DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

WATER RESOURCES INVESTIGATION 77-71
OPEN-FILE REPORT

# POTENTIAL FOR DOWNWARD LEAKAGE TO THE FLORIDAN AQUIFER, GREEN SWAMP AREA, CENTRAL FLORIDA

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TALLAHASSEE, FLORIDA
1977

## INTRODUCTION

In recent years attention has focused on the total water resources of the Green Swamp area and on the potential for managing these resources. At least two factors have caused this attention: (1) The lowering of the potentiometric surface of the Floridan aquifer of 20 feet or more over an area of about 120 square miles by pumping just south of the Green Swamp area (Stewart and others, 1971), and (2) the increasing urban development along the eastern side of the Green Swamp area.

Knowledge of the potential recharge to the Floridan aquifer by downward leakage from overlying sediments is needed to prudently develop and manage water in the area. The U.S. Geological Survey, in cooperation with the Southwest Florida Water Management District, made this study to (1) investigate the occurrence and permeability of unconsolidated sediments overlying the Floridan aquifer, and (2) to qualitatively evaluate the potential for downward leakage through these sediments into the Floridan aquifer.

The Green Swamp area as defined by Pride and others (1966) is about 870 square miles of gently sloping swampy terrain in central Florida (fig. 1). The altitude of swamps of 1 square mile or more ranges from about 130 feet above the mean sea level around Lake Lowery in the southeastern part of the area to about 65 feet along the Withlacoochee River in the northwestern part. Sand ridges ranging in altitude from 150 to 250 feet border the area on the east, west and south, and a few isolated sand ridges are interspersed within the swamp in the eastern one-third of the area. In the central and western part of the area, flat uplands and slightly lower swamps are interspersed, and water may stand on land of both types much of the time during the summer rainy season. In general this swampy condition occurs because the potentiometric surface of the Floridan aquifer is at or near land surface over most of the area.

The Floridan aquifer in the Green Swamp area consists of porous limestones of Oligocene and Eocene age. Most of the water supplies in central Florida are obtained from the Floridan aquifer. In the Green Swamp area, only a small quantity of the available ground water currently (1975) is being withdrawn.

Overlying the Floridan aquifer are unconsolidated beds of clay, sandy clay, and sand of Miocene and post-Miocene age. In the Green Swamp area, these sediments can be separated into two major categories: (1) The sand aquifer, or storage reservoir (called the nonartesian aquifer by Pride and others (1966, p. 69); and (2) the confining beds, composed of clays and sandy clays, which control the flow of water between the overlying sediments and the Floridan aquifer. Where the clay and sandy clay layers are absent, the confining beds consist of relatively impermeable zones in the sand aquifer. The transmissivity of the sand aquifer is low compared to that of the underlying Floridan aquifer.

Under conditions of little or no ground-water development in the Green Swamp area, the downward leakage from the overlying sediments to the Floridan aquifer is small. A recharge rate of 3 to 5 inches per year was calculated by Pride and others (1966, p. 128) for the Green Swamp area. According to Lichtler and others (1968, fig. 54) the sandy ridge areas on the eastern side of the Green Swamp area are major recharge areas for the Floridan aquifer; they contribute up to 14 inches of recharge per year (Knochenmus and Hughes, 1976, p. 51).

The potentiometric high of the Floridan aquifer in central Florida is in the southeast quarter of the Green Swamp area (fig. 1). Stringfield (1936, p. 148) noted that this high was one of the more conspicuous features of the potentiometric surface in central Florida.

Pride and others (1966, p. 126) suggested that lowering the potentiometric surface of the Floridan aquifer in the southeastern part of the Green Swamp area would increase the rate of seepage (recharge) from the overlying sand aquifer, downward through the confining beds, into the Floridan aquifer.

Kimrey (1974) suggested that recharge to the Floridan aquifer in the Green Swamp area could be increased in conjunction with prudent ground-water development from the Floridan aquifer. This type of ground-water development depends upon induced downward leakage to the Floridan aquifer from the overlying sediments in response to the increased vertical gradient created by withdrawing water from the Floridan. The amount of induced downward leakage (or increase in recharge) would depend on the ability of the overlying sediments to store and transmit water to the Floridan. Under nonpumping conditions, this water normally leaves the area by surface runoff or evapotranspiration.

For optimum regional development of the ground-water resource by a scheme such as that proposed by Kimrey (1974), the importance of the unconsolidated sediments cannot be overemphasized. The unconsolidated sediments must be sufficiently thick to provide space to store significant quantities of water. Otherwise, water will not be available to the underlying Floridan aquifer during the annual 6- to 8-month period of relatively low rainfall common to central Florida. In addition, the volume of water that confining beds of relatively low permeability can transmit over a large area may be appreciable; as stated by Neuman and Witherspoon (1968, p. 103), "An aquiclude above a prolific aquifer may be inconsequential to the total flow of a pumping well in the local sense but it may be of major importance in recharging the aquifer in a regional sense."

## METHODS OF INVESTIGATION

Continuous cores were obtained from land surface to the top of the Floridan aquifer at the 74 sites shown on figure 2 during the summer of 1974. The following guidelines were used in locating the core holes: (1) reasonably uniform areal coverage; (2) an unconsolidated section at least 20 feet thick. In a previous investigation, Pride and others (1966, p. 31, 70 and fig. 31) delineated two areas where the unconsolidated sediments are generally less than 25 feet thick or are absent. These areas, shown in figures 2, 3, 4 and 6 as limestone outcrop areas, cover about 270 square miles; and (3) roughly an equal number of holes in each of four zones. The four zones correspond to areas where the thickness of the unconsolidated sediments ranges from 25 to 50 feet, 50 to 75 feet, 75 to 100 feet, and 100 to 200 feet, respectively, as delineated by Pride and others (1966, fig. 31). Selected intervals of core were sent to the laboratory for determination of vertical hydraulic conductivity and particle size distribution. The lithology of the remaining core was determined by microscopic examination.

A change in color or texture was the basis for dividing the core samples into intervals or beds. The percentage of sand in each bed was estimated from microscopic examination of washed and unwashed samples. Gamma ray and single-point resistance logs were used to characterize the sediments when core recovery was less than 100 percent. Sand percentage in each bed was shown as a bar graph of the strip log that was prepared for each core hole. A sand bed is herein considered to contain 65 percent or more sand; a clay bed is considered to contain silt and clay but with less than 50 percent sand. The total thickness of sand beds and total thickness of clay beds for each core hole was determined from the bar graph of the strip log of each. Results are shown areally in figures 2 and 3, respectively.

The following criteria were used to evaluate the potential for downward leakage to the Floridan aquifer outside the limestone outcrop area:

1. Thickness of sand beds.
2. Thickness of clay beds.
3. Relative hydraulic conductivity of the confining beds.

The ranges of sand thickness and clay thickness were arbitrarily ranked from 1 to 3 as shown below.

| Rank | SAND Thickness (ft) | CLAY Thickness (ft) |
|---|---|---|
| 1 | > 40 | 0–10 |
| 2 | 21–40 | 11–20 |
| 3 | 0–20 | > 20 |

The combined thickness of the clay and sand beds in most instances does not account for the entire stratigraphic column of the core hole. For the purpose of this evaluation, which is qualitative, and which is based on an arbitrary numerical ranking of the thickness and hydraulic conductivity of the different materials involved, the intent was to include only the relatively pure sand beds, which would most readily store and transmit appreciable quantities of water, and the clay beds, which would most effectively retard the downward movement of water to the Floridan aquifer. In core holes where distinct layers of clay and sandy clay occurred, the clay beds effectively represent the confining bed. At sites where clay beds were clearly absent, the least permeable zones of the sand aquifer were considered to be the confining bed.

Laboratory vertical hydraulic conductivity values were arbitrarily divided into three groups which range from good (rank 1) to poor (rank 3) as shown in table 1. The confining bed at each core hole site was then classified as belonging to one of these three ranks. This subjective classification was guided by comparison of lithologic and geophysical logs, particle size distribution, sorting and consolidation. The areal distribution of these estimates of relative hydraulic conductivity is shown as figure 4.

The maps shown as figures 2, 3, and 4 were overlain, and rank values of the various components were determined and totaled for each core hole. Areas were then delineated as having good (total rank, 3 to 4), moderate (total rank, 5 to 6), or poor (total rank, 7 to 9) potential for downward leakage, as shown in figure 6. For example, core hole 74, in the southeast corner of the Green Swamp area, penetrated 112 feet of unconsolidated material, and had a sand-bed thickness of 75 feet (rank 1), a clay-bed thickness of 35 feet (rank 3), and a confining-bed hydraulic conductivity in the intermediate range (rank 2). According to the criteria outlined herein, the total rank value of 6 puts core hole 74 in an area of moderate potential for downward leakage.

## DISCUSSION OF RESULTS

### Sand Beds

The sand beds are generally more than 40 feet thick in an area of about 354 square miles in the eastern part of the Green Swamp. Within this area about 34 square miles were delineated where the sand beds are between 20 and 40 feet thick. Immediately west of this area is an elongated area of about 123 square miles where the sand beds are generally between 20 and 40 feet thick. In the remaining 393 square miles of the Green Swamp area to the west, sand beds are generally less than 20 feet thick. Almost 70 percent of this 393-square-mile area is in the limestone outcrop area where the unconsolidated sediments are thin to nonexistent.

The thickness of sand beds in the core holes varied from site to site. At some isolated sites, the total sand-bed thickness shown on figure 2 may be either greater than or less than that of the area in which it is included. For example, the sand-bed thickness of core holes 6 and 55 is much greater than that of the general area in which they are included; and the thickness of sand beds at core holes 20 and 41 is substantially less than that of the area in which they are included. A greater thickness may indicate that a filled sinkhole was encountered in the drilling. A lesser thickness may indicate that core recovery was less than 100 percent and the lack of geophysical logs precluded a reliable determination of total sand thickness. Loss of core is usually indicative of a sand or clayey sand as opposed to a clay.

### Clay Beds

The clay beds in the Green Swamp area are discontinuous, as shown in figure 5, and in many instances they vary greatly in total thickness over relatively short distances. Three clay beds with a total thickness of 28 feet were penetrated in core hole 30 (fig. 5) yet less than 2 miles to the southwest clay beds were absent in core hole 31. Total clay-bed thickness was 38 feet in core hole 6, but was only 5 feet in core hole 7 less than 1 mile to the south. The total clay thickness in the unconsolidated section ranged from zero in several core holes (numbers 31 and 34 for example) to as much as 42 feet in core hole 73. The total clay-bed thickness is generally less than 10 feet in an area of about 223 square miles outside the limestone outcrop areas or 25 percent of the Green Swamp area.

Although the clay beds in 69 percent of the core holes were more than 10 feet below land surface, they may occur anywhere throughout the unconsolidated section. For example, in core hole 30 (fig. 5) three clay beds of varying thickness were penetrated; one at a depth of less than 10 feet below land surface, the second about 5 feet below the first and the third about 25 feet below land surface, lying directly on the limestone.

Relative to inducing downward leakage over a large area, the total clay-bed thickness is more important than the position of the clay beds in any single core hole.

At some isolated sites the clay thickness shown in figure 3 may be either greater than or less than that for the area in which it is included. For example, core hole 58 is in an area that is generally underlain by more clay than was penetrated in this hole. Conversely, core hole 53 is in an area that is generally underlain by less clay than was penetrated at this site. At least two factors can account for such anomalies: (1) Drilling into a filled sinkhole, noted previously as a possible cause of areal irregularities in sand-bed thickness, and (2) the general discontinuity of the clay beds.

### Hydraulic Conductivity

The hydraulic conductivity of the confining beds in an area of about 116 square miles—mostly in the eastern part of the swamp—was classified as relatively good compared to other areas in the Green Swamp area (fig. 4 and table 1). The area included in the moderate and poor classes is 325 square miles and 159 square miles, respectively.

### Potential for Downward Leakage

About one-fifth (178 square miles) of the Green Swamp area has a good potential for downward leakage (fig. 6) if the potentiometric surface of the Floridan aquifer is lowered. Almost one-third of the area (about 268 square miles) has a moderate potential. Slightly less than one-half of the area (about 424 square miles) has a poor potential for downward leakage. Over one-half of this 424-square-mile area, or 270 square miles, is in the limestone outcrop areas.

The limestone outcrop areas have poor potential for downward leakage because the thin or nonexistent unconsolidated sediments there provide little or no storage capacity. However, the uppermost part of the limestone aquifer in the outcrop areas may be sufficiently permeable to accept appreciable quantities of water if artificial storage, such as a surface reservoir, is provided in conjunction with lowering the potentiometric surface of the limestone aquifer. Although it was not considered a factor in this study, the character of the limestone surface may also be important for other parts of the Green Swamp area. A clayey limestone of apparent low permeability was penetrated just below the unconsolidated sediments in several core holes (fig. 6). This characteristic of the limestone surface is most pronounced in and near the limestone outcrop areas and may be related to the subaerial weathering of the limestone.

## CONCLUSIONS

About 21 percent (178 square miles) of the Green Swamp area has a relatively good potential for downward leakage from the sand aquifer to the underlying Floridan aquifer. This area of good leakage potential is mostly in the eastern part of the Green Swamp area and is generally characterized by a sand-bed thickness in excess of 40 feet, clay beds 0–10 feet thick, and confining bed hydraulic conductivity approximately two orders of magnitude greater than that in the areas of relatively poor downward leakage potential. Over the swamp area as a whole, the clay beds are discontinuous and range from 0 to 42 feet thick. The sand aquifer is generally thin to nonexistent in the western part of the swamp.

Optimum development of water from downward leakage will require quantifying the vertical hydraulic conductivity of the confining beds by field tests. Initially, aquifer tests designed for this purpose should be conducted at two locations, one in an area of good potential for downward leakage and one in an area of poor potential. Analysis of these data should indicate the nature of subsequent effort that would be needed.

A study of the water-transmitting characteristics of the uppermost part of the limestone aquifer, particularly in the outcrop areas, would also be worthwhile.

## ACKNOWLEDGEMENTS

The author appreciates the assistance of John W. Chappelear, who described the lithology of core samples obtained during the study, and of James A. Miller, who directed that effort. Both are geologists of the U.S. Geological Survey.

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Table 1.—Vertical hydraulic conductivity of clay and sandy clay beds, Green Swamp area.

| Rank | Range of Hydraulic conductivity (ft/day) | Core hole number (fig. 1) | Sample depth (ft) | Vertical hydraulic conductivity (ft/day) |
|---|---|---|---|---|
| 1 (Good) | greater than 0.01 | 38 | 24 | 1.37 |
| | | 13 | 60 | $1.47 \times 10^{-1}$ |
| | | 72 | 78 | $1.22 \times 10^{-1}$ |
| 2 (Moderate) | 0.001 to 0.09 | 74 | 66 | $2.30 \times 10^{-2}$ |
| | | 18 | 41 | $1.29 \times 10^{-2}$ |
| | | 27 | 21 | $1.16 \times 10^{-2}$ |
| | | 26 | 53 | $8.63 \times 10^{-3}$ |
| | | 28 | 76 | $6.99 \times 10^{-3}$ |
| | | 9 | 20 | $6.82 \times 10^{-3}$ |
| | | 74 | 76 | $2.30 \times 10^{-3}$ |
| | | 13 | 32 | $1.39 \times 10^{-3}$ |
| 3 (Poor) | less than 0.001 | 68 | 35 | $1.03 \times 10^{-4}$ |
| | | 26 | 16 | $4.36 \times 10^{-5}$ |
| | | 73 | 94 | $9.81 \times 10^{-6}$ |
| | | 69 | 40 | $1.28 \times 10^{-6}$ |

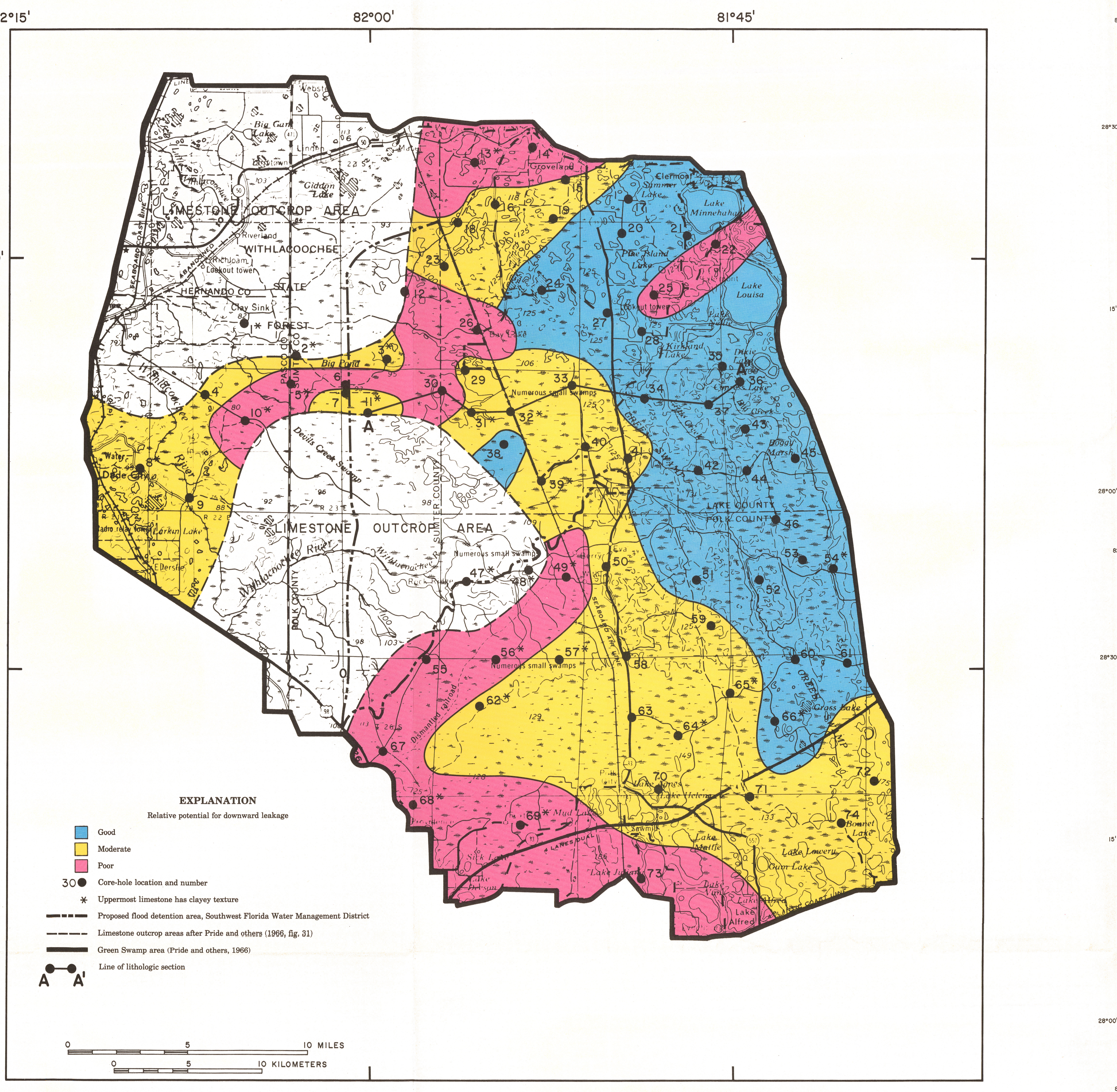

Figure 6.—Relative potential for downward leakage from unconsolidated sediments to the underlying Floridan aquifer, Green Swamp area.

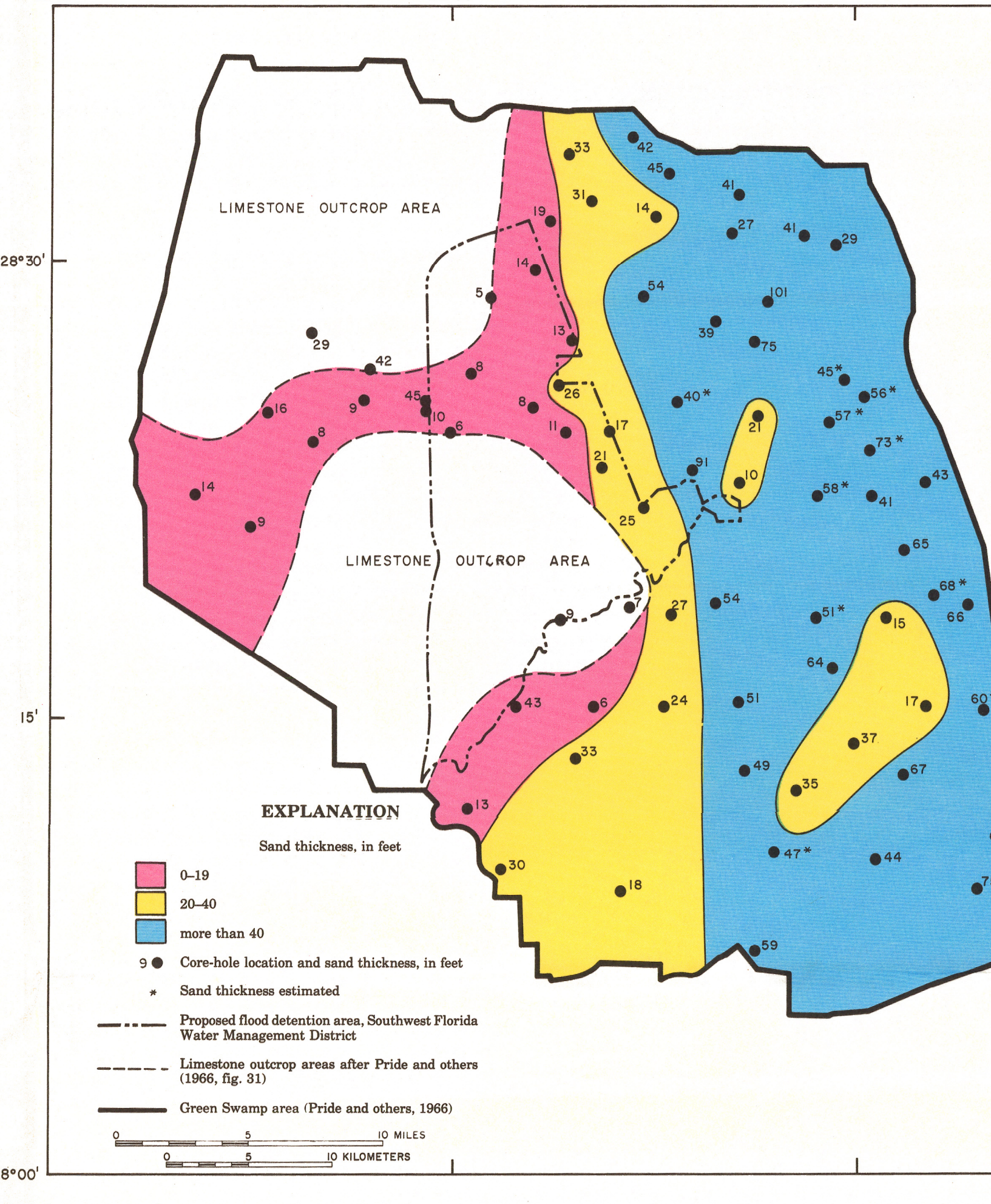

Figure 2.—Sand-bed thickness, Green Swamp area.

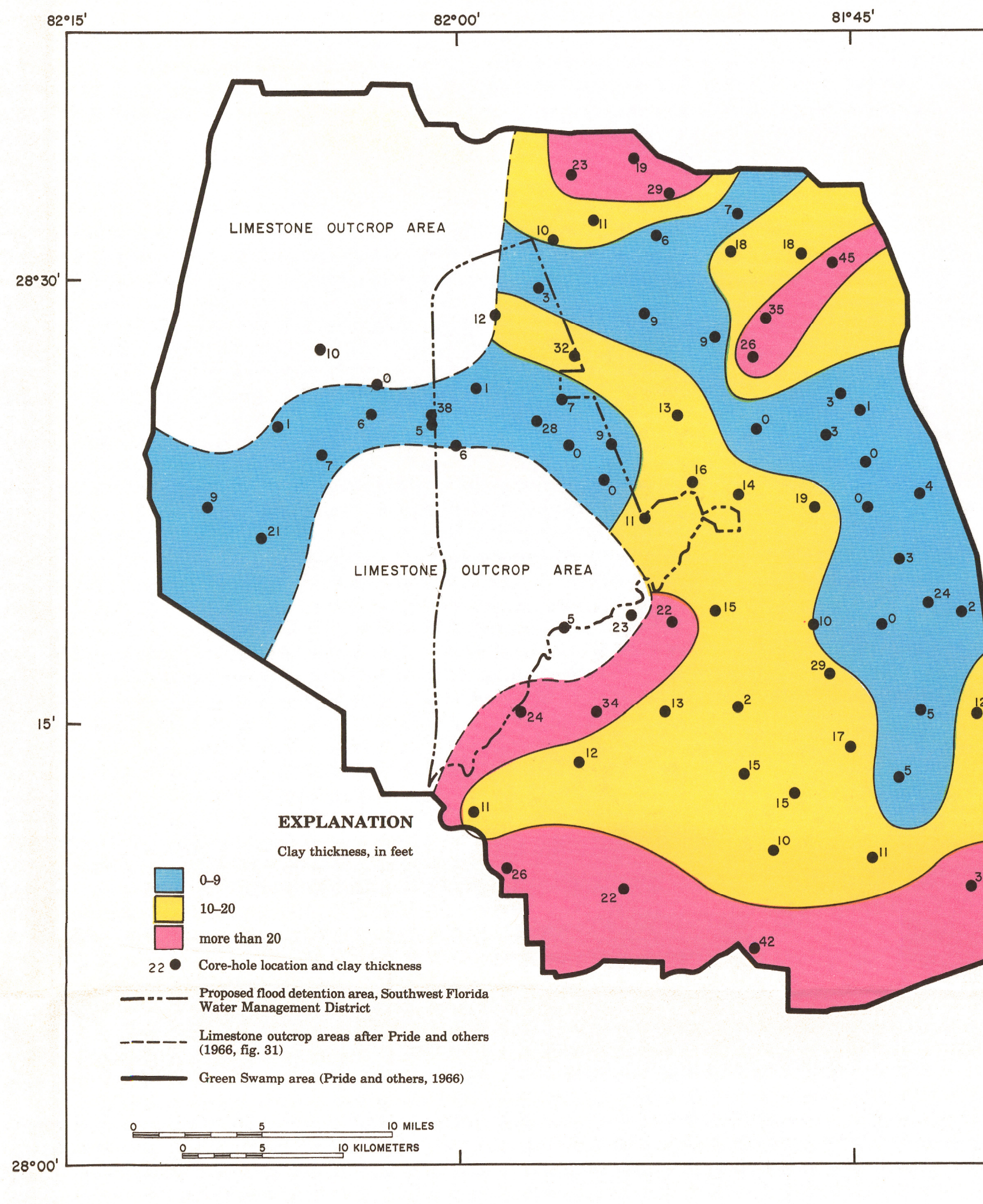

Figure 3.—Clay-bed thickness, Green Swamp area.

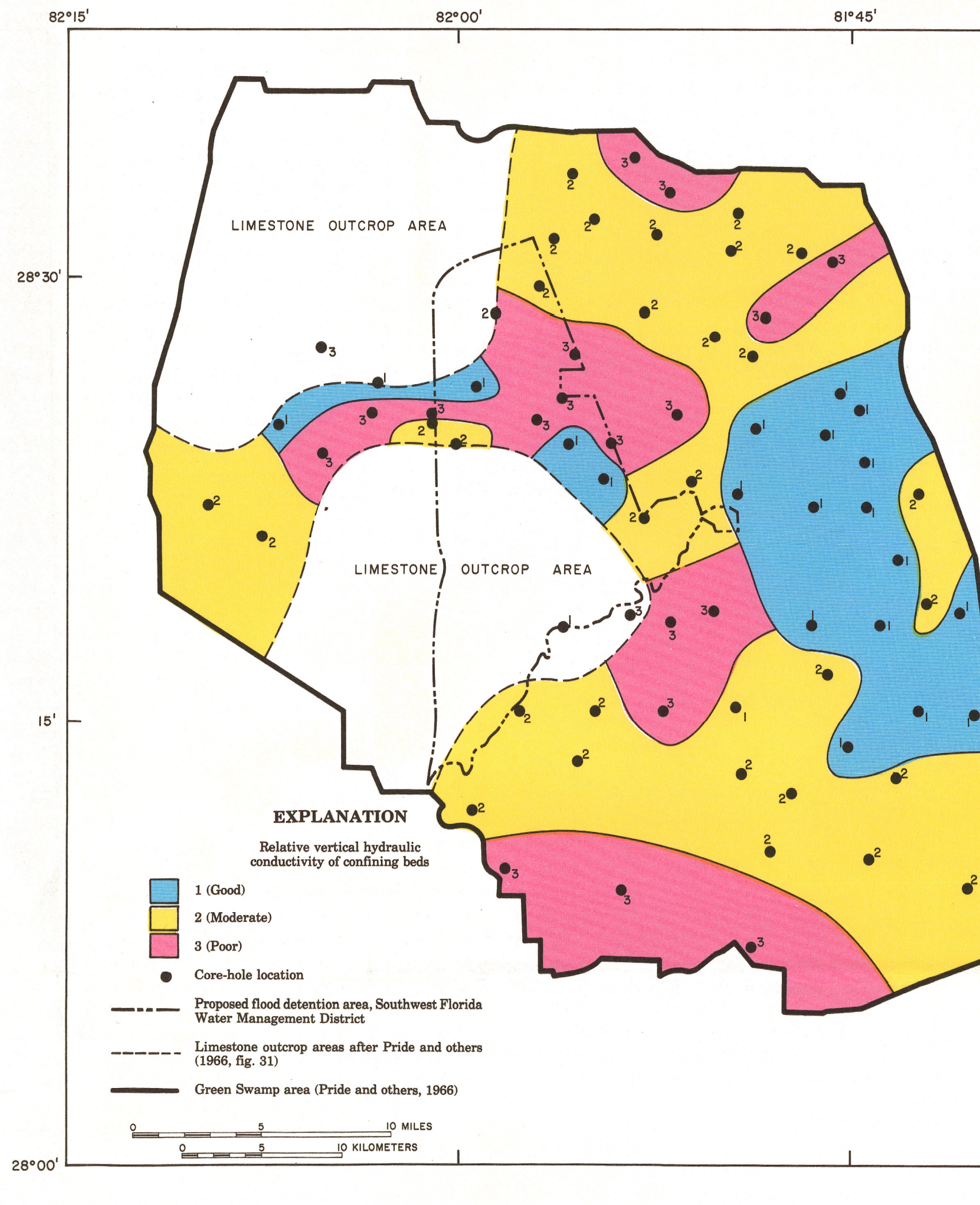

Figure 4.—Relative vertical hydraulic conductivity of the confining beds, Green Swamp area.

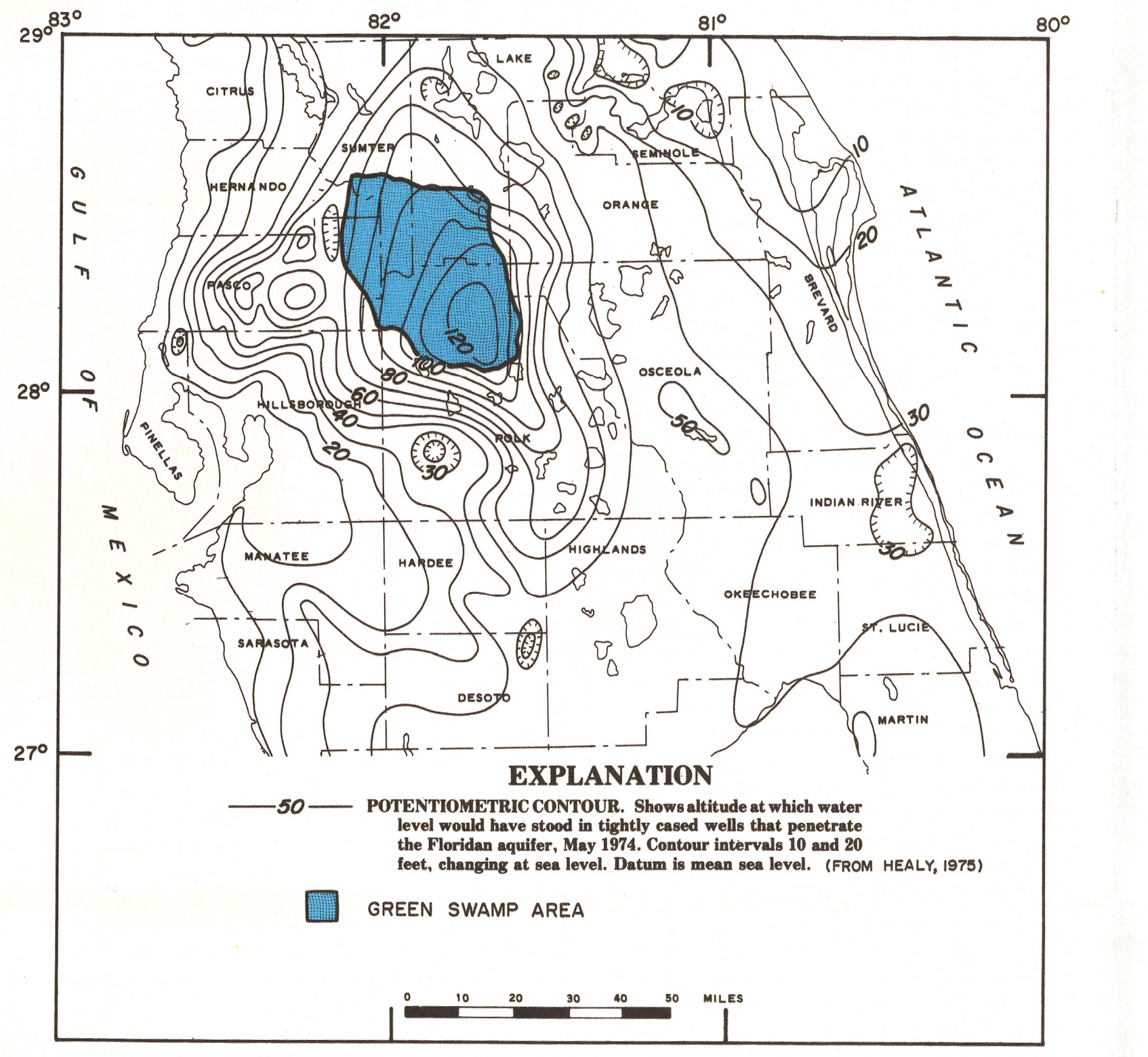

Figure 1.—Central Florida and the Green Swamp area showing the potentiometric surface of the Floridan aquifer, May, 1974.

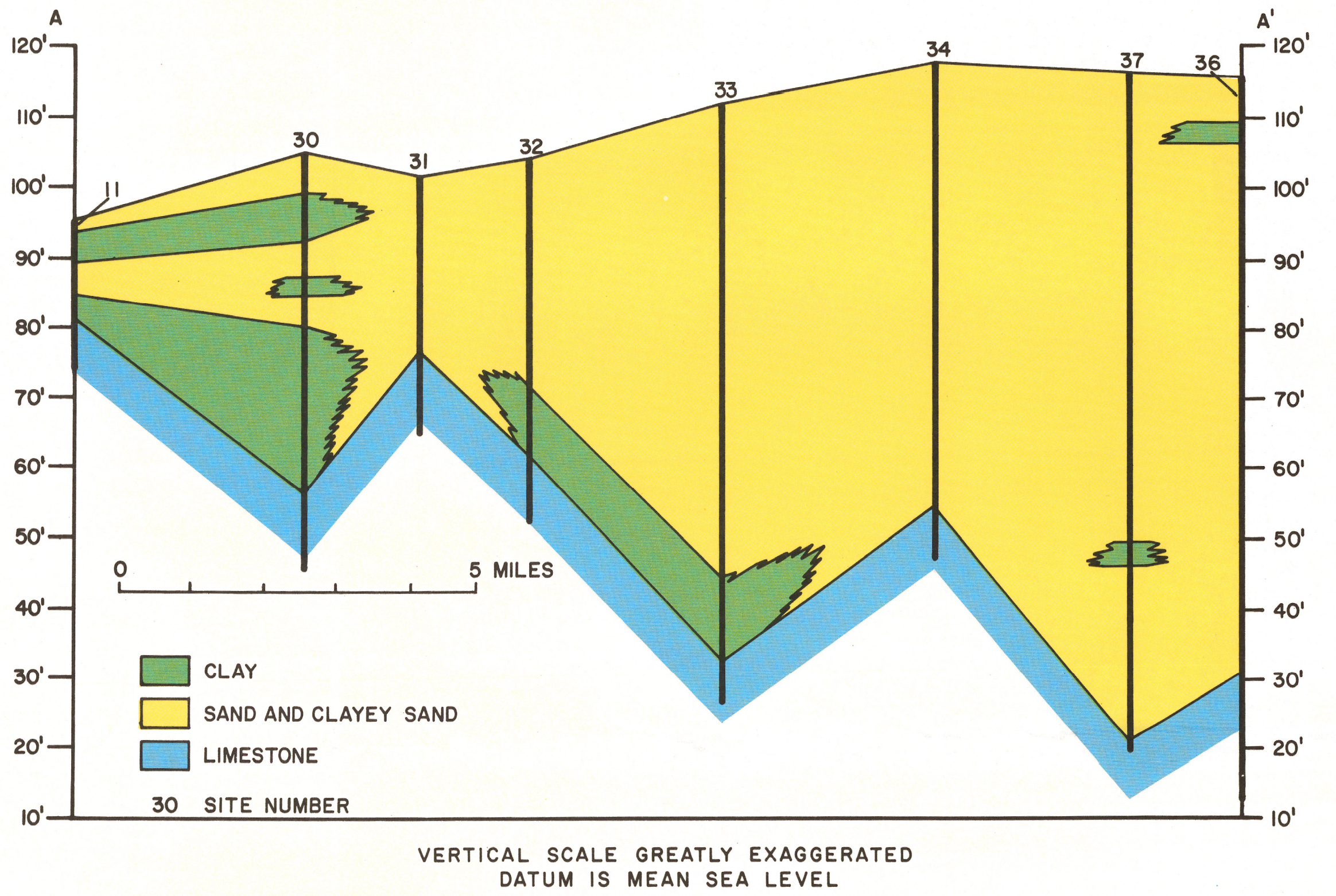

Figure 5.—Generalized lithologic section from south-central Sumter County to Big Creek. (Line of section shown on figure 6.)

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