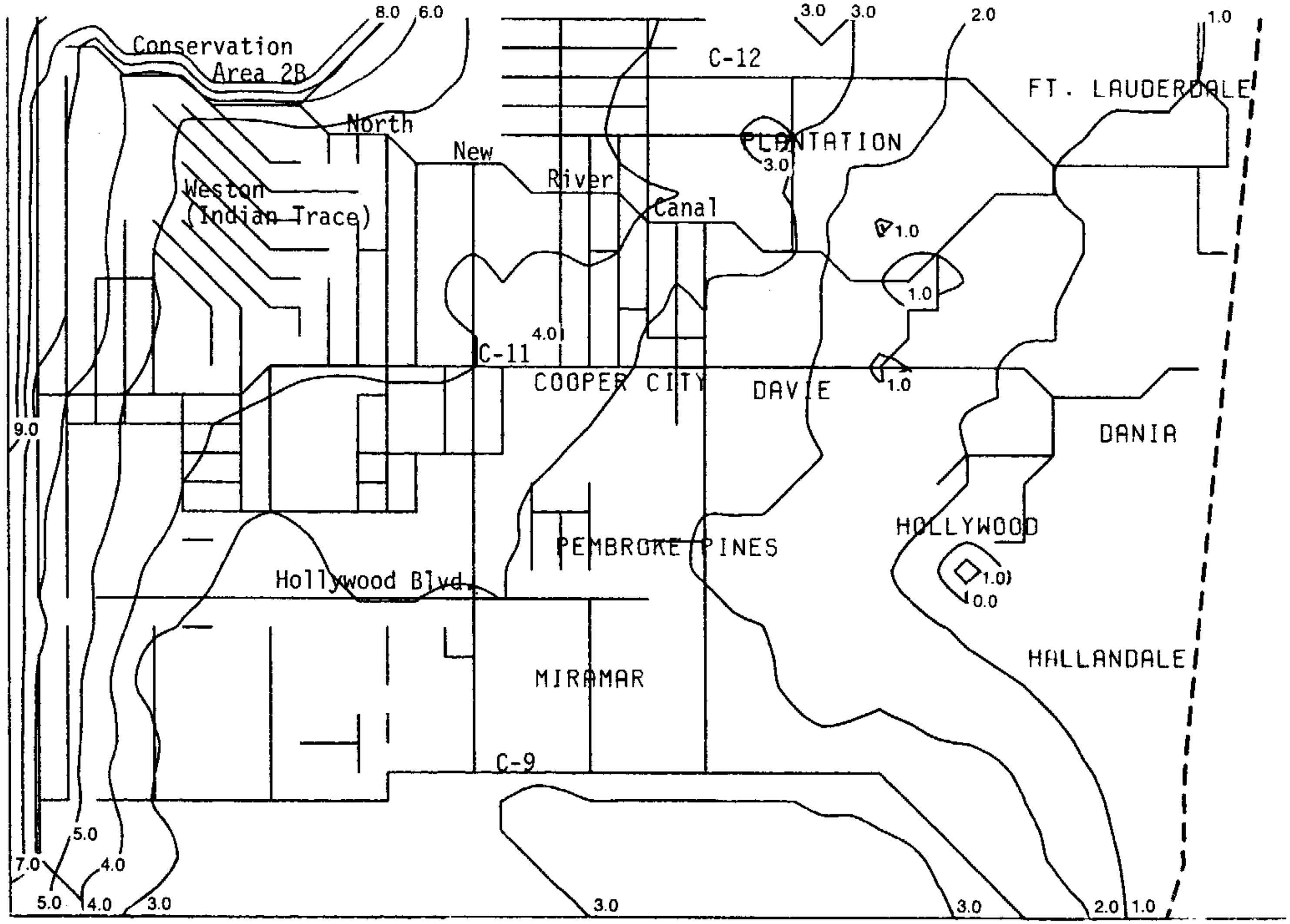


FIGURE 3A: GROUNDWATER TABLE FOR END OF APRIL 1969 — PROPOSED CONDITIONS

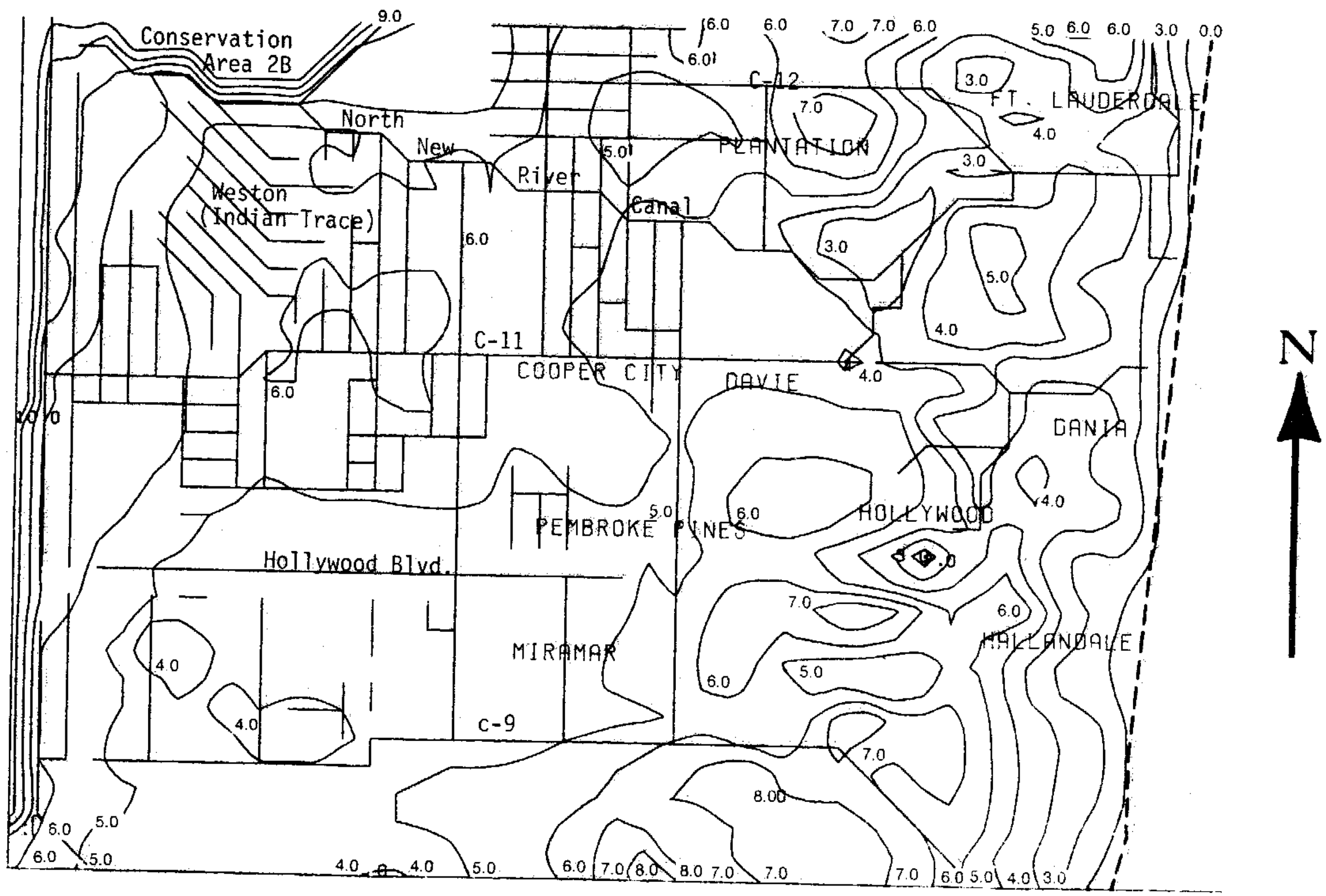


FIGURE 3B: GROUNDWATER TABLE FOR END OF OCTOBER 1969
—PROPOSED CONDITIONS

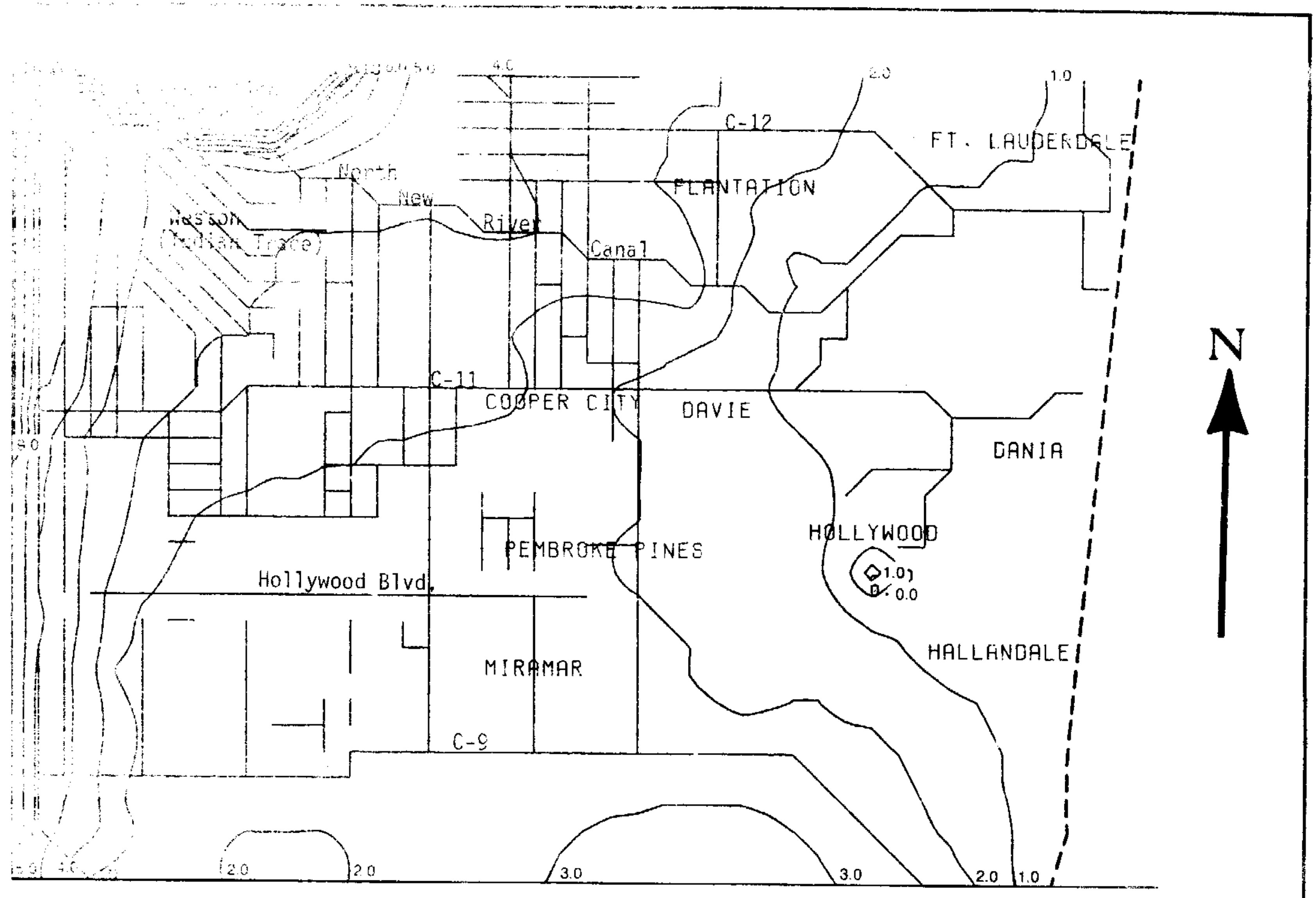


FIGURE 3C. GROUNDWATER TABLE FOR END OF APRIL 1970 — PROPOSED CONDITIONS

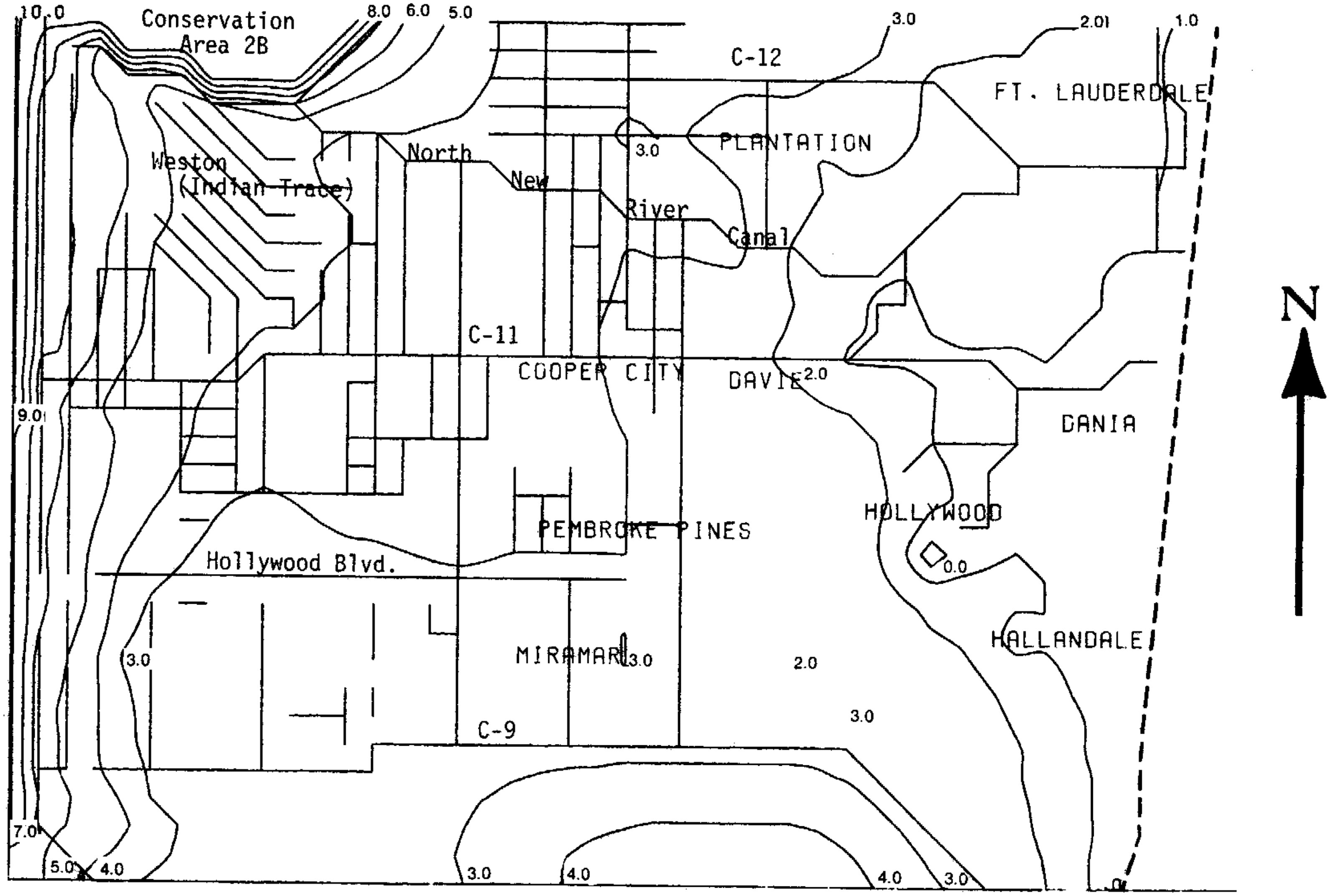


FIGURE 3D: GROUNDWATER TABLE FOR END OF OCTOBER 1970
—PROPOSED CONDITIONS

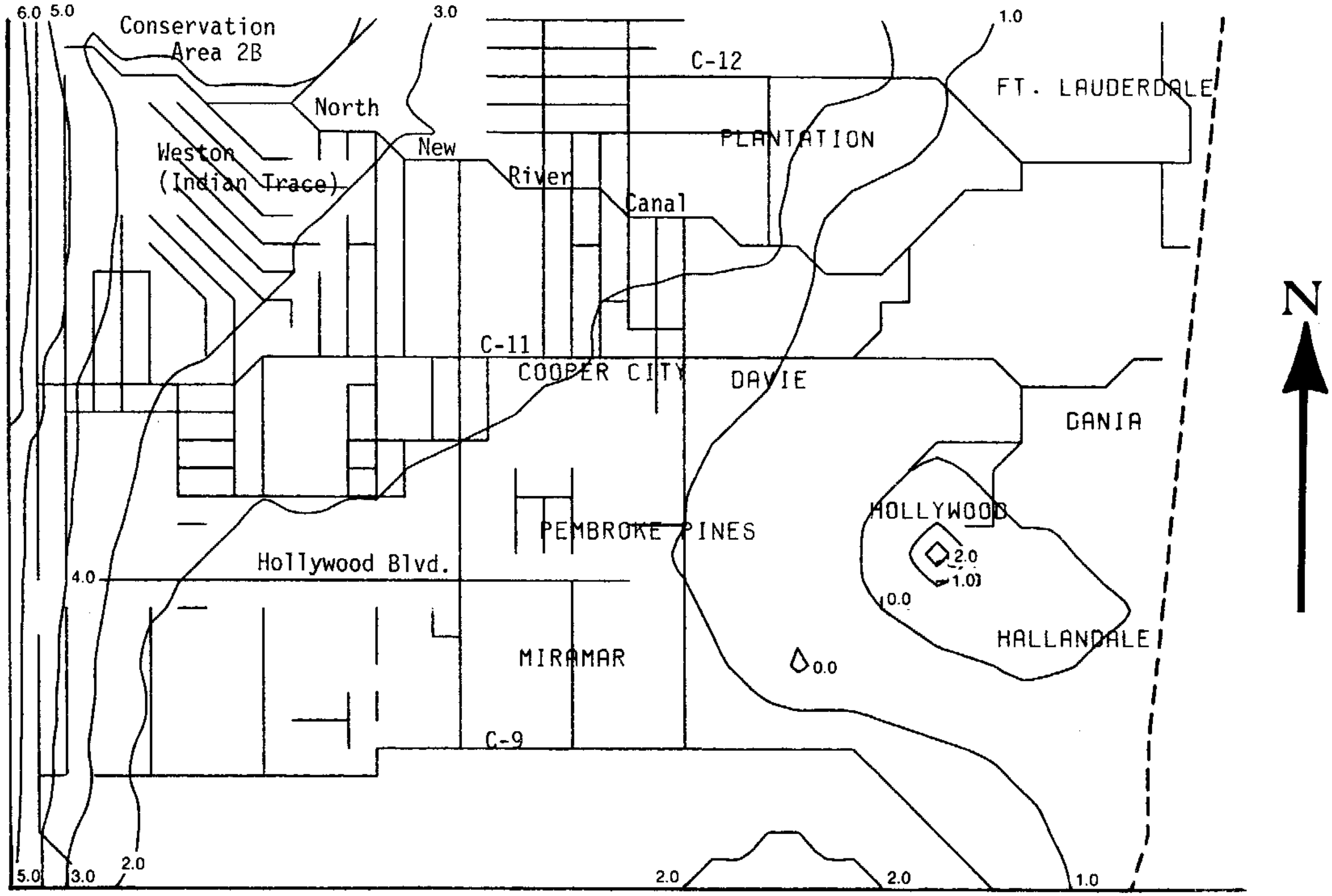


FIGURE 3E: GROUNDWATER TABLE FOR END OF APRIL 1971 — PROPOSED CONDITIONS

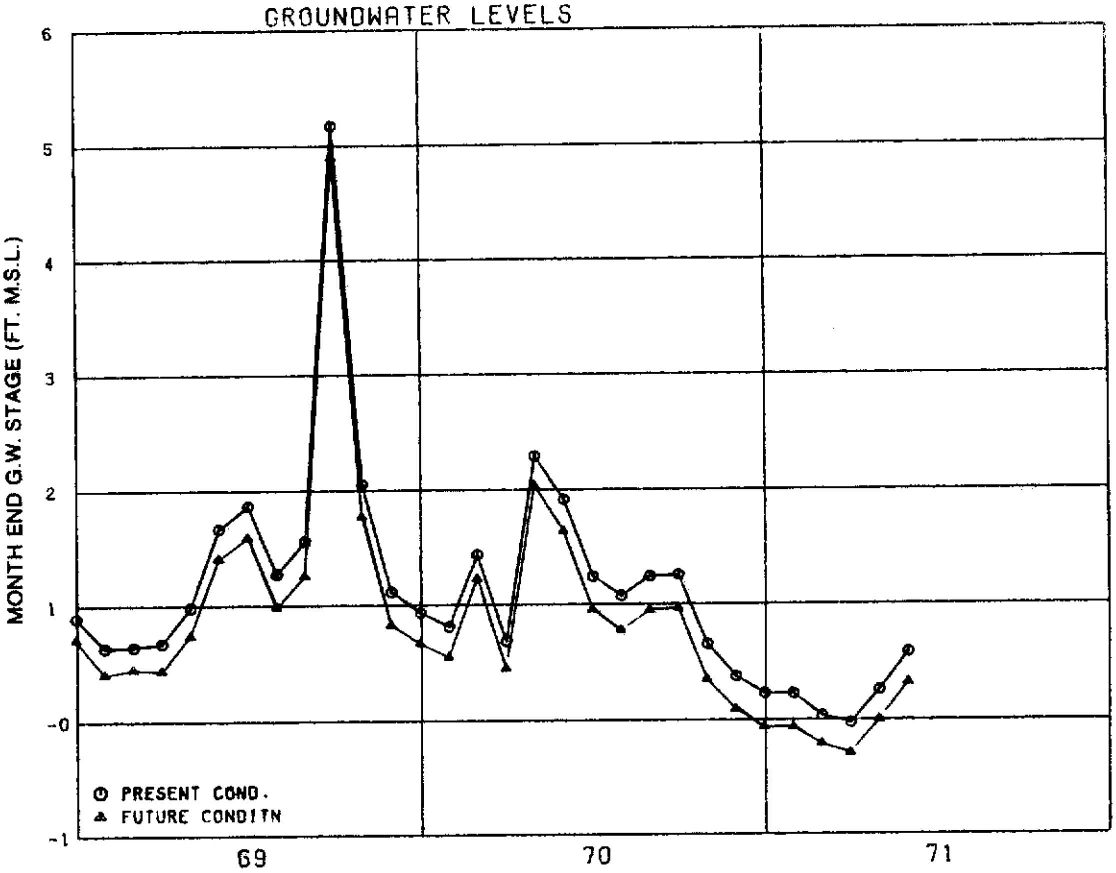


Figure 4A: HYDROGRAPH FOR F-291

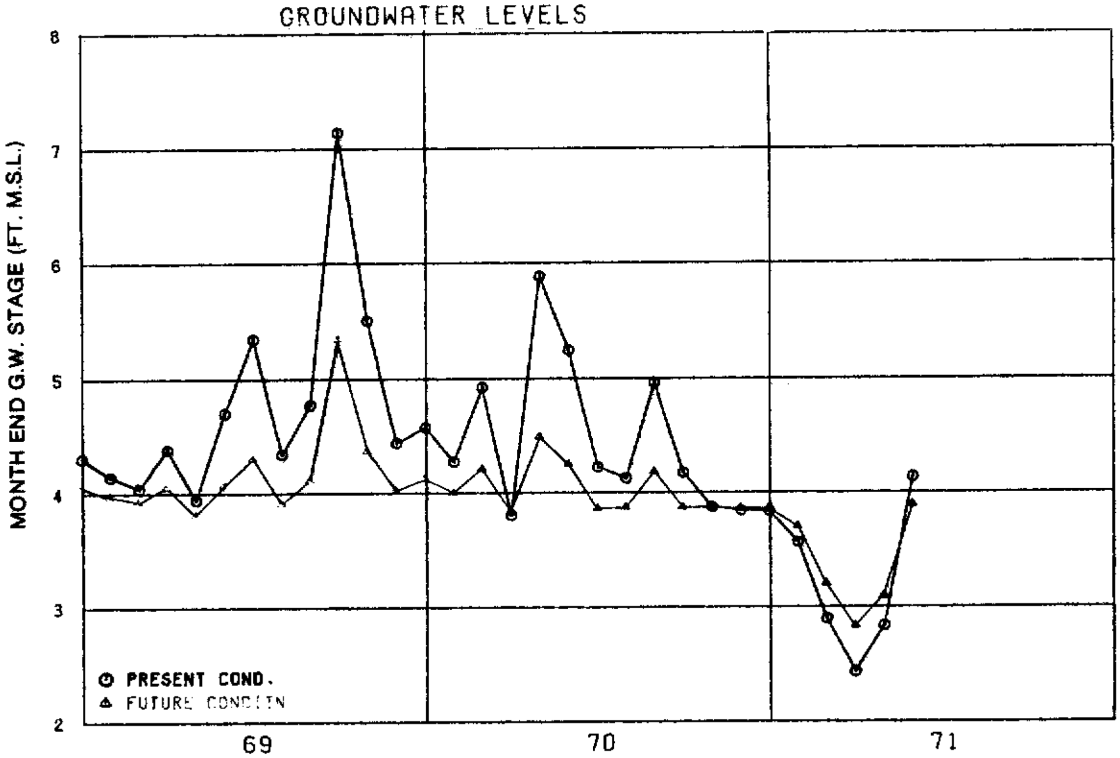


Figure 4B: HYDROGRAPH FOR G-617

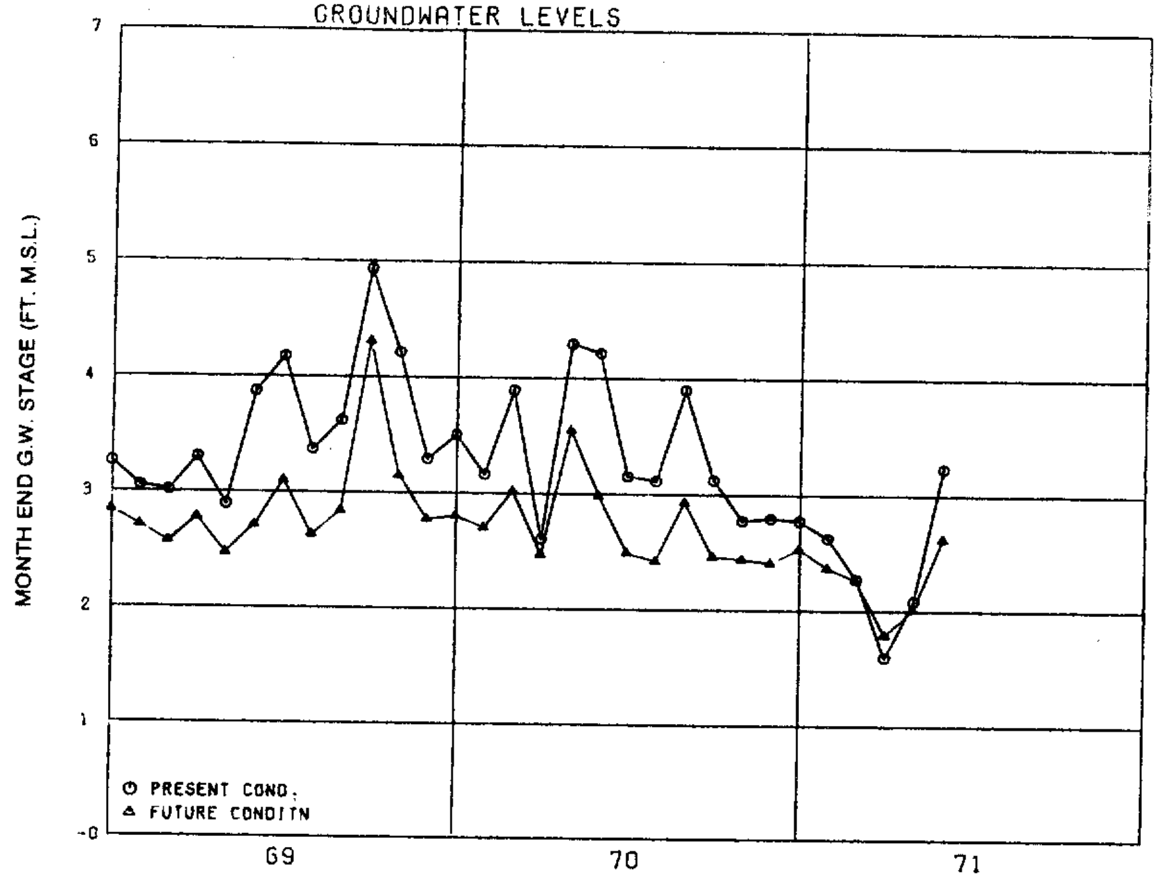


Figure 4C: HYDROGRAPH FOR G-1222

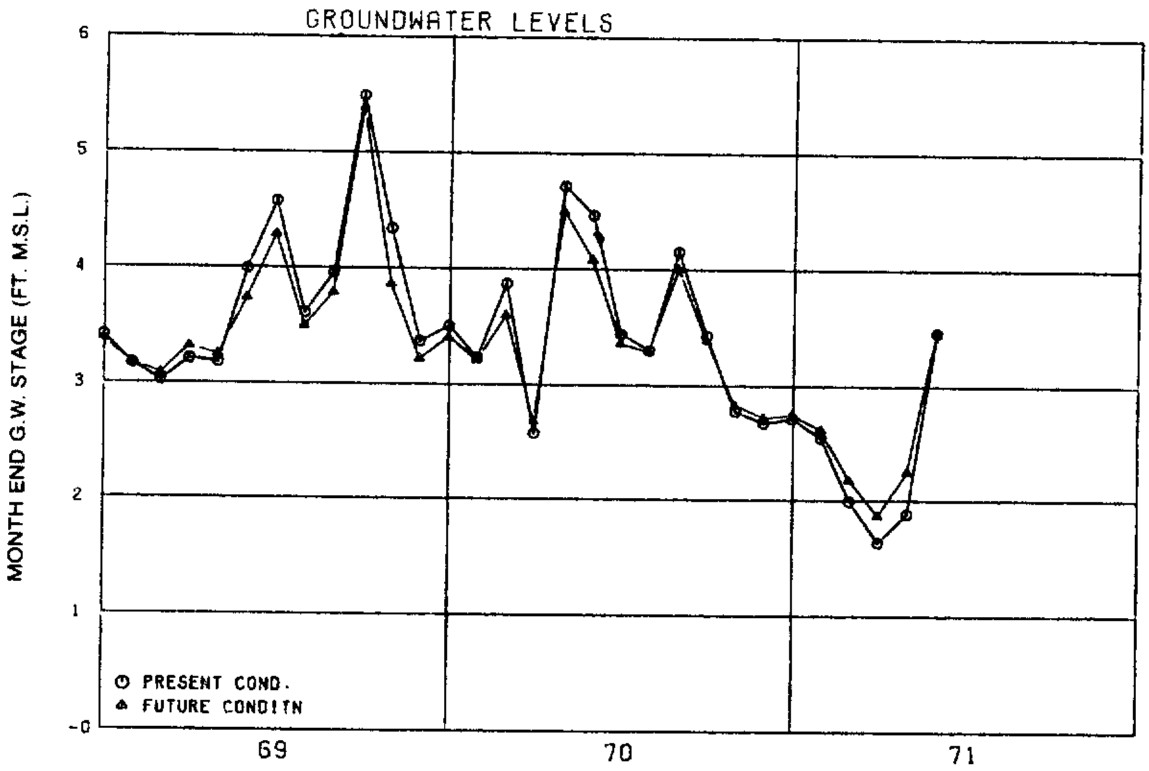


Figure 4D: HYDROGRAPH FOR G-1322

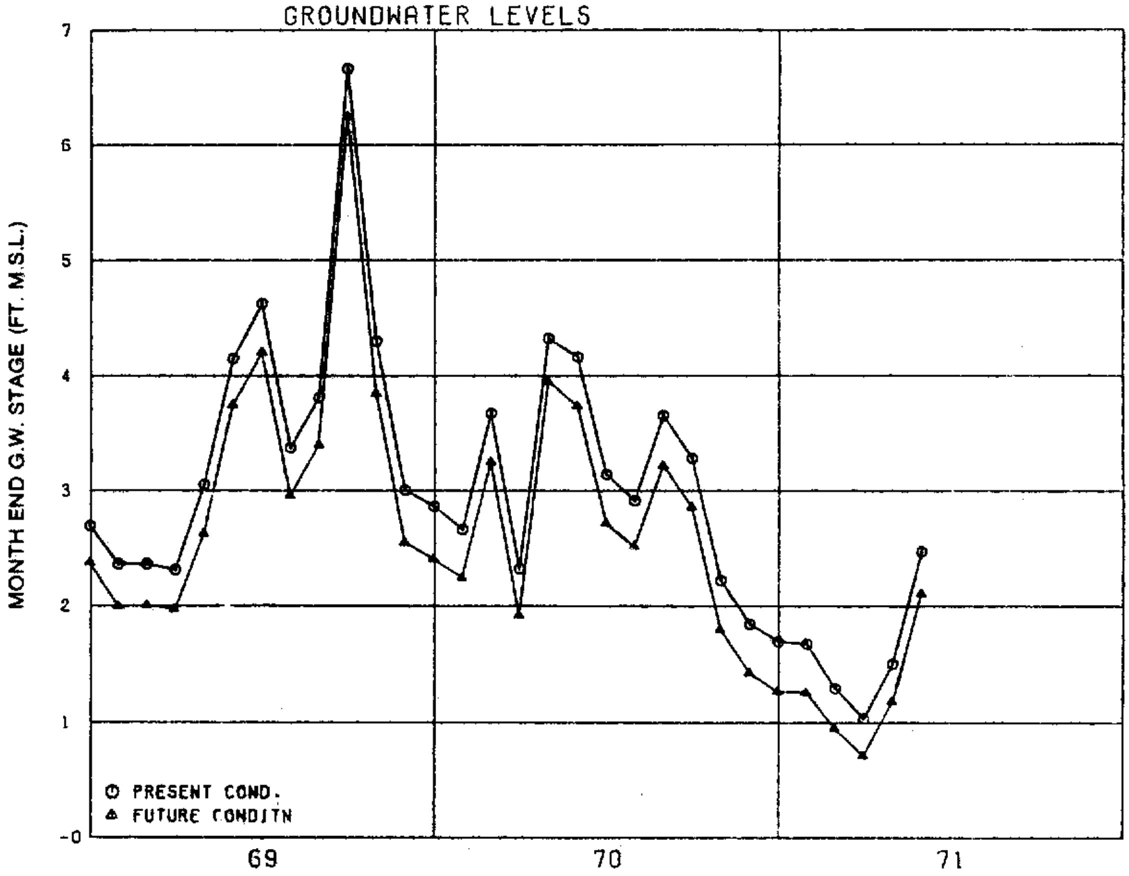


Figure 4E: HYDROGRAPH FOR G-1225

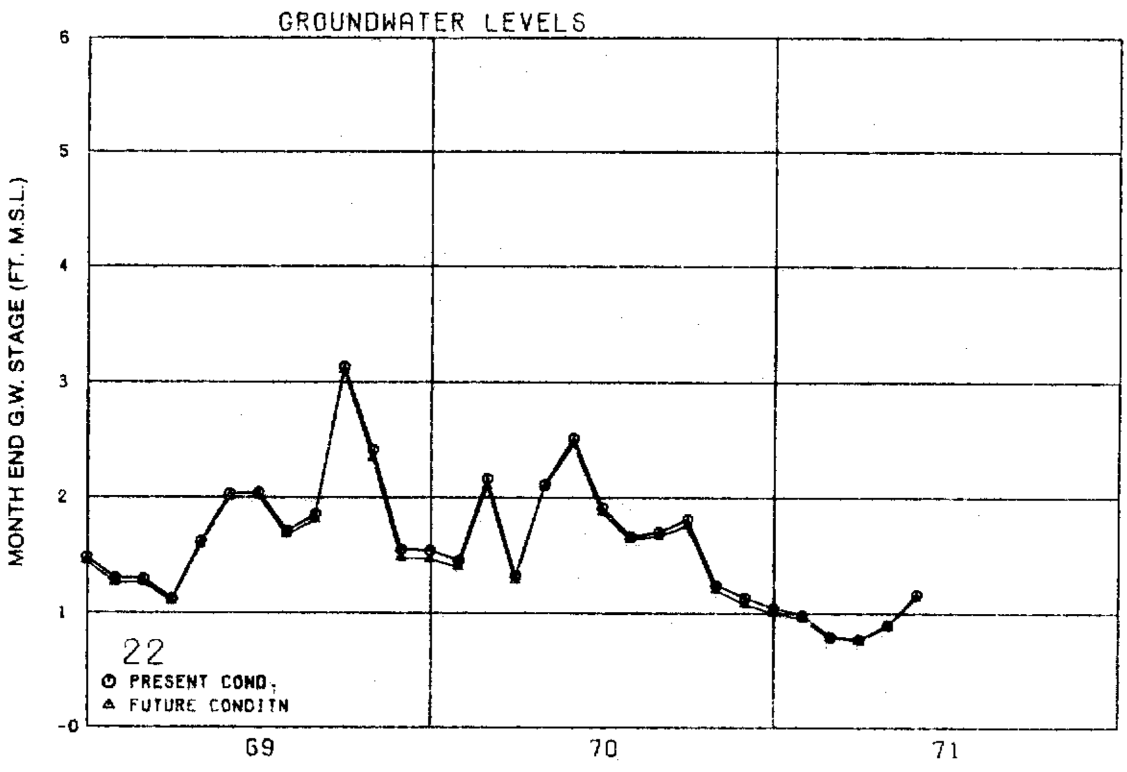


Figure 4F: HYDROGRAPH FOR G-1220

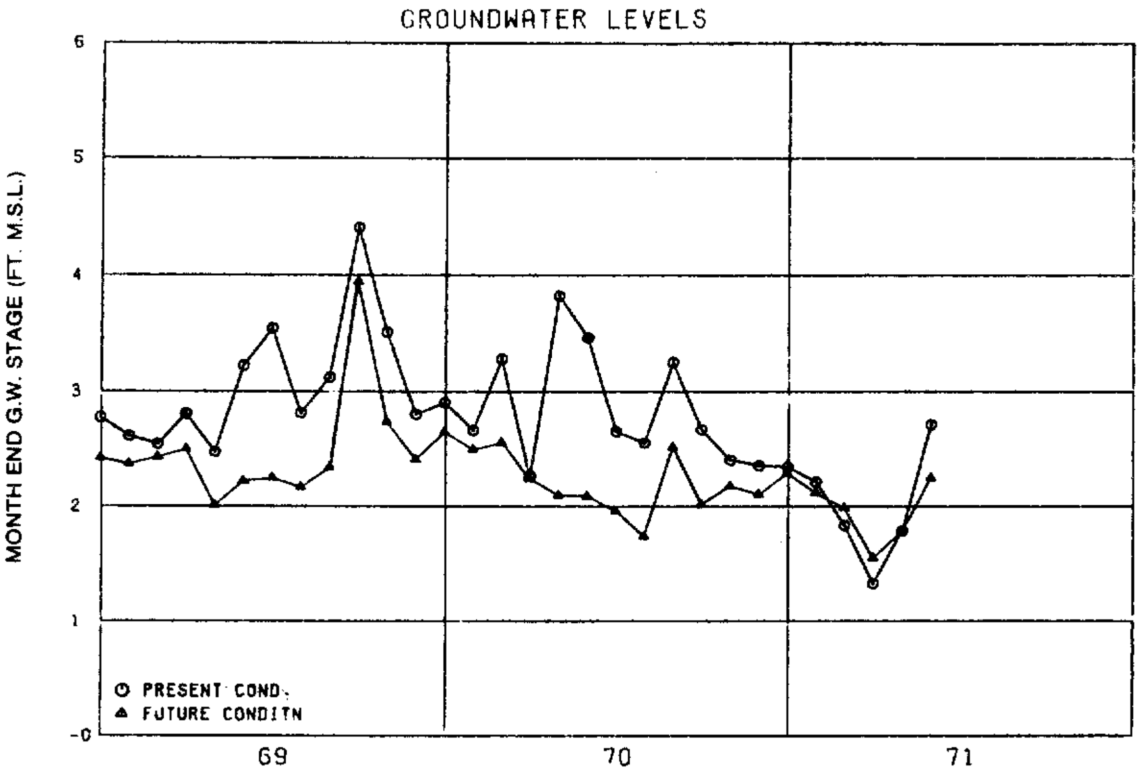


Figure 4G: HYDROGRAPH FOR PROPOSED BORROW PIT NEAR C-9

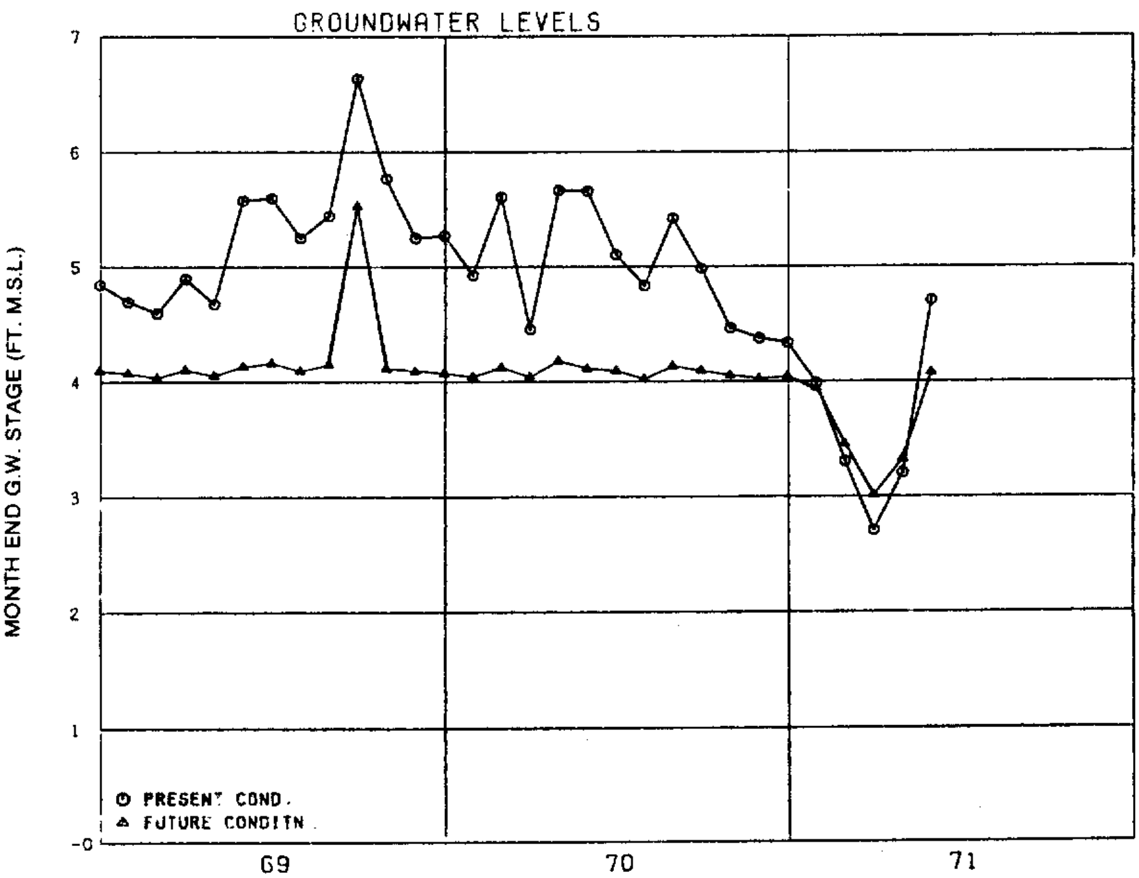


Figure 4H: HYDROGRAPH FOR PROPOSED WESTON (INDIAN TRACE) DEVELOPMENT

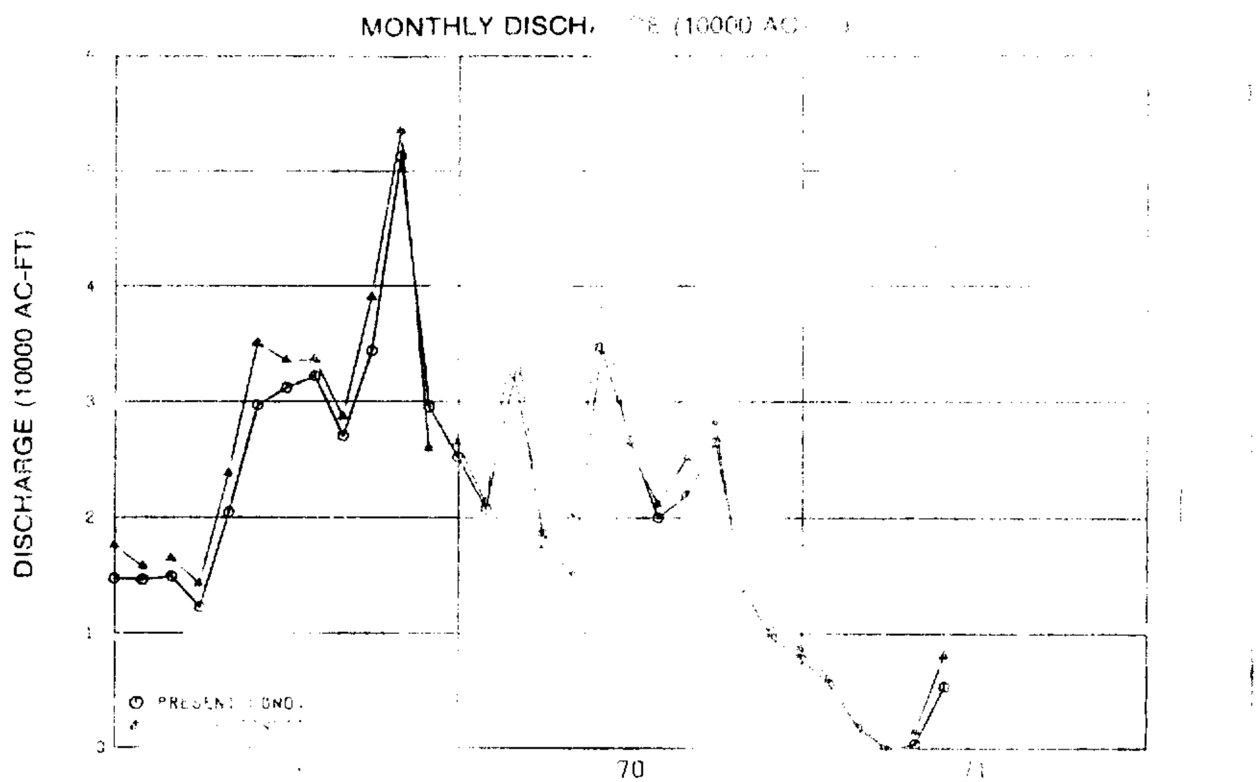


Figure 5A: DISCHARGE FOR S-9 PUMP STATION

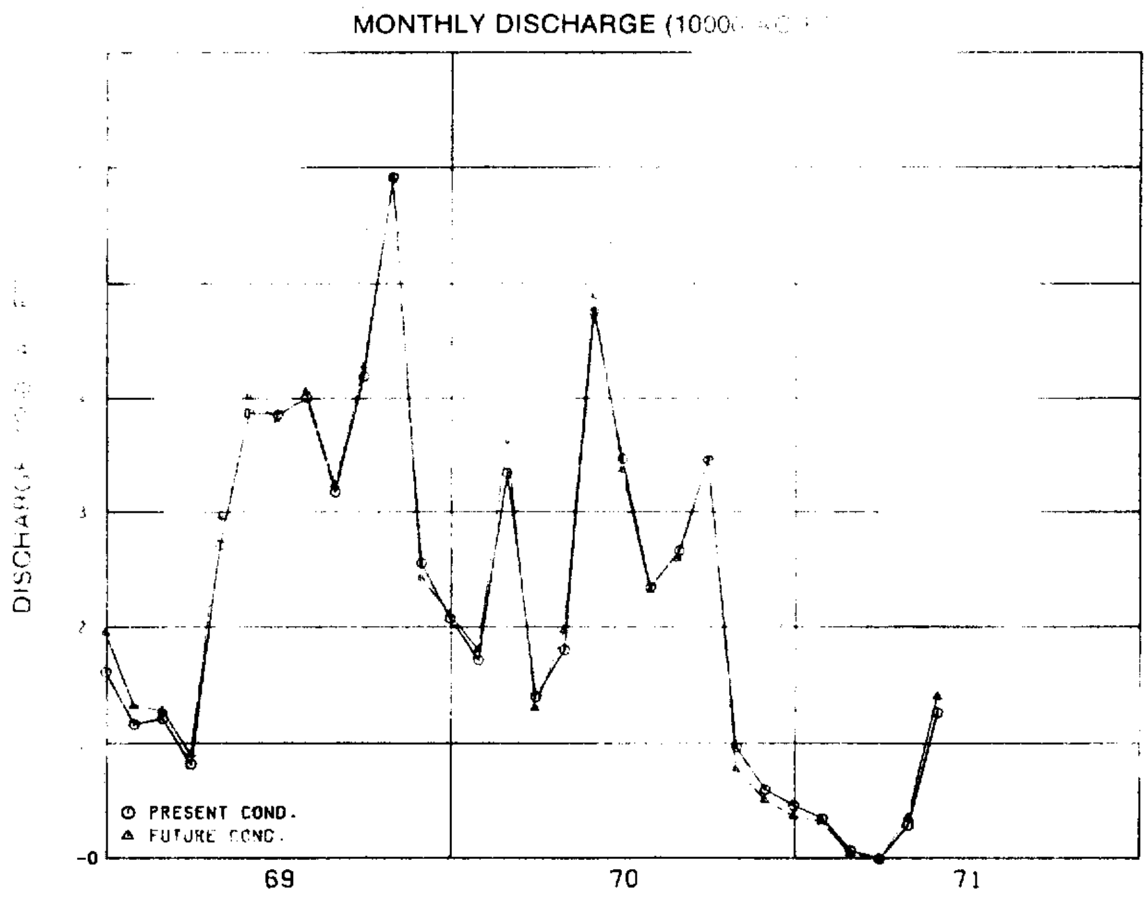


Figure 5B: DISCHARGE FOR S-29

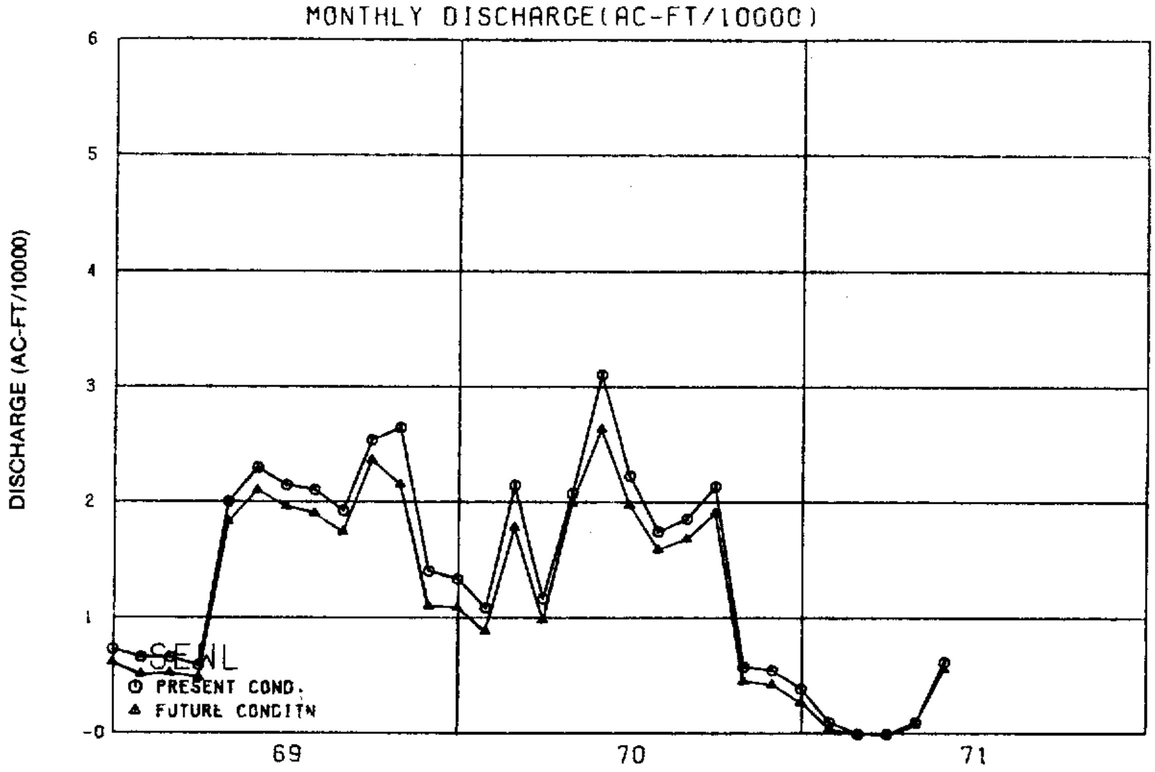


Figure 5C: DISCHARGE FOR SEWELL LOCK

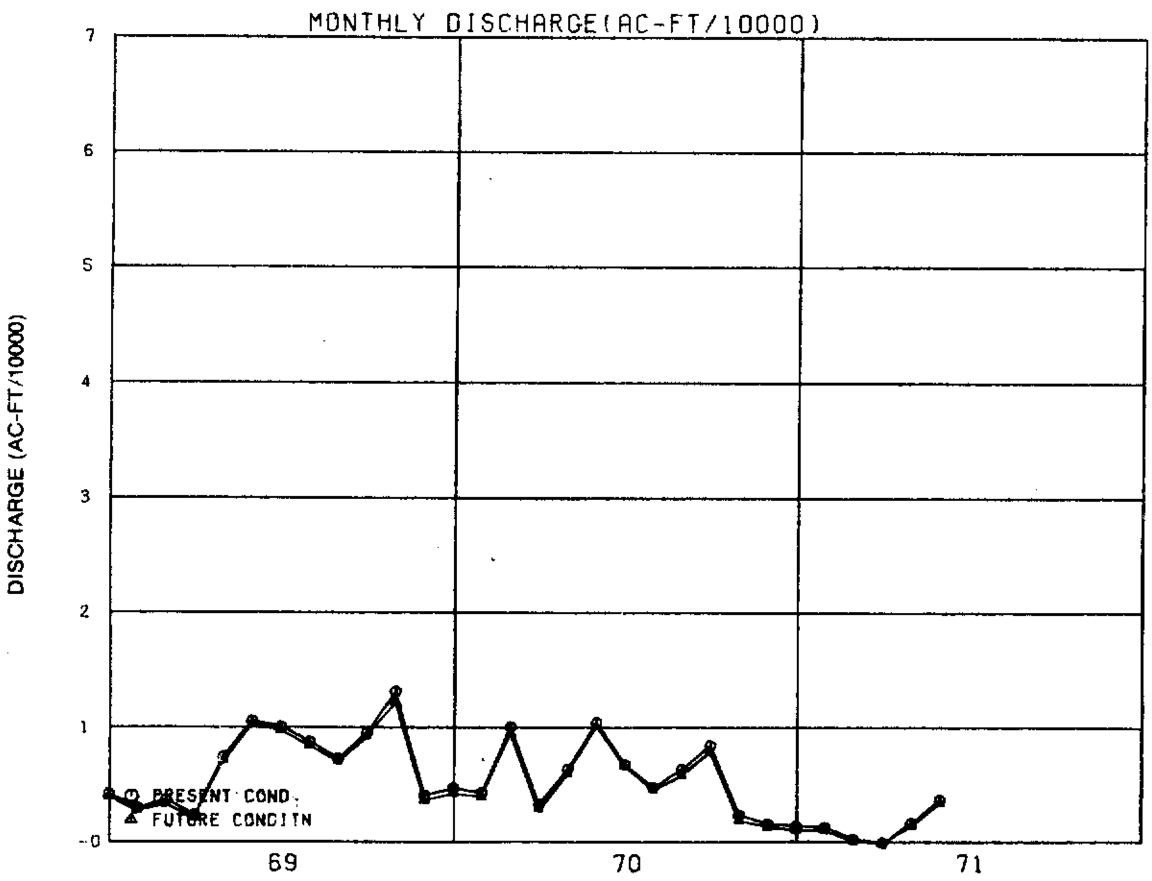


Figure 5D: DISCHARGE FOR S-13