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SALINE-WATER INTRUSION FROM DEEP ARTESIAN SOURCES IN THE McGREGOR ISLES AREA OF LEE COUNTY, FLORIDA

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SALINE-WATER INTRUSION FROM DEEP ARTESIAN SOURCES IN THE McGREGOR ISLES AREA OF LEE COUNTY, FLORIDA

By

C. R. Sproul[1], D. H. Boggess[2], and H. J. Woodard[3]

ABSTRACT

Upward leakage of saline water from an artesian aquifer below 1,500 feet has caused an increase in chloride concentration in the lower Hawthorn aquifer from less than 1,000 mg/l (milligrams per liter) to values ranging from about 1,300 to 15,000 mg/l. Similarly the higher temperatures of the intruding water has caused an increase in water temperatures in the aquifer from 82°F to values ranging from 83 to 93°F. The intruding water moves upward either through the open bore hole of deep wells or test holes, or along a fault or fracture system, which has been identified in the area. From these points of entry into the lower Hawthorn aquifer, the saline water spreads laterally toward the south and southeast, but is generally confined to components of the fault system.

The saline water moves upward from the lower Hawthorn aquifer into the upper Hawthorn aquifer through the open bore hole of wells, which connect the aquifers. This movement has resulted in an increase in chloride from less than 200 mg/l in the unaffected parts of the upper Hawthorn aquifer to values commonly ranging from about 300 to more than 3,000 mg/l in parts of the aquifer affected by upward leakage. The upper Hawthorn aquifer is the principal source of ground-water supply for public water-supply systems in western Lee County.

Similar effects have been noted in the water-table aquifer, where chloride increased from less than 100 to concentrations ranging from about 500 to more than 5,000 mg/l. This was caused by the downward infiltration of water discharged at land surface from wells tapping the lower Hawthorn aquifer.

The spread of saline water throughout most of the McGregor Isles area is continuing as of 1971.

INTRODUCTION

Nearly all of southwest Florida is underlain at shallow depths by permeable

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strata which are sources of water supply for domestic, municipal, agricultural, and industrial purposes. Strata at greater depths, although equally permeable contain highly mineralized water under artesian pressure high enough that a head difference exists between the deeper and shallower aquifers. Because the deeper aquifers are normally under higher artesian pressure, the existence of any path or conduit of high permeability between the two will result in upward movement of more highly mineralized water into the overlying aquifers. Under natural conditions, the water in these different formations is in a state equilibrium and is prevented from intermixing by relatively impermeable beds which separate them. Lowering of the artesian pressure in the shallower aquifers by pumping increases the difference in head between the aquifers.

Water from the deeper strata can then move upward into the shallow strata in at least two different ways. First, penetration of the impermeable beds by drilling, whereby both the shallow and deeper strata are interconnected through the open well bore, will allow the movement of water from the deeper strata (under higher artesian pressure) into the shallow strata (under lower pressure). Second, the existence of faults, extending downward at least through the Ocala group[1], can provide a conduit through which the saline water can move upward. Both these possibilities will be explored later in the report.

PURPOSE AND SCOPE

The problems of saline water movement into the shallow aquifers by upward leakage from deep artesian sources is of considerable magnitude in Lee County, where an estimated 2,500-3,000 deep artesian wells and test holes have been drilled. The purpose of this report is to present the results of an analysis of available geologic and hydrologic data for a small area in Lee County where saline water from deep artesian sources has moved upward into several different aquifers.

From an analysis of the available data, the authors attempt to define not only the source of the highly mineralized water, but also to describe the mechanism through which upward leakage occurs and the effects of intrusion on water quality in each of the aquifers underlying the area. The effects of upward leakage of saline water through the open bore hole of existing wells connecting aquifers at depths of less than 300 feet and those which occur to depths of about 1,000 feet is evident from the data presented herein and from similar studies conducted in other parts of Lee County. However, the mechanism responsible for upward leakage of saline water from an artesian aquifer below 1,500 feet into the aquifers between 400 and 1,000 feet is not well known and can only be surmised from the available data. That such leakage does occur is evident from the information presented herein.

[1] The nomenclature used in this report conforms to that of the Bureau of Geology, Florida Division of Interior Resources, Department of Natural Resources, and not necessarily to that of the U.S. Geological Survey.

ACKNOWLEDGMENTS

The authors are indebted to the landowners and residents of the McGregor Isles area for providing information on wells and for permitting the logging and other measurements on privately owned wells. The authors acknowledge the assistance of local well drillers, particularly Joseph M. Maharrey, for providing valuable data on the location and construction of wells. Test hole logs provided by the Humble Oil and Refining Company and the Mobil Oil Corporation were helpful in the identification of geologic formations.

The interest and continued support of the County Commissioners of Lee County in the study described herein is greatly appreciated.

DESCRIPTION OF THE AREA

The McGregor Isles area is about 5 miles southwest of Fort Myers in Lee County, Florida. The 9-square-mile area is bounded on the east by U.S. Highway 41 (Tamiami Trail) and on the west by the Caloosahatchee River (figs. 1, 2). Drainage ditches or canals form the northern and southern limits.

McGregor Isles, where the problems of salt-water intrusion were first recognized and studied in detail, is a small waterfront development on the Caloosahatchee River. The name has been applied to the entire report area, although there are several other subdivisions within the area.

Between 1940 and 1958 a large number of deep, flowing artesian wells were drilled to provide water for irrigation during the winter growing season. Much of the land was used for truck crops, flower farms, citrus groves, and plant nurseries, and the use of ground water increased rapidly. Since 1958, urban development has largely displaced agriculture and most of the deep artesian wells have been abandoned. Most of the homes were supplied with water from small diameter wells until recently, when public water-supply systems were installed. As of 1970 the small diameter wells are used primarily for lawn irrigation, although a few wells continue to provide water for domestic use.

To obtain data for this study, a fairly complete inventory of the deep, artesian wells was made, together with a scattered sampling of the newer, shallow domestic wells. Not all the domestic wells were visited because of the large number of such wells. All the wells inventoried are listed in table 1 and their location is shown on figure 2.

WELL NUMBERING SYSTEM

Each well plotted on figure 2 is identified by a number designating the

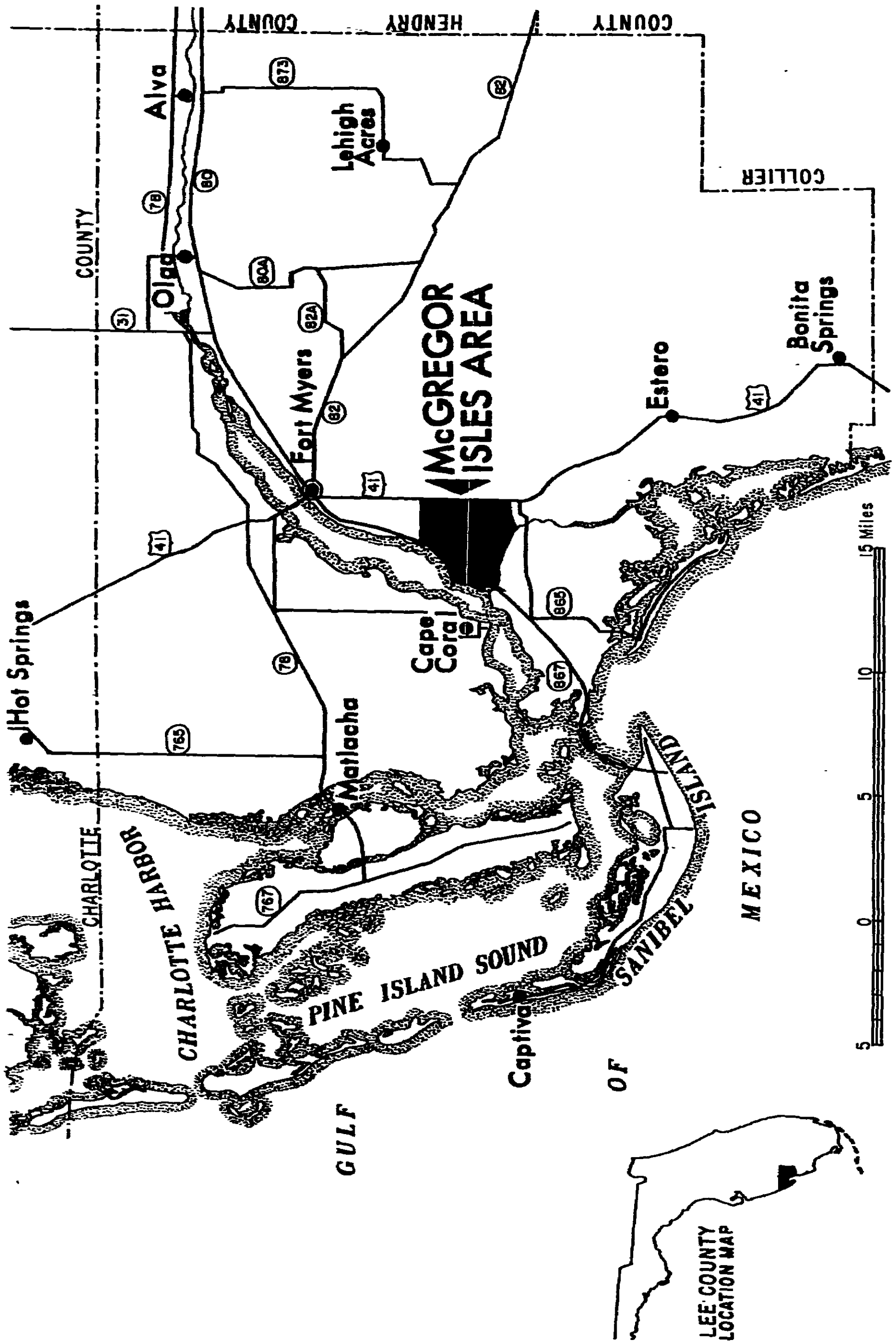

Figure 1. Map of Lee County showing the location of the McGregor Isles area.

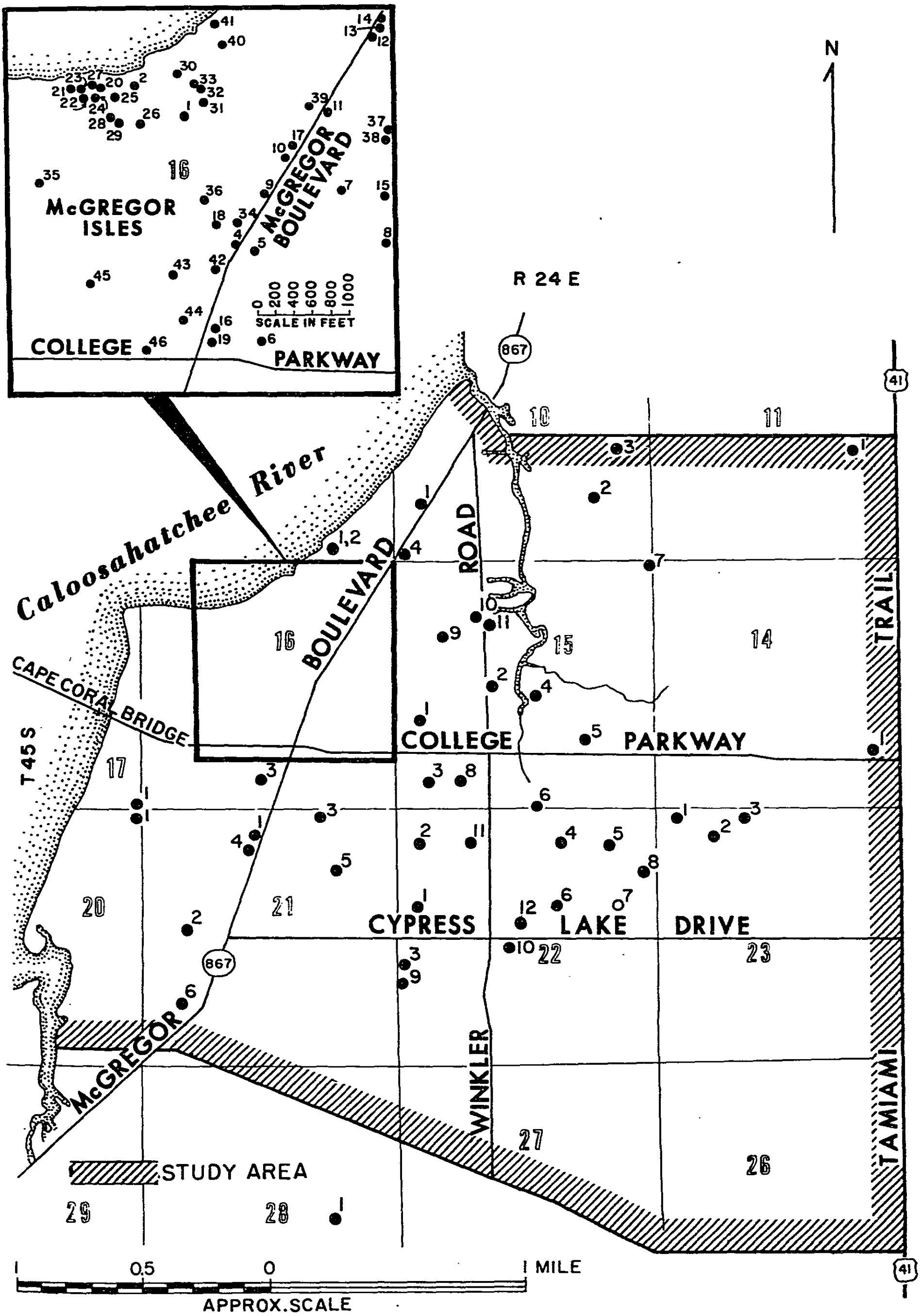

Figure 2. Map showing the location of wells.

section in which it is located followed by a number assigned sequentially within each section. For example, well 21-5 is the fifth well inventoried in section 21; well 15-5 is the fifth well inventoried in section 15. In section 16, where 46 wells were inventoried, the well numbers range from 16-1 to 16-46.

DESCRIPTION OF AQUIFERS

The formations underlying McGregor Isles were identified by the use of geophysical logs and other information obtained on existing wells. Some of these data–chiefly geophysical logs and test-hole data–have been used in preparing the composite geologic column shown in figure 3. The usage of formation names that appear in figure 3 conforms generally to that of Puri and Vernon (1964, p. 43) except for the usage of the term Tampa Limestone, which conforms to that of Cooke (1945, p. 111-121).

Using these data, 6 and possibly 7 different aquifers also were identified. The stratigraphic positions of these aquifers are shown on figure 3. The names which have been assigned the aquifers refer to the geologic formations in which they occur, except the two uppermost, the water table and sandstone aquifers. All the aquifers shown on figure 3 probably occur in other parts of Lee County.

The gamma ray log included in figure 3 serves chiefly to illustrate characteristic features which make possible the identification of formations from this log. The radiation intensity at any point in a well depends principally upon the kinds and concentrations of radioactive materials in the formation surrounding the well (Patten and Bennett, 1963, p. 45). In McGregor Isles, as well as much of Florida, the highest radiation levels, and therefore the highest peaks on gamma ray logs, are caused by the existence of phosphorite-bearing zones. The phosphorite in these zones exhibits relatively high radioactivity because it contains a small but significant percentage of uranium (Altschuler, Clarke and Young, 1958). Clay, which is slightly radioactive due to the presence of a radioactive isotope of potassium (potassium-40), is represented by lower peaks. Clean sand, shell, or limestone is indicated on gamma ray logs by a low level of radioactivity. Certain peaks on the logs, when matched with the lithology of the rock units determined from test hole data, provide useful correlation markers as shown in figure 3.

WATER-TABLE AQUIFER

The water-table aquifer consists of sand, sandy limestone, and calcareous

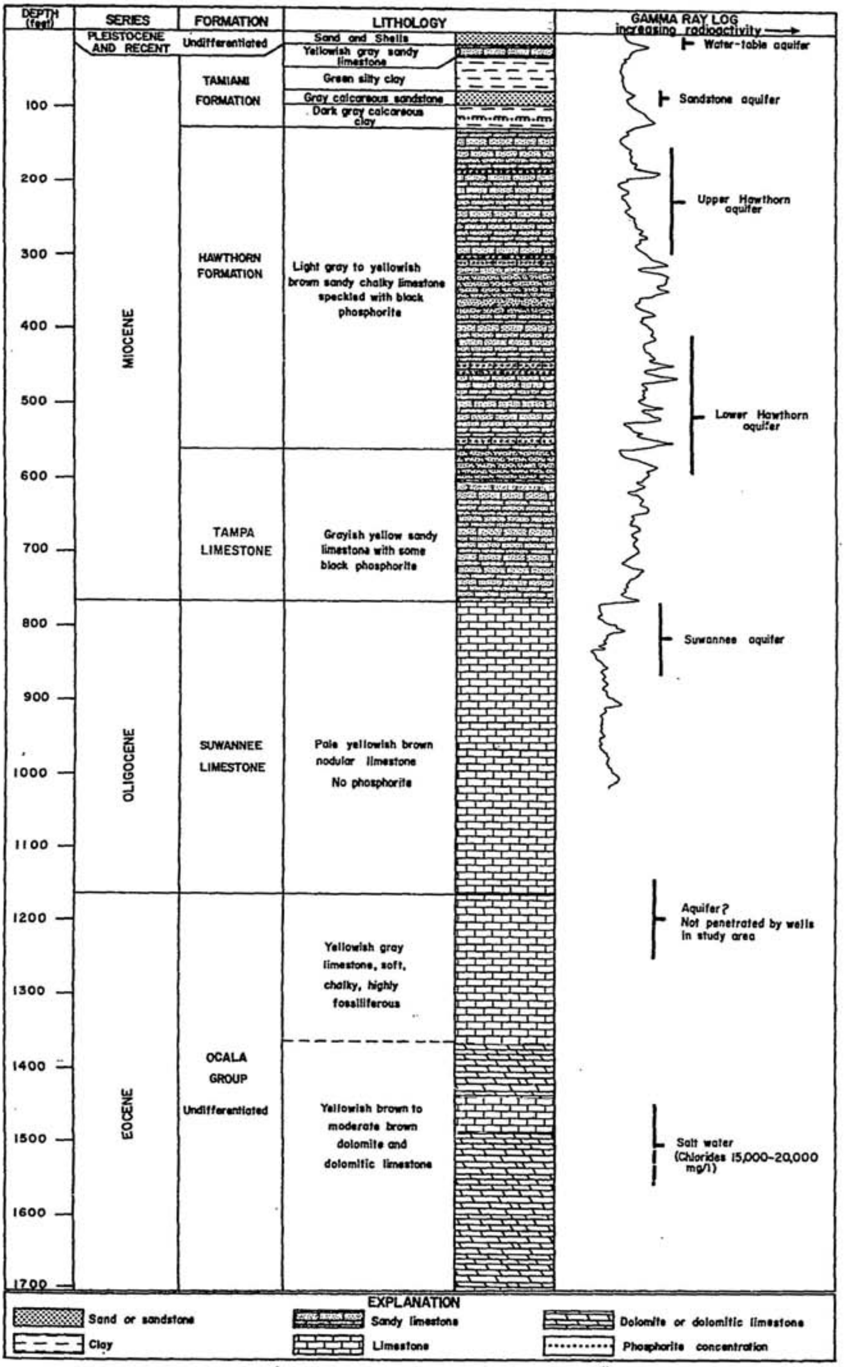

Figure 3. Geologic column showing lithology, aquifers, and typical gamma ray log of formations underlying McGregor Isles.

sandstone ranging in thickness from less than 10 feet to about 30 feet. Its base almost everywhere is not more than 30 feet below land surface although some localized shell beds which occur at greater depths are included as part of this aquifer.

The aquifer, under atmospheric pressure, is recharged directly from rainfall. Water levels rise in response to recharge by rainfall and fall in response to discharge as base flow to streams, or by evapotranspiration or pumping. Although the annual range in fluctuation of the water table has not been established, the maximum range is estimated at 5 or 6 feet in areas of higher elevation and only 2 or 3 feet in the low lying areas. Seasonally, water levels normally are low in May or June near the end of the dry season and high in September or October.

SANDSTONE AQUIFER

The sandstone aquifer consists of calcareous sandstone and loose quartz sand, which in places grades downward into a sandy limestone. The aquifer probably is present throughout the report area although it is nonproductive in some places. Its thickness ranges from a few feet to a maximum of about 35 feet. The aquifer is separated from the overlying water-table aquifer by 50 feet or more of green sandy clay. The stratum of green sandy clay underlies most of the county, including McGregor Isles, and provides an effective barrier against the downward movement of salt water from the Caloosahatchee River or from tidal inland canals.

The sandstone aquifer is under slight artesian pressure and probably receives recharge from rainfall in the eastern part of Lee County. Water levels in wells tapping the sandstone aquifer fluctuate seasonally in about the same manner as those tapping the water-table aquifer.

UPPER HAWTHORN AQUIFER

The Hawthorn Formation contains two well defined water-bearing zones designated herein as the upper and lower Hawthorn aquifers. The upper Hawthorn aquifer consists of a gray-white limestone containing numerous small grains of black and brown phosphorite. This aquifer may be hydraulically connected with the overlying sandstone aquifer at McGregor Isles, and, of course, with underlying permeable formations containing saline water, for without such continuity it would not have become contaminated. The upper

Hawthorn aquifer is separated from the lower Hawthorn aquifer by relatively impermeable clay and marly limestone, except where these are penetrated by wells or displaced by faults.

The upper Hawthorn aquifer nearly everywhere in the report area is within the depth range 100-300 feet below land surface. The aquifer is under artesian pressure. Records from observation wells in less highly developed parts of the county indicate that under natural conditions the water level in this aquifer at McGregor Isles may have reached a maximum altitude of about 20-25 feet above mean sea level or about 15 feet above land surface. As of 1970, because of pumping from the aquifer, water levels are considerably lower. For example, records from observation well 14-1 (fig. 2 and table 1) show that the highest water level recorded since October 1968 was about 6 feet below land surface, which represents a decline of about 20 feet from pre-development water levels at that location. In 1969, the highest water level recorded in well 14-1 was about 10 feet below land surface, indicating a further lowering of 4 feet due to increased pumping. The water level in this well is affected by the pumping of nearby large-capacity wells (14-4 through 14-12). This decline is similar to that which occurred at Cape Coral and adjacent areas over the same period. This trend of declining water levels will continue as pumping draft increases. Wells 6 inches or more in diameter yield 100-200 gpm (gallons per minute); those 2-3 inches in diameter yield 10-30 gpm.

The upper Hawthorn aquifer is the principal source of water for public water systems, domestic, and lawn irrigation uses in western Lee County. It is presently (1970) used as a source of supply for water systems which serve Cape Coral, Pine Island, Fort Myers Beach, and other offshore islands, and for thousands of small diameter domestic wells. Maximum pumpage occurs during the winter and spring, coinciding with the period of minimum recharge. An estimated 6 mgd (million gallons per day) were withdrawn from the aquifer for public-water supply during the period of maximum demand in 1969.

LOWER HAWTHORN AQUIFER

The lower Hawthorn aquifer as defined herein, includes the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone. This limestone aquifer consists of sediments similar in appearance to those in the upper Hawthorn aquifer.

Confined above and below by clay and marly limestone this aquifer has sufficient permeability and is under sufficient artesian pressure to provide 300-500 gpm to large diameter wells by natural flow. Both the artesian pressure and flow rates vary from well to well. This variation is related to differences in construction of individual wells and in hydraulic properties of the aquifer penetrated by the well. Because wells that tap this aquifer nearly always are hydraulically connected to the upper Hawthorn aquifer through the uncased section of the bore hole, the pressure and discharge measurements usually represent a composite of conditions in both aquifers. On the basis of measurements made in the eastern part of Lee County, where the artesian head within the aquifer is about 50 feet above mean sea level, it is estimated that under natural conditions at McGregor Isles the artesian head may have been 30-35 feet above mean sea level. Earlier records of wells at the McGregor Isles tend to confirm this estimate: In well 16-4 in October 1957, the artesian head was about 32 feet above mean sea level; in well 16-9 in February 1934, the head was about 37 feet above. The highest water level measured in recent years was at well 23-3 where, in April 1969, the artesian head was 27 feet above. A review of all available records indicates that the artesian head within the aquifer at McGregor Isles has fallen about 10-15 feet.

Only small quantities of water are withdrawn from the lower Hawthorn aquifer at the present time (1970). However, water is discharged from this aquifer by leakage upward from the uncased portion of wells. The amount of leakage in individual wells, as measured by geophysical logging methods, ranged from about 30 gpm to nearly 100 gpm. Flows less than 30 gpm could not be measured reliably with the instruments used, but it may be assumed that such flow does occur in most wells penetrating the aquifer. Assuming an average leakage rate of only 30 gpm per well, and that at McGregor Isles 40 wells are open to both the upper and lower Hawthorn aquifers, about 1.7 mgd (million gallons per day) is discharged from the lower aquifer as vertical leakage. The quantity of water discharged from the lower aquifer either through wells or along faults probably will increase as the head in the shallower aquifers is lowered by pumping.

SUWANNEE AQUIFER

The Suwannee aquifer as the term is used herein, consists of a permeable zone in the upper part of the Suwannee Limestone. As indicated in figure 3, the top of the Suwannee Limestone is readily determined from gamma ray logs by the decrease in radioactivity, and from test-hole data by the absence of phosphorite. Relatively impermeable beds above and below separate the Suwannee aquifer from the lower Hawthorn aquifer and those occurring at greater depths.

Flow rates up to 400 gpm may be obtained from large-diameter wells drilled to the Suwannee aquifer, although well yields at McGregor Isles are generally lower. The low discharge rate of 30 gpm measured from well 16-14, where no leakage to upper formations was apparent, indicates that this well penetrated a zone of low permeability within one or more of the aquifers penetrated.

Under natural conditions, the artesian head within the aquifer probably ranged from 35 to 40 feet above mean sea level at McGregor Isles. The level in well 16-14 in September 1944 was 36 feet above mean sea level, 29 feet above land surface. In February 1967, the head in this well was 23 feet above mean sea level, indicating a reduction in artesian head of 13 feet. This reduction probably has not occurred throughout the aquifer; in April 1969 the level in well 10-2, about a mile distant, was 30 feet above mean sea level.

Wells in the Suwannee aquifer usually are hydraulically connected to both the lower and upper Hawthorn aquifers through the uncased sections of the well bores. The distribution of artesian pressure within the well bore is such that water can move upward from the Suwannee aquifer into the overlying aquifers.

Only about 18 wells have been drilled to the Suwannee aquifer in the report area, less than half as many as have been drilled to the lower Hawthorn aquifer and only a few are presently used (1970) for irrigation.

DEEPER AQUIFERS

Little is known about the water-bearing properties of formations underlying the Suwannee Limestone. The deepest well in the report area, number 16-14, drilled to a depth of 1,106 feet, reportedly did not penetrate water-bearing zones beneath the Suwannee aquifer. Well 15-11, a 1,360-foot test well, penetrated limestone of the Ocala Group at a depth of 1,150 feet. This well was subsequently plugged back to 590 feet, and no information is available concerning the possible existence of water-bearing zones between 590-1,360 feet. Records of water wells in nearby areas indicate that a water-bearing zone is present within the upper 50-100 feet of the Ocala Group. These records also suggest that water from this zone is more mineralized than water from the Suwannee aquifer. Data concerning the water-bearing properties of still deeper aquifers was obtained principally from geophysical logs and drillers reports of nearby oil exploratory wells. Geophysical logs of two wells drilled just beyond the eastern boundary of the study area show salt water present below a depth of 1,570 feet in the northernmost well and 1,500 feet in the southernmost well.

The electric log of a well about 5 miles southeast of McGregor Isles (outside the report area) shows salt water present at a depth of 1,570 feet. Strong flows of salt water have been reported from depths ranging from 1,518 feet to 1,707 feet in other parts of the county, and salt water is flowing (1970) from a well 1,641 feet deep at Hot Springs (fig. 1) in Charlotte County, 18 miles north of McGregor Isles. On October 17, 1957, its shut-in pressure was 39 feet above mean sea level.

From these data it is generally concluded that water from these deeper aquifers, particularly at depths greater than about 1,500 feet, is highly mineralized and unsuitable for most purposes. The artesian pressure within these aquifers probably is higher than in any of the overlying aquifers under natural conditions, and considerably higher than in those aquifers where the pressure has been lowered by pumping.

EVIDENCE OF FAULTING

A study of gamma ray logs obtained during the study shows vertical offsetting of beds. The offset is apparently caused by a series of faults. Figure 4 shows a geologic section based on correlation of distinctive features on the gamma ray logs. One particularly distinctive peak which occurs on all the gamma ray logs has been selected as a point of correlation between wells to show the presence of faults. This peak, herein referred to as the gamma ray correlation marker, represents the uppermost bed identifiable on the logs which shows substantial displacement caused by faulting. This marker is indicated by a dotted line in figure 4.

The altitude of gamma ray correlation marker, the approximate location of faults and of the geologic section are shown in figure 5.

As shown in figures 4 and 5, the vertical displacement of comparable beds ranges from about 50 to 110 feet. The depth to which the faults extend has not been determined. It is assumed that the faults extend at least through the Ocala Group, and probably deeper. The available data seem to indicate that most, but not all, of the displacement occurred after the unit represented by the gamma ray correlation marker was deposited, and prior to deposition of the upper part of the Hawthorn Formation. Displacement of beds above the gamma ray correlation marker is not so obvious from an examination of the logs. The configuration of the Caloosahatchee River shoreline in the vicinity of the northeast corner of section 17, and the alignment of a tributary to Whisky Creek near the center of section 15 are suggestive of fault controlled features and may indicate that some displacement of near-surface beds has occurred in comparatively recent times. Tanner (1964, p. 41) notes a fault in Lee County " . . . active in the last 10,000 years, responsible for offset in the coast line." Tanner, in the reference cited above, suggests the presence of two shear planes in south Florida, oriented approximately N. 50 degrees E., and N. 70 degrees W. This orientation, within a few degrees, is identical with that of the faults in McGregor Isles.

WATER QUALITY AND THE EFFECTS OF SALINE-WATER INTRUSION

Complete or partial chemical analyses have been made on water from 15 wells in McGregor Isles as summarized in table 2.

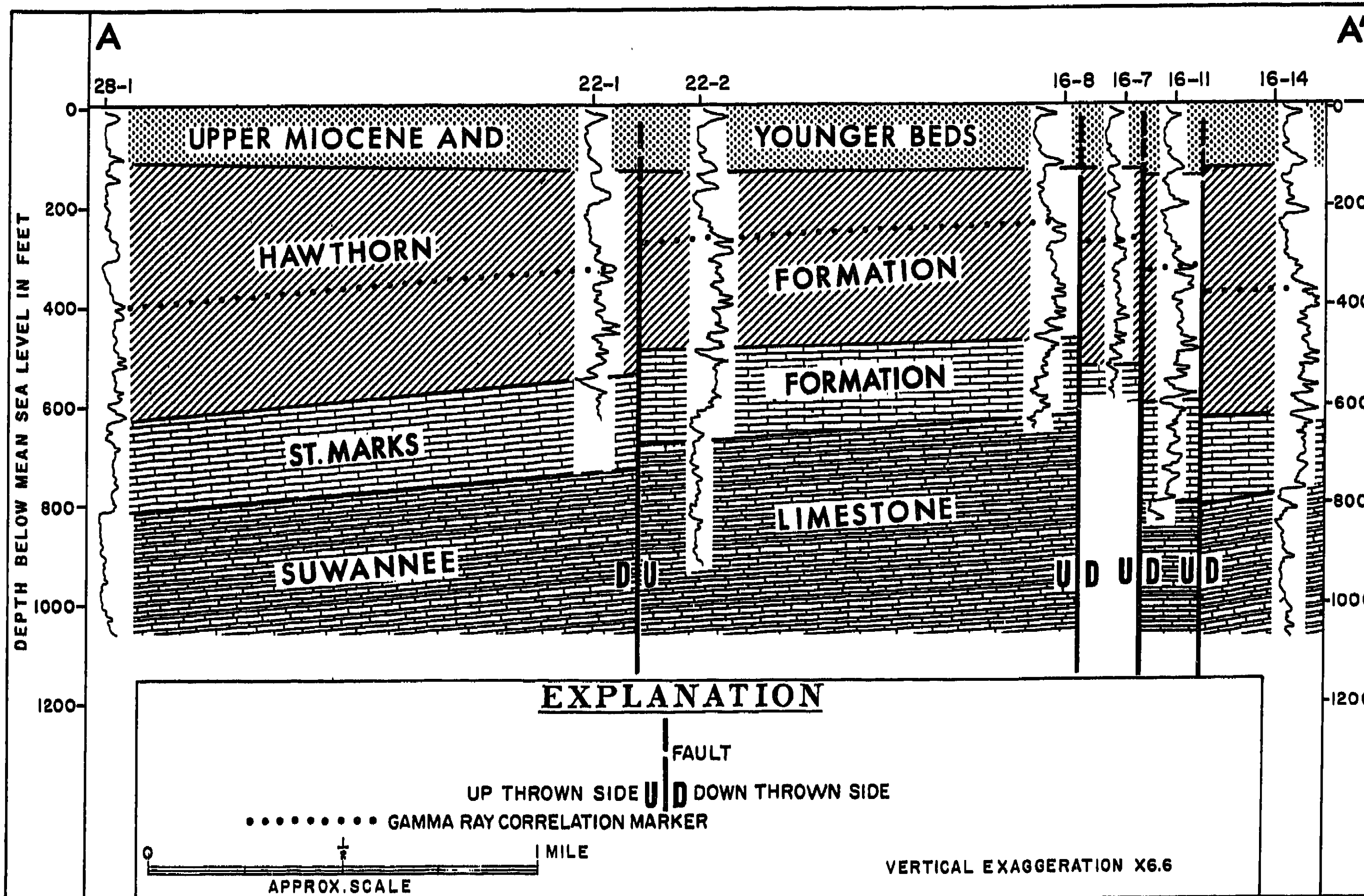

Figure 4. Geologic section showing faults based on interpretations of gamma-ray logs.

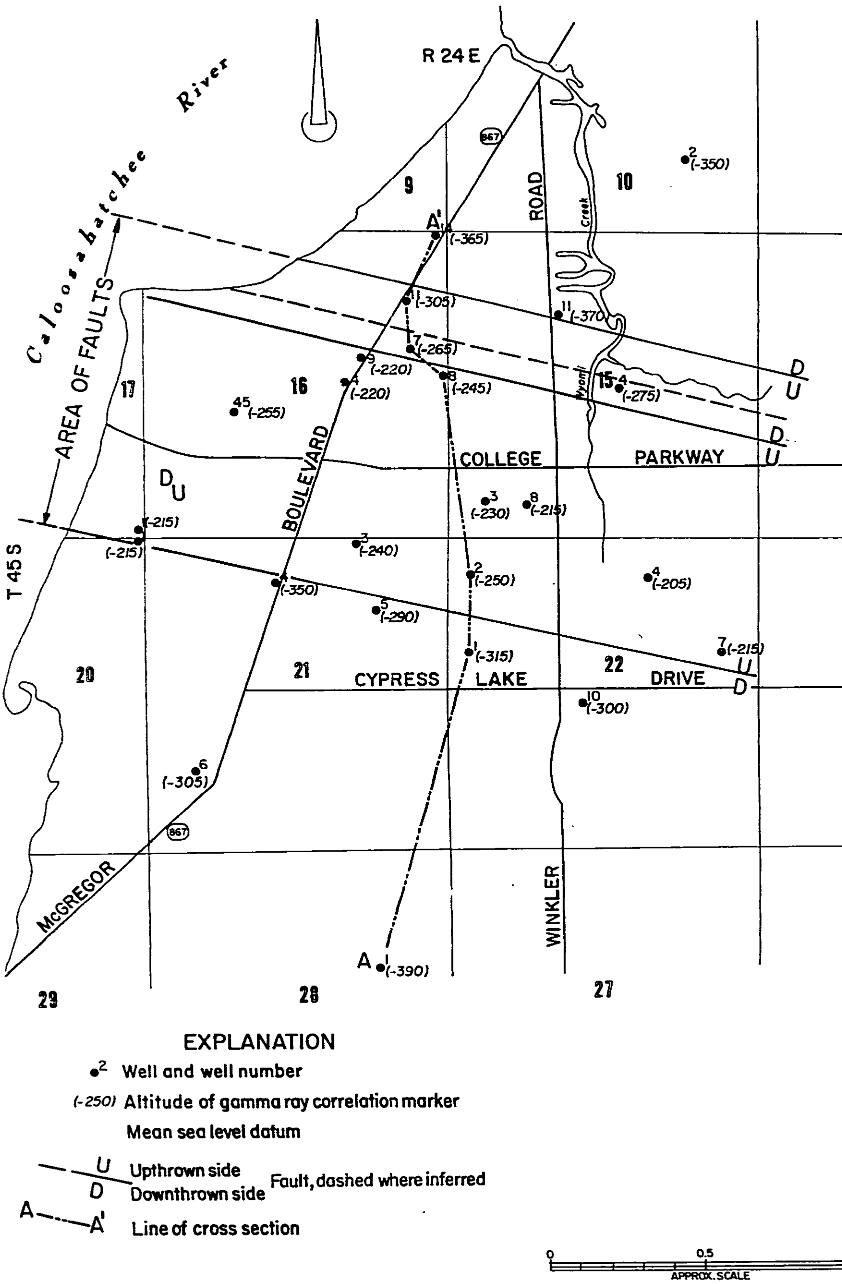

Figure 5. Map of McGregor Isles showing the approximate location of faults.

Also included for purposes of comparison is a chemical analysis of water from a well at Hot Springs in Charlotte County, about 18 miles northwest of McGregor Isles (fig. 1). Additional temperature and chloride measurements for wells are included in table 1. The analyses in table 2 are presented in descending order of depth of the aquifers. Within each aquifer, the analyses are arranged to show the increasing effects of saline-water intrusion.

Based on water quality data from the 1,641-foot well at Hot Springs, and other data from wells near the study area, the authors believe that the primary source of the saline water causing deterioration in water quality in the lower Hawthorn aquifer is an artesian aquifer at a depth of 1,500-1,700 feet. Although the chemical characteristics of the water from this aquifer have not been determined in McGregor Isles, the analysis given for Hot Springs (table 2) probably is generally representative of its water quality. The water is highly mineralized, containing 34,000 mg/l of dissolved solids and 18,700 mg/l of chloride. The water temperature in this aquifer, as measured at Hot Springs, was 96°F.

LOWER HAWTHORN AQUIFER

Intrusion of highly saline water has caused deterioration in water quality within the lower Hawthorn aquifer. The chemical character of water contained in the unaffected part of the aquifer is generally represented by the analysis for well 22-1 (table 2) where the chloride content was 560 mg/l. The analyses of water from wells 21-3, 22-8, 16-4, and 16-7 show the progressively increasing effects of the intruding water on the aquifer, with a range in chloride concentration from 1,490 mg/l to 10,200 mg/l. The greatest chloride concentration determined from wells in the lower Hawthorn aquifer was 15,200 mg/l for well 16-45 (table 1). It is interesting to note from table 3 that the

Table 3.–Comparison of the arithmetic mean of chemical constituents for wells 22-1 and Hot Springs, with the chemical analysis for well 16-7. (Chemical constituents in milligrams per liter).

Wells	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	DS 1/	Sp. C 2/
Average for 22-1 and Hot Springs	12	353	577	5366	202	168	1468	9630	1.7	17,730	27,370
16-7	14	428	640	5620	188	164	1370	10,200	1.7	18,600	29,500

1/ DS = Sum of determined constituents

2/ Sp.C = specific conductance, micromhos at 25°C average of the analysis for well 22-1, in the unaffected part of the aquifer, and the analysis for Hot Springs, is much like the analysis shown for well 16-7, in the affected part of the aquifer. It is not to be expected that observed and theoretical mixtures will be exactly the same because of chemical reactions which can take place when waters of different origin become mixed within the aquifer (Hem, 1959, p. 227). However, the comparison is a valid indicator of the source and effects of the intruding saline water.

The chloride concentration in water is a reliable indicator of changes in water quality and is readily measured with field or laboratory equipment. The chloride content of water from most wells in McGregor Isles is indicated in table 1. A map showing the chloride content of water from wells in the lower Hawthorn aquifer is shown in figure 6a. The lines of equal chloride content show that the intruding water enters the aquifer in the central part of section 16 and spreads laterally in the aquifer. The elongated paths of spreading toward the southeast and southwest may be due to the permeable zones along the fault planes. The effects of the intruding water seemingly are largely confined to an area bounded by components of the fault system.

Another indicator of changes occurring within an aquifer is water temperature. Ground-water temperatures generally increase with depth. From the data included in table 1, water temperatures ranged from 74°F in the water-table aquifer at a depth of about 20 feet, to 87°F in the Suwannee aquifer at a depth of about 900 feet. This represents an increase of about 1°F for each additional 70 feet of depth. At this rate of increase, the water temperature at 1,600 feet would be about 10°F higher than in the Suwannee aquifer, or about 97°F. The water temperature from the Hot Springs well in Charlotte County, considered to be from about this depth, was 96°F.

Significant upward leakage from this deep artesian aquifer would cause some change in the normal temperature distribution within the intruded aquifer. Figure 6b shows the distribution of water temperature in the lower Hawthorn aquifer which clearly shows the effects of intrusion from this deep artesian source. The normal water temperature in this aquifer as determined in this and in other parts of the county was 82°F. The highest temperatures occur in the vicinity of wells 16-7 and 16-45 thus indicating, as does the chloride data in figure 6a that the intruding water enters the aquifer in the central part of section 16. From there, the temperatures decrease laterally to normal or near normal values. As in the case of chloride shown in figure 6a, the anamalous water temperatures are largely confined to the area bounded by the NW-SE trending components of the fault system, and the pattern of spread is elongated to the southeast and southwest. The higher temperature strongly suggests that the source of intruding water is a deep artesian aquifer below 1,500 feet.

Most of the chloride and temperature data shown on figures 6a and 6b were obtained during the period 1967-69 and should not be considered

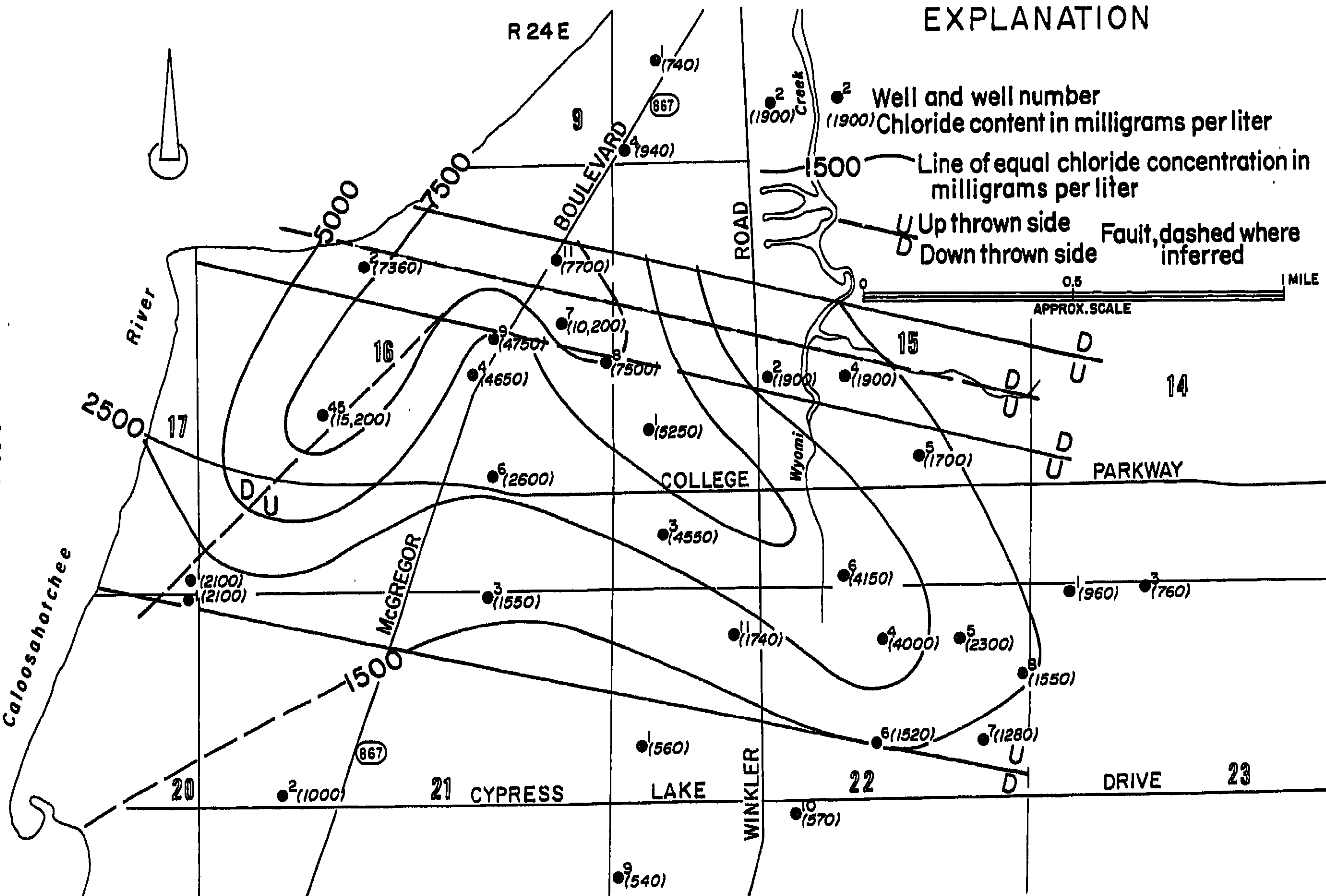

Figure 6a. Map of McGregor Isles showing the extent of saline-water intrusion into the lower Hawthorn aquifer.

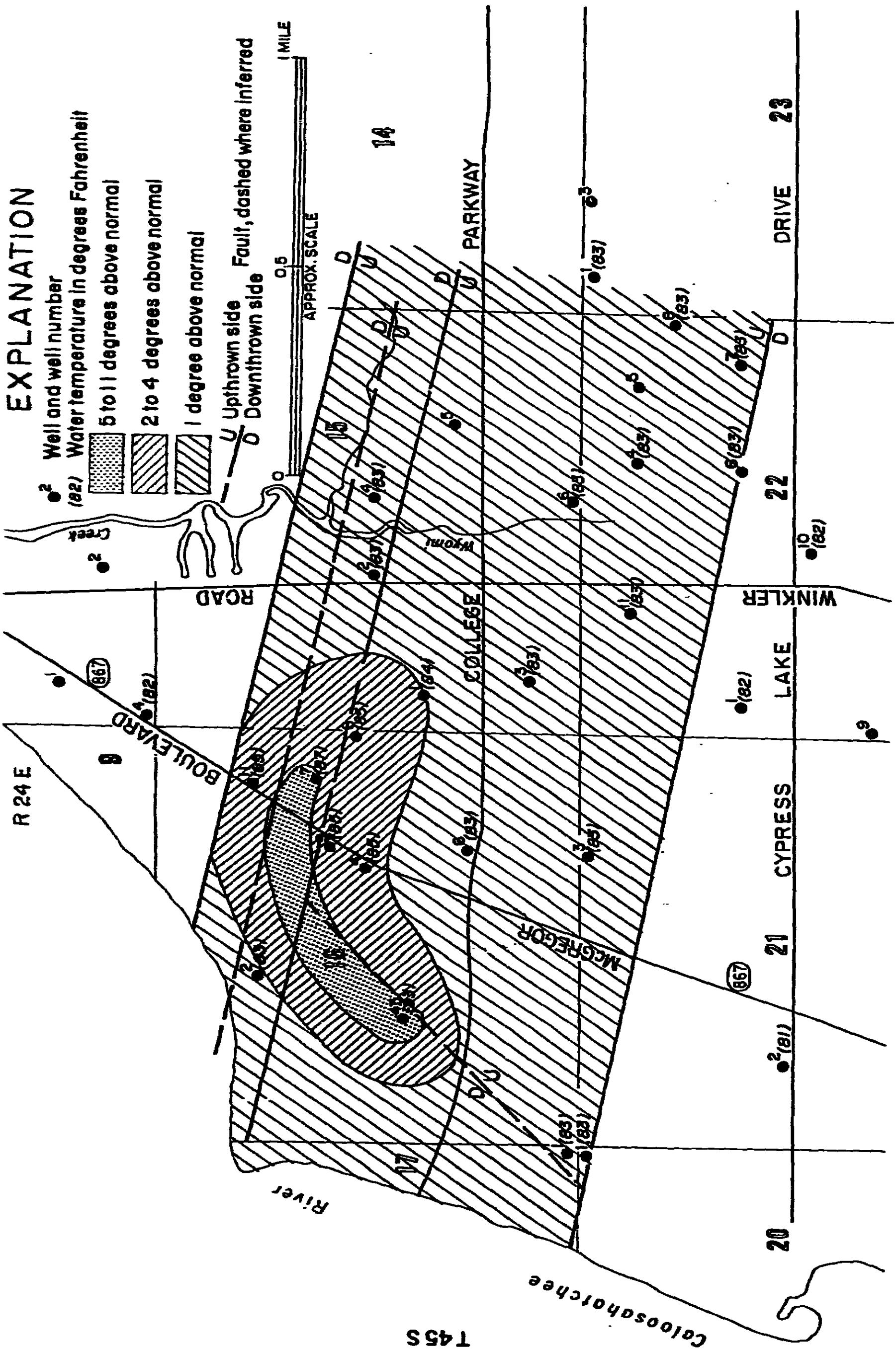

Figure 6b. Map showing the effects of intrusion on water temperatures in the lower Hawthorn aquifer. (Principal faults from Fig. 5.)

representative of a single point in time. Resampling of several wells during this period showed only small changes in water quality. However, this does not imply that static conditions exist within the aquifer, only that changes probably occur at a relatively slow rate. The long-term changes in the chloride content of water from selected wells in the lower Hawthorn aquifer are shown in figure 7. Wells

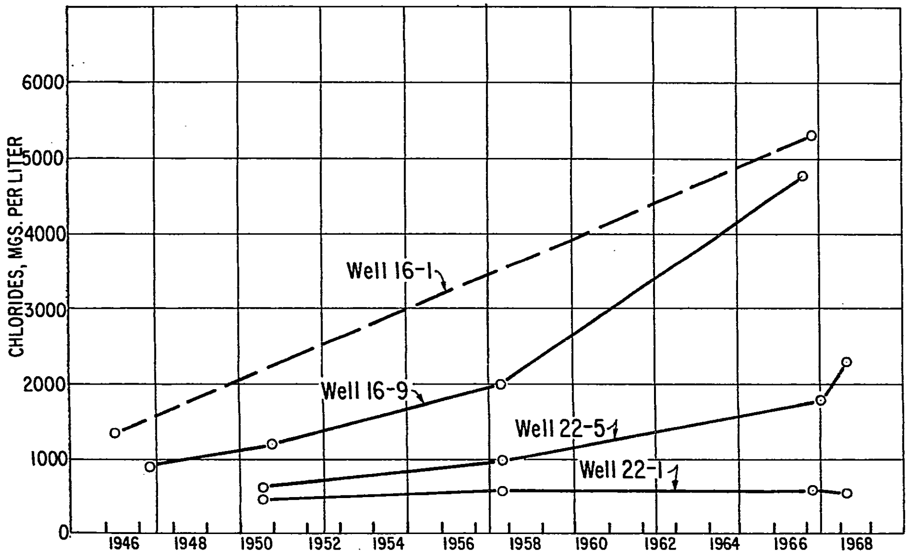

Figure 7. Graph showing changes in chloride content of water from the lower Hawthorn aquifer, 1946-68.

16-1 and 16-9 which are near the point where saline water enters the aquifer have shown the greatest increase in chloride content. As indicated by the initial chloride measurement on well 16-1 (1,520 mg/1), some change in water quality in the aquifer had occurred prior to 1946. Well 22-5 showed a progressive increase in chlorides since 1950, although this well is more than a mile from the principal area of intrusion. In contrast, well 22-1, which is south of the fault system, has shown little change in chloride content since 1950.

The advancing front of saline-water to the southeast is evident from samples of water from wells 22-8 and 23-3 near the 1,500 mg/1 chloride line shown on figure 6a. The chloride content of water from these wells increased from 1,550 and 760 mg/1 in June 1967, to 1,940 and 920 mg/1 in May 1970.

UPPER HAWTHORN AQUIFER

The quality of water from the upper Hawthorn aquifer is generally good except where affected by intrusion of saline water. The chemical analysis for well 16-35 (table 2), is generally representative of water quality in the unaffected part of the aquifer. As shown by this analysis, the dissolved solids content was 426 mg/1 with chloride content of 170 mg/1. Deterioration in water quality is indicated by the analysis for well 16-23 in table 2, where the dissolved solids were 3,470 mg/1 and the chloride wat 1,940 mg/1.

The chloride content of water from wells at McGregor Isles is shown on figure 8. Changes in water quality in the upper Hawthorn aquifer are greatest near wells drilled to the lower Hawthorn aquifer. For example, water from wells 16-20 through 16-25, all drilled into the upper Hawthorn aquifer, ranges in chloride content from 500 to 2,160 mg/1. Chloride content generally decreases with distance from well 16-2, which taps both the upper and lower aquifer. Similar conditions exist near well 16-4 as indicated by the chloride content of water from wells 16-18, 16-36, 16-42, and 16-43, which ranges from 440 to 1,560 mg/1.

Flowmeter surveys in numerous wells confirmed that water was flowing from the lower Hawthorn and Suwannee aquifers into the upper Hawthorn aquifer. Internal flows of nearly 100 gpm were measured in wells penetrating the lower Hawthorn and deeper aquifers. The water from the lower aquifers was entering the upper Hawthorn aquifer through the uncased part of the borehole.

The salinity of water from the upper Hawthorn aquifer is increasing in some parts of the area. Water from well 16-20, formerly used for domestic purposes, had a reported chloride content of 800 mg/1. In June 1969, chloride content had increased to 2,160 mg/1, and in January 1970, to 3,050 mg/1. The chloride content of water from well 16-36 increased from 715 mg/1 on October 31, 1967 to 1,100 mg/1 on June 5, 1969. In other parts of the area, attempts to obtain usable water from the upper Hawthorn aquifer have been abandoned because the water is too saline for use.

The continued spread of saline water within the upper Hawthorn aquifer may cause a substantial change in the quality of water from wells 14-3 through 14-12 and 23-4 through 23-6 which supply water to Fort Myers Beach and adjacent areas. The chloride content of water from these wells ranged from 81 to 183 mg/1 when drilled. An increase in chlorides has been noted in wells 14-8, 14-9, and 14-10. In well 14-8, the chloride content increased from 141 mg/1, July 1967, to 376 mg/1, June 1970. Similarly in well 14-10, the chloride increased from 105 mg/1, August 1967, to 224 mg/1, June 1970. The increase in chloride in well 14-9 from 81 to 162 mg/1 from July 1967 to June 1970, although of lesser magnitude, is equally significant in indicating the potential changes which may occur.

OTHER AQUIFERS

The water-table aquifer normally contains water of relatively good quality

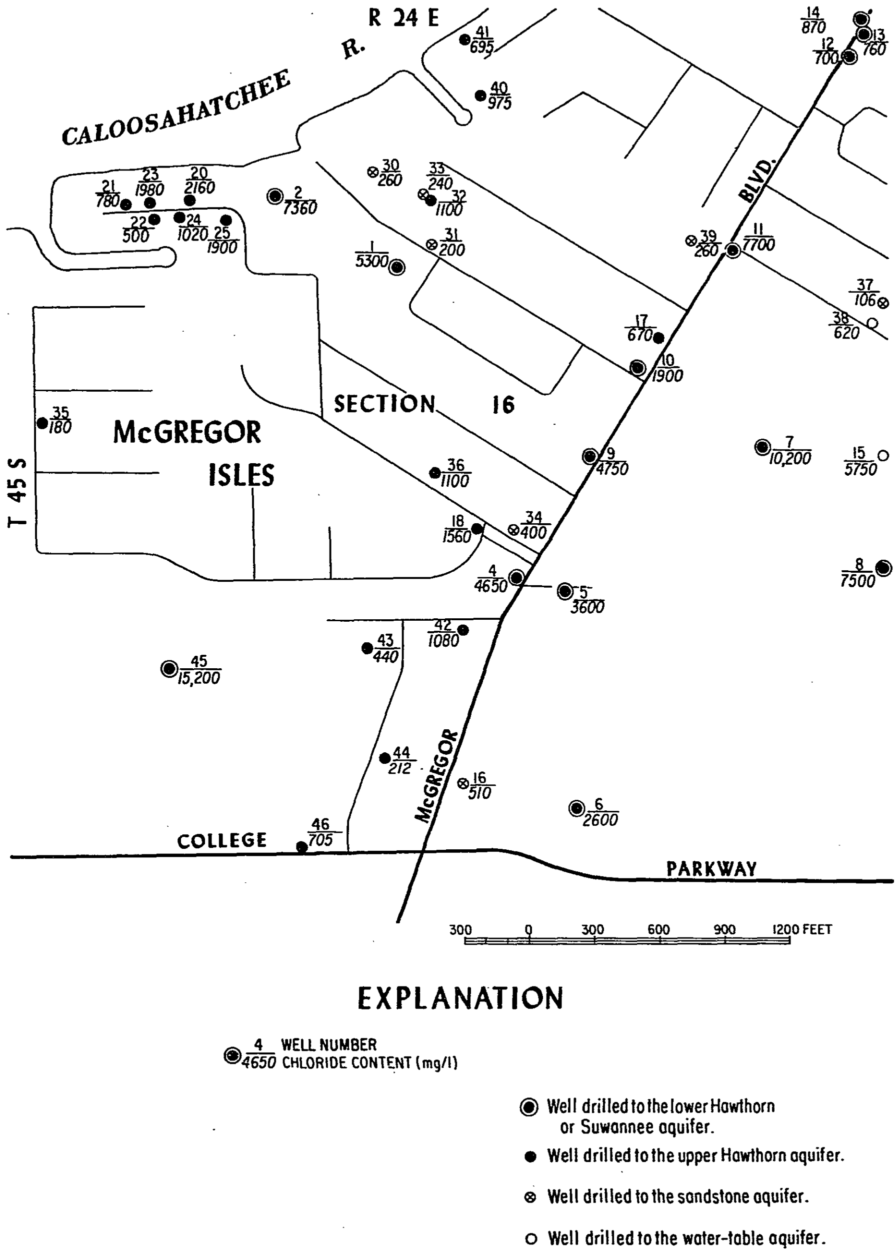

Figure 8. Map showing the chloride content of water from wells in McGregor Isles, 1967-69.

as indicated by the analysis for well 21-1 in table 2, which shows a total dissolved solids content of 477 mg/l and chloride content of only 96 mg/l. One of the most objectionable characteristics of water from this aquifer is the high concentration of iron. Although no analysis for iron has been made in the report area, the typical metallic taste imparted to water by iron and staining of surfaces sprayed with the water can be observed in many places. The water may also contain organic compounds which cause taste or odor problems, or discoloration as indicated by the color value of 30 in the analysis for well 21-1. Salt water has entered this aquifer at places as shown by the analysis for well 16-15 (fig. 8 and table 2) where the chloride content was 5,750 mg/l. These wells probably were affected by water from well 16-7 (chloride content 10,200 mg/l) which has been flowing uncontrolled for years into a ditch from which it percolates downward to the water table. Saline water intrusion into the water-table aquifer probably is general in areas immediately bordering the Caloosahatchee River, and along the tidal reaches of surface streams and canals as a result of inland movement of salt water from the river during the dry season.

Chloride content of water from the sandstone aquifer at McGregor Isles and analyses of water from this aquifer in the eastern part of Lee County suggest that the chemical characteristics are similar to water contained in the unaffected part of the upper Hawthorn aquifer. Inasmuch as the two aquifers are hydraulicaly connected to some extent at McGregor Isles, it is assumed that the water quality is similar. However, saline-water intrusion into the sandstone aquifer apparently has not progressed as rapidly as in the upper Hawthorn aquifer, probably because all the deeper wells are cased through this aquifer. For example, the chloride content of water from well 16-33 (sandstone aquifer) was 240 mg/l, whereas water from well 16-32 (upper Hawthorn aquifer) about 50 feet away, contained 1,100 mg/l of chloride (see fig. 8). Similarly, wells 16-31 and 16-34, both tapping the sandstone aquifer, yield water containing 400 mg/l chloride or less, even though wells nearby, tapping the lower Hawthorn aquifer yield water whose chloride content is more than 3,500 mg/l. Locally, water in the sandstone aquifer is less saline than that from the underlying upper Hawthorn aquifer. This suggests that water of better quality may be developed from the sandstone aquifer in places where water in the upper Hawthorn aquifer is too saline for use. However, a significant increase in use of water from the sandstone aquifer might cause an increase in leakage from the deeper aquifers, and result in a progressive deterioration in its chemical quality.

The Suwannee aquifer contains water generally similar, although somewhat more highly mineralized, than that contained in the unaffected part of the lower Hawthorn aquifer as shown by the analyses for wells 22-2 and 16-14 in table 2, where the total dissolved solids range from 1,720 to 1,790 mg/l and the chloride concentration is about 700 mg/l. Apparently little intrusion of saline water has occurred within this aquifer although, as shown in figure 3, it lies between the deep salt-water source and the highly saline lower Hawthorn aquifer. Chloride data show that some salt invasion of this aquifer has occurred in the vicinity of wells 16-11 and 16-45, but that the intruding water has not spread beyond the immediate vicinity of these wells. The artesian pressure within the Suwannee aquifer may remain sufficiently high to retard movement of saline water, or the aquifer may contain zones of relatively low permeability adjacent to avenues of upward leakage.

Wells which yield water from both the lower Hawthorn and Suwannee aquifers show evidence of saline-water intrusion as indicated by the analyses for wells 15-8 and 17-1, with chloride ranging from 1,325 to 2,100 mg/1. An interesting feature of these multiple aquifer wells concerns the changes in water quality which occur when the wells are allowed to discharge after they have been inactive for some time. This phenomenon is illustrated in figure 9, from a test on well 17-1, April 15, 1969. This well had been inactive for about a week prior to the test. As shown on figure 9, the chloride content of the water remained relatively constant at 840-860 mg/1 for 10 minutes, then increased progressively to about 1,600 mg/1 after 2 hours, and to 1,930 mg/1 after about 15 hours of discharge. The flow rate was about 400 gpm. The chloride content continued to increase over a period of about 3 days to a maximum of 2,060 mg/1.

Apparently this phenomenon is related to differences in water quality and artesian pressure between the lower Hawthorn and Suwannee aquifers. During the period when the well is closed, water under higher artesian pressure moves

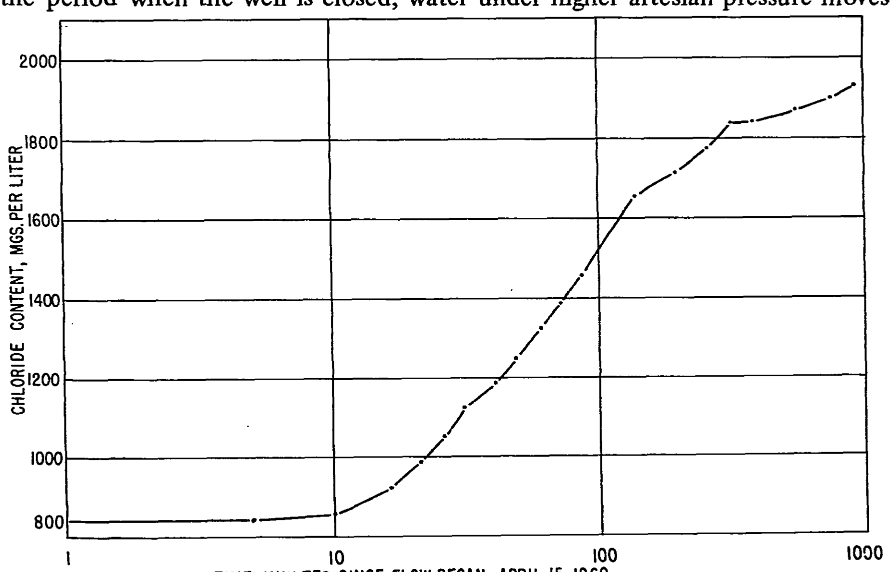

Figure 9. Graph showing changes in chloride content of water from well 17-1 on April 15, 1969.

upward from the Suwannee through the open well bore into the lower Hawthorn aquifer. In this well it is believed that yield from the upper Hawthorn may be minor. Under these conditions, the intruding water is of better quality, resulting in a reduction in the chloride content of water in the lower Hawthorn aquifer around the well. When the well is opened, the discharge consists largely of Suwannee water from both aquifers, but with continued discharge, the Suwannee water that had entered the lower Hawthorn aquifer becomes exhausted and the contribution from the intruded lower Hawthorn aquifer increases resulting in a progressive increase in chloride content. Flowmeter and water-resistivity logs, run after the well had been flowing long enough for the chloride content of the well discharge to stabilize, indicated that the Suwannee aquifer was contributing about 10 percent of the flow to the well, of water containing about 800 mg/l of chloride. The lower Hawthorn aquifer transmissivity in the vicinity of well 17-1 doubtless is higher than either the Suwannee or upper Hawthorn aquifer transmissivity so that it yields water to a discharging well more freely than the other aquifers. Consequently, most of the water discharged from the well comes from the lower Hawthorn even though the Suwannee may have the higher head.

MECHANICS OF INTRUSION

The mechanism of intrusion responsible for the chloride concentration in the lower Hawthorn aquifer has not been positively identified because of the several possibilities that exist. Two hypotheses are here described to explain the apparent hydraulic connection between this aquifer and the salt-water aquifer or aquifers occurring at greater depths, for example, those of the Ocala. The first hypothesis concerns the upward movement of saline water in a deep well or test hole which provides a connection between the aquifers. Essentially, this represents a point source of saline water, or where several wells are involved, would represent several point sources. The saline water from the deeper aquifer, under higher artesian pressure, would enter the lower Hawthorn aquifer at these points and spread out laterally through the aquifer. The increase in chloride in the lower Hawthorn aquifer would be greatest near these points and would decrease with increased distance from these points. The lateral spread of saline water would be controlled by pressure gradients, permeability distribution, subsurface barriers, and other related factors.

This hypothesis would be consistent with most of the observed facts. The date of drilling of such wells, or test holes would mark the beginning of the intrusion, probably between 1940 and 1945. Although a detailed study has failed to disclose any well or test hole that could be the source of the saline water, this does not preclude the possibility that they exist although there is no longer any surface evidence of the well or wells. As mentioned earlier, less than half as many wells tap the Suwannee aquifer than tap the lower Hawthorn, and it has been shown that although Suwannee water can and has intruded the lower Hawthorn, it has resulted in a freshening, rather than a deterioration of the water in the lower Hawthorn. In summary, the point-source hypothesis appears tenable in explaining a mechanism for the upward migration of water from the lower to the upper Hawthorn aquifer. It does not, as implied above, provide a realistic mechanism whereby the lower Hawthorn has become contaminated.

A second, and more tenable, hypothesis concerns the upward leakage of saline water along the fault or fracture system which has been shown to exist in the report area, and which can provide a hydraulic connection between the lower Hawthorn aquifer and deeper aquifers containing saline water. It is postulated that faulting has created paths of high vertical permeability through what would otherwise be relatively impermeable sediments. Under these conditions upward leakage could occur resulting in what may be considered as point or line sources of saline water intrusion into the lower Hawthorn aquifer. This process apparently occurs elsewhere in Florida. At Warm Mineral Springs in Sarasota County, about 35 miles northwest of the report area, upward leakage of saline water occurs along a fracture system to emerge at the surface as a spring (S. R. Windham, oral commun., 1970). In St. Johns County, in northeastern Florida, Bermes and others (1963, p. 88) found a chloride anomaly that he ascribed to the upward leakage of water along a fault.

This hypothesis is consistent, as is the first one, with the fact that the beginning of the intrusion of high-chloride water coincides with the period of increased use of water from the lower Hawthorn aquifer, about 1940-45. The lowering of artesian pressure within the aquifer increased the difference in head between the lower Hawthorn and the saline-water aquifer, resulting in an increase in upward leakage. Upon entering the lower Hawthorn aquifer, the saline water was of high concentration near the points of entry and moved laterally through the formation.

Additional information will be required to prove the validity of either of the hypotheses described. In either case, saline water may enter the lower Hawthorn aquifer in the vicinity of wells 16-7 and 16-45 inasmuch as water from these wells show the greatest effects of intrusion. The quality of the water from well 16-45 (chloride 15,200 mg/l and temperature 93°F), indicates a more direct hydraulic connection with the deep saline-water aquifer near this well site. Apparent offset of beds, as determined from a study of the gamma ray logs, suggests that well 16-45 is near a fault plane, which could be a zone of greater vertical permeability. Zones of greater permeability developed along fault planes may also account for the pattern of spreading of the intruding water as indicated on figures 6a and 6b. The existence of unmapped faults could affect the water quality, as well.

The uncased wells constructed to the lower Hawthorn and Suwannee aquifers provide a conduit through which water can flow to the upper Hawthorn aquifer. Typical well construction in western Lee County includes the installation of well casing to the top of the limestone that forms the uppermost part of the upper Hawthorn aquifer. By seating the casing in this limestone, the overlying sand is prevented from entering the well. After seating the casing, an open hole is drilled until sufficient water is obtained for the required purpose. Thus, wells drilled to the Suwannee aquifer are also connected to the upper and lower Hawthorn aquifers through the open bore hole. Those drilled to the lower Hawthorn are also connected to the upper Hawthorn aquifer.

Each well drilled to the deeper aquifers is a potential source of saline water leakage to the upper Hawthorn aquifer. Where a large number of these wells exist, the effects of a single well may be obscured. In the case of a somewhat isolated well (16-2), the effects have been noted for a distance of about 1,000 feet.

The sandstone aquifer is not ordinarily directly connected to the deeper aquifers through open well bores. As previously indicated, in constructing wells to the Hawthorn aquifers, the casings usually are seated in limestone beneath the sandstone aquifer to prevent sand problems. Except for faulty construction, therefore, transfer of saline water to the sandstone apparently is the result of upward leakage from the part of the upper Hawthorn aquifer through the thin beds which separate them. (See also p. 13.) At places where the upper Hawthorn aquifer contains salty water, water of better quality may be obtained from the sandstone aquifer, but progressive changes in water quality may occur with increased use of water from the aquifer.

Water quality changes in the water-table aquifer may occur as a result of intrusion of sea water from surface-water sources, or from the discharge of saline water from artesian aquifers through wells. In McGregor Isles, deterioration in water quality from the water-table aquifer results primarily from the discharge or surface storage of saline water from the artesian aquifers. Where the water is discharged into drainage or irrigation ditches, the effects may be noted for considerable distances from the source. Discharge into a pond or other storage reservoir would similarly affect the water-table aquifer in the surrounding area. The lateral spread of saline water probably is accelerated during the winter and spring when the water table reaches a seasonal low. Some dilution probably occurs during the period of heavy rainfall, although it is unlikely that the saline water is completely flushed from the water-table aquifer.

CONTROL PROCEDURES

Procedures for eliminating the intrusion of saline water from the artesian aquifer below 1,500 feet into the lower Hawthorn and Suwannee aquifers cannot be developed without additional detailed information to identify the mechanism of intrusion. However, the effects could be minimized–that is, the transfer of saline water could be slowed somewhat–if the artesian pressure within the lower Hawthorn and Suwannee aquifers was allowed to increase, particularly if heads could be established comparable to those which existed prior to the extensive development of water supplies from these aquifers. Placing cement plugs in individual wells between the upper and lower Hawthorn aquifers would prevent upward movement of saline water through the well into the upper Hawthorn. It would also prevent draft from the lower Hawthorn and Suwannee so that their potentiometric heads would have opportunity to recover. However, this increase in head may force water in the Suwannee and lower Hawthorn to the faults, from which it could continue its upward migration. In those parts of the report area, where the saline water may be coming into the Suwannee, plugging wells just below the lower Hawthorn aquifer doubtless would be at least partially effective. To be effective, all deep wells in the McGregor Isles and surrounding area would have to be plugged in this way. The proper positioning of these cement plugs can be readily determined from geophysical logs, many of which are available for wells at McGregor Isles.

By plugging the deep artesian wells where indicated, some of the salt water now entering the upper Hawthorn, sandstone, and water table aquifers might be eliminated. If these wells were plugged the salt water eventually might be diluted or flushed from the aquifers above 300 feet. In some cases, improvement in quality of water from wells in the water table, sandstone, or upper Hawthorn aquifers may be obtained by plugging wells which have been identified as localized sources of saline water. The proper positioning of plugs is important, since plugging a well improperly could be a waste of time and, at most, could be harmful: capping a well at the surface in no way diminishes the effects of the intruding water into the upper Hawthorn or sandstone aquifers, and may actually exacerbate the problem.

A monitoring program could determine the effectiveness of well plugging and obtain information for the correction of similar problems in other areas.

SUMMARY AND CONCLUSIONS

There are six and possibly seven aquifers within the uppermost 1,700 feet of sediments underlying McGregor Isles. Under natural conditions the artesian pressure, temperature, and mineralization of the water generally increases with depth. The aquifers which occur above depths of 300 feet normally contain water suitable for public water supplies. The aquifers between 300 feet and 1,000 feet contain water that is too highly mineralized for public supplies, but at some places, may be suitable for irrigation. The aquifer which occurs at depths below 1,500 feet probably contains water similar to that determined at Hot Springs where the dissolved solids were 34,000 mg/l with a chloride content of 18,700 mg/l and a water temperature of 96°F.

The intrusion of saline water from the deep artesian aquifer has caused deterioration in water quality in parts of the lower Hawthorn aquifer where a maximum chloride concentration of 15,200 mg/l and water temperature of 93°F have been measured. The saline water from the deep artesian aquifer moves upward, either through the open bore hole of as yet unidentified wells or test holes which connect the aquifers, or along a fault or fracture zone which provides a connection between them. In either case, the intruding saline water apparently enters the lower Hawthorn aquifer along faults or otherwise in the vicinity of wells 16-7 and 16-45, and spreads laterally, with the effects decreasing with increased distance from the source. The saline water has spread over an area of about 2.5 square miles and continues unabated at the present time (1970).

This saline-water that has migrated into the lower Hawthorn aquifer has, in turn, begun to migrate into the upper Hawthorn aquifer. The maximum chloride content of water from the upper Hawthorn aquifer was 3,050 mg/l from well 16-20 in contrast to the 15,200 mg/l for the lower. Each well drilled to the lower Hawthorn aquifer is a potential source of saline water leakage into the upper Hawthorn aquifer. There are a large number of such wells. Chemical quality records of water from this and other wells indicates a progressive increase in chlorides in the upper Hawthorn aquifer in some parts of the area, including several public-water wells in section 14.

The high chloride content of water at places in the sandstone aquifer probably is the result of upward leakage from the upper Hawthorn aquifer through the thin beds which separate the aquifers. As of 1970, water within the sandstone aquifer has not been seriously affected by migration of saline water; this aquifer may be a suitable source of supply where the underlying aquifer contains saline water. However, any significant increase in water use from the sandstone aquifer may cause an increase in upward leakage rates as long as the upper Hawthorn aquifer contains saline water under higher head.

The leakage of saline water into the upper Hawthorn, sandstone, and water-table aquifers would be reduced or eliminated by preventing the upward movement of water from the lower Hawthorn aquifer, and to a lesser extent from the Suwannee aquifer. A control procedure that probably would be effective in at least some parts of the report area involves setting cement plugs within these wells to separate the aquifers. This procedure will prevent intermixing of water from the different formations, where a major part of the migrating waters are flowing upward through the well bores. The proper positioning of these plugs can be readily determined from geophysical logs, and the improper placement of these plugs may result in the well becoming a permanent source of salt-water leakage.

When drilling new wells to the lower Hawthorn or Suwannee aquifers, extending the well casing to a depth at least 300 feet and sealing in place with concrete grout would prevent any upward leakage through the open-well bore into the upper Hawthorn and sandstone aquifers.

It is estimated that 30 deep wells yielding water with chloride concentrations of 1,000 mg/l or more, are present in the area. The location of most of these wells are included in this report. Although detailed records are not available on all of these wells, most of them probably allow upward transport of saline water into the water table, sandstone and upper Hawthorn aquifers.

On the basis of data currently (1970) available, the saline water doubtless will continue to spread laterally into areas not presently affected as long as the supply of saline water lasts, and as long as hydraulic and density gradients near the sources of salt water remain sufficiently high. Within the lower Hawthorn aquifer, the lateral movement probably will be toward the south, southeast, and east. Within the upper Hawthorn aquifer, the saline water will continue to spread laterally from wells open to the lower Hawthorn aquifer. Problems of the greatest magnitude probably will occur in the vicinity of artesian wells which contain high concentrations of saline water and where the pressure in the upper Hawthorn aquifer has been significantly lowered by pumping. . Similar effects may be noted in the sandstone aquifer.

As previously indicated, separating the upper and lower Hawthorn aquifers in existing wells, by plugging would be a good start toward corrective action. Establishment of a monitoring program would provide data concerning the effectiveness of a well plugging program. A well plugging and monitoring program would require the coordinated efforts of public and private agencies, as well as the cooperation of land owners and other residents of the area.

Corrective action will not prevent the saline water from spreading further than it is now but would eventually limit its spread and, assuming continued withdrawals from the upper Hawthorn, would decrease the salinity over large areas if all man-made connections between the upper Hawthorn and the deeper aquifers were sealed off.

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Section and well number	Latitude - Longitude number	Depth (feet)	Casing (feet)	Diameter (inches)	Altitude of land surface (feet)	Water level above (+) or below (–) lsd	Date of measurement	Yield, gpm Flow-F	Temperature °F	Chloride (milligrams per liter)	Date	Chemical analysis	Aquifer(s)	Geophysical logs
9-1	263403N0815430.1	105	100	2	6					228	7-69		SS	
9-2	263403N0815430.2	168	120	2	6					512	7-69		UH	
10-1	263415N0815409.1			6	8	+18.6	6-11-58		83	740	6-58		(LH), UH	
10-2	263417N0815323.1	880	150	6	10	+19.5	4-16-69	150F	87	730	4-68		(Su), LH, UH	E, GR, C, F
10-3	263428N0815318.1			4	5	+21.6	6-11-58	100F	85	716	6-58		(Su, LH), UH	
10-4	263404N0815413.1			6	8	+23.6	10-22-57	100F	82	940	4-68		(LH), UH	
11-1	263428N0815303.1	27	24	2	14				79	64	7-69		WT	
14-1	263323N0815224.1	225	138	8	9	7.7	10-30-68			109	4-68		UH	
14-2	263337N0815246.1	270	126	4	8			95		69	2-66		UH	
14-3	263325N0815213.1	235	121	8	7								UH	
14-4	263325N0815202.1	225	136	8	8					102	10-67		UH	
14-5	263317N0815244.1	186	134	8	7			69	77	134	5-69	X	UH	
14-6	263317N0815239.1	187	134	8	7			55		135	9-67		UH	
14-7	263317N0815233.1	235	138	8	8								UH	
14-8	263312N0815244.1	183	130	8	7			97		141	7-67		UH	
14-9	263312N0815238.1	197	124	8	7			71		81	7-67		UH	
									78	162	6-70			
14-10	263312N0815233.1	184	127	8	8			83		105	8-67		UH	
									79	224	6-70			
14-11	263312N0815228.1	206	130	8	8			123		87	8-67		UH	
14-12	263312N0815221.1	225	126	8	9			87		87	8-67		UH	
15-1	263329N0815412.1			6	6			200F	84	5250	4-67		(LH), UH	
15-2	263337N0815354.1			6	6	+13.5	4-16-69	50F	83	1900	6-67		(LH), UH	
15-3	263317N0815407.1	626	130	6	7	+13.0	4-16-69	300F	83	4550	4-68		(LH), UH	E, GR, C, F, R
15-4	263336N0815343.1	640	240	4	6			15F	83	1900	4-67		LH	E, C, F
15-5	263327N0815332.1			6	6			300F		1300	6-58		(LH), UH	
										1700	4-67			
15-6	263311N0815342.1			6	6	+18.5	8-30-68	450F	83	4150	6-67		(LH), UH	
15-7	263403N0815317.1	600+		6	11	+14.0	6-11-58	200F	87	720	6-58		(Su), LH, UH	
15-8	263317N0815400.1	861	119	6	7			225F	84	1325	4-67	X	(Su, LH), UH	E, GR, C, F, R
15-9	263347N0815403.1	200	140	4	7					300	4-67		UH	
15-10	263352N0815356.1	160		2	8					310	8-67		UH	
15-11	263351N0815353.1	590	100	6	8								(LH), UH	
16-1	263351N0815439.1	583	142	4	6	+22.3	4-8-46		83	1520	4-46		(LH), UH	
										5300[a]	4-67			
16-2	263353N0815447.1			6	5	+14.5	4-16-69	100F	83	7360	2-69		(LH), UH	
16-3	263317N0815447.1			6				175F		1400	1957		(LH), UH	
16-4	263337N0815435.1	520	132	6	7	+15.5	4-16-69	485F	85	4650	4-68	X	(LH), UH	E, GR, C, F
16-5	263335N0815431.1	600		6	9				81	3600	10-68		(LH), UH	

[a] Analysis doubtful; not shown on Figure 6A

Table 1. – Record of wells in the McGregor Isles area.

Abbreviations used in table: *Aquifers*–WT (water table), SS (sandstone), UH (upper Hawthorn), LH (lower Hawthorn), and Su (Suwannee). For wells which produce from more than one aquifer, the principal aquifer(s) is shown in brackets. *Geophysical logs* – E (electric log), GR (gamma ray), C (caliper), F (flowmeter), and R (resistivity).

Table 1. — continued

Section and well number	Latitude - Longitude number	Depth (feet)	Casing (feet)	Diameter (inches)	Altitude of land surface (feet)	Water level above (+) or below (–) lsd	Date of measurement	Yield, gpm Flow-F	Temperature °F	Chloride (milligrams per liter)	Date	Chemical analysis	Aquifer(s)	Geophysical logs
16-6	263325N0815430.1	950		6	7	+18.0	6-12-58			2044	6-58		(Su, LH), UH	
									83	2600	6-67			
16-7	263343N0815422.1	582	138	6	8			20F	87	10200	4-68	X	(LH), UH	E, GR, C, F
16-8	263338N0815416.1	657	126	6	7			200F	85	7500	4-68		Su, (LH), UH	E, GR, C, F
16-9	263342N0815432.1	764	170	6	7	+30.3	2-10-34	475F	82	950	2-34		Su, (LH), UH	E, GR, C, F
						+15.0	2-16-67		85	4750	2-67			
16-10	263347N0815428.1			5	6					1900	9-57		(LH), UH	
16-11	263351N0815423.1	797	125	4	6	– 4	4-2-68	10	85	7700	4-68	X	Su, (LH), UH	E, GR, C, F, R
16-12	263359N0815418.1			4	9	+23.9	10-22-57	125F	85	700	10-57		(Su), LH, UH	
16-13	263402N0815416.1	997		6	9	+22.5	10-22-57	125F	85	760	10-57		(Su), LH, UH	
16-14	263403N0815417.1	11-6	120	6	7	+29.3	9-25-44	30F	85	870	9-50	X	(Su), LH, UH	E, GR, C, F
						+15.5	2-16-67			740	7-69			
16-15	263343N0815416.1	20	20	4	6	– 6.5	4- 3-68	65	74	5750	4-68	X	WT	E
16-16	263325N0815437.1	90		2	8					510	8-67		SS	
16-17	263347N0815428.1	140		2	8					670	8-67		UH	
16-18	263337N0815436.1	220	183	2	7			30	79	1560	4-67		UH	
16-19	263324N0815438.1	95		2	7	– 2.3	7-28-69						SS	
16-20	263354N0815452.1	185		2	6				78	2160	6-69		UH	
16-21	263354N0815454.1	180		2	6				78	780	5-69		UH	
16-22	263353N0815453.1	190		2	6				78	1980	5-69	X	UH	
16-23	263354N0815453.1	200		2	6					1020	5-69		UH	
16-24	263353N0815452.1													
16-21	263354N0815454.1	180		2	6				78	780	5-69		UH	
16-22	263353N0815453.1	190		2	6				78	500	5-69		UH	
16-23	263354N0815453.1	190		2	6				78	1980	5-69	X	UH	
16-24	263353N0815452.1	200		2	6					1020	5-69		UH	
16-25	263353N0815449.1	180		2	6				78	1900	5-69		UH	
16-26	263350N0815445.1	150		2	6					500	5-69		UH	
16-27	263354N0815453.1	180		2	6								UH	
16-28	263350N0815448.1	185		2	6				78	420	5-69		UH	
16-29	263350N0815448.2	60		2	6					520	5-69		WT	
16-30	263355N0815441.1	90		2	6					260	5-69		SS	
16-31	263351N0815437.1	92		2	6					200	5-69		SS	
16-32	263353N0815433.1	167		2	6				78	1100	5-69		UH	
16-33	263353N0815433.2	93		2	6					240	5-69		SS	
16-34	263338N0815434.1	80		2	7					400	5-69		SS	
16-35	263343N0815457.1	189	160	2	6					180	5-69	X	UH	
16-36	263339N0815436.1	190		2	7					1100	6-69		UH	
16-37	263348N0815416.1	100		2	9					106	7-69		SS	
16-38	263348N0815416.2	40		4	9	– 1.5	7-23-69		76	620	7-69		WT	

Table 1. – continued

Section and well number	Latitude - Longitude number	Depth (feet)	Casing (feet)	Diameter (inches)	Altitude of land surface (feet)	Water level above (+) or below (–) lsd	Date of measurement	Yield, gpm Flow-F	Temperature °F	Chloride (milligrams per liter)	Date	Chemical analysis	Aquifer(s)	Geophysical logs
16-39	263353N0815425.1	94		2	9					260	7-69		SS	
16-40	263358N0815432.1	200		2	8					975	7-69		UYH	
16-41	263401N0815437.1	168	147	2	8					695	7-69		UH	
16-42	263333N0815437.1	200		2	7					1080	7-69		UH	
16-43	263333N0815441.1	150		2	6					440	7-69		UH	
16-44	263327N0815441.1	150	140	2	6					212	7-69		UH	
16-45	263332N0815455.1	710	252	6	6			250F	93	15200	10-69		(Su, LH)	E, GR, C, F
16-46	263324N0815446.1	165	141	2	6	+ 2.5	11- 3-69	5F		705	10-69		UH	
17-1	263312N0815513.1	682	137	6	7	+17.0	4-25-67	400F	83	2100	4-67	X	(Su, LH), UH	E, GR, C, F
20-1	263309N0815513.1	582	136	6	7			150F	83	2100	5-67		(LH), UH	E, GR, C, F
21-1	263304N0815447.1	60	42	4	8					90	5-67	X	WT	
21-2	263244N0815501.1	383	129	8	5	+18.3	10-25-57	100F	81	1000	5-67		(LH), UH	E
21-3	263310N0815432.1	538	121	6	8				83	1550	6-67	X	(LH), UH	E, GR, C, F, R
21-4	263302N0815447.1	803	130	6	8			200F	84	900	5-67		(Su, LH), UH	E, GR, C, F
21-5	263258N0815429.1	938	146	5	8	+15	4-25-67	100F	84	700	4-67		(Su, LH), UH	E, GR, C, F
21-6	263222N0815504.1	697	130	6	6			200F	84	1000	2-69		(LH), UH	E, GR, C, F, R
22-1	263251N0815411.1	626	130	6	6	+ 9.5	4-26-67	60F	82	555	9-50	X	(LH), UH	E, GR, C, F
										560	4-68			
22-2	263304N0815409.1	897	172	6	7	+14.5	4-14-67	400F	86	660	10-57	X	(Su), LH, UH	E, GR, C, F
						+23.5	9-13-50			700	9-50			
22-3	263237N0815414.1	206	137	6	6	+ 8.6	10-10-57	100F	78	120	8-67		UH	E
22-4	263304N0815338.1	629	128	6	6			300F		2000	10-57		(LH), UH	E, GR, C, F
									83	4000	6-67			
22-5	263304N0815326.1			6	7			300F	84	650	9-50		(LH), UH	
										2300	4-68			
22-6	263252N0815337.1			6	6	+18.0	4-16-69	100F	83	1520	6-67		(LH), UH	
22-7	263252N0815325.1	599	172	6	7	+16.5	4-16-69	500F	83	650	9-50		(LH), UH	
										1280	4-68			
22-8	263300N0815317.1			6	7			200F	83	1550	6-67	X	(LH), UH	
										1940	5-70			
22-9	263232N0815414.1	670		6	6	+ 9.5	10-23-67	200F	84	540	6-67		(LH), UH	
22-10	263242N0815349.1	677	151	6	8			200F	82	570	2-69		(LH), UH	
22-11	263304N0815358.1	596	148	6	7	+13.5	4-20-67	350F	83	1740	4-68		(LH), UH	
22-12	263248N0815347.1	155	126	3	8					225	2-69		UH	

Section and well number	Date of coll-ection	Aquifer(s)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Strontium (Sr)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids (sum)	Hardness as $CaCO_3$ Ca, Mg.	Hardness as $CaCO_3$ Non-carbonate	Alkalinity as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH	Color
21-1	7-14-69	WT	20	120	12	40	1.4		372	3.2	96	0.2	477	376	71	305	800	7.9	30
16-15	4- 3-68	WT									5750		11,500				17,700		
14-5	5-15-69	UH	24	42	33	59	7.5	1.8	242	0.0	134	1.2	420	243	44	198	750	8.1	5
16-35	7-14-69	UH	16	52	31	60	3.9		180		170	1.4	426	263	116	148	800	7.6	5
16-23	7-14-69	UH	15	171	153	876	17	87	176	202	1940	1.2	3470	1067	923	144	750	7.4	3
22-1	4- 3-68	(LH), UH	17	67	85	332	19	11	206	275	560	2,0	1470	529	360	169	6250	7.6	10
21-3	4- 4-68	(LH), UH									1490		3240				5400		
22-8	4- 4-68	(LH), UH									1620		3420				5700		
16-4	4- 4-68	(LH), UH	14	248	318	2460	77	38	176	624	4650	1.5	8530	1970	1830	144	14,300	7.4	5
16-7	4- 2-68	(LH), UH	14	428	640	5620	18.3	39	164	1370	10,200	1.7	18,600	3740	3610	135	29,500	7.4	5
15-8	4- 3-68	(Su, LH), UH	17	111	120	668	29	19	180	344	1250	1.7	2650	792	644	148	4620	7.4	5
17-1	4- 4-68	(Su, LH), UH									1960		4070				6800		
16-11	4- 2-68	Su (LH), UH	18	340	494	4280	150	26	170	1180	7700	1.9	14,300	2910	2770	139	23,200	7.4	5
22-2	4- 4-68	(Su), LH, UH	18	86	87	418	24	15	184	340	700	1.7	1790	590	438	151	3050	7.5	5
16-14	4- 4-68	(Su), LH, UH	19	94	91	382	18	17	184	296	710	1.6	1720	628	478	151	3000	7.4	5
Hot																	52,100		
Springs	12-23-64		8	639	1070	10,400	385		131	2660	18,700	1.4	34,000	6330	6220		52,100	7.8	

Table 2. – Chemical analyses of water from wells in McGregor Isles and at Hot Springs.

(For description of aquifer codes see table 1).

Chemical constituents in milligrams per liter.