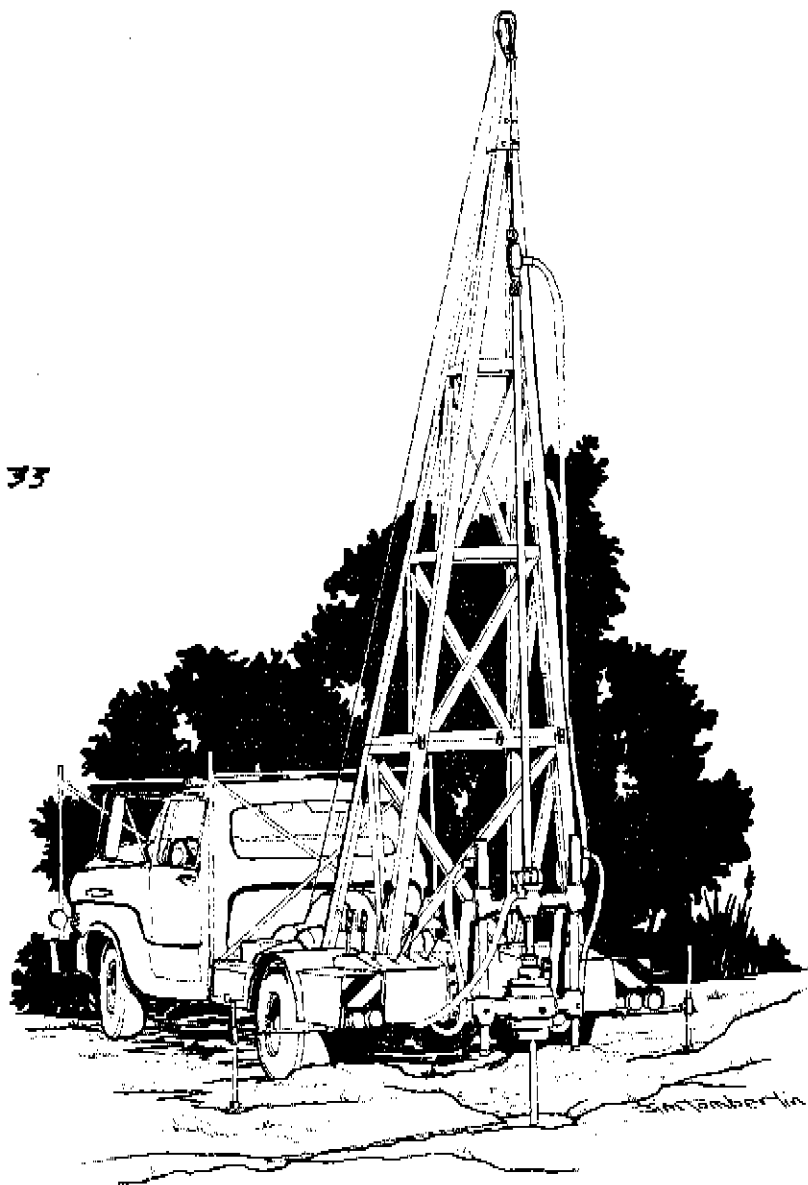


SALINE-WATER INTRUSION RELATED TO WELL CONSTRUCTION IN LEE COUNTY, FLORIDA

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-33



Prepared in cooperation with the
BOARD OF COUNTY COMMISSIONERS OF LEE COUNTY



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| 16. Abstract An estimated 30,000 wells have been drilled in Lee County, Florida since 1900. These wells range in depth from about 10 to 1,240 feet and tap the water-table aquifer or one or more of the artesian aquifers underlying the area. Many of these wells are sources of saline-water intrusion into freshwater aquifers. The artesian aquifers in the lower part of the Hawthorn Formation and upper part of the Tampa Limestone and the Suwannee Limestone have high water levels and contain water with dissolved solids concentrations ranging from 1,500 to 2,400 (mg/L) milligrams per liter. Few of the 3,000 wells drilled to these water-bearing units contain sufficient casing to prevent upward leakage into overlying aquifers; intrusion into the upper part of the Hawthorn Formation has resulted in an increase in chloride concentrations from a normal of 80-150 mg/L to 300-2,100 mg/L. Saline-water intrusion into the upper part of the Hawthorn Formation also has occurred as a result of downward leakage of saline water through corroded metal casings of wells drilled in areas adjacent to tidal water bodies. Where this leakage has occurred, the chloride concentration has increased to as much as 9,500 mg/L. | | | 14. | |
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CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

For additional information write to:

U. S. Geological Survey
325 John Knox Road
Suite F-240
Tallahassee, Florida 32303

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SALINE-WATER INTRUSION RELATED TO
WELL CONSTRUCTION IN LEE COUNTY, FLORIDA

By

D. H. Boggess, T. M. Missimer, and T. H. O'Donnell

ABSTRACT

Ground water is the principal source of water supply in Lee County, Florida where an estimated 30,000 wells have been drilled since 1900. These wells range in depth from about 10 to 1,240 feet and tap the water-table aquifer or one or more of the artesian water-bearing units or zones in the Tamiami Formation, the upper part of the Hawthorn Formation, the lower part of the Hawthorn Formation and the Tampa Limestone and the Suwannee Limestone. Before 1968, nearly all wells were constructed with galvanized or black iron pipe. Many of these wells are sources of saline-water intrusion into freshwater-bearing zones.

The water-bearing zones in the lower part of the Hawthorn Formation, Tampa Limestone, and Suwannee Limestone are artesian--they have higher water levels and usually contain water with a higher concentration of dissolved solids than do the aquifers occurring at shallower depths. The water from these deeper aquifers generally range in dissolved solids concentration from about 1,500 to 2,400 mg/L, and in chloride from about 500 to 1,000 mg/L. A maximum chloride concentration of 15,200 mg/L has been determined. Few of the 3,000 wells estimated to have been drilled to these zones contain sufficient casing to prevent upward flow into overlying water-bearing zones. Because of water-level differentials, upward movement and lateral intrusion of saline water occurs principally into the upper part of the Hawthorn Formation where the chloride concentration in water unaffected by saline-water intrusion ranges from about 80 to 150 mg/L. Where intrusion from the deep artesian zones has occurred, the chloride concentration in water from the upper part of the Hawthorn Formation ranges from about 300 to more than 2,100 mg/L.

Surface discharge of the saline water from wells tapping the lower part of the Hawthorn Formation and the Suwannee Limestone also has affected the water-table aquifer which normally contains water with 10 to 50 mg/L of chloride. In one area, the chloride concentration in water from the water-table aquifer ranged from 200 to 590 mg/L as a result of intrusion.

In areas adjacent to tidal-water bodies, the water-table aquifer contains water that is very saline. Where the wells in such areas have been constructed with metal casings, the metal corrodes when exposed to the saline water, and many ultimately develop holes. This permits

saline water to leak into the well where the water level in the well is lower than the water table. The intrusion of saline water from the water-table aquifer into the upper part of the Hawthorn Formation is a major problem in parts of Cape Coral. Withdrawal of water from the upper part of the Hawthorn Formation has caused water levels to decline below the lowest annual position of the water table, so that downward leakage is perennial. In some coastal areas, wells that tap the upper part of the Hawthorn Formation contain water whose chloride concentration is as much as 9,500 mg/L.

Upward leakage of saline water from the deep artesian aquifers and downward leakage of saline water from the water-table aquifer can be prevented by proper well construction.

INTRODUCTION

Ground water is the principal source of water supply for domestic, municipal, and agricultural purposes in Lee County (fig. 1). About 30,000 wells are estimated to have been drilled since 1900, most during the last 20 years. Most of the wells are along the Caloosahatchee River and in Fort Myers and adjacent areas, in parts of Cape Coral, Lehigh Acres, and Bonita Springs. Ironically, wells which are the principal means of obtaining water in Lee County also are a major source of degradation of ground-water quality. Degradation of fresh ground water is largely a result of saline-water intrusion related to the presence of saline water underlying the county, as well as saline water along the coast and in some interior waterways. The intrusion of saline water into the freshwater-bearing formations is largely related to the construction of wells and the decline in water levels associated with withdrawal of water from wells.

Until now (1977) the county's ground-water supply and water quality have been adequate to meet the county's water needs. Soon, however, this may change. Continued urbanization over the last several decades--each year hundreds of wells are being drilled--has been placing greater stress on the ground-water system. This increased demand, not likely to lessen soon, will cause water levels to decline, which, in turn, will increase the hazard of saline-water intrusion. Many existing wells, old and no longer functional, may also be potential sources of saline-water intrusion. Seeking out such wells and carefully plugging them would forestall, to some extent at least, the onset of serious saline-water intrusion.

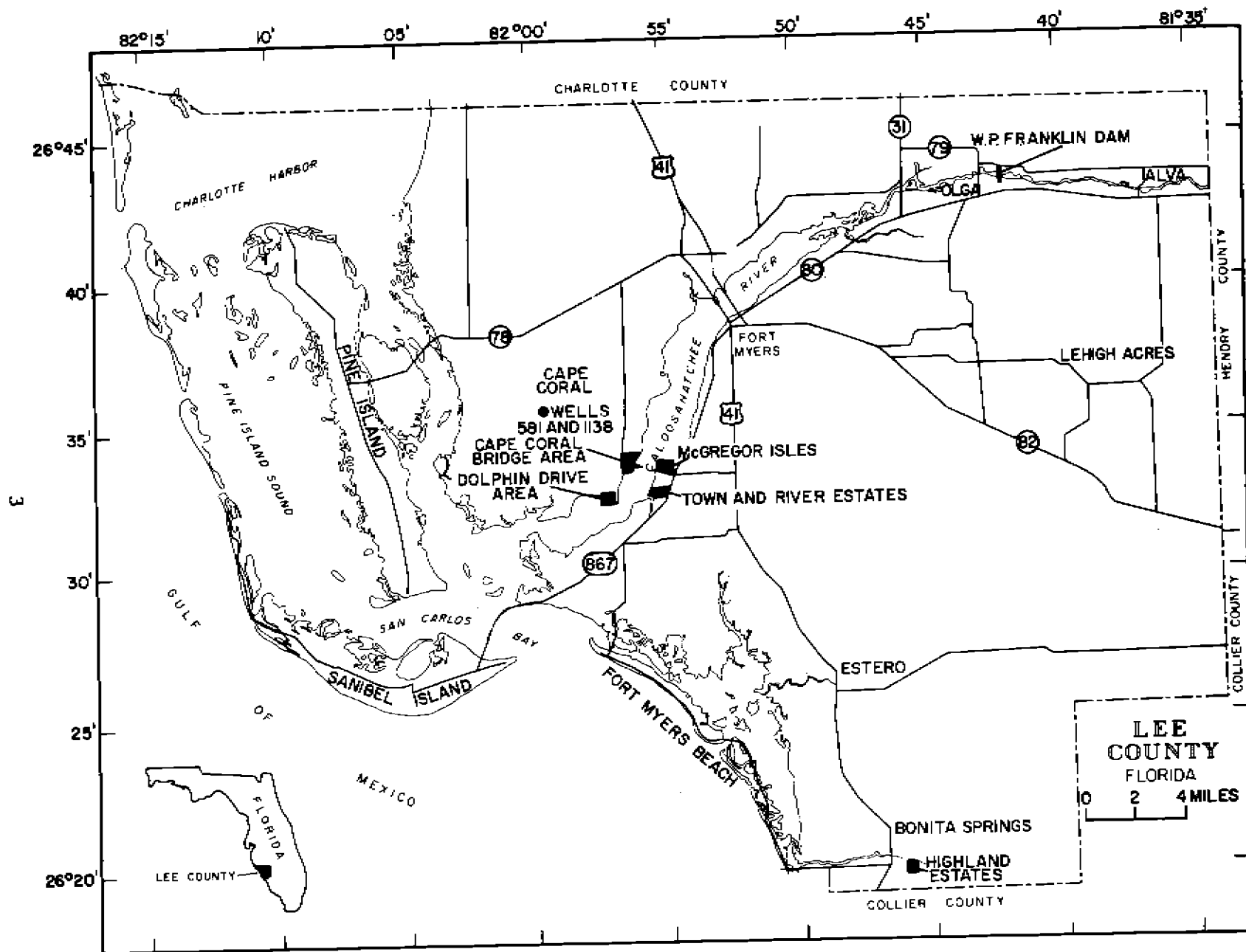


Figure 1.--Lee County showing the location of areas and wells 581 and 1138.

* * * * *

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for terms listed in this report are listed below:

| <u>English</u> | <u>Multiply by</u> | <u>Metric</u> |
|---------------------------------|------------------------|----------------------------|
| inches (in) | 25.4 | millimeters (mm) |
| feet (ft) | 0.3048 | meters (m) |
| miles (mi) | 1.609 | kilometers (km) |
| Gallons per minute (gal/min) | 6.309×10^{-2} | liters per second (L/s) |
| * * * * * | | * * * * * |

PURPOSE AND SCOPE

This report is intended to identify many of the causes of saline-water intrusion into freshwater aquifers in Lee County, and to describe some of the effects of the intrusion on ground-water quality. Particular emphasis is placed on saline-water intrusion as related to the construction, operation, and maintenance of wells drilled primarily for water-supply, and to the plugging of wells that are no longer used.

ACKNOWLEDGMENTS

The authors thank the residents of Highland Estates, McGregor Isles, Town and River Estates, and Cape Coral for their cooperation during this investigation. This study was part of a continuing program of water-resources investigations in cooperation with the Commissioners of Lee County whose continued interest and support is greatly appreciated.

HYDROGEOLOGIC SETTING

Ground water in Lee County is obtained from wells that tap one or more of the five principal water-bearing zones or units (fig. 2), all of which have varying degrees of continuity beneath the county. In order of increasing depth, these are the water-table aquifer, and water-bearing zones or units in the Tamiami Formation, the upper part of the Hawthorn Formation, the lower part of the Hawthorn Formation and the Tampa Limestone. On the basis of local useage, all are known as aquifers, and the lowermost four, again

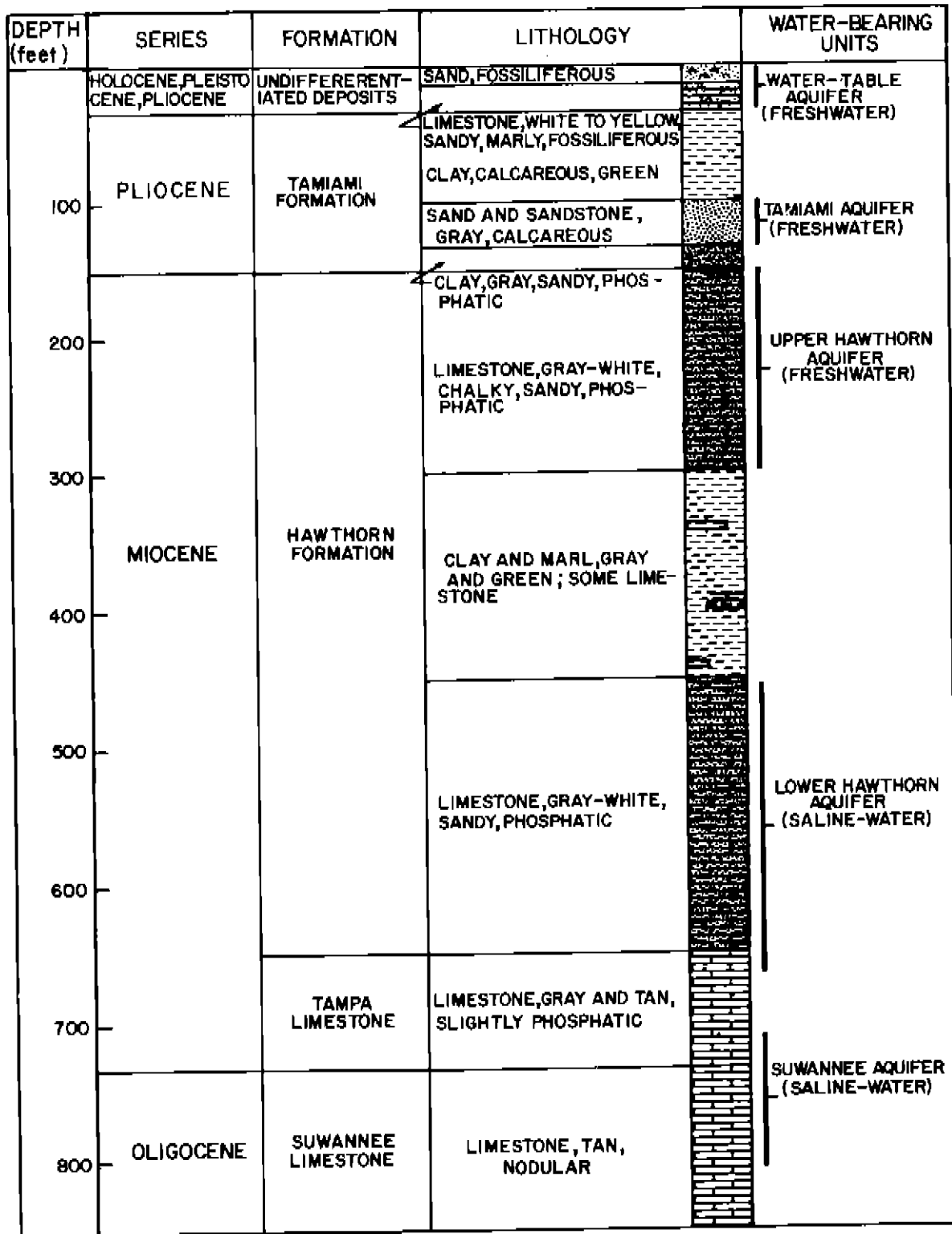


Figure 2.--Generalized section showing the geologic formations, lithology, and water-bearing units underlying Lee County.

in order of increasing depth, have been given local designations, as follows: Tamiami aquifer, upper Hawthorn aquifer, lower Hawthorn aquifer, and the Suwannee aquifer. These names have no formal significance, they have been applied only for convenience.

It is estimated that 30,000 wells tap the principal water bearing zones in Lee County. Of these, 7,000 tap the water-table aquifer, 5,000 the Tamiami Formation, 15,000 the upper part of the Hawthorn Formation, and 3,000 tap either the lower part of the Hawthorn Formation, or Suwannee Limestone, or both.

Throughout this report, the authors use chloride concentration in water as a criterion of saline-water intrusion. The chloride analysis is easy to perform, is reliable, and an increase in chloride concentration usually is associated with an increase in other chemical constituents as well, resulting in an increase in the dissolved solids concentration. Water containing dissolved solids concentrations in excess of 1,000 mg/L is classified by the U. S. Geological Survey as saline (Krieger and others, 1957, p. 4).

Water-table Aquifer

The water-table aquifer consists primarily of unconsolidated fine to medium-grained quartz sand with interbedded sandy limestone and shell units. The thickness of this aquifer varies from less than 5 to nearly 100 ft.

The aquifer is unconfined; its upper surface is in contact with the atmosphere. Its water level rises in response to recharge from rainfall and declines as a result of discharge by evaporation, transpiration, discharge into surface-water bodies, and pumping of wells. A description of factors that cause water levels in the aquifer in Lee County to fluctuate is given by Missimer and Boggess (1974, p. 8).

Of the 7,000 irrigation and domestic wells that tap the water-table aquifer in Lee County, most range in depth from 10 to 50 ft. The aquifer is the principal source of water supply for the city of Fort Myers.

Except for excessive iron concentrations and color, water from the water-table aquifer generally is of good quality: chloride concentrations generally range from about 10 to 50 mg/L and dissolved solids concentrations generally range from about 150 to 400 mg/L as shown in table 1.

Table 1.--Range in chloride and dissolved solids concentrations in ground water in Lee County where unaffected by saline-water intrusion.

| Aquifer or water-bearing zone | Chloride (mg/L) | Dissolved solids (mg/L) |
|---|-----------------|-------------------------|
| Water-table aquifer | 10-50 | 150-400 |
| Tamiami Formation | 30-80 | 200-600 |
| Upper part of the Hawthorn Formation | 80-150 | 450-700 |
| Lower part of the Hawthorn Formation and Suwannee Limestone | 400-1,000 | 1,500-2,400 |

Tamiami Formation

The Tamiami Formation in Lee County consists of sand, limestone, calcareous sandstone, clay, and marl and underlies all of eastern Lee County. The Tamiami Formation is lithologically complex due to numerous lateral facies changes. Several water-bearing units occur within the Tamiami, the uppermost of which is highly productive and serves as the principal source of municipal and domestic water supply at Lehigh Acres.

The uppermost water-bearing unit or zone is confined beneath areally extensive clay and marl deposits and thus is artesian. Some recharge to this unit in Lee County occurs from leakage downward from the water-table aquifer through the confining materials. Water levels in wells that tap the Tamiami Formation generally are lower than they are in wells that tap the water-table aquifer except in low areas along the Caloosahatchee River. Water levels in this water-bearing zone have been lowered in some areas because of heavy local withdrawals for domestic and municipal supply (Missimer and O'Donnell, 1976, p. 41).

Most of the wells drilled into the Tamiami Formation are of small diameter, 2- to 4-in; a few are of large diameter and are used for irrigation or municipal supply.

Water in the Tamiami usually contains 30 to 80 mg/L of chloride and dissolved solids concentrations generally range from about 200 to 600 mg/L (table 1).

Upper Part of the Hawthorn Formation

In western and parts of eastern Lee County, the upper part of the middle Miocene Hawthorn Formation is water-bearing. This water-bearing unit consists predominantly of sandy, phosphatic, limestone and ranges in thickness from about 75 ft to about 200 ft in western Lee County.

This artesian aquifer, in the upper part of the Hawthorn Formation is the most extensively used source of water-supply in Lee County, and is tapped by as many as 15,000 wells. Water from this aquifer is used for municipal supply in Cape Coral, south Fort Myers, Fort Myers Beach, and Pine Island. Most withdrawals however, are from individual home wells and are used primarily for lawn irrigation.

Prior to large-scale urbanization and increasing water demand, water levels in the aquifer commonly stood above land surface in most of western Lee County. Since 1966, when records began, water levels have declined to nearly 70 ft below land surface in some areas. This trend is exemplified by the hydrograph of well 581 (fig. 3), located in Cape Coral (see fig. 1), and whose water level is declining about 3 ft per year.

In areas not affected by intrusion of saline-water, chloride concentrations in water from the aquifer range from about 80 to 150 mg/L and concentrations of dissolved solids range from about 450 to 700 mg/L (table 1).

Lower Part of the Hawthorn Formation, Tampa Limestone, and Suwannee Limestone

The deepest parts of the limestone sequence tapped for water supply in Lee County are the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone and the Suwannee Limestone. The water-bearing unit in the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone (fig. 2) is locally designated the lower Hawthorn aquifer (Sproul and others, 1972). Stratigraphically lower, another water-bearing unit (the Suwannee aquifer) occurs in the upper part of the Suwannee Limestone. Both water-bearing zones consist predominantly of limestone, but the one in the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone also contain phosphorite whereas the Suwannee aquifer--in the Suwannee Limestone--contains quartz sand beds.

Water levels both in the lower part of the Hawthorn Formation and in the Suwannee Limestone--the lower Hawthorn and Suwannee aquifers--range from more than 50 ft above mean sea level in the northeastern part of the county to less than 30 ft above in the westernmost part

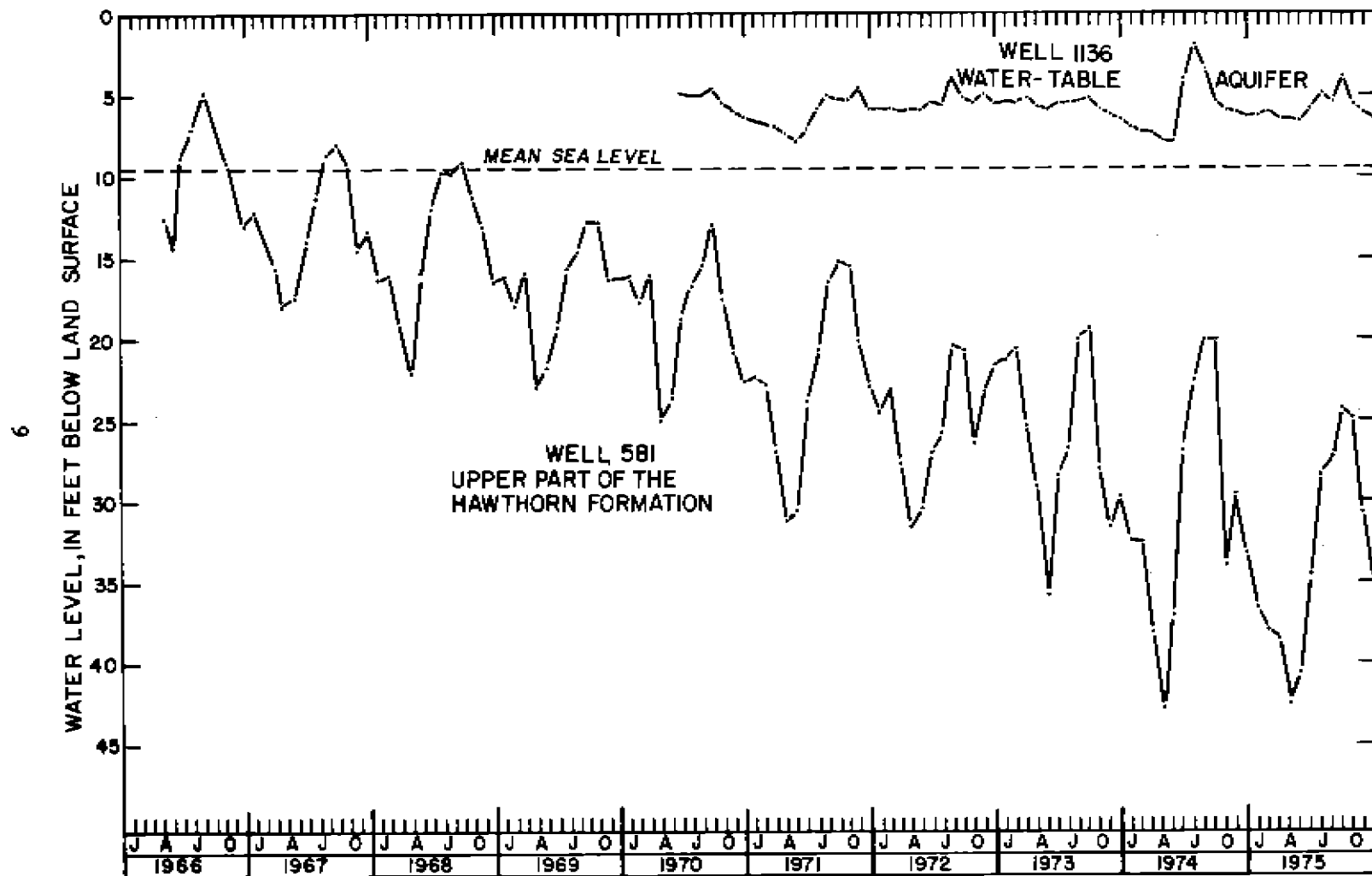


Figure 3.--Hydrograph of wells 581 (1966-75) and 1136 (1970-75).

of the county (Bogges, 1974, p. 23). Throughout the county, wells, about 3,000 in all, that tap these formations will flow. They range in depth from 400 to 1,240 ft, and casing diameters range from 6 to 10 in.

The concentrations of dissolved solids in water from these wells range from about 1,500 to 2,400 mg/L; the waters are classified as saline. Chloride concentrations range from about 400 to 1,000 mg/L, although a maximum of 15,200 mg/L has been determined.

In the past, water from the lower part of the Hawthorn Formation and the Tampa Limestone, and from the Suwannee Limestone were used extensively as sources of water for stock watering and irrigation of pasture land, truck crops, citrus groves, and flower farms. In recent years, they have also been used as a source of water for desalination plants serving Pine Island and Sanibel Island. A third desalination plant which utilizes water from the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone was placed in operation in 1977 for the city of Cape Coral. Additional demands for water have been placed on these deep artesian zones for maintaining pond levels and for irrigation of private lawns and golf courses.

WELL CONSTRUCTION

Before 1968, most water wells in Lee County were drilled by the cable-tool, or percussion-drilling method and were cased with galvanized or black iron pipe. This method consists of alternately driving into the ground and removing (or bailing) material from inside the casing until solid rock is reached. Then an open hole is drilled beneath the casing to permit entry of water into the well.

In recent years, rotary drilling has become increasingly popular. This method consists of an advancing rotating drill bit through which either air (air rotary) or liquid (hydraulic rotary) is forced under high pressure to provide additional cutting action and to lift the drilled material to the surface. Generally, the well casing is installed after the desired water production zone has been reached. After the casing has been installed, an open hole is drilled below the casing to permit entry of water into the well. With this method, either metal or PVC (polyvinyl chloride) well casing may be installed. This method also permits installation of well screens where needed.

Subsurface hydrologic and geologic conditions in Lee County indicate the following desired characteristics for well construction: (1) Selection of the type of well casing to be used based on the possible occurrence of saline-water zones; (2) installation of well casing from the land surface to several feet into the topmost part of the zone that is to supply water to the well; (3) provision for an effective seal of the annular space (rotary drilling method) outside the

well casing with clay or cement grout; and (4) limitation of the length of the open-hole section of the well so that only one aquifer is penetrated. Subsequent discussions will illustrate the consequences of not following these procedures.

INTRUSION OF SALINE WATER FROM UNDERLYING ARTESIAN SOURCES

As mentioned earlier, water in the lower part of the Hawthorn Formation and the upper part of the Tampa Limestone, and the Suwannee Limestone are under much higher pressure than in water-bearing zones nearer the surface, including the water-table aquifer. Most of the wells that tap the deeper water-bearing zones flow at land surface. Because the water from these deeper zones is of higher salinity than water from the upper part of the Hawthorn Formation and the Tamiami Formation and from the water-table aquifer (table 1), any interconnection between the deep and shallow zones such as the uncased section of a well will result in upward flow of saline water, and degradation of the quality of the water in the shallower zones must follow.

Unfortunately, most of the deep wells in Lee County provide an interconnection with the shallow aquifers, either within the uncased section of the well bores or through corrosion holes in the well casings as shown for wells A and B on figure 4. Much of this corrosion of the of the metal casings has occurred at or just beneath the surface. In addition, the flow-control valves on many of the old, deep wells are inoperable, allowing saline water to leak continuously upon the land surface. Numerous other deep wells, not equipped with flow-control valves, continuously discharge large volumes of saline water upon the surface.

Although degradation of the quality of the water in the water-table aquifer has occurred in both ways--by leakage directly into the aquifer through defective casings of deep wells, and by infiltration of the saline water that is allowed to discharge upon land surface because of defective valves--most of the saline-water intrusion of the water-table aquifer has occurred as a result of infiltration of the saline water being discharged at land surface.

In contrast, intrusion of saline water into the upper part of the Hawthorn and the Tamiami Formations occurs as a result of upward leakage in the uncased section of deep wells. As previously noted, this occurs as a result of differences in artesian pressure between the shallow and deep aquifers. Upward leakage rates of as much as 100 gal/min have been measured (Sproul and others, 1972, p. 10). Some leakage occurs in all wells where two or more aquifers are interconnected within the uncased section of the bore hole. The leakage rates are not constant, increasing or decreasing with changes in differential pressure between the aquifers. For example, the artesian pressure within the upper part of the Hawthorn Formation in western Lee County has been declining steadily

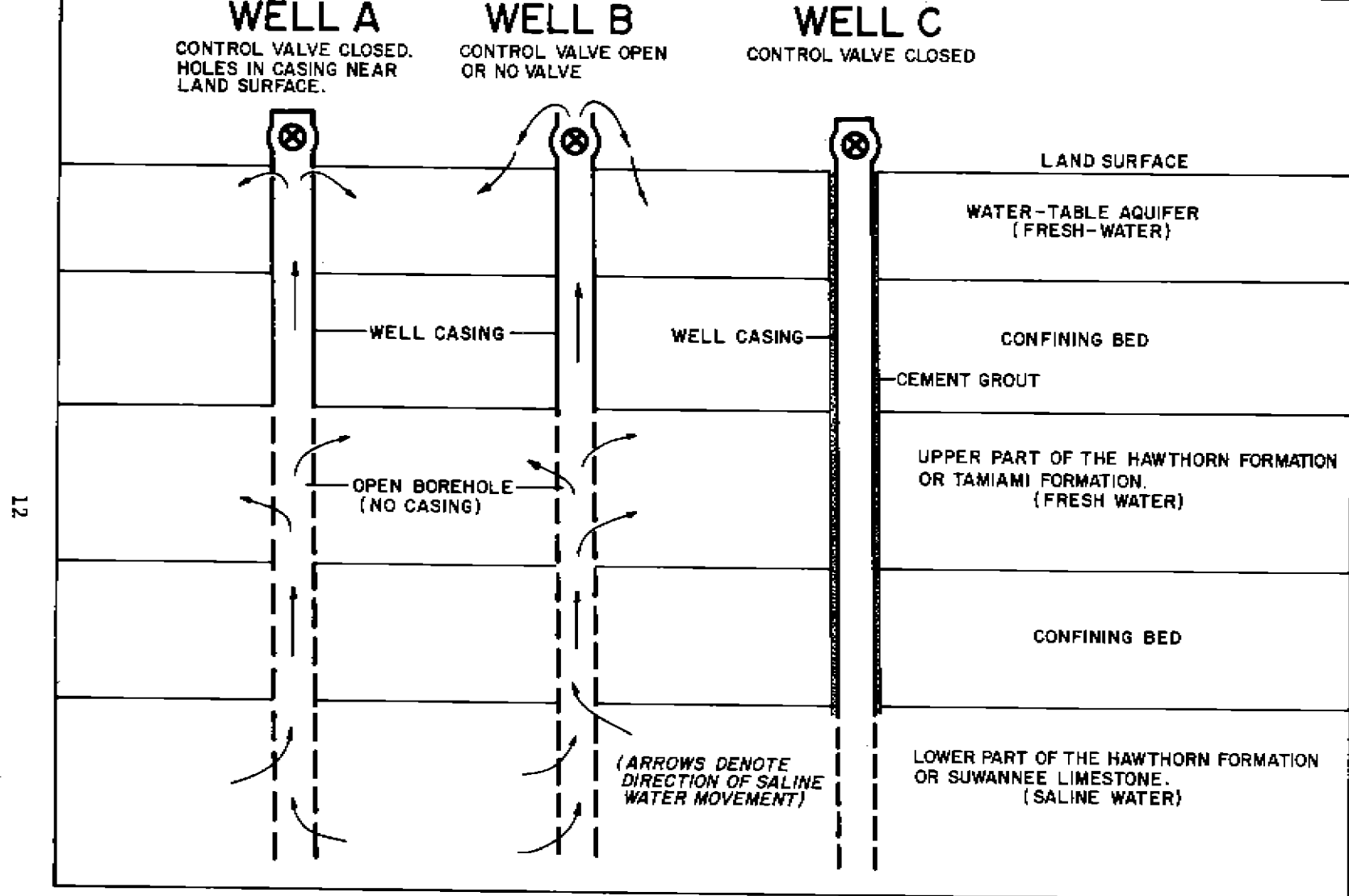


Figure 4.--Diagrams of three wells showing mechanism of saline-water intrusion. (Wells A and B are open to saline-water zones in the lower part of the Hawthorn Formation or Suwannee Limestone and to fresh-water zones in the upper part of the Hawthorn, or Tamiami Formation. In both wells, saline water is moving upward into the freshwater zones. In well A, saline water also is moving into the water-table aquifer through corroded in the casing, and in well B, saline water is flowing out of the well at land surface through an opened valve. Well C is cased to the top of the lower part of the Hawthorn Formation and saline water cannot move into freshwater zones through the well bore. Water is available for use only when the valve at the wellhead is opened).

over the last decade as a result of the progressive increase in water demand (fig. 3). A comparable increase in water demand from the water-bearing unit in the lower part of the Hawthorn Formation has not occurred. The resulting greater difference in artesian pressure between the two in some areas has probably accelerated the leakage rate of saline water from the lower part to the upper part of the Hawthorn Formation where the two parts become hydraulically connected by uncased wells.

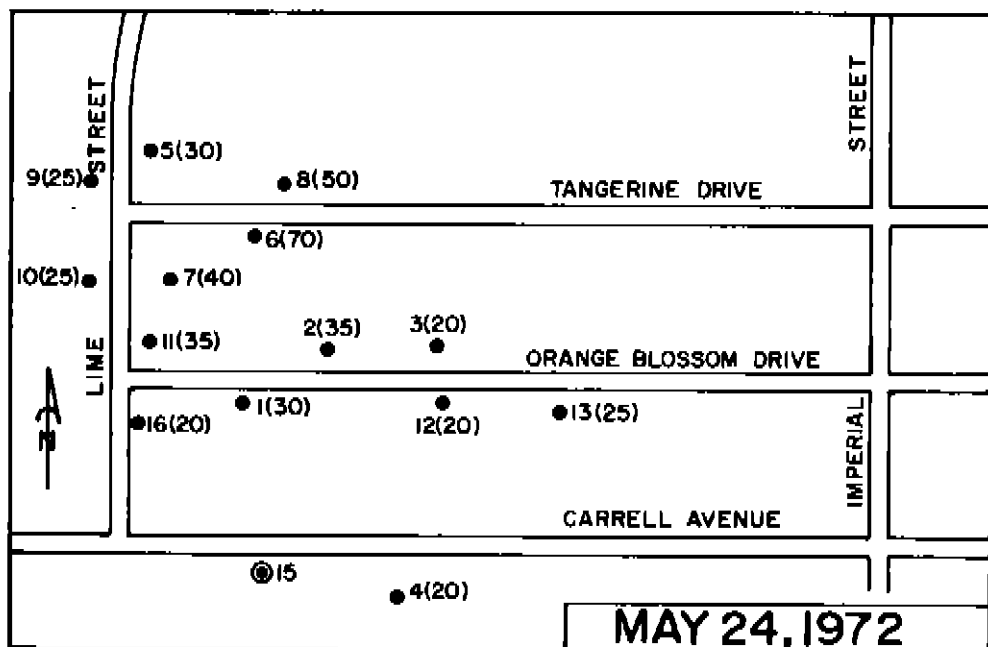
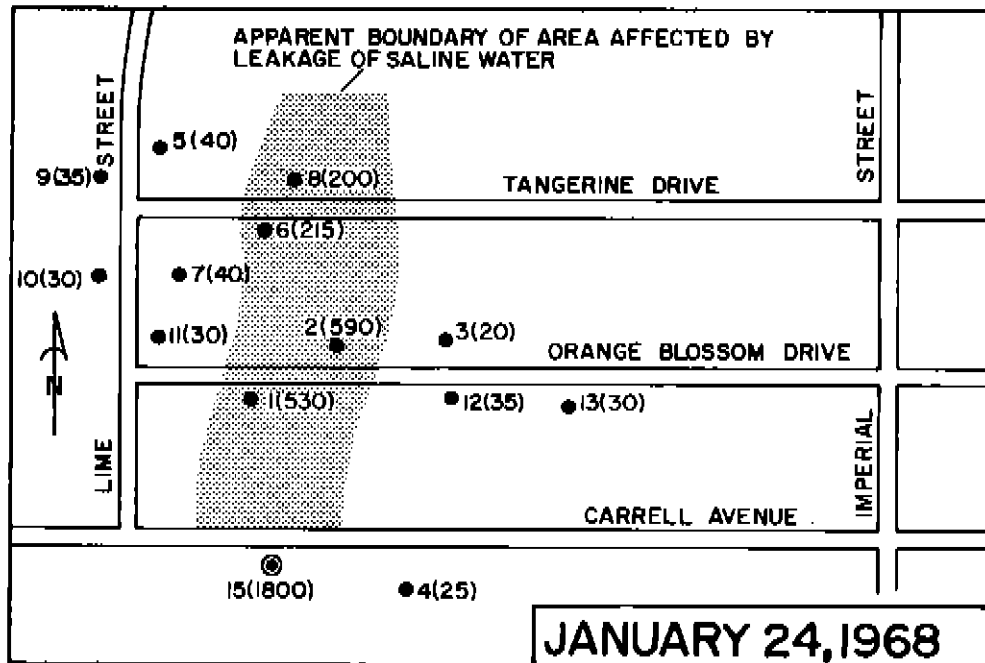
Saline water intruding the upper part of the Hawthorn Formation--the upper Hawthorn aquifer--from a deep well moves radially from that well. The direction and rate of movement is controlled primarily by the hydraulic gradient and the transmissivity of the aquifer. Changes in the quality of the water from the upper Hawthorn aquifer have been detected 1,000 ft from the source well (Sproul and others, 1972, p. 26). At one site in central Lee County, the changes in water quality were noted 4,000 ft from the source well. Most likely, saline-water intrusion of the Tamiami Formation--Tamiami aquifer--also has occurred as a result of upward leakage from deep wells. The effects of this intrusion on water quality in the Tamiami Formation are less well known because of the fewer number of wells tapping the Formation.

The intrusion of saline-water into the water-bearing zones in the upper part of the Hawthorn Formation and in the Tamiami Formation can be reduced effectively but not eliminated entirely. Such reduction would require installing, in new wells, casing in a manner that will prevent any direct interconnection between deep and shallow aquifers as shown for well C on figure 4. Where rotary drilling methods are used, the annulus between the casing and bore hole can be filled with cement grout to prevent circulation. In some old wells, additional casing could be installed and cemented in place to achieve the same results. Other old wells, either abandoned or in poor condition, or both, could be plugged with cement.

Case History: Highland Estates

Highland Estates is a small residential development about 0.5 mi east of Bonita Springs in southern Lee County. Before 1972, when the municipal water-supply system was constructed, most of the residents of Highland Estates obtained water for domestic use from wells tapping the water-table aquifer. Most wells ranged in depth from 20 to 25 ft and the chloride concentration in water from them was 20 to 40 mg/L.

On January 24, 1968, an investigation of the area made in response to reports of the occurrence of salty water, indicated that the chloride concentration in water from some wells ranged from 200 to 590 mg/L (fig. 5). The source of the intruding saline water apparently was well 15, which taps the lower part of the Hawthorn Formation. Although well 15 was leaking only a small volume of water from the casing above land



EXPLANATION

- 2 WELL TAPPING THE WATER-TABLE AQUIFER AND NUMBER
- ⊙ 15 WELL TAPPING THE LOWER PART OF THE HAWTHORN FORMATION AND NUMBER

0 200 400 600 FEET

CHLORIDE CONCENTRATION IN MILLIGRAMS PER LITER SHOWN IN PARENTHESIS

Figure 5.--Highland Estates showing chloride concentrations in water from wells on January 24, 1968 and May 24, 1972.

surface, corrosion of the metal casing was allowing a larger volume of water to leak from the well at and immediately beneath the land surface. The chloride concentration in the water from well 15 was 1,800 mg/L. This well, apparently drilled for irrigation of a nearby citrus grove, had not been used for many years.

In February 1968, well 15 was completely plugged with cement grout. Continued monitoring of the water from the shallow wells showed a progressive decrease in chloride concentrations and by May 1972 (fig. 5), most of the saline water had dissipated--probably by being diluted or flushed by the infiltration of rainfall. A complete description of the Highland Estates investigation is given in Boggess (1973).

Case History: Town and River Estates

Town and River Estates is a residential community on the Caloosahatchee River about 7 mi southwest of Fort Myers. Before 1972, when a public water-supply system began providing service to the area, most of the residents obtained water for domestic use from wells tapping the upper Hawthorn aquifer--the water-bearing unit in the upper part of the Hawthorn Formation. In response to reports of the occurrence of salty water in some of these wells, an investigation of the problem began in November 1970.

Early results of the investigation showed that the chloride concentration in water from these wells ranged between 80 and 1,190 mg/L and that the principal source of the intruding saline water was a series of four deep artesian wells (numbers 520, 1162, 1179, and 1180 on fig. 6) tapping the lower part of the Hawthorn Formation and the Suwannee Limestone. The intrusion of saline water into the upper part of the Hawthorn Formation underlying Town and River Estates occurred over an extended period, possibly 25 or 30 years. The wells, formerly used for agriculture, contained water with chloride concentrations ranging from 1,100 to 1,420 mg/L. The depth of the wells ranged from 482 to 820 ft but were cased to depths ranging from 129 to 160 ft. Not enough casing was used (300 ft would have been required) in these wells to seal off the aquifer in the upper part of the Hawthorn Formation: this water-bearing zone and those in the lower part of the Hawthorn Formation and the Suwannee Limestone were connected by the uncased section of the bore hole (fig. 4). This connection permitted saline water to flow upward because the deeper zones are under higher artesian pressure. All four deep artesian wells shown on figure 6 were plugged with cement grout between December 1970 and June 1973. Most of the wells whose locations are shown on figure 6, tap the upper part of the Hawthorn Formation--the upper Hawthorn aquifer--and range in depth from 190 to 220 ft. Water from those wells nearest the former sources of saline-water intrusion (wells 520, 1162, 1179, and 1180) show the highest chloride

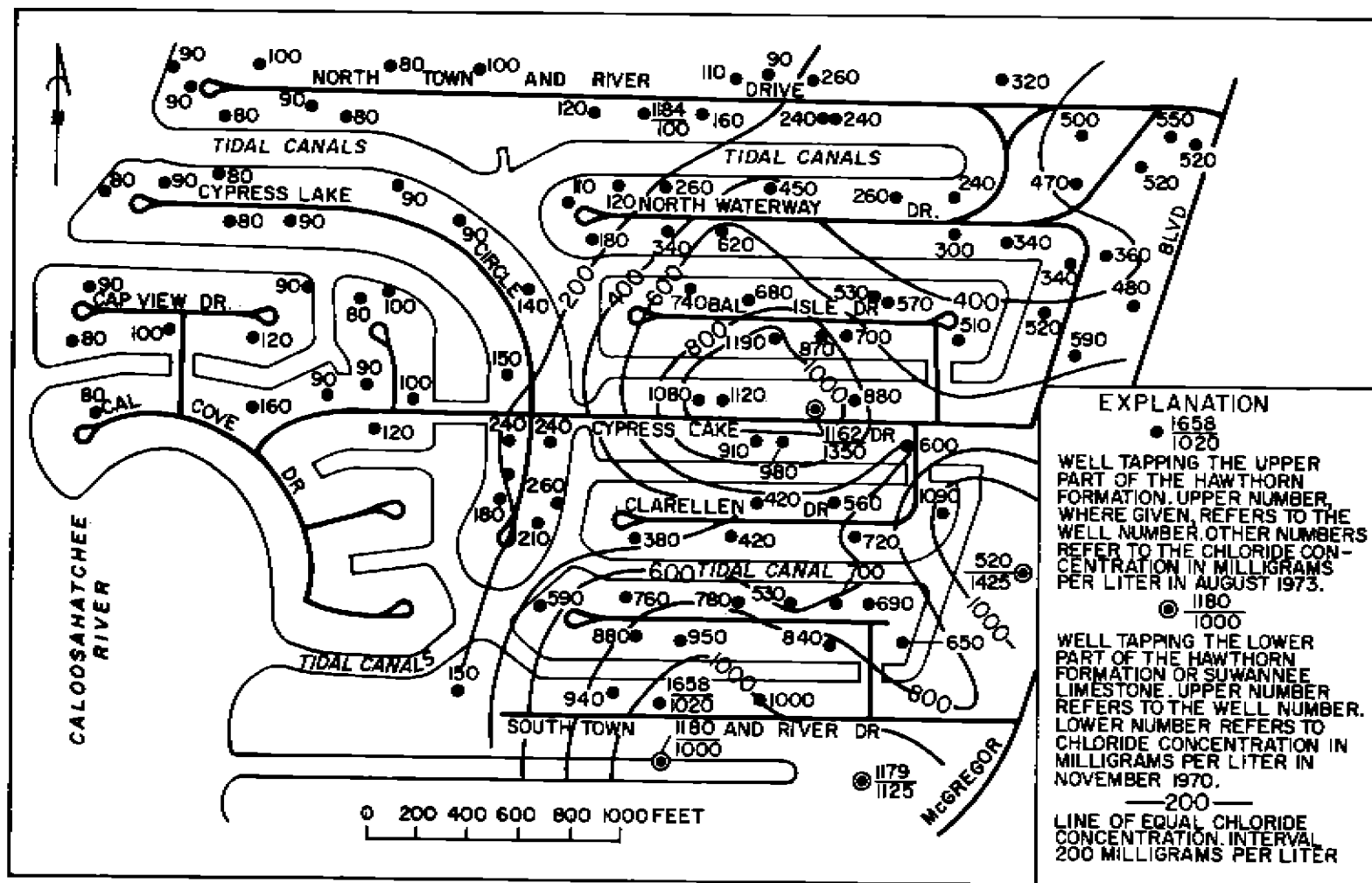


Figure 6.--Town and River Estates showing the chloride concentrations in water from wells tapping the upper part of the Hawthorn Formation, August 1973.

concentrations. Although the effects of intrusion tend to diminish away from the sources of saline water, all the wells in the eastern part of Town and River Estates have been affected to some extent as shown by the higher chloride concentrations shown on figure 6.

As previously mentioned, the concentration of chloride in water is used throughout this report as an indicator of saline-water intrusion: the saline water is high in chloride, and an increase in chloride concentrations is associated with an increase in other chemical constituents, as shown in table 2. The chemical analysis of water from well 1180, tapping the lower part of the Hawthorn Formation, shows high concentrations of most chemical constituents. Conversely, water from well 1184 which taps the upper part of the Hawthorn Formation shows relatively low concentrations of most chemical constituents in comparison. The chemical analysis of water from well 1658, tapping the same zone as well 1184, shows the effects on water quality of intrusion of saline-water from the lower part of the Hawthorn Formation. The analysis of water from well 1658 indicates a near complete displacement of water in the upper part of the Hawthorn Formation in the vicinity of well 1658 by intrusion of water from well 1180 about 200 ft to the south.

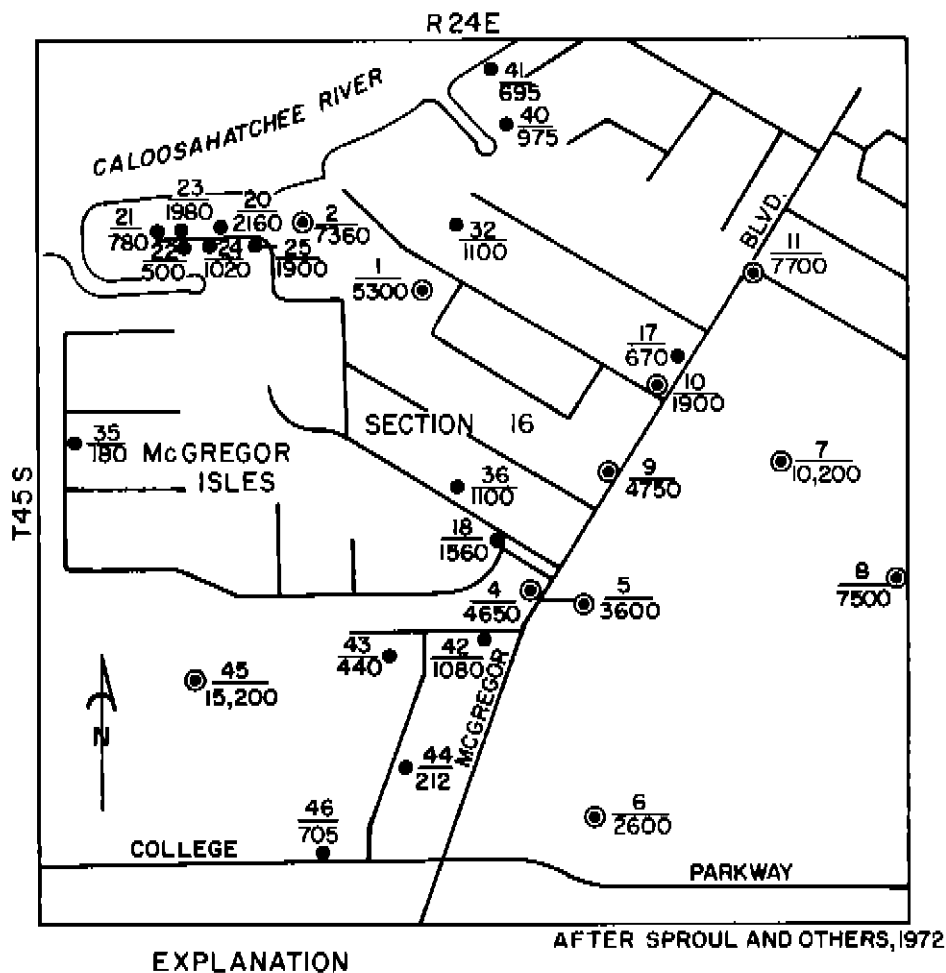
Case History: McGregor Isles

McGregor Isles, another residential community along the Caloosahatchee River is located about 5 mi southwest of Fort Myers. As in Town and River Estates, residents obtain water for lawn irrigation from wells tapping the water-bearing unit in the upper part of the Hawthorn Formation. In the area are numerous deep wells drilled to the lower part of the Hawthorn Formation and the Suwannee Limestone. These deep artesian wells, particularly those tapping the lower part of the Hawthorn contain water of higher salinity than elsewhere in the county. The highly saline water in the lower part of the Hawthorn Formation is the result of upward leakage from much deeper artesian sources (Sproul and others, 1972, p. 15). The effect of this upward leakage is seen in figure 7 where the chloride concentration in the water-bearing zones or units in the lower part of the Hawthorn Formation and the Suwannee Limestone ranges from 2,600 to 15,200 mg/L.

Highly saline water is transmitted upward into the upper part of the Hawthorn Formation through the uncased section of wells tapping the lower part of the Hawthorn Formation and the Suwannee Limestone. An upward discharge rate of 100 gal/min from the lower part of the Hawthorn Formation into the upper part was measured in well 4 (fig. 7). The effects of intrusion of saline water into the upper part of the Hawthorn is evident in wells 20 through 25 where the chloride concentrations ranged from 500 to 2,160 mg/L in May 1969. The saline water in these wells apparently is the result of intrusion from well 2 tapping the lower part of the Hawthorn Formation which contained water with a

Table 2.--Chemical analyses of water from the lower part of the Hawthorn Formation and the upper part of the Hawthorn Formation underlying Town and River Estates. (Chemical constituents in milligrams per liter).

| Well No. | 1180 | 1184 | 1658 |
|-------------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Depth, ft | 482 | 200 | 210 |
| Formation | lower part of the Hawthorn | upper part of the Hawthorn | upper part of the Hawthorn |
| Sample collection date | 5-8-73 | 5-9-73 | 5-8-73 |
| Silica (SiO ₂) | 22 | 21 | 23 |
| Iron (Fe) | .02 | .04 | .03 |
| Strontium (Sr) | 17 | 2.1 | 12 |
| Calcium (Ca) | 100 | 43 | 100 |
| Magnesium (Mg) | 110 | 27 | 110 |
| Sodium (Na) | 620 | 52 | 560 |
| Potassium (K) | 26 | 6 | 24 |
| Bicarbonate (HCO ₃) | 180 | 236 | 184 |
| Carbonate (CO ₃) | .0 | .0 | .0 |
| Sulfate (SO ₄) | 260 | 10 | 250 |
| Chloride (Cl) | 1,100 | 84 | 1,000 |
| Fluoride (F) | 2.2 | 0.2 | 1.7 |
| Nitrate (NO ₃) | .0 | .0 | .0 |
| Dissolved solids | | | |
| Calculated | 2,300 | 360 | 2,200 |
| Residue | | 377 | |
| Hardness as CaCO ₃ | | | |
| Calcium-magnesium | 720 | 220 | 720 |
| Non-carbonate | 570 | 26 | 550 |
| Alkalinity as CaCO ₃ | 148 | 194 | 151 |
| Specific conductance (micromhos) | 4,100 | 660 | 3,900 |
| pH | 7.5 | 7.7 | 7.6 |
| Color | 20 | 10 | 15 |



EXPLANATION

- $\frac{43}{440}$ WELL TAPPING THE UPPER PART OF THE HAWTHORN FORMATION AND WELL NUMBER.(UPPER NUMBER)
 - ⊙ $\frac{6}{2600}$ WELL TAPPING THE LOWER PART OF THE OF THE HAWTHORN FORMATION OR SUWANNEE LIMESTONE AND WELL NUMBER (UPPER NUMBER)
- (LOWER NUMBER REFERS TO CHLORIDE CONCENTRATION IN MILLIGRAMS PER LITER)

0 300 600 900 1200 FEET

Figure 7.--McGregor Isles area showing chloride concentrations in water from wells tapping the upper part of the Hawthorn Formation and the lower part of the Hawthorn Formation and the Suwannee Limestone, May 1969.

chloride concentration of 7,360 mg/L. The upper part of the Hawthorn Formation formerly contained water lower in concentration of chloride as indicated by well 35: in May 1969, water from that well contained only 180 mg/L of chloride.

Although wells 8 and 45 (fig. 7), have been plugged with cement and no longer discharge saline water into the upper part of the Hawthorn Formation the other deep wells probably still do.

INTRUSION OF SALINE WATER FROM SURFACE-WATER AND SHALLOW GROUND-WATER SOURCES

All of the streams in Lee County affected by tides in the Gulf of Mexico contain very saline water during part of the year, particularly during the dry season. This includes the Caloosahatchee River upstream to the W. P. Franklin Dam and the lower reaches of all small streams connected to the river or other tidal water bodies. Also included are the lower reaches of canals and drainage ditches connected to tidal sources.

Because of the ease of exchange of water between surface water and the water-table aquifer, the aquifer nearly always contains saline water in areas adjacent to saline surface-water bodies as shown on figure 8 (well A). In some areas, very saline water may occur within the water-table aquifer where no direct connection with saline surface-water bodies exists (fig. 8, well C).

Deep wells that penetrate zones of shallow saline water are subject to two potential problems: (1) vertical leakage along the outside of a well casing that is not properly sealed, and (2) leakage through the well casing as a result of corrosion. Leakage outside the well casing is less probable for wells drilled with a cable-tool rig because the casing is driven into place. Leakage outside of the well casing is more probable for wells constructed with a rotary drill because the diameter of the borehole is larger than the diameter of the casing which is installed after the hole has been drilled. Effective sealing of the annulus between the outside of the casing and the borehole with cement grout will prevent leakage outside of the well casing (fig. 8, well B).

Continuous water-level records for wells that tap the upper part of the Hawthorn Formation begin in 1966. Since then, the decline in water levels has been progressive; levels are below sea level (fig. 3) throughout the area of heavy pumpage. Thus, as shown on figure 8 (wells A and C) where saline water is present in the water-table aquifer, and a connection with the upper part of the Hawthorn Formation exists, then saline water will leak downward because of its higher head. Even where there is no difference in water levels, the greater density of saline water in the water-table aquifer may permit downward leakage.

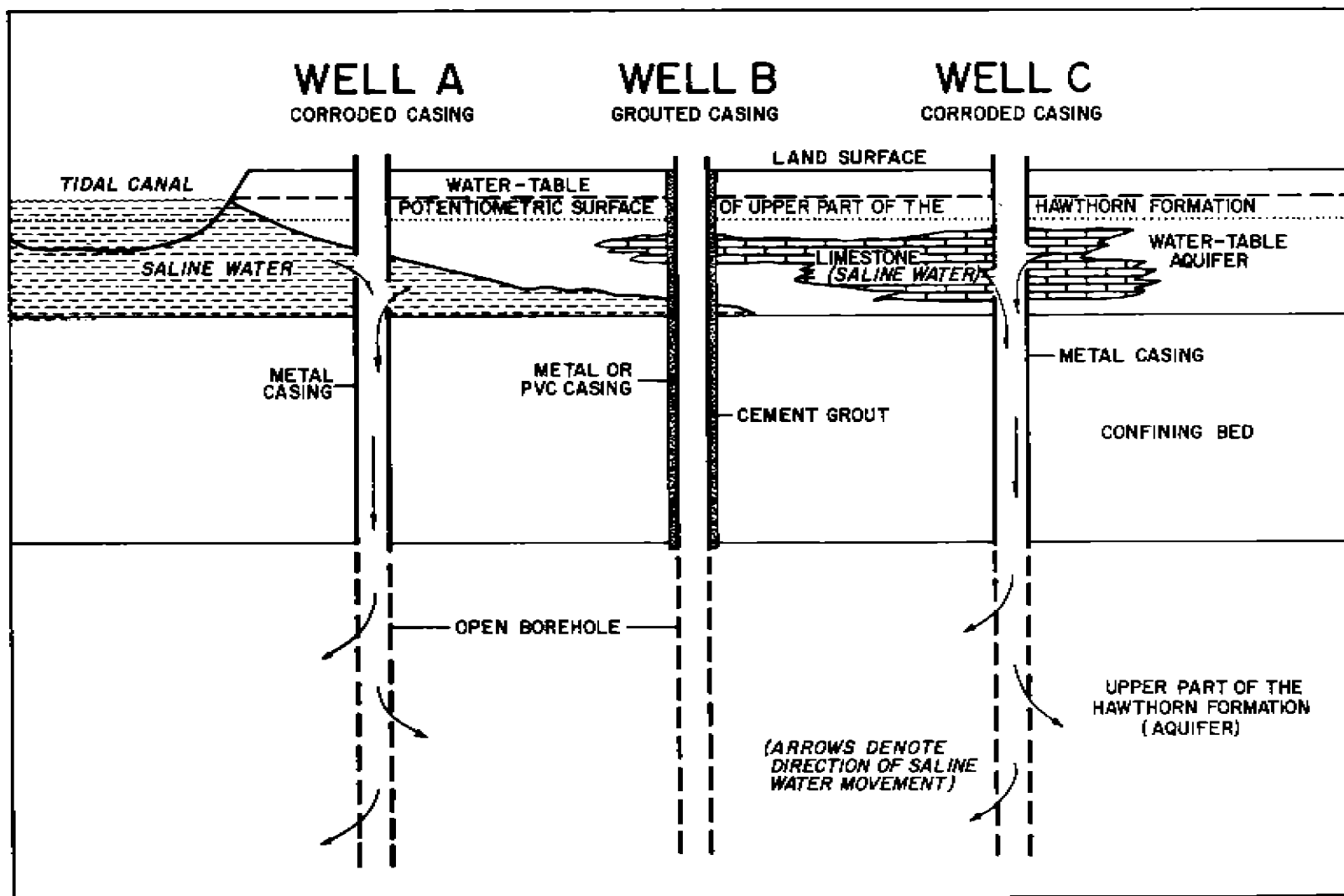


Figure 8.--Diagram showing intrusion of saline water from the water-table aquifer through wells tapping the upper part of the Hawthorn Formation (wells A and C) and properly constructed well (B).

Of the thousands of cable-tool wells that tap the upper part of the Hawthorn Formation--the upper Hawthorn aquifer--in Fort Myers, Cape Coral, Fort Myers Beach, and adjacent area along the Caloosahatchee River, many penetrated saline-water zones in the water-table aquifer. Initially these wells did not permit leakage because the metal casing was new. However, after several years of corrosion by the saline water in the water-table aquifer, the casings developed small holes. As the holes became enlarged, the leakage of saline water into the well increased. Where water levels in the upper part of the Hawthorn Formation declined to or below water levels in the water-table aquifer, leakage into the casing began.

As shown on figure 8 (well B), a properly constructed well can effectively prevent downward leakage of saline water either outside of the casing, or through the well casing.

Case History: Dolphin Drive Area of Cape Coral

In August 1969, one of the earliest investigations of saline-water intrusion from the water-table aquifer into the upper part of the Hawthorn Formation in Cape Coral was conducted. Intrusion occurred along Dolphin Drive near the yacht basin in the south part of Cape Coral (fig. 9). Dolphin Drive is almost completely surrounded by tidal canals that usually contained very saline water.

Most wells in the area tapped the upper part of the Hawthorn Formation at depths ranging from 165 to 210 ft. Well 952, drilled to the upper part of the Hawthorn Formation in 1961 and cased with galvanized iron pipe, contained in 1969, water with a chloride concentration of 26,400 mg/L. The owner indicated that the well had been in use until 1967 when the water became too salty for lawn irrigation. Although no analysis was made, it appeared unlikely that the canal north of the well site was the source of the high chloride water in well 952, inasmuch as sea water normally contains about 19,000 mg/L of chloride.

In an attempt to identify the source of the high chloride concentrations, test well 962 was drilled to a depth of 62 ft about 10 ft from well 952, and water samples were collected during drilling. The chloride concentration in water from test well 962 increased with depth, from 1,260 mg/L in the depth interval from 10 to 12 ft below land surface to 26,400 mg/L in the interval 56 to 60 ft below, as shown in table 3.

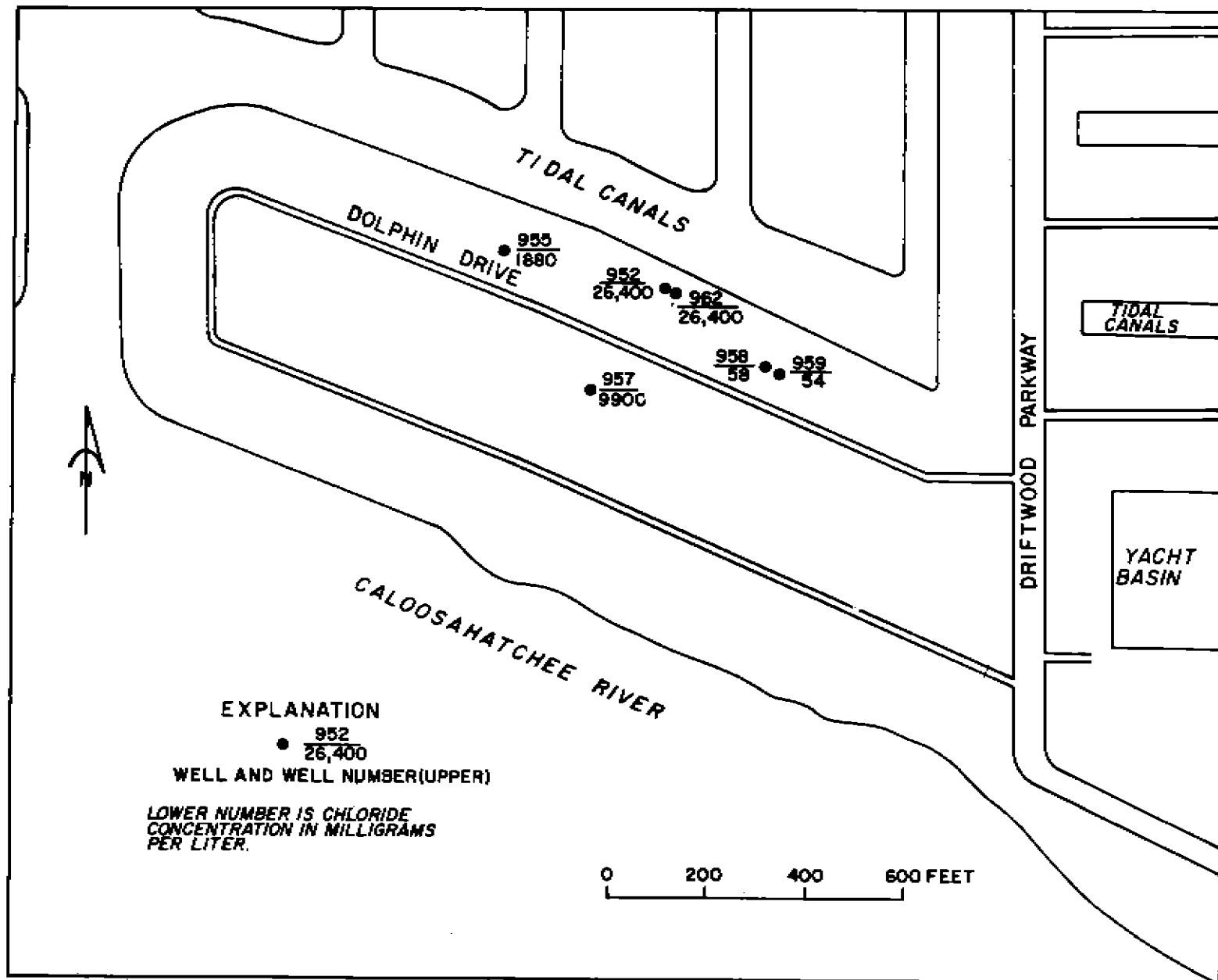


Figure 9.--Dolphin Drive area of Cape Coral showing the chloride concentrations in water from wells tapping the upper part of the Hawthorn Formation, August 1969.

Table 3.--Lithology, pumping rate, and chloride concentrations in water from test well 962. (Water sampled and well yield determined when bottom of well was within the depth range shown.)

| Depth (ft) | Pumping rate (gal/min) | Chloride concentration (mg/L) | Lithology |
|---------------|------------------------------|-------------------------------------|--------------------------------------|
| 10-12 | -- | 1,260 | Sand, fine to medium, brown |
| 16-21 | -- | 2,600 | Clay, sandy, gray; shell fragments |
| 26-27.5 | -- | 17,000 | Limestone, tan and some gray |
| 30-31 | 40 | 21,600 | Do. |
| 35-36 | 50 | 23,000 | Limestone, blue-gray, some tan |
| 44-46 | 43 | 25,600 | Do. |
| 50-52.5 | 75 | 26,400 | Do. |
| 56-60 | 50 | 26,400 | Sand, medium, gray, some phosphorite |
| 61-62 | -- | -- | Clay, gray |

The chloride concentration of water in the interval 50 to 60 ft was identical to water in well 952. Water in the canal north of these wells contained 3,900 mg/L of chloride which was higher than the concentration found in test well 962 at depths less than 21 ft. Nevertheless, holes had developed in the casing of well 952 beginning at a depth of about 8 ft and, as indicated by the high chloride concentration, must have extended to a depth of at least 50 ft. The available evidence suggests that some source other than the canal must be causing the high chloride concentration in water in well 952.

From the available information it is concluded that two major sources of saline water are present in some parts of Cape Coral and possible in other parts of Lee County. The first source is the water-table aquifer which usually contains saline water near tidal water (fig. 8, well A). The inland extent of saline ground water in these areas is limited largely by the hydraulic conductivity of the sediments, and by differences in water levels and water density. The second source of saline water, as identified in table 3, is the limestone which forms the lower part of the water-table aquifer and which is present at test well 962 (fig. 8, well C). The sandy clay between 16 and 21 ft in that well (table 3) apparently limits the interchange of water between the upper and lower parts of the aquifer.

Chloride concentrations in water from the other wells shown on figure 9 vary widely. Water from wells 958 and 959 contained only 58 and 54 mg/L of chloride. Conversely, well 957, about the same distance from well 952, yielded water with a chloride concentration of 9,900 mg/L. Whether this high chloride was the result of lateral movement of saline

water from well 952 or leakage within well 957 could not be determined. Both well 952 and test well 962 were completely filled with cement grout in September 1969 so that no further leakage of saline water could occur at these sites.

Case History: Cape Coral Bridge Area

An inventory of wells was made in November 1974 in the area north and south of the Cape Coral Bridge as shown on figure 10. Most of the wells tap the upper part of the Hawthorn Formation, range in depth from 130 to 230 ft, and were cased with galvanized iron pipe. The chloride concentration in water from these wells ranged from 100 to 9,500 mg/L.

The Caloosahatchee River and tidal canals contain saline water most of the time and adjacent parts of water-table aquifer also contain saline water. To verify the occurrence of saline water in the water-table aquifer, test well 2279 was drilled on SE 20th Avenue (fig. 10) in April 1976. Information from this test well (table 4) shows that the river and canals likely are the source of the saline water.

Table 4.--Lithology, chloride concentrations, and pH in water from test well 2279. (Water sampled when bottom of well was within depth range shown.)

| Depth (ft) | Chloride concentration (mg/L) | pH | Formation description |
|------------|-------------------------------|-----|--|
| 0-5 | - | - | Sand, medium and tan limestone (fill). |
| 5-10 | - | - | Sand, medium, tan. |
| 10-15 | 9,840 | 7.8 | Limestone, sandy, tan. |
| 15-20 | 13,800 | 7.8 | Limestone, light tan, slightly marly. |
| 20-25 | 13,650 | 7.8 | Limestone, light tan, slightly sandy. |
| 25-30 | 7,250 | 7.9 | Limestone, tan and gray, slightly sandy. |
| 30-35 | 16,950 | 7.2 | Limestone, sandy, gray, phosphatic. |
| 35-40 | 18,100 | 6.9 | Same with some shell fragments. |
| 40-45 | 16,750 | 7.4 | Clay, sandy, green; shell fragments. |
| 45-48 | - | - | Clay, sandy, green. |

Very saline water occurs at the top of the water-bearing zone and throughout the interval from 10 to 45 ft, with a maximum chloride concentration of 18,100 mg/L between 35-40 ft. This lower interval also contained water with the lowest pH (6.9).

The chloride concentrations determined in test well 2279 are sufficiently high to account for the high chloride concentrations found in water from wells tapping the upper part of the Hawthorn Formation (fig. 10). The principal mechanism for this intrusion of saline water appears to be downward leakage from the water-table aquifer through corroded casings of wells that tap the water-bearing unit in the upper part of the Hawthorn Formation. The decline in artesian pressure in the upper part of the Hawthorn in the Cape Coral Bridge area has been sufficient to permit downward leakage.

Saline water intruding the upper part of the Hawthorn Formation tends to move radially away from the point of entry and may be accelerated by heavy pumping in adjacent areas. The rate and direction of movement is also influenced by aquifer characteristics. The distribution of chloride concentrations in water from wells shown on figure 10 indicates that leakage is occurring in some wells and the effects are spreading to other nearby wells. Those wells containing water with chloride concentrations greater than about 200 mg/L have probably been affected by the downward leakage. It also appears likely that changes in chloride concentrations resulting from leakage in adjacent wells may occur rapidly. Chloride concentrations in water from well 17 on Sandy Circle (fig. 10) showed an increase from 450 mg/L in November 1974 to 2,100 mg/L in May 1975.

Leakage of saline water into the upper part of the Hawthorn Formation in the Cape Coral Bridge area has continued unabated to the present (1977). Leakage probably will continue until action is taken to identify and plug leaky well casings.

SUMMARY AND CONCLUSIONS

Ground water is the principal source of water supply in Lee County. It is estimated that 30,000 wells have been drilled since 1900 with the greatest concentration of wells located along the Caloosahatchee River and in Fort Myers and adjacent areas, Cape Coral, Lehigh Acres, and Bonita Springs. Many wells are sources of saline water intrusion into freshwater aquifers.

Five water-bearing units or zones occur beneath Lee County, including, in order of increasing depth, the water-table aquifer, units in the Tamiami Formation (the Tamiami aquifer), in the upper part of the Hawthorn Formation (upper Hawthorn aquifer), the lower part of the Hawthorn Formation and upper part of the Tampa Limestone (lower Hawthorn aquifer), and in the Suwannee Limestone (the Suwannee aquifer). Only the uppermost three units contain freshwater; the two deeper ones contain saline water in which the dissolved solids concentrations range from 1,500 to 2,400 mg/L. Water levels in these deeper zones are higher than levels

in the shallower zones and range from about 30 to 50 ft above mean sea level.

Of the estimated 3,000 wells which tap the lower part of the Hawthorn Formation and the Suwannee Limestone, few contain sufficient casing to prevent an interchange of water between deep and shallow water-bearing zones. Saline water moves upward through the uncased part of wells into freshwater zones. Intrusion of saline water from the lower part of the Hawthorn Formation and Suwannee Limestone has resulted in widespread deterioration in water quality in the upper part of the Hawthorn Formation. Surface discharge or leakage of saline water resulting from the corrosion of metal casing of deep wells, has caused degradation in water quality in the water-table aquifer.

At Town and River Estates, intrusion of saline water from the deeper water-bearing units--those below the upper Hawthorn aquifer--has resulted in an increase in chloride in water from the upper Hawthorn aquifer from a normal concentration of about 80 mg/L to 1,190 mg/L. In McGregor Isles an increase from a normal concentration of about 180 mg/L to 2,160 mg/L occurred. Complete chemical analyses on wells 1180 and 1658 in Town and River Estates indicated nearly complete displacement of freshwater in the upper part of the Hawthorn for a distance of about 200 ft from well 1180 which was the source of intruding saline water.

Another major source of saline-water intrusion occurs within the water-table aquifer. In areas adjacent to tidal water, the aquifer commonly contains saline water. In some localized areas, the aquifer contains very saline water as a residual of depositional processes. Wells that tap the upper part of the Hawthorn Formation may penetrate this saline-water zone. Where metal casing is used without grouting, it will develop leaks as a result of corrosion. Inasmuch as water levels in the upper part of the Hawthorn Formation in many areas are lower than the water table, downward leakage of saline water can occur. Saline-water intrusion from the water-table aquifer is a major problem in some parts of Cape Coral. In one area this resulted in an increase in chloride concentration from about 60 mg/L to 26,400 mg/L. In another area near the Cape Coral Bridge, the chloride concentrations increased from about 100 mg/L to 9,500 mg/L.

Upward leakage of saline water from the lower part of the Hawthorn Formation and Suwannee Limestone into the upper part of the Hawthorn Formation (the upper Hawthorn aquifer) or into the Tamiami Formation (the Tamiami aquifer) can be prevented or diminished by proper well construction. In new well construction, extending the well casing from the surface to the top of the lower part of the Hawthorn Formation or Suwannee Limestone, precludes a connection between these saline water units and overlying freshwater units and prevents migration of saline water.

Grouting the casing in place can help prevent corrosion and subsequent leakage. Eliminating leakage from existing wells requires the installation and cement grouting of additional casing. Eliminating leakage in some wells, particularly where the casing is in poor condition could be accomplished only by plugging the well with cement grout.

The problem of downward leakage of saline water through corroded well casings also could be prevented in new well construction by grouting the casing in place. Because of the small diameter of most existing wells, installing and cement grouting new casing is seldom practical. Complete sealing of the wells with cement grout will usually prevent further downward leakage of saline water.

Unless corrective action can be taken to resolve the problems of saline-water intrusion, the effects on the quality of the water in the freshwater-bearing zones will grow progressively worse and further limit their utilization.

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