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Design of a Real-Time Ground-Water Level Monitoring Network and Portrayal of Hydrologic Data in Southern Florida

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
Report 01-4275

Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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By Scott T. Prinos, A.C. Lietz, *and* R.B. Irvin

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Tallahassee, Florida
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Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
foot per year (ft/y)	0.3048	meter per year (m/y
mile (mi)	1.609	kilometer (km)

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Water level in this report refers to daily maximum water level. Mean water level refers to mean daily maximum water level.

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Abstract

Ground-water resources in southern Florida are under increasing stress caused by a rapid growth in population. As a result of increased demands on aquifers, water managers need more timely and accurate assessments of ground-water conditions in order to avoid or reduce adverse effects such as saltwater intrusion, loss of pumpage in residential water-supply wells, land-surface subsidence, and aquifer compaction.

Hydrologic data were analyzed from three aquifer systems in southern Florida: the surficial aquifer system, which includes the Biscayne aquifer; the intermediate aquifer system, which includes the sandstone and mid-Hawthorn aquifers; and the Florida aquifer system represented by the lower Hawthorn producing zone. Long-term water-level trends were analyzed using the Seasonal Kendall trend test in 83 monitoring wells with a daily-value record spanning 26 years (1974-99). The majority of the wells with data for this period were in the Biscayne aquifer in southeastern Florida. Only 14 wells in southwestern Florida aquifers and 9 in the surficial aquifer system of Martin and Palm Beach Counties had data for the full period. Because many monitoring wells did not have data for this full period, several shorter periods were evaluated as well. The trend tests revealed small but statistically significant upward trends in most aquifers, but large and localized downward trends in the sandstone and mid-Hawthorn aquifers.

Monthly means of maximum daily water levels from 246 wells were compared to monthly rainfall totals from rainfall stations in southwestern and southeastern Florida in order to determine which monitoring wells most clearly indicated decreases in water levels that corresponded to prolonged rainfall shortages. Of this total, 104 wells had periods of record over 20 years (after considering missing record) and could be compared against several drought periods. After factors such as lag, seasonal cyclicity, and cumulative functions were considered, the timing of minimum values of water level from 15 ground-water monitoring wells and average minimum rainfall values agreed 57 to 62 percent of the time over a 20 to 26 year period. On average, the timing of water-level minimums and rainfall minimums agreed about 52 percent of the time, and in some cases only agreed 29 percent of the time.

A regression analysis was used to evaluate daily water levels from 203 monitoring wells that are currently, or recently had been, part of the network to determine which wells were most representative of each aquifer. The regression also was used to determine which wells provided data that could be used to provide estimations of water levels at other wells in the aquifer with a coefficient of determination (R^2 value) from the regression of 0.64 or greater. In all, the regression analysis alone indicated that 35 wells, generally with 10 years or more of data,

could be used to directly monitor water levels or to estimate water levels at 180 of 203 wells (89 percent of the network). Ultimately, factors such as existing instrumentation, well construction, long-term water-level trends, and variations of water level and chloride concentration were considered together with the R^2 results in designing the final network.

The Seasonal Kendall trend test was used to examine trends in ground-water chloride concentrations in 113 wells. Of these wells, 61 showed statistically significant trends. Fifty-six percent (34 of 61 wells) of the observed trends in chloride concentration were upward and 44 percent (27 of 61 wells) were downward. The relation between water level and chloride concentration in 114 ground-water wells was examined using Spearman's ρ and Pearson's *r* correlation coefficients. Statistically significant results showed both positive and negative relations. Based on the results of statistical analyses, period of record, well construction, and existing satellite telemetry, 33 monitoring wells were selected that could be used to assess ground-water conditions in 167 monitoring wells in southern Florida on an interim basis.

A real-time ground-water level monitoring network was designed to provide this information, and a prototype website (http://www.sflorida.er.usgs.gov/ddn_data/index.html) was constructed to provide water managers with daily updates on ground-water conditions in southern Florida. Many of the same analytical tools used to select monitoring wells representative of aquifer conditions are also employed to analyze data for this website. These tools include regression analysis, the Seasonal Kendall trend test, and frequency analysis. The website also includes image maps showing the current conditions for stations in selected geographical areas and aquifers and statistical comparison plots for each station.

INTRODUCTION

In recent decades, southern Florida has experienced rapid population growth that is expected to continue into the next millennium. Because of the increasing demand on water supply, timely and in-depth analytical information is needed by water managers to assess current and long-term ground-water conditions in the region. This information is critical to management of the water supply and to avoid potential adverse effects on the hydrologic system including saltwater intrusion, loss of pumpage in residential water-supply wells, and aquifer compaction.

The U.S. Geological Survey (USGS) operates a ground-water monitoring network that presently consists of 476 wells and spans 10 counties and 3 aquifer systems in southern Florida (as of 2000). This existing network provides water managers with a reasonably comprehensive coverage of data reflecting changes that affect the aquifers. In most instances, water-level data from network wells are collected and analyzed monthly, and therefore, are not available for assessment on a near real-time basis. Although water managers generally make decisions regarding withdrawals from aquifers on a weekly or monthly basis, sometimes these decisions must be based on changes in water levels that occur over just a few days. A subset of the ground-water level monitoring network that has been equipped with satellite telemetry could provide the real-time water-level information that is needed. While this subset would be unable to provide the same spatial coverage of the complete network, it could still give insight into changes that occur during those intervals when data from the complete network are unavailable.

The USGS, in cooperation with the South Florida Water Management District (SFWMD), recently conducted a study to: (1) design a real-time ground-water level monitoring network that consists of representative wells from the existing larger network in southern Florida, (2) develop portrayal techniques as a tool for water managers to rapidly assess ground-water conditions, and (3) create a page on the World Wide Web to transmit the hydrologic information to water managers and the public as it is received. This timely information will enable water managers to plan and make decisions in advance of (and during) droughts, water shortages, and other severe hydrologic events.

Purpose and Scope

The purpose of this report is to document the design of a real-time ground-water level monitoring network that provides in-depth, analytical information on the current state of hydrologic conditions in southern Florida with the information accessible on the World Wide Web. The Seasonal Kendall trend test is used to assess long-term water-level trends in various aquifers. A frequency analysis is made to compare rainfall deficiencies and water levels in monitoring wells. A regression analysis helps to identify those wells most representative of the existing continuous monitoring network in each aquifer. A correlation analysis of instantaneous water levels and chloride concentrations and an analysis of trends in chloride concentration are used to identify areas where a real-time ground-water level monitoring network well could aid in assessing saltwater intrusion.

Description of Study Area

The study area encompasses all of southern Florida, except for Monroe County (fig. 1). Collier, Lee, and Hendry Counties are in southwestern Florida; Miami-Dade, Broward, Palm Beach, Martin, and St. Lucie Counties are in southeastern Florida. In the study area, the

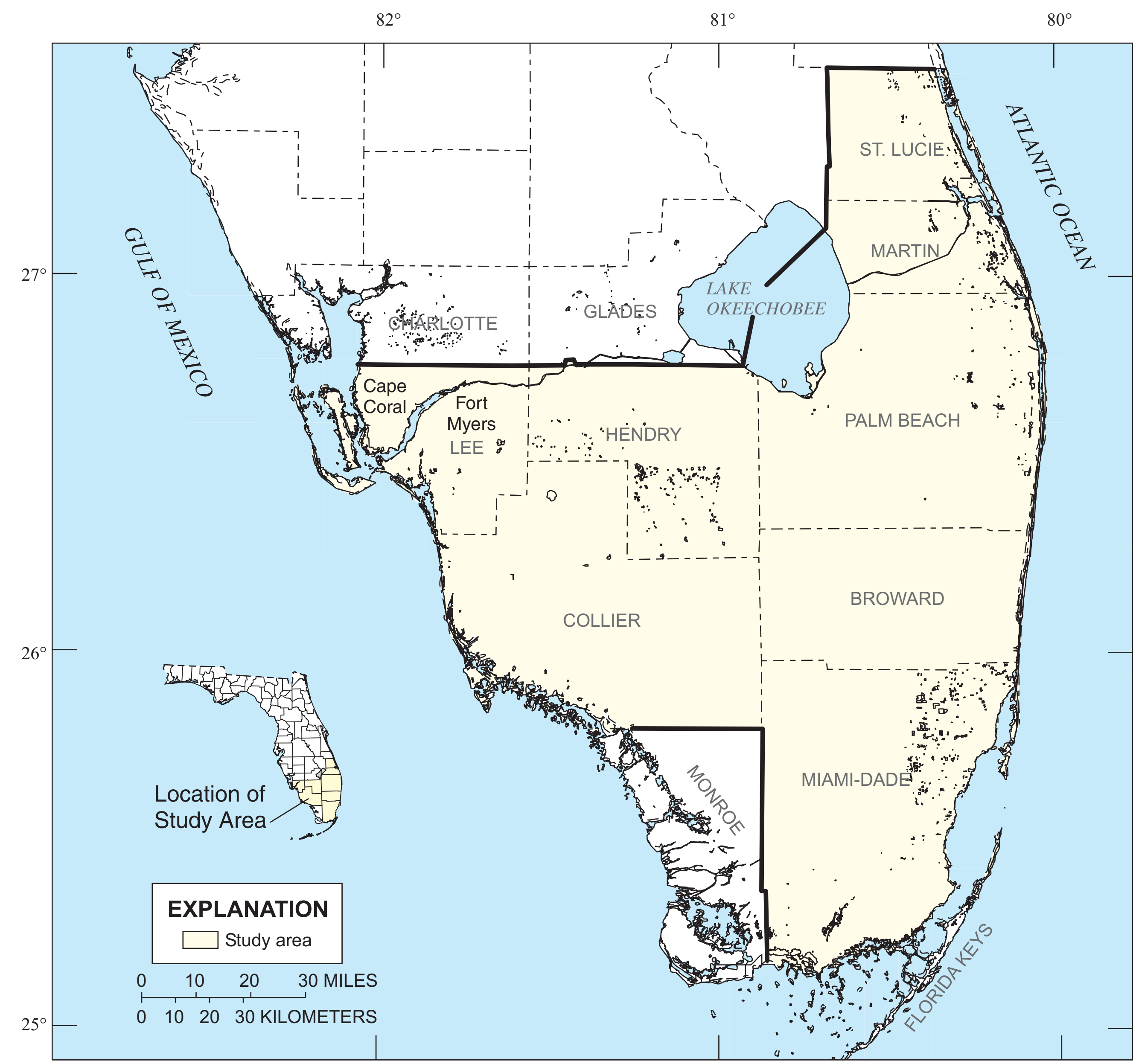

Figure 1. Location of study area.

network also includes one monitoring well in Glades County that was considered in the analysis. The principal hydrologic units used for municipal and private water supply in southern Florida are the surficial aquifer system, intermediate aquifer system, and the uppermost part of the Floridan aquifer system (fig. 2).

Hydrogeologic Setting

The three principal aquifer systems in southern Florida include locally named aquifers (fig. 2). In southwestern Florida, the surficial aquifer system includes the water-table and lower Tamiami aquifers; the intermediate aquifer system includes the sandstone and mid-Hawthorn aquifers; and the uppermost part of the Floridan aquifer system includes the lower Hawthorn producing zone. In southeastern Florida, the surficial aquifer system includes the Biscayne aquifer and gray limestone aquifer in Miami-Dade and Broward Counties. Of these two aquifers, the gray limestone aquifer is not used extensively for municipal water supply. In Martin, Palm Beach, and St. Lucie Counties, the three principal aquifers are not differentiated into locally named aquifers.

Because these aquifers are composed of different types of rocks and unconsolidated sediments, the rate that water can flow through them varies. The Biscayne aquifer is exceptionally permeable, a large part of the aquifer has transmissivities that are greater than 1,000,000 ft^2/d, and in some areas transmissivity can be as much as

<table>
<tr><th rowspan="2">Southeastern Geological Society in Florida Bureau of Geology Special Publication 28</th><th colspan="5">This report</th></tr>
<tr><th colspan="2">Southwestern Florida (Lee, Collier, and Hendry Counties)</th><th colspan="2">Southeastern Florida (Miami-Dade and Broward Counties)</th><th>Southeastern Florida (Martin, Palm Beach, and St. Lucie Counties)</th></tr>
<tr><td rowspan="4">Surficial aquifer system</td><td rowspan="4">Surficial aquifer system</td><td>Water-table aquifer</td><td rowspan="4">Surficial aquifer system</td><td>Biscayne aquifer</td><td rowspan="4">Surficial aquifer system</td></tr>
<tr><td rowspan="2">Confining beds</td><td>Semiconfining unit</td></tr>
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<tr><td>Lower Tamiami aquifer</td><td>Semiconfining unit</td></tr>
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<tr><td>Confining unit</td></tr>
<tr><td rowspan="2">Floridan aquifer system</td><td rowspan="2">Floridan aquifer system</td><td>Lower Hawthorn producing zone</td><td rowspan="2" colspan="2">Floridan aquifer system</td><td rowspan="2">Floridan aquifer system</td></tr>
<tr><td>Remaining portion of the Floridan aquifer system</td></tr>
</table>

Figure 2. Comparison of hydrogeologic nomenclature for southern Florida.

2,900,000 ft^2/d (Fish and Stewart, 1991). The other aquifers in southern Florida are not as permeable. Even the most permeable parts of the lower Tamiami, mid-Hawthorn and sandstone aquifers have transmissivities of only about 134,000, 9,000, and 5,000 ft^2/d respectively (Wedderburn and others, 1982; Knapp and others, 1986).

Transmissivities for the most permeable parts of the lower Hawthorn producing zone and gray limestone aquifer are about 47,000 and 300,000 ft^2/d, respectively (Knapp and others, 1984; Reese and Cunningham, 2000). There are no wells in the gray limestone aquifer and only two wells in the lower Hawthorn producing zone that had data of the type required for the analyses described in the subsequent sections of this report. As a result, these two aquifers were not considered for this study.

Previous Studies

Several studies have been undertaken to examine the spatial coverage of parts of the USGS ground-water monitoring network in southern Florida. Burns and Shih (1984) used semiannual water-level data collected over a 5-year period to define optimal coverage for the water-table and lower Tamiami aquifers in Collier County, southwestern Florida. Time-series analyses were also used to predict optimal sampling frequency for several monitoring wells using daily maximums recorded every 5 days. Burns and Shih (1984) also performed a qualitative assessment by mapping the effects of well-field withdrawals on monitoring wells to define areas of uncertainty. The ground-water monitoring network in Collier, Hendry, and Lee Counties, southwestern Florida, was examined by Hosung Ahn (South Florida Water Management District, written commun., 1996) using monthly water-level data from 342 wells collected over a 3-year period. Ahn used the Auto Regressive Integrated Moving Average (ARIMA) model and kriging to determine the optimal well network and sampling frequency. Swain and Sonenshein (1994) documented statistical techniques developed for analysis of the spatial coverage of a well network, redundancy of a well network, and optimal water-level measurement intervals for numerous wells completed in the Biscayne aquifer in Broward County, southeastern Florida.

Acknowledgments

The authors would like to acknowledge the considerable contribution made by Curtis Lamar Sanders of the USGS in Columbia, S.C. Mr. Sanders graciously provided many ideas regarding the types of statistical analyses and procedures that could be performed for this study. His suggestions and contributions proved to be invaluable. Michael Deacon and Richard Verdi of the USGS in Miami, Fla., contributed to the quality of the report by helping in the verification process.

WATER USE AND PRECIPITATION

Although southern Florida generally receives abundant annual rainfall, retention of this resource is low and a large percentage is discharged to the ocean through natural and anthropogenic surface-water drainage systems. This is particularly true when extreme rainfall events occur. Much of this water is discharged to the ocean and does not provide recharge to aquifers. Additionally, some of the water that recharges the aquifers is lost to evapotranspiration. Water that is retained in the aquifers becomes a source of water supply for municipal, domestic, and agricultural purposes.

Population and Water Use

In Broward, Miami-Dade, Hendry, Martin, and St. Lucie Counties, ground water is the sole source of municipal water supply. Ground water provides 83 to 93 percent of the municipal water supply for the remaining counties in the study area (Marella, 1999). In 1998, about 68 percent of the municipal water extracted in the study area was withdrawn from the Biscayne aquifer in Miami-Dade and Broward Counties (R.L. Marella, U.S. Geological Survey, written commun., 1998). These withdrawals supported a population of 3,551,204 in Miami-Dade and Broward Counties as well as 85,646 people in Monroe County (Bureau of Economic and Business Research, 1998). This population represents about 65 percent of the population in southern Florida at that time.

Water usage is directly related to population (Toomey and Woehlcke, 1979). Between 1980 and 1998, the population in the United States increased by about 19 percent (U.S. Bureau of the Census, 1996; U.S. Census Bureau, 1999), whereas the population in the study area increased by more than 30 percent. A comparison of

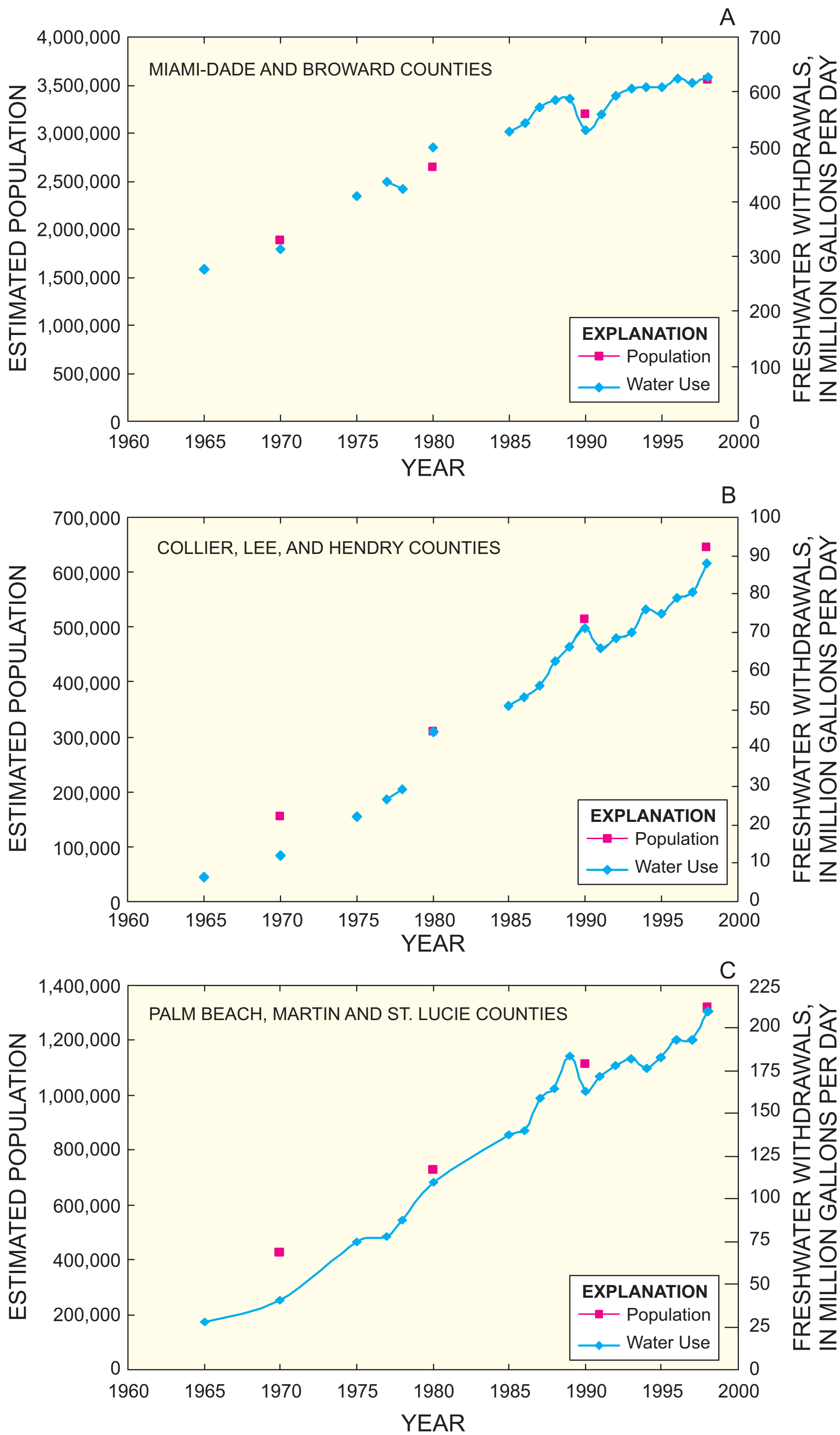

Figure 3. Population and ground-water use in the southeastern (Miami-Dade and Broward Counties), southwestern (Collier, Lee, and Hendry Counties), and northeastern (Palm Beach, Martin, and St. Lucie Counties) parts of the study area.

water-use data compiled by R.L. Marella (U.S. Geological Survey, written commun., 1998) and population estimates (Bureau of Economic and Business Research, 1998) illustrates this relation in figure 3. Between 1980 and 1998, the population in Miami-Dade and Broward Counties increased by 34 percent, which corresponds to an increase in ground-water withdrawals of 26 percent (fig. 3A). Relative increases in population and water use are even greater in the southwestern and northeastern parts of the study area (fig. 3B-C). Between 1980 and 1998, the population increased in these areas by 109 and 82 percent, respectively. This growth corresponded to increases in ground-water withdrawals of 99 and 91 percent, respectively. Population in the study area is increasing at a rate that is well above the national growth rate.

Precipitation

Florida typically receives about 54 in. of rainfall annually (Southeast Regional Climate Center, 2001). In southern Florida, eastern Miami-Dade and Broward Counties generally receive about 60 to 64 in. of rain annually, whereas southwestern Florida receives about 52 to 56 in. of rain annually (Winsberg, 1996). The wet season generally lasts from June to October, and the dry season lasts from November to May. About 70 percent of the annual rainfall occurs during the wet season. Florida is susceptible to large differences in annual precipitation caused by the effects of El Niño and La Niña. November to March precipitation in El Niño years can be about 30 percent higher than normal. In years affected by La Niña, precipitation can be 10 to 30 percent lower than normal from autumn to spring (The Florida Consortium, 2001). Tropical storms and hurricanes that produce tremendous amounts of rainfall over very short periods can also contribute to large differences in annual precipitation.

Waller (1985) cites four types of droughts:

- Meteorologic Drought -- Defined only in terms of precipitation deficiencies in absolute amounts for specific durations.
- Climatologic Drought -- Defined in terms of precipitation deficiencies as a ratio to mean or normal values not in specific quantities.
- Hydrologic Drought -- Defined in terms of reduction of streamflows, reduction in lake reservoir storage, and lowering of ground-water levels.
- Water-Management Drought -- This classification is included to characterize water deficiencies caused by the difficulty of water-management practices or facilities (such as integrated water-supply system, surface, and subsurface storage) to provide adequate water supplies during periods of reduced rainfall.

The first three definitions can be described in readily quantifiable terms. The fourth, however, is more difficult to quantify, but most closely describes the concerns of water managers in southern Florida. Water managers commonly refer to this fourth type of drought as a "water shortage." The primary concern of water managers is to provide sufficient water supply to the public, while at the same time minimizing any detrimental effects to the water supply or the environment. It is difficult to quantify a water shortage because the long-term effects to the water-supply system, or the potential for such effects, may not be precisely known. In the case of ground water, the potential for adverse effects to the aquifer depends largely on the characteristics of the aquifer. These characteristics commonly vary throughout the aquifer, and are generally known from aquifer tests conducted at a limited number of locations.

Sustained droughts occurred: during various time periods. These periods include: 1943-46 (Parker and others, 1955); 1949-57 (Waller, 1985; Bridges and others, 1991, p. 231-238); 1960-63 (Waller, 1985; Bridges and others, 1991, p. 231-238); 1970-77 (Benson and Gardner 1974; Waller, 1985; Bridges and others, 1991, p. 231-238); 1980-82 (Waller, 1985; Bridges and others, 1991, p. 231-238); 1985 (South Florida Water Management District, 1985); and 1989-90 (Trimble and others, 1990).

Influxes of water to, and withdrawals from, the aquifers also tend to vary from location to location. Complex mathematical models are used to approximate the potential effects of water shortages on aquifers. Quantifying the severity of a drought is a combination of evaluating model results with all available data and using considerable professional judgment.

Effects of Water Use

The rates of ground-water withdrawal from southern Florida aquifers required to support increasing population demands have often exceeded rates of aquifer recharge. As a result, cones of depression have developed in the potentiometric surface of most aquifers near many of the public-supply well fields. During droughts, the growth potential of these cones of depression increases because recharge is reduced and withdrawals often increase. It is during droughts that the balance between withdrawal rates and recharge rates is most critical.

Because the Biscayne aquifer is highly transmissive, the water-management system in southeastern Florida can be, and has been, operated in a manner to mitigate the detrimental effects of increased ground-water usage in this aquifer. Cones of depression have formed around the major well fields in the Biscayne aquifer, but these cones of depression are of limited spatial extent and depth (Sonenshein and Koszalka, 1996; A.C. Lietz, U.S. Geological Survey, written commun., 2001), when compared to those that have formed in the mid-Hawthorn and sandstone aquifers.

Even though population and ground-water usage in southwestern Florida are substantially less than in Broward and Miami-Dade Counties, the effects of ground-water withdrawals are much more evident. The confined and semiconfined aquifers in southwestern Florida are substantially less transmissive than the unconfined Biscayne aquifer. As a result, these aquifers in southwestern Florida, which have shown the largest declines in water levels, respond differently to stress than the Biscayne aquifer. Large cones of depression have formed in many of the aquifers in southwestern Florida. During 1974-98, water levels in parts of the mid-Hawthorn and sandstone aquifers, as well as the lower Hawthorn producing zone declined by about 1 ft/yr on average (Prinos and Overton, 2000).

Loss of Pumpage

As cones of depression from major municipal well fields increase in size, they may intersect with areas of influence of neighboring water-supply wells, thus causing the water levels in these wells to fall below the pump intakes. This problem has been reported in southwestern Florida a number of times during recent dry periods. Once the dry period ends, however, water levels in the aquifer can recover sufficiently to allow the affected wells to resume operation. If the cones of depression continue to grow, however, these periods of lost pumpage in neighboring wells may become prolonged.

Aquifer Compaction

If water levels are lowered sufficiently, aquifer compaction and land subsidence could occur. Water in the pore spaces of rocks and sediments helps to support the weight of the overlying materials. If this support is lost because of decreased water levels, it is possible for the materials comprising the aquifer to permanently compact or collapse. In this case, even if water levels recovered to higher levels, the loss of pore space in the compacted materials would prevent the aquifer from holding as much water as in previous instances.

In some cases, sinkholes may form as water levels are lowered. Several large and deep sinkholes are present in southern Florida (Parker and Cooke, 1944); however, catastrophic sinkhole formation in southern Florida is not generally considered to be a significant factor (Sinclair and Stewart, 1985; Spencer and Lane, 1995). The potential for sinkhole formation, land subsidence, and aquifer compaction is related to properties of the materials forming the aquifer and the diagenetic and geologic history of these materials.

Saltwater Contamination

Saltwater contamination has been observed in all of the principal water-supply aquifers of southern Florida. In many cases, this contamination has been caused by lowered freshwater head in aquifers near the coast, which in turn, has resulted in lateral intrusion of seawater (Merritt, 1996; Sonenshein and Koszalka, 1996; Schmerge, 2001). Another major source of saltwater contamination is cross-aquifer contamination (Fitzpatrick, 1986; Schmerge, 2001). Cross-aquifer contamination has been caused by wells that are open to multiple aquifers or have casings that have been corroded or broken. In some cases, poor natural confinement may have allowed cross-aquifer contamination. In some areas, contamination has been attributed to upconing of saltwater from the lower parts of the aquifers (McCoy, 1962).

In many cases, lateral saltwater intrusion was caused by the lowering of the water table in a large area through the use of drainage canals or other features, such as boat basins (Klein, 1954; Schroeder and others, 1958; Klein and Waller, 1985). Initially many canals did not have salinity control structures. As a result, saline-water intruded directly into the canals or intruded where the freshwater head around the canals decreased. After salinity control structures were added, the rates of landward intrusion of saltwater were reduced; however, this issue remains a concern because rates of ground-water withdrawal from coastal aquifers in southern Florida are increasing.

Examples of each source of contamination have been documented in southwestern Florida. The water-table aquifer (west coast) was contaminated by the lateral intrusion of saltwater from the Gordon River, which killed several rows of litchi trees in the Caribbean Botanical Gardens near Naples (McCoy, 1962). Wedderburn and others (1982) documented an area of contamination in the water-table aquifer (west coast) of Lehigh Acres that may have been caused by either upconing of saltwater from lower parts of the aquifer, or by contamination from leaking wells drilled into deeper aquifers. In the lower Tamiami aquifer, both lateral saltwater contamination from the Gulf of Mexico and cross-aquifer contamination through leaking wells have occurred (Schmerge, 2001). Declines in water levels in the mid-Hawthorn aquifer allowed downward movement of saltwater from the surficial aquifer system and upward movement of saltwater from the Floridan aquifer system to contaminate parts of the mid-Hawthorn aquifer (Fitzpatrick, 1986).

In the Biscayne aquifer, lateral intrusion of saltwater occurred in both Miami-Dade and Broward Counties. In southeastern Broward County, the saltwater front moved inland as much as 0.5 mi between

1945 and 1993 (Merritt, 1996). Koszalka (1995), in his examination of saltwater encroachment in eastern Broward County, showed that chloride concentration increased in monitoring wells east of the major well fields between 1980 and 1990.

In Miami-Dade County, the use of poorly regulated drainage canals caused 1 to 3 mi of saltwater encroachment along the coast, and also caused saltwater contamination 6 mi inland along the Miami Canal from 1904 to 1953 (Parker and others, 1955; Schroeder and others, 1958). Parker and others (1955) indicated that much saltwater encroachment occurred during a major drought between 1943 and 1946. This drought caused record low water levels in 1945. During a 27-month period that overlapped 1943-44, the interface moved inland by about 2,000 ft.

Improved control of the water-management system in Miami-Dade County has helped to mitigate saltwater encroachment. Between 1953 and 1995, the saltwater front in much of Miami-Dade County remained in about the same location. Some additional encroachment occurred between 1970 and 1971 (Klein and Waller, 1985) and between 1984 and 1990 in south-central and southeastern Miami-Dade County (Sonenshein, 1997). However, the amount of landward movement of the interface during these periods was minor relative to that which occurred prior to 1953.

In the surficial aquifer system in southern Martin and Palm Beach Counties, saltwater underlies several of the major well fields (Hittle, 1999). This creates a situation where upconing of the saltwater interface could occur under certain circumstances. Near the Hobe Sound Well Field, lateral movement of the saltwater interface is occurring in a sandy limestone production zone. Saltwater has intruded to within about 500 ft of a production well in that area (Hittle, 1999).

REAL-TIME GROUND-WATER LEVEL MONITORING NETWORK DESIGN

A real-time ground-water level monitoring network that contains only a fraction of wells in the existing ground-water monitoring network cannot provide the spatial coverage of the full network, but can still provide considerable insight into changes that occur during those intervals when data from the larger network are unavailable. Considerable care must be taken to ensure that this subset provides data that are as representative of changing aquifer conditions as possible. The subset of wells selected need to: (1) provide unambiguous and quantitative real-time information on unique and potentially damaging ground-water level events that are occurring and signal these events as early as possible; (2) represent ground-water conditions over a substantial area of the aquifer; (3) monitor specific areas where the aquifer may be more susceptible to water-level related problems; and (4) provide information that aids in the assessment of salt-water intrusion in those areas of the aquifer where such considerations are relevant.

Criteria for Selecting Network Wells

Several quantitative and qualitative assessments need to be made when evaluating candidate wells for the real-time ground-water level monitoring network. The evaluation of well construction and period of record and the statistical approaches used to select real-time network wells are addressed in the subsequent sections of this report. Maps showing continuous ground-water monitoring wells used for this study are presented in figures 4 to 6. Figure 4 shows the location of wells in southwestern Florida; figure 5 shows the location of wells along the upper east coast of Florida in Palm Beach, Martin, and St. Lucie Counties; and figure 6 shows the location of ground-water monitoring wells along the lower east coast of Florida in Miami-Dade and Broward Counties.

Well Construction and Period of Record

Well construction is an important consideration in the design of any ground-water monitoring network. It is the construction of the well that determines whether or not water levels from that well will be truly representative of the aquifer. Factors such as an indeterminate open interval, an insufficient annular seal, or an improper emplacement technique may adversely affect analysis of the water-level and water-quality data from the well. Although many characteristics of monitoring wells are set at the time of construction, others may change over time. For example, the part of a monitoring well left open to the aquifer may collapse over time, or sand may be forced up into the casing of a well by hydrostatic pressure in the aquifer. Well casings also can corrode, which in turn, may result in leakage from other parts of the same aquifer or other aquifers.

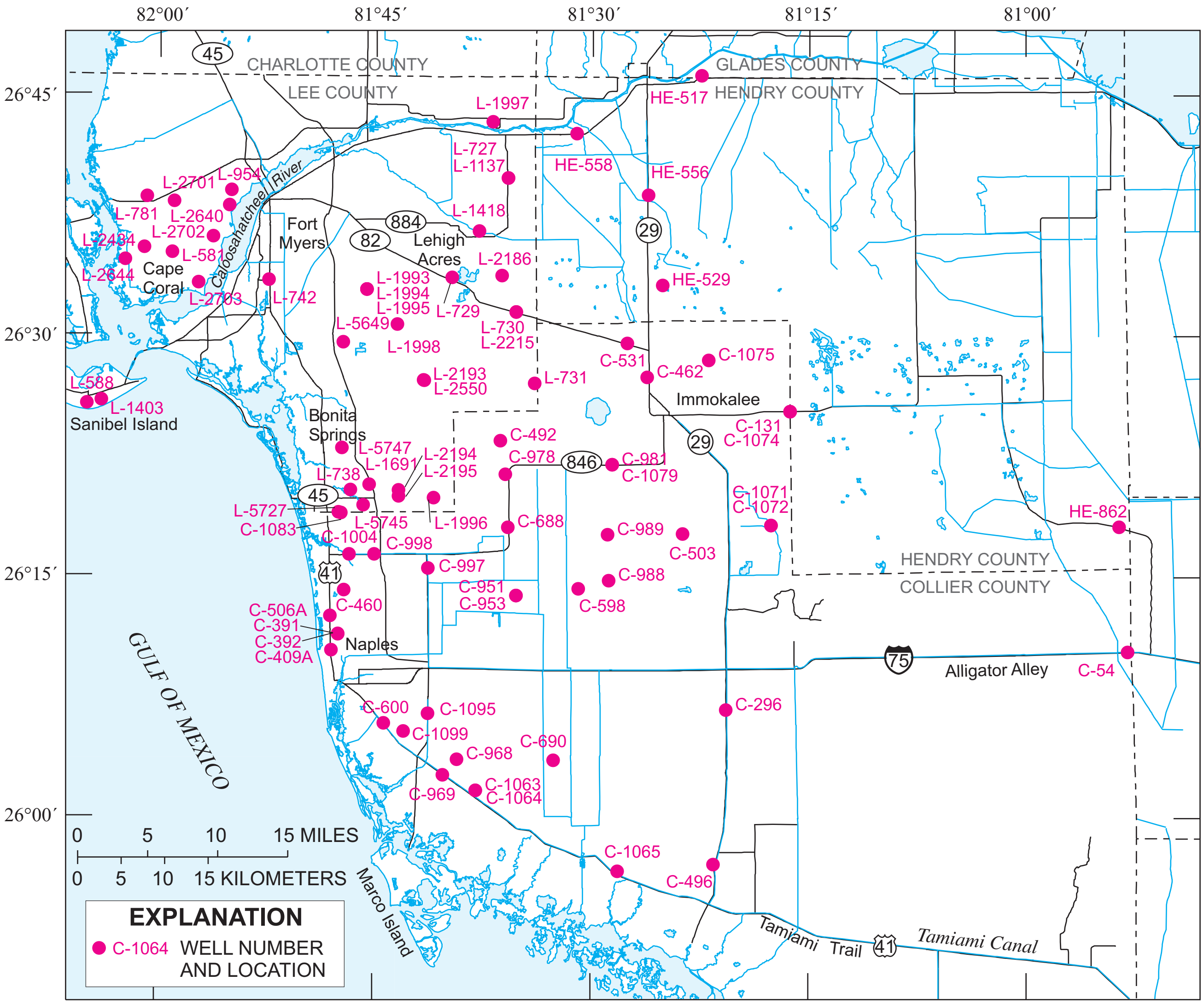

Figure 4. Locations of continuous ground-water level monitoring wells that were considered for the real-time ground-water level monitoring network in Collier, Lee, and Hendry Counties.

Network monitoring wells have been installed using a variety of methods. These methods vary because of differences in cost, aquifer lithology, types of drilling equipment, changes in available technology, or evolution of monitoring techniques. Some network wells were originally installed as water-supply wells and were designed to provide maximum water yield rather than to monitor the aquifer at discrete depths. The network also includes wells that have relatively long open intervals, short open intervals, and short screened intervals. For each candidate network well, well construction has been considered to determine if the data obtained from that well will yield unambiguous results (app. I).

Although well construction is important, period of record is one of the most important considerations in selecting representative wells and determining reasonable statistical results. The period of daily water-level record available for analysis differs from well to well. Several monitoring wells have less than 2 years of daily maximum water-level data, whereas others have greater than 60 years of daily value data. One area where data from many of the recorders do not span the full period of evaluation is southwestern Florida; continuous water-level monitoring of many of these wells did not start until the mid-1980’s. Many of these water-level recorders were either removed

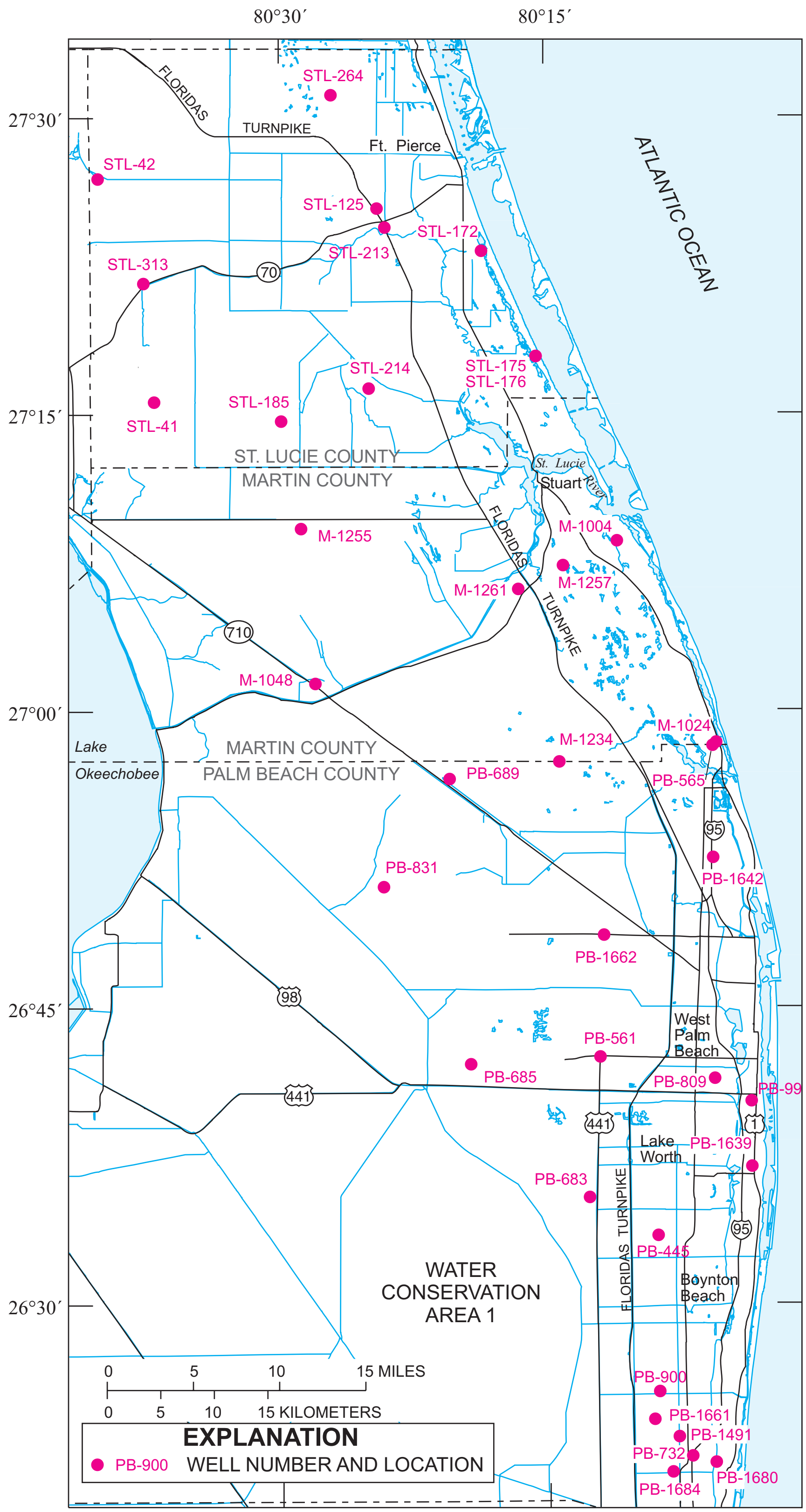

Figure 5. Locations of continuous ground-water level monitoring wells that were considered for the real-time ground-water level monitoring network in Palm Beach, Martin, and St. Lucie Counties.

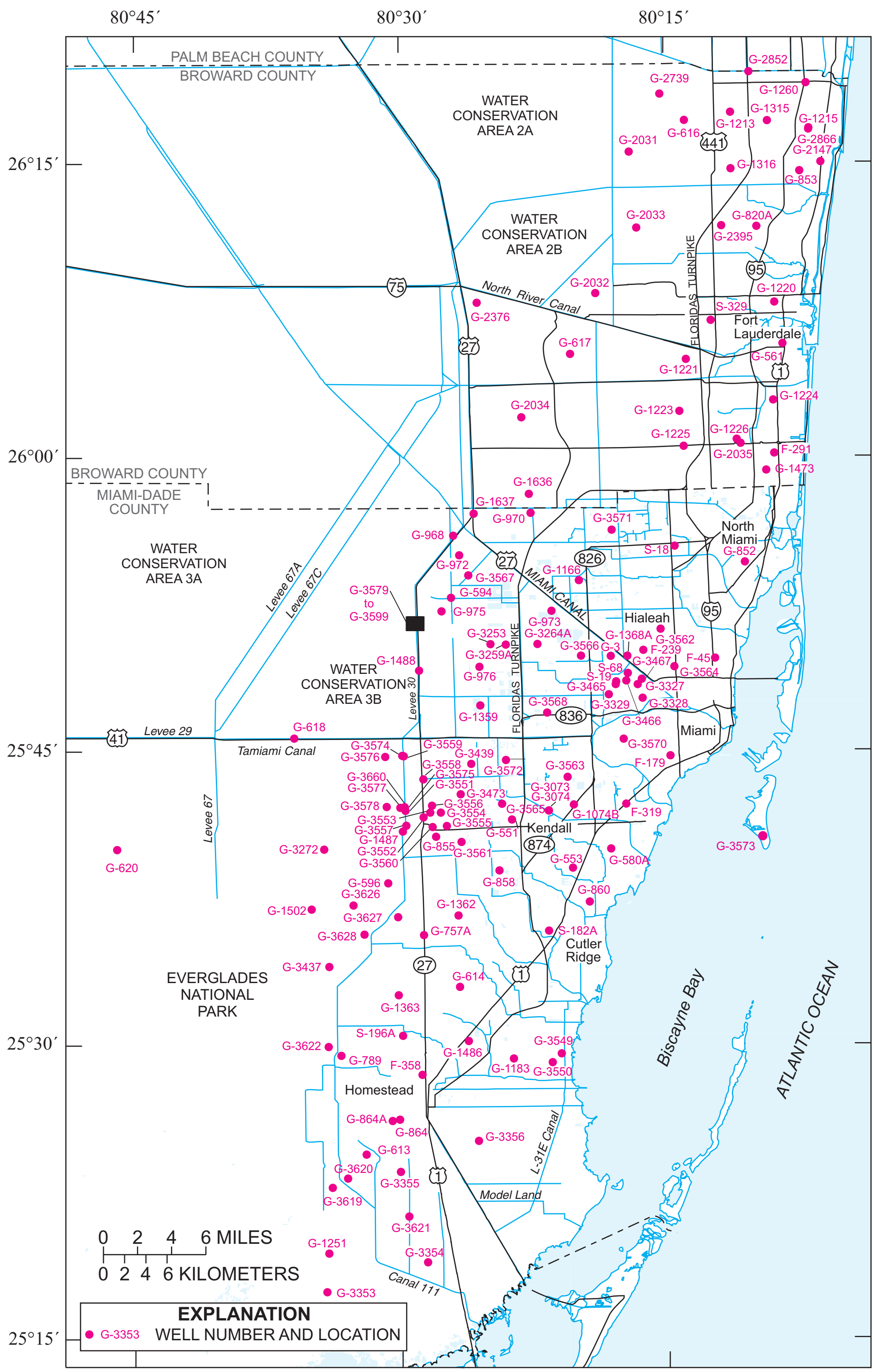

Figure 6. Locations of continuous ground-water level monitoring wells that were considered for the real-time ground-water level monitoring network in Miami-Dade and Broward Counties.

or relocated to other wells in 1996, based in part on a statistical evaluation of well coverage (Hosung Ahn, South Florida Water Management District, written commun., 1996). Water-level recorders have been periodically removed and replaced in many aquifers throughout the network. In some cases, continuous recorders were replaced by periodic instantaneous manual measurements made by using a steel tape and chalk on a quarterly or monthly basis; in others, no data were collected during the intervening years.

There are several problems with using ground-water level data prior to 1974 for this analysis:

- When the computer systems became available to store large amounts of data, much of the data that had been published was entered into the USGS National Water Information System (NWIS) database. However, much of these data had been published as 5-day tables rather than listing a value for each day. Therefore, much of the daily-value data prior to 1974 is only available for every 5th day and for the end of each month.
- Although most of the published data have been stored in the NWIS database, some may still not be available.
- There are differences in the type of data stored prior to and after 1974.

From 1974 to present, the data from almost all continuous ground-water level monitoring wells consist of daily maximum water-level elevation referenced to sea level.

For a long-term period of analysis, it is infeasible to accurately compare periodic instantaneous manual water-level measurements (collected monthly) to those obtained by a continuous water-level recorder (recording hourly) because of the large daily water-level cycles in many southern Florida ground-water wells. Computation of daily maximum water levels using hourly data essentially smooths these data by sampling the peak of each cycle. Conversely periodic, instantaneous manual measurements taken at different times of the day sample the water levels at different points in the daily cycle. These daily cycles are most pronounced in southwestern Florida.

Thus, daily maximum water levels provided by continuous hourly recorders or monthly means of these daily values have been used for all analyses, and period of record remains a critical component for interpreting the results from these analyses. Well construction and period of record information for each candidate well is presented in appendix I. The period of record information pertains only to the maximum daily value data entered in the NWIS database.

Analysis of Long-Term Water-Level Trends in Network Wells

The distribution-free, nonparametric Seasonal Kendall trend test was used to test for the existence of trends in water-level data in candidate wells. This test, modified from the Mann-Kendall test (Helsel and Hirsch, 1992, p. 338), measures the monotonic association between two variables, determines whether these variables increase or decrease with time, and compares relative ranks of data values from the same season.

Monthly means of daily maximum water levels were used for the Seasonal Kendall trend tests. Because the period of record for each well was different, Locally Weighted Scatterplot Smoothing (LOWESS) of hydrographs from wells in each aquifer was used to help determine break points for the trend analysis for each aquifer, and trends were then analyzed for these shorter periods. For those wells where sufficient data exist, trends have been analyzed for the full period (1974-99) in addition to the shorter periods for each aquifer. The period of record available for each well was weighed against the number of wells that could be evaluated for that period. Trend tests were then run separately for each of these periods so that results could be compared. For example, if the period 1974-99 were selected, then only the wells that had record for all 26 years (83 wells) were analyzed for trends during this period. In this way, the trend results would be comparable between these 83 wells. Results of the trend analysis are presented in appendix II.

Summary Statistics of Water-Level Data from Candidate Monitoring Wells

The monthly means of daily maximum water levels were compiled for each candidate well in the ground-water level monitoring network for the 1974-99 period. Summary statistics (mean, standard deviation, minimum, maximum, median, first quartile, third quartile, and interquartile range) were derived from these values for each well and are presented in appendix III. The summary statistics can be used to show those areas of each aquifer that have the greatest variation or lowest minimum values. These are the areas most susceptible to drought-related problems, depending on the physical characteristics of the aquifer and the effect of long term trends in water levels.

Determining Water-Level and Rainfall Correlation

Water levels in some monitoring wells may not closely correspond to changes in rainfall. This is because monitoring wells are commonly located near areas where withdrawals of water from the aquifer are extensive. In some cases, water levels in a monitoring well may reflect local changes in withdrawal rates, rather than changes that affect large parts of the aquifer such as sustained reduction of recharge to the aquifer during a meteorologic drought. Changes in withdrawal rates may in turn be caused by crop cycles, population cycles related to tourism, and/or mandated decreases in pumpage as water restrictions are implemented. As previously discussed, however, the balance between recharge and withdrawals is most tenuous during droughts. Thus, it is important to identify monitoring wells where the relation between meteorologic droughts and water levels is clear.

A frequency analysis is commonly used to quantify variation in environmental data. For example, severe hydrologic events, such as floods, are said to have a 100-year recurrence interval. That is, historical water-level data from a stream are used in conjunction with a frequency analysis to determine which water level has a 1-percent chance of occurring each year. When water levels in the stream rise above that water level, a "100-year flood" has occurred.

A similar frequency analysis can be used to examine the relation between rainfall and water-level minimums. Theoretically, if extreme lows in water levels for a given monitoring well directly correspond to extreme lows in precipitation (meteorologic droughts), the well then could be used to assess the effect of meteorologic droughts on the aquifer. Conversely, if these extreme values do not correspond, the monitoring well may only provide useful information concerning a small area within the aquifer. One possible analysis is to compare the lowest 5 percent of monthly rainfall and water-level values for the same period to determine if they occur for the same periods. This concept was used herein to compare rainfall deficiencies and water levels in monitoring wells.

Preprocessing of Data

Monthly rainfall and water-level data usually are not comparable using frequency analysis without first performing some mathematical preprocessing of the data. The factors that were assessed before a correlation analysis was made between water level and rainfall from network wells, included: (1) long-term trends in data, (2) cumulative effects and lags, (3) recharge area uncertainty, and (4) seasonal cycles in data.

Rainfall was examined for long-term trends (1974-97) using the Seasonal Kendall trend test, but in almost every case, the trend determined was not statistically significant (p-value greater than 0.05). Rainfall data consisted of monthly rainfall totals from all cooperatively supported National Climatic Data Center stations that had data for the 1974-97 period. Nineteen stations were available for analysis of rainfall in southeastern Florida, and nine stations were available in southwestern Florida (table 1). Because data from the National Climatic Data Center were unavailable for the 1998-99 period, monthly rainfall totals from SFWMD rainfall stations were used to estimate rainfall for these years. One set of rainfall stations showed a statistically significant trend, but the trend indicated was very small. As a result, rainfall data were not trend adjusted prior to use.

Water-level data may have significant long-term trends that can be upward or downward, and either monotonic or not. If these trends were not removed before performing the frequency analysis, then the results would be seriously skewed. For example, a severe drought may cause a 5-ft decline in water levels at a well, but this same amount of decline could be caused by a long-term (1 ft/yr) decline in the water levels within 5 years. Therefore, water-level data collected 5 years after the drought could be at the same elevation or lower on average as that collected during the drought (fig. 7). If the water-level data from wells affected in this way were directly compared to rainfall, the correlations between rainfall and water-level minimums would then be poor.

To compensate for the effect of linear or nonlinear long-term trends in water-level data, three mechanisms were used to trend adjust the data from each monitoring well examined: (1) linear regression, (2) second degree polynomial regression, and (3) LOWESS smoothing with an f-value of 1/5. (The f-value indicates the fraction of the data used to compute each point.) The residuals from these approximations were used for the subsequent analysis, rather than the raw data. Data that had less than 6 years of record were not trend adjusted.

Table 1. Rainfall stations used for the southeastern and southwestern rainfall models

Station identification number[1]	Station name	Latitude	Longitude	County
Southeastern Florida Model				
080611	Belle Glade Exp Stn	264000	803800	Palm Beach
081276	Canal Point USDA	265200	803800	Palm Beach
081654	Clewiston U.S. Engineers	264500	805500	Hendry
083020	Flamingo Ranger Stn	250900	805600	Monroe
083163	Fort Lauderdale	260600	800900	Broward
083207	Fort Pierce	272600	802000	St. Lucie
083909	Hialeah	255000	801700	Miami-Dade
084091	Homestead Exp Stn	253000	803000	Miami-Dade
084095	Homestead Gen Aviation	253000	803300	Miami-Dade
085182	Loxahatchee	264100	801600	Palm Beach
085184	Loxahatchee NWR	263000	801300	Palm Beach
085658	Miami Beach	254700	800800	Miami-Dade
085663	Miami Intl Arpt	254900	801700	Miami-Dade
087254	Pompano Beach	261400	800900	Broward
087760	Royal Palm Ranger Stn	252300	803600	Miami-Dade
088620	Stuart 1 N	271200	801500	Martin
088780	Tamiami Trail 40 mi Bend	254500	805000	Miami-Dade
088841	Tavernier	250100	803100	Monroe
089525	West Palm Beach WSO AP	264100	800600	Palm Beach
Southwestern Florida Model				
082298	Devils Garden	263600	810800	Hendry
082850	Everglades	255100	812300	Collier
083186	Fort Myers FAA Airport	263500	815200	Lee
084210	Immokalee 3 NNW	262800	812600	Collier
084662	La Belle	264600	812600	Hendry
084667	La Belle	264600	812700	Hendry
086078	Naples	260900	814900	Collier
086406	Oasis Ranger Stn	255100	810200	Collier
087397	Punta Gorda 4 ESE	265800	815800	Charlotte

[1]National Climatic Data Center stations.

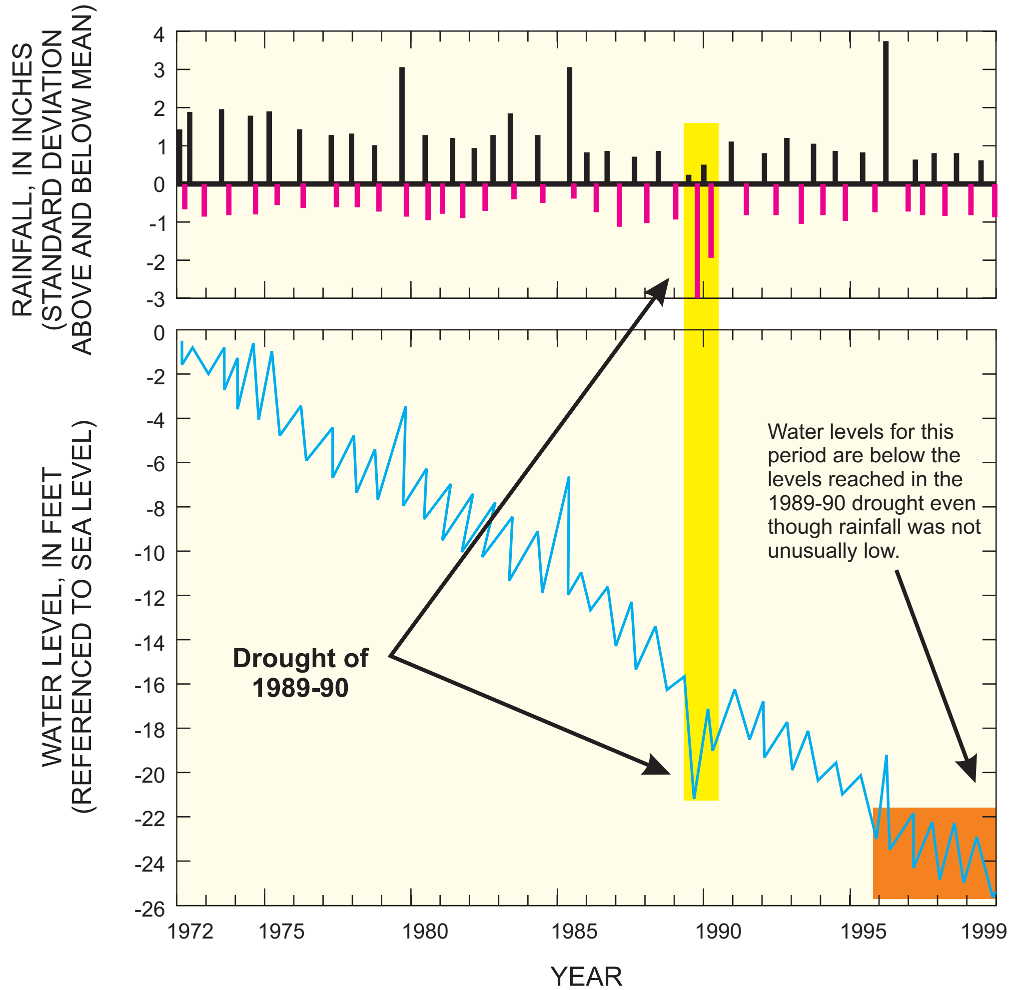

Figure 7. Effect of long-term trends on correlation analyses of water level in well and rainfall at well. Unique events in rainfall and water levels, such as droughts, cannot be directly correlated without considering the possible effect of trends.

Declines in water levels of aquifers tend to show the net or cumulative effect of decreases in rainfall over time and tend to lag behind these decreases (fig. 8). The amount of lag differs from aquifer to aquifer and also from well to well. To estimate the cumulative effects of rainfall deficiencies in ground-water levels, four different f-values were used for the LOWESS smoothing of rainfall data. The f-values used were 1/26, 1/52, 1/78, and 1/104. For 26 years of monthly rainfall data, these values correspond to using 1 year, 6 months, 4 months, and 3 months of data, respectively, to compute each point in the LOWESS smooth. The preprocessing of rainfall data using an f-value of 1/26 is shown in figure 9. Smaller f-values result in less smoothing of the rainfall data. Lag was addressed by mathematically lagging the water-level data by 0, 1, 2, 3 and 4 months relative to the rainfall data.

Recharge areas are poorly defined in the confined aquifers in southern Florida because of karstification and confining units of highly variable thickness and composition. Therefore data from one rainfall station may not necessarily correspond with changes in water levels at a water-level monitoring well, even if that well is near a rainfall station. An initial attempt was made to compare water levels in an aquifer with only those rainfall stations that were in each aquifer’s recharge area, but there were too many uncertainties regarding confinement of the aquifers in southern Florida. Even the surficial aquifer system in Martin, Palm Beach, and St. Lucie Counties, though not differentiated into separate aquifers based on confinement, includes semipermeable units that slow

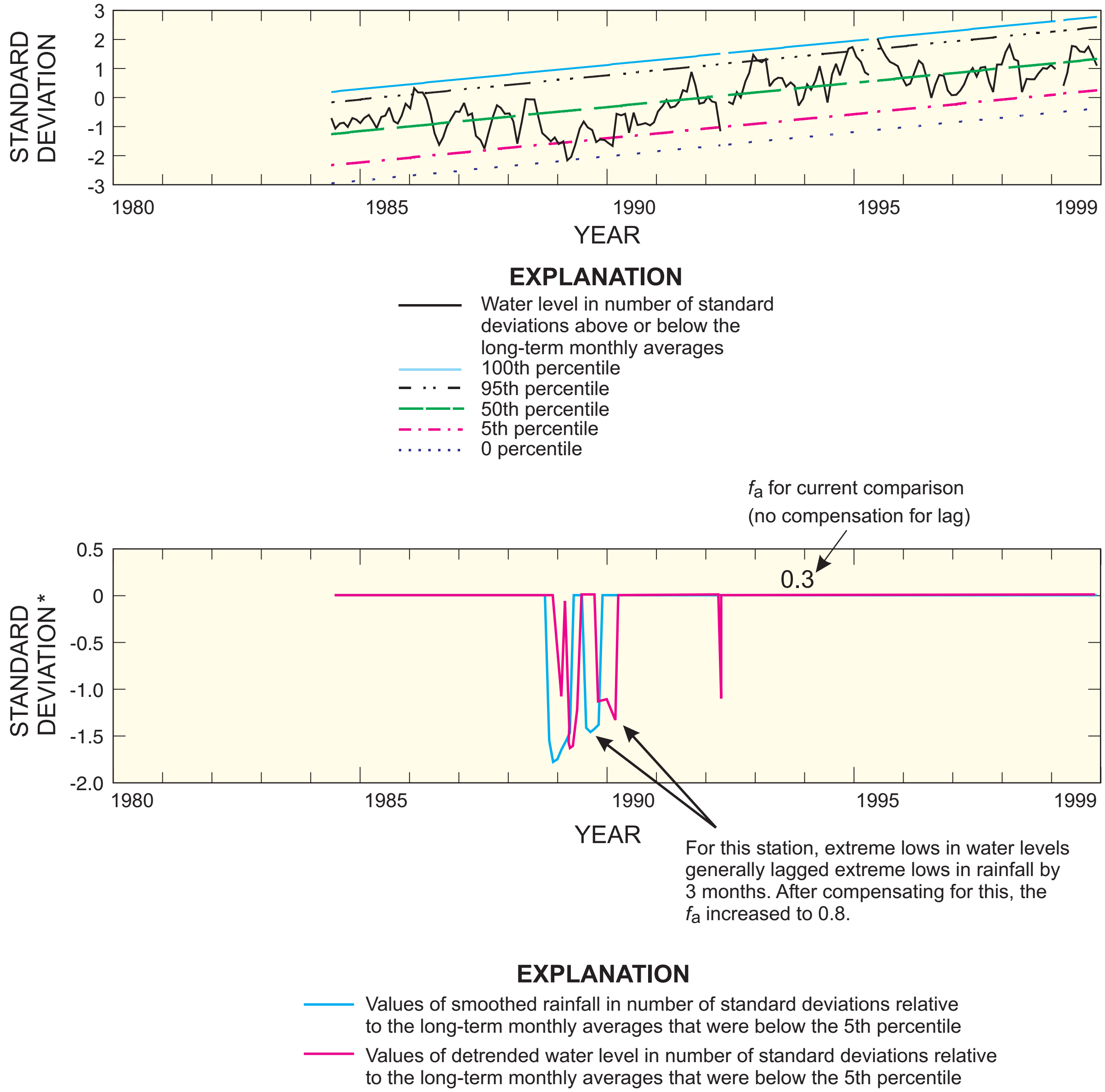

Figure 8. Comparison of smoothed average rainfall deviations and trend adjusted water-level deviations in well G-3264A. Fraction of agreement is represented by f_a. Asterisk represents standard deviation below the long-term monthly averages of water level and rainfall. These values for rainfall have been multiplied by 3 so that the resulting rainfall values can be readily compared to the water-level results. This multiplication does not affect the f_a.

direct recharge. Thus, two different rainfall models; one for southeastern Florida and one for southwestern Florida were used in this assessment (table 1). These models consisted of the average of rainfall data from all monitoring stations in each area.

A simple frequency analysis of rainfall and water level fails to account for normal seasonal fluctuation. Decreased water levels in monitoring wells can be produced by either reduced precipitation in the dry season or by lower than normal precipitation during the wet season as well as by increased municipal pumpage or increased drainage. To address the issue of seasonal cyclicity in rainfall and water-level data, monthly values were compared to the normal monthly mean values and monthly standard deviations for the period of record. The long-term monthly mean was subtracted from the value for that month, and the difference was expressed in number of standard deviations above or below the mean.

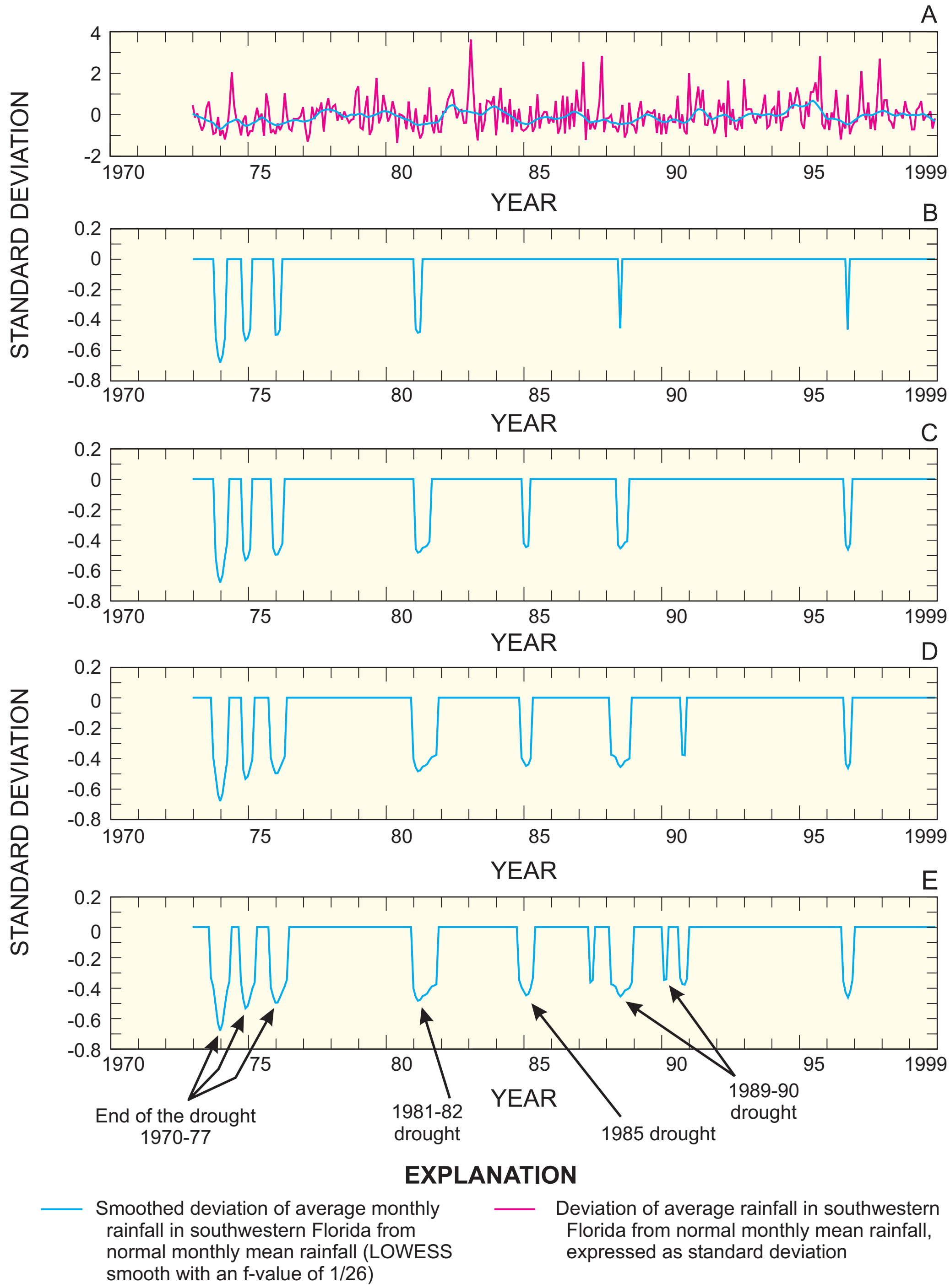

Figure 9. Steps used in computation of rainfall model. (A) Rainfall from recording stations in southwestern Florida was averaged and period of record monthly mean values were computed. The monthly deviation of rainfall from these mean values was computed (expressed as standard deviation above or below the normal monthly mean). A LOWESS smooth of these data was computed. A frequency analysis was performed on the resulting smoothed rainfall values, and the values below the (B) 5th percentile, (C) 10th percentile, (D) 15th percentile, and (E) 20th percentile were computed. The model of rainfall constructed in this way is in good agreement with the timing of droughts in the area.

Application of Analytical Technique

Water-level data consisted of monthly means of daily maximum ground-water levels from candidate monitoring wells, and rainfall data consisted of monthly rainfall totals from the previously mentioned National Climatic Data Center and SFWMD stations. An analysis of water-level and rainfall data was performed using S-plus Statistical Software. S-plus scripts were written to perform the following steps:

- Average the rainfall data from individual stations into two aggregate data sets, one for southwestern Florida and one for southeastern Florida, for the 1974-99 period.
- Compute long-term monthly means and standard deviations for rainfall and water-level data.
- Transform the monthly water-level and rainfall data into monthly departures from the long-term monthly mean values, expressed as number of standard deviations above or below the mean.
- Create a rainfall model based on a smooth of the data computed in the preceding steps.
- Reduce the rainfall model to include only the periods of data available from candidate wells in the ground-water level monitoring network.
- Trend adjust the water-level data.
- Lag the water-level data relative to rainfall by amounts ranging from 0 to 4 months.
- Perform a frequency analysis on the resulting water-level and rainfall data sets and determine the percentiles.
- Determine which values of water level and rainfall are below the 5th, 10th, 15th, and 20th percentiles of data and store those values with their corresponding dates in a separate file.
- Compare the resulting files from the water-level and rainfall frequency analysis to determine the fraction of agreement (f_a). This comparison is based on the timing of the water-level and rainfall values computed in the previous step. The f_a can be expressed as:

$$f_a = v_c / v_t \quad ,$$

where v_c is the total number of minimum rainfall and water-level values that are concurrent in time between the two data sets, and v_t is the total number of minimum values. The total number of minimum values is a direct function of the frequency analysis and the total number of values available from the data sets. For example, if 100 monthly values were available in both the rainfall and water-level data sets, 10 values in each data set would be less than or equal to the 10th percentile ($\pm$ 1 because of potential rounding issues). To account for rounding, the total number of values in the final rainfall file and the final water-level file were counted and divided by 2.

These 10 steps were performed iteratively for each well to include the 3 types of water-level trend adjusting, amounts of lag (0 to 4 months), and the rainfall models available for each area (LOWESS smooths with f-values of 1/26, 1/52, 1/76, and 1/104). Additionally, the lowest 5, 10, 15, and 20 percent of water-level and rainfall values were compared for each iteration. This analysis provided the f_a for 240 combinations of these factors for each well examined to determine the closest relation between the rainfall data for the region and the water level for each candidate monitoring well.

Analyses were made for 246 wells. The best f_a for each candidate monitoring well was determined, and results were arranged by period of record and completeness of record. The best f_a for each well ranged from 29 to 100 percent and averaged 52 percent. Most of the wells that showed very high f_a (80 percent or higher) had very short period of records (about 8 years, on average, after considering missing data). Of the 104 wells examined that had periods of record greater than 20 years (after considering missing data), only 15 wells showed an f_a of 57 percent or greater. No f_a for each of these 15 wells was greater than 62 percent. The period of record and completeness of record are the most important considerations in this analysis because agreement between water-level and rainfall minimums over a few years may show good statistical agreement, but they may not necessarily indicate what would occur during severe droughts. Final results from this analysis are presented in table 2.

Table 2. Rainfall and water-level minimum comparison for aquifers in southern Florida

Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete
Water-Table Aquifer (West Coast)			
C-54	0.50	26	0.99
C-131	.41	23	.99
C-296	.39	26	.52
C-392	.57	26	.98
C-496	.54	26	.98
C-503	.56	26	.54
C-598	.53	16	.95
C-690	.46	19	.88
C-953	.44	15	.97
C-968	.44	15	.95
C-969	.50	12	.99
C-978	.67	3	1.00
C-981	.57	3	.95
C-997	.59	14	.95
C-1063	.60	3	.92
C-1065	1.00	3	.97
C-1071	.42	13	.99
C-1075	.67	3	.85
HE-558	.47	19	.74
HE-862	.57	22	.69
L-730	.55	25	.98
L-954	.45	23	.94
L-1137	.52	23	.99
L-1403	.59	26	.97
L-1995	.50	25	.97
L-1997	.43	22	.98
L-2195	.51	22	.97
Lower Tamiami Aquifer			
C-391	.35	26	.91
C-409A	.36	12	.94
C-460	.47	15	.91
C-462	.44	23	1.00
C-492[1]	.45	26	.89
C-506A	.57	12	.97
C-600	.53	16	.99
C-951	.53	15	.99
C-988	.44	15	.87
C-998	.47	6	.97
C-1004	.47	15	.95
C-1064	.83	10	1.00
C-1074	.51	10	.98
C-1083	.59	8	.91
L-738	.50	8	.96
L-1691	.43	23	.99
L-2194	.54	22	.98
L-5727	.67	4	.94
L-5745	.60	6	.96
L-5747	.67	3	.97

Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete
Sandstone Aquifer			
C-531	0.43	20	0.95
C-688	.75	3	.95
C-989	.57	12	.99
C-1072	.45	13	.92
C-1079	.48	13	.97
C-1099	1.00	3	.97
HE-517	.60	23	.91
HE-529	.47	20	.93
HE-556	.52	24	.93
L-727	.51	26	.98
L-729	.51	22	.98
L-731	.43	26	.97
L-1418	.49	23	.93
L-1994	.51	25	.99
L-1996[2]	.49	21	.96
L-1998	.43	25	.90
L-2186	.47	19	.98
L-2215	.29	3	.61
L-2550	.80	8	.90
L-5649	.44	14	.99
Mid-Hawthorn Aquifer			
L-581	.48	26	.99
L-742	.41	26	.94
L-781	.33	23	.99
L-1993	.29	25	.98
L-2193	.50	7	.90
L-2640	.50	2	.72
L-2644	.40	18	.98
L-2701	.44	21	.95
L-2702	.48	19	.93
L-2703	.50	18	.92
Surficial Aquifer System			
M-1004	.44	26	.54
M-1024	.52	24	.43
M-1048	.52	25	.98
M-1234	.44	10	.98
M-1255	.45	7	.95
M-1257	.71	4	1.00
M-1261	.69	7	.98
PB-99	.52	26	.97
PB-445	.35	26	.99
PB-561	.56	26	.92
PB-565	.52	26	.99
PB-683	.58	26	.90
PB-685	.40	26	.36
PB-689	.35	26	.36
PB-732	.57	25	.96
PB-809	.41	25	.99

Table 2. Rainfall and water-level minimum comparison for aquifers in southern Florida (Continued)

Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete	Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete
Surficial Aquifer System--Continued				**Biscayne Aquifer--Continued**			
PB-831	0.51	25	0.97	G-864A	0.48	26	0.97
PB-900	.52	20	.99	G-968	.55	26	.99
PB-1491	.63	16	.96	G-970	.46	26	.97
PB-1639	.44	10	.99	G-972	.48	23	.96
PB-1642	.73	6	.99	G-973	.53	26	.99
PB-1661	.58	10	.98	G-975	.62	26	.97
PB-1662	.42	8	.96	G-976	.58	26	.99
PB-1680	.64	6	.96	G-1074B	.37	16	.96
PB-1684	.60	6	.97	G-1166	.41	26	.97
STL-41	.43	26	.45	G-1183	.39	26	.98
STL-42	.42	26	.46	G-1213	.52	26	.99
STL-125	.32	26	.29	G-1215	.59	22	.98
STL-172	.83	25	.40	G-1220	.46	26	.99
STL-175	.65	25	.43	G-1221	.43	26	.85
STL-176	.63	25	.42	G-1223	.54	26	.97
STL-185	.62	7	.96	G-1224	.47	26	.99
STL-213	.62	7	.95	G-1225	.41	26	.97
STL-214	.50	7	.94	G-1226	.48	26	.97
STL-264	.50	7	.94	G-1251	.53	26	.95
STL-313	.67	7	1.00	G-1260	.56	26	1.00
Biscayne Aquifer				G-1315	.61	26	.98
F-45	.43	26	1.00	G-1316	.49	26	.82
F-179	.43	26	.99	G-1359	.67	5	.98
F-239	.34	26	.98	G-1362	.49	26	.98
F-291	.48	26	.99	G-1363	.47	26	1.00
F-319	.49	26	.99	G-1368A	.30	26	.99
F-358	.45	26	.99	G-1473	.50	26	.99
G-3	.29	26	1.00	G-1486	.53	26	.96
G-551	.41	15	.94	G-1487	.43	26	.73
G-553	.56	26	.95	G-1488	.60	26	.98
G-561	.48	26	.99	G-1502	.58	26	.99
G-580A	.55	23	1.00	G-1636	.53	26	.99
G-594	.50	8	.84	G-1637	.57	26	.96
G-596	.47	26	.99	G-2031	.48	26	.99
G-613	.53	26	1.00	G-2032	.53	26	.98
G-614	.50	26	.98	G-2033	.48	26	.97
G-616	.55	21	.87	G-2034	.46	26	.98
G-617	.42	26	.99	G-2035	.48	26	.99
G-618	.61	26	.98	G-2147	.57	25	1.00
G-620	.54	26	.87	G-2376	.70	13	.98
G-757A	.48	26	.98	G-2395	.53	16	.88
G-789	.41	26	.98	G-2739	.53	8	.97
G-820A	.55	22	.71	G-2852	.40	4	1.00
G-852	.46	26	.98	G-2866	.44	4	1.00
G-853	.57	26	.97	G-3073	.36	18	1.00
G-855	.49	26	.98	G-3074	.36	22	.99
G-858	.55	20	.99	G-3253	.54	18	.93
G-860	.54	26	1.00	G-3259A	.60	17	1.00
G-864	.48	26	.99	G-3264A	.80	16	.98

Table 2. Rainfall and water-level minimum comparison for aquifers in southern Florida (Continued)

Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete	Station name	Fraction of agreement (f_a)	Period compared (years)	Percent record complete
Biscayne Aquifer--Continued							
G-3272	0.41	17	0.36	G-3563	0.42	5	0.91
G-3327	.50	16	.99	G-3564	.64	5	.97
G-3328	.54	16	.97	G-3565	.42	5	.95
G-3329	.50	16	.98	G-3566	.56	5	.97
G-3353	.65	14	.96	G-3567	.62	5	1.00
G-3354	.50	14	.89	G-3568	.50	5	.98
G-3355	.55	14	.96	G-3570	.60	5	1.00
G-3356	.47	14	.98	G-3571	.56	5	.98
G-3437	.44	13	.99	G-3572	.57	5	.98
G-3439	.39	13	.90	G-3574	.67	5	1.00
G-3465	.52	12	1.00	G-3575	.56	5	1.00
G-3466	.40	12	.90	G-3576	.56	5	.98
G-3467	.48	12	.99	G-3577	.56	5	1.00
G-3473	.50	8	.93	G-3578	.56	5	.98
G-3549	.31	6	.90	G-3619	.67	4	1.00
G-3550	.42	6	.86	G-3620	.60	4	1.00
G-3551	.64	6	.97	G-3621	.78	4	1.00
G-3552	.70	6	.97	G-3622	.67	4	1.00
G-3553	.71	6	.99	G-3626	.67	4	1.00
G-3554	.50	6	.80	G-3627	.67	4	1.00
G-3555	.70	6	.97	G-3628	.57	4	1.00
G-3556	.62	5	.97	G-3660	.33	2	.60
G-3557	.64	6	.99	S-18	.43	26	.98
G-3558	.64	6	1.00	S-19	.34	26	.99
G-3559	.64	6	.99	S-68	.31	26	.99
G-3560	.53	6	.88	S-182A	.51	26	1.00
G-3561	.64	6	.97	S-196A	.49	26	1.00
G-3562	.64	5	1.00	S-329	.53	26	.99

[1] The casing of well C-492 has been found to be open to the water-table aquifer. Extent of hydrologic connection to the lower Tamiami aquifer is unclear.
[2] The casing of well L-1996 has been found to be open to multiple aquifers. Extent of hydrologic connection to the sandstone aquifer is unclear.

Regression Analysis of Network Wells

Stepwise polynomial regressions were used to compare the water-level data from 203 candidate wells in each aquifer to determine which wells were most representative of the ground-water level monitoring network. The stepwise polynomial regression determines the best fit for the water-level data from one well relative to the water-level data from a comparable well, the best fit with the water level squared as an additional explanatory variable, and the best fit with time as another explanatory variable. For each iteration of this stepwise regression, a coefficient of determination (R^2) is computed. The R^2 value is a measure of the amount of variation in the dependent variable that is determined by the explanatory variable and must be from 0 to 1. The greatest value of R^2 represents the best fit that can be provided using the explanatory variables available. A mean R^2 value was computed for each candidate well based on an average of the greatest R^2 values that were determined for all of the comparative wells; this process was repeated for every candidate well in each aquifer. The candidate wells with the greatest mean R^2 value from each aquifer were considered to be the most representative of the water-level monitoring wells in the aquifer.

The interval of time over which the data from the wells can be compared is an important consideration. If one well has 20 years of water-level data and another well has only 1 year, the wells can be compared only for the 1 year of overlapping record. The R^2 value for that comparison may be close to 1; however, because the two wells are only compared for 1 year, the result would not be very significant. If the water-level data from the two wells can be compared for a long-term period, differences can be assessed more thoroughly. This factor has been considered in conjunction with the regression analysis performed for this study.

The most representative wells (termed index wells) were selected based on the values of mean R^2 and period of record. Index wells were required to have a minimum of 10 years of continuous water-level data. To evaluate the network coverage that these index wells would provide, the R^2 values from individual well comparisons were considered. If the comparison of water-level data at the index well and a network well resulted in an R^2 value of 0.64 or better, then the index well was considered to provide a fair estimate of water levels for that network well. (An R^2 value of 0.64 corresponds to a correlation coefficient of 0.80.) This evaluation was repeated for each potential index well. Results of the analysis are discussed in subsequent sections of this report.

Analysis of Water-Level and Chloride Data

Although the primary goal of the real-time ground-water level monitoring network is to monitor water levels, the network also has the potential to provide water managers with early information about saltwater intrusion and upconing of saltwater as a result of aquifer withdrawals. To help assess the relation between changes in water level and chloride concentration, two factors were considered: (1) long-term trends in chloride concentration, and (2) correlation between water levels and chloride concentrations. The locations of the monitoring wells considered in these analyses are shown in figure 10.

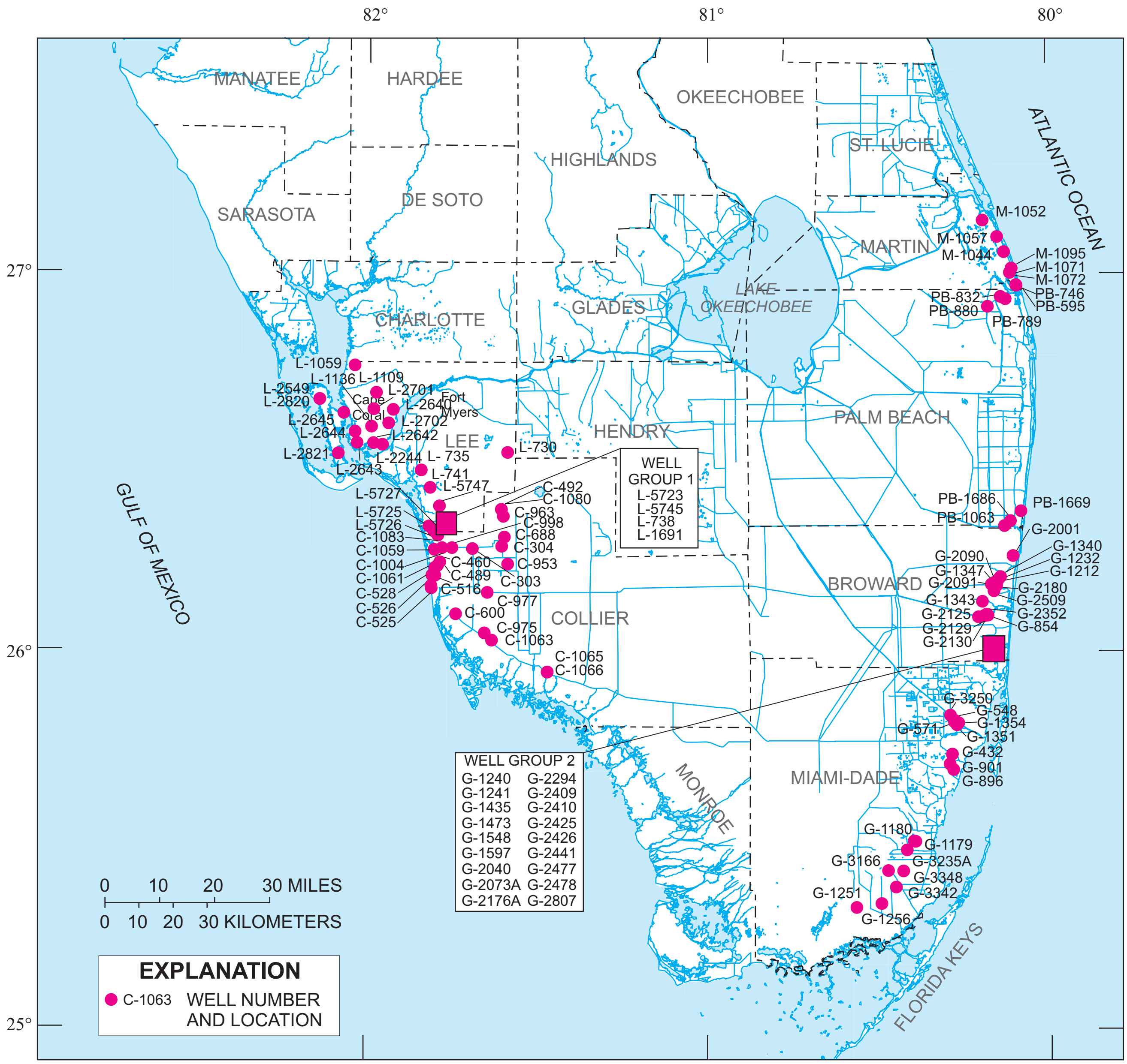

Figure 10. Locations of salinity monitoring wells.

Chloride Concentration Trends

To provide information concerning saltwater intrusion or upconing, long-term trends in chloride concentration were determined. Determination of water-quality trends for specific water-quality constituents requires that extraneous variation caused by natural phenomena (such as seasonality, streamflow, or precipitation) be compensated for so that temporal changes resulting from anthropogenic activities may be discerned. One of the principal causes of variation in water quality is seasonality. Many water-quality constituents may vary seasonally as a result of biological reactions, climactic changes, or changes in land use or water-management practices. This is also true for salinity monitoring based on chloride concentrations. The water-management system in southern Florida is regulated by control structures along the east coast canals. These structures are closed during the dry season to prevent saltwater intrusion and are opened during the wet season to discharge excess water to prevent flooding during heavy rainfall events. During the dry season, when lowered freshwater heads prevail in the aquifer systems, encroachment or upconing of the saltwater interface is more likely and may be reflected by increases in chloride concentration. Conversely, during the wet season, when higher freshwater heads are maintained, there is a likelihood of seasonal retardation of the saltwater interface, with resultant lower chloride concentration. However, the movement of the saltwater interface may not be immediate and may lag water-level changes. The seasonal variation in chloride concentration from well G-1351 in Miami-Dade County is shown in figure 11. Negating the variation caused by seasonality on chloride concentration enables an investigator to determine the long-term changes that have taken place over the years. The principal statistical tool used for trend detection was the Seasonal Kendall trend test.

Tests for trends in chloride concentration based on two seasons, wet and dry, were conducted on data from water years 1974 to 1998 for 50 wells in the Biscayne aquifer in Miami-Dade and Broward Counties and for 14 wells in the surficial aquifer system in Palm Beach and Martin Counties. In Lee and Collier Counties, tests for trends in chloride concentration were conducted on data from 1974 to 1998 for 9 wells in the water-table aquifer (west coast), 22 wells in the lower Tamiami aquifer, 15 wells in the mid-Hawthorn aquifer, and 3 wells in the sandstone aquifer. Statistically significant results are presented in table 3.

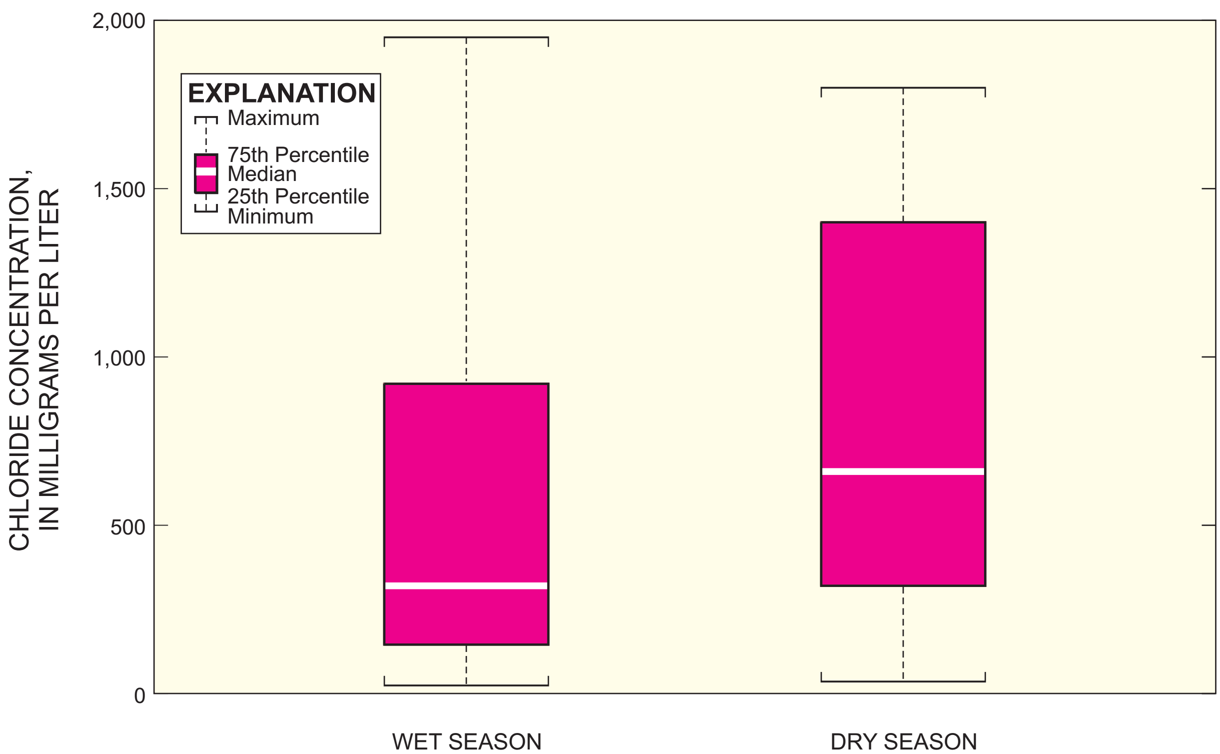

Figure 11. Seasonal variation in chloride concentration in well G-1351.

Table 3. Statistically significant Seasonal Kendall trend test results for chloride concentrations in water at selected wells in southern Florida based on two seasons per year

[Statistically significant at p-value <0.05]

Well number	County	Period of record	Slope (milligrams per year)	p-value
Water-Table Aquifer (West Coast)				
C-953	Collier	1984-98	0.71	0.001
C-1063	Collier	1986-97	1	.000
C-1065	Collier	1986-98	-500	.018
L-1136	Lee	1974-98	2	.050
Lower Tamiami Aquifer				
C-489	Collier	1975-98	1.54	$7.11x10^{-8}$
C-492[1]	Collier	1975-97	2.8	0.016
C-525	Collier	1975-98	8.89	.020
C-528	Collier	1975-98	.5	.000
C-975	Collier	1984-98	-4.57	.000
C-977	Collier	1984-98	7	.000
C-998	Collier	1985-98	1.11	.008
C-1083	Collier	1987-97	-38.3	.028
L-738	Lee	1974-98	6.66	$4.41x10^{-6}$
L-5725	Lee	1986-98	-20	.000
L-5727	Lee	1986-97	-10	.000
Sandstone Aquifer				
C-303	Collier	1981-98	-6.67	0.002
C-688	Collier	1981-98	.56	.000
Mid-Hawthorn Aquifer				
C-1080	Collier	1986-98	1	0.002
L-735	Lee	1980-98	-35	$3.54x10^{-9}$
L-1109	Lee	1975-98	10	.003
L-2640	Lee	1978-98	2.5	.000
L-2644	Lee	1978-98	-3.48	.050
L-2702	Lee	1978-97	-3.92	$4.48x10^{-6}$
L-2820	Lee	1978-98	-15.56	.008
Surficial Aquifer System				
M-1052	Martin	1975-95	-3	0.012
PB-595	Palm Beach	1975-94	-300	$1.24x10^{-7}$
PB-1669	Palm Beach	1993-98	-2	.000
Biscayne Aquifer				
G-432	Miami-Dade	1978-98	128	$1.19x10^{-8}$
G-548	Miami-Dade	1974-98	-20	.001
G-571	Miami-Dade	1975-98	-26	$5.56x10^{-12}$
G-896	Miami-Dade	1974-98	14.7	.003
G-901	Miami-Dade	1974-98	117	.003
G-1180	Miami-Dade	1974-98	.33	$5.47x10^{-6}$
G-1251	Miami-Dade	1974-98	.91	$3.50x10^{-101}$
G-1351	Miami-Dade	1974-98	-60	$5.59x10^{-8}$
G-1354	Miami-Dade	1974-98	-5	.005
G-3235A	Miami-Dade	1981-98	.5	.010
G-854	Broward	1974-98	50	$1.68x10^{-21}$
G-1212	Broward	1974-98	-1.67	.018
G-1232	Broward	1974-98	.33	$2.25x10^{-06}$
G-1241	Broward	1981-98	47.8	$2.02x10^{-10}$
G-1340	Broward	1974-98	-.86	$6.79x10^{-12}$
G-1343	Broward	1974-98	1.5	$1.15x10^{-10}$
G-1347	Broward	1974-98	.20	.004
G-1435	Broward	1974-98	266	$2.27x10^{-35}$
G-1473	Broward	1980-98	-.32	.000
G-1597	Broward	1974-98	-8	$3.71x10^{-17}$
G-2001	Broward	1974-98	-1.67	.000
G-2073A	Broward	1974-98	-.92	.000
G-2090	Broward	1974-98	-1.69	$41.8x10^{-13}$
G-2125	Broward	1974-98	.33	.001
G-2129	Broward	1975-98	-.37	.007
G-2130	Broward	1975-98	.40	$2.05x10^{-07}$
G-2176	Broward	1974-98	12.5	.000
G-2176A	Broward	1974-98	.17	.008
G-2294	Broward	1981-98	2.84	$2.34x10^{-08}$
G-2352	Broward	1981-98	6.67	$2.05x10^{-06}$
G-2410	Broward	1985-98	3.30	$2.79x10^{-10}$
G-2441	Broward	1986-98	-10	0.00
G-2478	Broward	1988-98	2.67	$2.15x10^{-08}$
G-2509	Broward	1994-98	-20	.015

[1]The casing of well C-492 has been found to be open to the water-table aquifer. Extent of hydrologic connection to the lower Tamiami aquifer is unclear.

Relation Between Chloride Concentrations and Water Levels

One aspect of the real-time ground-water network project was the examination of the relation between chloride concentrations and water levels. Wells that exhibit a statistically significant correlation between instantaneous water levels and chloride concentrations might logically be wells selected for high priority monitoring during drought periods depending on their proximity to the saltwater/freshwater interface. A correlation analysis between instantaneous water levels and chloride concentrations were performed for 114 wells in southern Florida during water years 1974-98.

Correlation coefficients measure the strength of the association between two variables but do not indicate a causal relation between the two. Variables may be correlated with each other in either a linear or nonlinear manner (Helsel and Hirsch, 1992, p. 210). For this aspect of the study, Spearman's ρ and Pearson's *r* correlation coefficients were employed, both of which measure monotonic (as x increases, y either increases or decreases) relations between two variables. Spearman's ρ is based on ranks, is resistant to outliers, and measures both linear and nonlinear monotonic associations. Pearson's *r* measures only linear monotonic associations between variables (Helsel and Hirsch, 1992, p. 210). Those wells for which a statistically significant correlation (p-value less than 0.025) was determined by Spearman's ρ were also analyzed by Pearson correlation coefficients. Correlation coefficients for these analyses are presented in table 4.

Table 4. Statistically significant correlation between chloride concentrations and instantaneous water levels for selected wells in southern Florida

[Statistically significant if p-value is less than or equal to 0.025]

Well number	County	Number of observations	Spearman's ρ	p-value (two-tailed)	Pearson's *r*	p-value (two-tailed)
Lower Tamiami Aquifer						
C-528	Collier	89	-0.32	0.00	-0.29	0.01
C-975	Collier	29	-.80	.00	-.64	.00
L-5747	Lee	85	.32	.00	.24	.02
Mid-Hawthorn Aquifer						
L-735	Lee	35	.74	0.00	.74	0.00
L-2244	Lee	31	.52	.00	.53	.00
Biscayne Aquifer						
G-548	Miami-Dade	98	.42	0.00	.47	0.00
G-571	Miami-Dade	106	.24	.01	-.23	.02
G-1351	Miami-Dade	124	-.21	.02	-.22	.01
G-1473	Broward	132	-.20	.02	-.22	.01
G-2073A	Broward	64	-.39	.00	-.36	.00
G-2125	Broward	97	-.51	.00	-.46	.00
G-2294	Broward	46	-.39	.01	-.51	.00
G-3166	Miami-Dade	68	-.45	.00	-.55	.00
G-3250	Miami-Dade	35	-.65	.00	-.53	.00
G-3342	Miami-Dade	76	-.31	.01	-.15	.21[1]
G-3348	Miami-Dade	77	-.39	.00	-.41	.00

[1]Not statistically significant for Pearson's *r*.

Parker and others (1955, p. 611) indicate that there are both seasonal and long-term changes in the saltwater/freshwater interface that occur over time, with long-term changes in the position of the interface lagging water-level changes. Merritt's (1996) assessment of saltwater intrusion in Broward County also documents seasonal as well as long-term changes in the position of the saltwater interface, and indicates that long-term water-level changes are more responsible for changes in the position of the saltwater interface than seasonal fluctuations. The significant, but relatively weak, correlations between chloride concentrations and instantaneous water levels documented by this study may be representative of short-term seasonal variations and not long-term changes in the position of the saltwater/freshwater interface. The South Florida Water Management District (1998) found that persistently lowered water levels, for greater than 6 months duration, resulted in a permanent inland movement of the saltwater interface, as opposed to lowered water levels over shorter time periods.

In order to examine the possible correlation between chloride concentrations and lagged water levels, three wells for which sufficient long-term monthly instantaneous water-level and chloride concentration data exist were tested for correlation between incrementally lagged chloride concentrations and water levels. The three wells (G-1179, G-1180, and G-1251) are located in the Biscayne aquifer in southern Miami-Dade County near the city of Homestead. At all three wells, chloride concentration data were lagged at monthly increments, from 1 to 60 months, and then correlated with instantaneous water-level data. No significant correlations were found for well G-1179, located slightly east of the approximate extent of the saltwater interface, as determined by Sonenshein (1997). Well G-1180, located at the saltwater interface, showed a significant but weak inverse correlation (Spearman correlation coefficient of -0.24) at a lag of 54 months. Well G-1251, located west and inland of the saltwater interface, showed significant but weak correlations at lags of 35, 36, 37, 38, 39 and 48 months, with Spearman correlation coefficients of -0.27, -0.36, -0.44, -0.40, -0.36 and -0.20, respectively.

Of the correlation coefficients determined from the water-level and chloride concentration data, 50 percent of Spearman's r coefficients were higher than Pearson's r coefficients. Results indicate that the water-level and chloride concentration relations between the wells were both linear and nonlinear in nature.

Selection of Index Wells by Aquifer

Selection of wells for the real-time ground-water level monitoring network was based on a combination of the factors discussed in preceding sections. In this section, an "initial" real-time network is presented for each aquifer that is based on regression analysis alone. A "preferred" real-time network is then proposed that considers additional factors (for example, analysis of water-level trends and minimums, chloride concentration trends, and so forth). Only data from the "preferred" or final network is presented in tables.

Wells that are already equipped with satellite telemetry were examined to see if they could be substituted into potential index well networks without seriously reducing the statistical validity of the network. In some instances, however, these real-time wells have little data available for analysis and as such, are not very useful. Because of the dynamic nature of the ground-water usage and changes in the drainage system, real-time ground-water level network wells should be frequently reevaluated to determine if they are still representative of regional aquifer conditions.

Water-Table Aquifer

The lowest monthly mean water level recorded in the water-table aquifer (west coast) of southwestern Florida was 1.70 ft below sea level (well L-954 in app. III). Mean water levels in the water-table aquifer (west coast) are about 29 ft above sea level at well C-1075 (located about 5 mi northeast of Immokalee) and decrease toward the coast, particularly in the southern part of the study area. Several monitoring wells in the water-table aquifer (west coast) near the coast have recorded minimum monthly mean water levels that are near or below sea level. Wells C-969 and C-1063 have recorded minimum water levels less than 1 ft above sea level (app. III). Well L-954 in Cape Coral, well L-1403 on Sanibel Island, and well C-1065 near the Tamiami Trail in southernmost Collier County all have recorded monthly mean water levels below sea level. Variation in this aquifer tends to be small. Interquartile ranges vary from 0.75 ft at well C-981 to 3.58 ft at well C-1071.

Water-Level and Chloride Concentration Trend and Correlation Results

Wells C-392 and C-496 showed water-level increases of 0.04 and 0.03 ft/yr, respectively, for the full period analyzed during 1974-99 (app. II). No statistically significant trends toward decreased water levels were found in any of the wells examined for the various time periods. Large increases in water levels were observed at wells C-131, C-496, C-953, C-1071, L-1403, L-1997, and L-2195 during 1989-95, ranging from 0.19 to 0.98 ft/yr (app. II). The largest increases during this period occurred at wells C-131 and C-1071 (0.57 and 0.98 ft/yr, respectively) southwest of Immokalee in northeastern Collier County.

Chloride concentrations in water at monitoring wells C-953 and C-1063 have shown increases of about +1 mg/L (milligram per liter) per year over the last 15 and 12 years, respectively (table 3). Despite this trend, chloride concentrations in both wells are still very low (less than 50 mg/L). Well C-953 is about 14 mi from the coast. The mostly likely sources of saltwater are leakage from other aquifers or upconing of connate water. Well C-1063 is much closer to the coast (less than 4 mi). The proximity of well C-1063 to the coast, combined with the minimum water levels that are near sea level in the vicinity of well C-1063, suggest that this well may be more susceptible to lateral saltwater intrusion. Well C-1063 only has about 3 years of daily maximum water-level record.

A downward trend in chloride concentration of -500 mg/L per year has been determined at well C-1065 over the 13 years evaluated. Although this is a very large decrease, chloride concentrations were initially well over 10,000 mg/L.

Discussion of Well Coverage

Regression analysis alone indicated that 4 index wells would be able to cover 89 percent of the water-table monitoring network (28 wells) in southwestern Florida, with an average R^2 value of 0.80. These four wells are L-2195, L-1137, C-131, and C-997. Data from well L-2195 alone can be used to estimate water levels at 15 other wells (which would cover 57 percent of the network) with a mean R^2 value of 0.66.

Analysis of water-level trends and minimums, chloride concentration trends, and correspondence of minimum water levels to droughts leads to the suggestion of a proposed network for the water-table aquifer (west coast) that includes index wells C-131, C-392, C-496, C-503, C-969, and L-2195 (tables 5 and 6). Considered together, these 6 wells could provide direct coverage or estimations of water levels at 89 percent of the 28 continuous monitoring wells in the network, with an average R^2 value of 0.82 (table 6). Figure 12 shows parts of the network that are covered using these six index wells.

Table 5. Potential index wells and well groupings based on regression analysis of aquifers in southern Florida

[Wells in each group are selected based on the regression R^2 of index well and individual well water-level data. If R^2 is greater than 0.64, then the well could be considered to be within that index well's group, unless one of the other index wells provides a better fit for this same comparison. Wells may be fit by more than one index well. Text for the selected fit is black, and text for other fits is red. In some cases wells were assigned, or not assigned, to groups based on both regression information and spatial criteria]

Local well number	Years of record	Mean R^2 value	Cumulative network coverage (percent)	Wells in group	R^2 value	Wells in group	R^2 value	Wells in group	R^2 value
Water-Table Aquifer (West Coast)									
L-2195	22.3	0.66	57	C-598	0.76	C-953	0.66	C-969	0.65
				C-978	.80	C-981	.78	C-997	.85
				C-1063	.72	C-1065	.75	C-1075	.88
				C-1095	.91	HE-862	.70	L-730	.64
				L-1137	.65	L-1995	.67	L-1997	.73
C-503	14.4	.65	75	C-296	.72	C-392	.68	C-598	.82
				C-953	.80	C-968	.67	C-978	.78
				C-981	.70	C-997	.76	C-1063	.66
				C-1065	.69	C-1071	.68	L-1137	.67
C-969	11.6	.60	82	C-392	.64	C-598	.66	C-690	.66
				C-968	.78	C-997	.64	C-1071	.64
				C-1075	.91	L-954	.68	L-1997	.66
				L-2195	.65				
C-131	38.9	.53	85	C-296	.64	C-1071	.74	C-1095	.90
				HE-862	.72				
C-496	26.3	.46	89	C-997	.66	C-1075	.68	C-1095	.90
				C-1065	.76				
C-392	26.3	.56	89	C-503	.66	C-978	.70	C-1063	.68
				C-1065	.66	C-1095	.88		

Table 5. Potential index wells and well groupings based on regression analysis of aquifers in southern Florida (Continued)

[Wells in each group are selected based on the regression R^2 of index well and individual well water-level data. If R^2 is greater than 0.64, then the well could be considered to be within that index well's group, unless one of the other index wells provides a better fit for this same comparison. Wells may be fit by more than one index well. Text for the selected fit is black, and text for other fits is red. In some cases wells were assigned, or not assigned, to groups based on both regression information and spatial criteria]

Local well number	Years of record	Mean R^2 value	Cumulative network coverage (percent)	Wells in group	R^2 value	Wells in group	R^2 value	Wells in group	R^2 value
Lower Tamiami Aquifer									
L-2194	22.2	.72	74[1]	C-460	0.75	C-600	0.66	C-951	0.83
				C-988	.73	C-998	.73	C-1004	.82
				C-1064	.71	C-1083	.88	L-738	.88
				L-1691	.92	L-5727	.88	L-5745	.90
				L-5747	.84				
C-462	23.0	.54	84[1]	C-1074	.75	L-5747	.64		
C-391	26.1	.53	100[1]	C-409A	.78	C-506A	.70		
Sandstone Aquifer									
L-729	22.5	0.67	58[2]	C-688	0.75	C-1072	0.66	C-1099	0.71
				L-727	.80	L-1418	.78	L-1994	.86
				L-2186	.84	L-2215	.95	L-2550	.70
				L-5649	.75				
L-2186	18.9	.63	68[2]	C-531	.72	C-1072	.67	C-1099	.64
				HE-529	.66	L-727	.89	L-729	.84
				L-1418	.81	L-1994	.68	L-2550	.67
L-731	26.2	.56	74[2]	C-688	.76	C-1099	.70	L-729	.64
				L-2186	.67	L-2215	.89	L-2550	.65
C-1079	13.1	.56	84[2]	C-989	.85	C-1072	.70	L-2215	.80
HE-556	23.2	.55	89[2]	C-688	.66	C-1072	.72	C-1099	.65
L-1998	24.3	.32	95[2]	No other wells					
Mid-Hawthorn Aquifer									
L-581	26.3	.67	67	L-1993	0.72	L-2644	0.93	L-2701	0.83
				L-2702	.77	L-2703	.80		
L-742	26.0	.57	78	L-1993	.70	L-2644	.88	L-2701	.77
Surficial Aquifer System									
PB-689	9.7	.56	36	M-1024	0.68	M-1234	0.69	M-1261	0.64
				PB-99	.72	PB-565	.69	PB-683	.80
				PB-685	.66	PB-809	.75	PB-831	.78
				PB-1662	.66	STL-175	.67	STL-176	.72
STL-41	34.6	.47	47	PB-683	.72	PB-689	.69	STL-213	.66
				STL-214	.69	STL-313	.68		
M-1004	14.7	.49	56	M-1024	.66	M-1257	.67	PB-809	.71
				STL-172	.73	STL-175	.70	STL-176	.76
PB-732	25.3	.42	61	PB-683	.64	PB-689	.70	PB-1680	.83
PB-99	46.8	.46	64	M-1024	.70	M-1261	.65	PB-689	.76
				PB-1639	.80				
STL-125	8.6	.51	72	M-1261	.79	PB-1491	.65	PB-683	.73
				PB-689	.68	STL-185	.72	STL-213	.87
PB-565	26.4	.44	--	PB-99	.64	PB-689	.72	M-1024	.96
PB-1491	15.8	.34	--	No other wells					
Biscayne Aquifer									
S-196A	46.2	0.50	23	F-358	0.92	G-553	0.68	G-580A	0.64
				G-596	.76	G-613	.83	G-614	.89
				G-757A	.90	G-789	.90	G-820A	.71
				G-855	.72	G-858	.71	G-864	.85
				G-864A	.84	G-1183	.64	G-1251	.78
				G-1363	.95	G-1486	.87	G-1487	.69
				G-1502	.77	G-3259A	.66	G-3264A	.73
				G-3354	.70	G-3355	.72	G-3356	.65
				G-3437	.81	G-3439	.76	G-3473	.74
				G-3575	.65	S-182A	.69		

Table 5. Potential index wells and well groupings based on regression analysis of aquifers in southern Florida (Continued)

[Wells in each group are selected based on the regression R^2 of index well and individual well water-level data. If R^2 is greater than 0.64, then the well could be considered to be within that index well's group, unless one of the other index wells provides a better fit for this same comparison. Wells may be fit by more than one index well. Text for the selected fit is black, and text for other fits is red. In some cases wells were assigned, or not assigned, to groups based on both regression information and spatial criteria]

Local well number	Years of record	Mean R^2 value	Cumulative network coverage (percent)	Wells in group	R^2 value	Wells in group	R^2 value	Wells in group	R^2 value
Biscayne Aquifer (Continued)									
F-291	45.3	.46	36	F-45	0.85	G-561	0.85	G-820A	0.70
				G-852	.68	G-1220	.76	G-1223	.65
				G-1224	.78	G-1225	.77	G-1226	.86
				G-1473	.97	G-2035	.92	G-2147	.67
				G-3264A	.65	S-18	.65	S-329	.68
G-580A	39.8	.51	46	F-179	.71	F-319	.80	F-358	.70
				G-551	.67	G-553	.85	G-613	.68
				G-614	.71	G-757A	.72	G-789	.66
				G-820A	.71	G-855	.67	G-858	.72
				G-860	.85	G-864	.65	G-864A	.64
				G-1251	.71	G-1363	.71	G-1486	.67
				G-1502	.69	G-3264A	.66	S-182A	.75
				S-196A	.70				
G-975	41.2	.42	59	G-618	.83	G-620	.70	G-853	.65
				G-968	.69	G-972	.69	G-976	.74
				G-1487	.71	G-1488	.94	G-1502	.74
				G-1637	.68	G-2147	.70	G-2376	.71
				G-3259A	.82	G-3264A	.77	G-3437	.70
				G-3439	.74	G-3575	.81		
G-620	40.9	.34	62	G-618	.79	G-975	.67	G-1488	.70
				G-1502	.69	G-2147	.64	G-3253	.68
				G-3259A	.74	G-3264A	.69	G-3353	.66
				G-3437	.64	G-3575	.81		
G-1260	26.4	.35	68	G-820A	.65	G-853	.82	G-1215	.89
				G-1315	.71	G-2147	.88	G-2395	.68
				G-3259A	.71	G-3264A	.71		
G-1221	22.7	.41	69	G-1223	.69				
F-239	26.3	0.32	78	G-3	0.79	G-1368A	0.79	G-3327	0.83
				G-3465	.77	G-3466	.84	G-3467	.89
				S-19	.85	S-68	.85		
G-1636[3]	26.6	.40	80	G-970	.79	G-3264A	.65		
G-3329[3]	16.2	.44	84	G-973	.65	G-3327	.83	G-3328	.81
				G-3465	.73	G-3467	.76	S-19	.70
G-3074[3]	22.3	.14	86	G-3073	.70				
S-18[3]	49.8	.39	88	F-45	.64	F-291	.66	G-852	.67
				G-1166	.71	G-1473	.67	G-2035	.66

[1]Well C-492 was eliminated because its casing has been found to be open to the water-table aquifer. Extent of hydrologic connection to the lower Tamiami aquifer is unclear.

[2]Well L-1996 was eliminated because its casing has been found to be open to multiple aquifers. Extent of hydrologic connection between aquifers is unclear.

[3]Index well was not recommended.

Table 6. Subnetwork regression characteristics by aquifer

Hydrologic system	Number of wells considered in R^2 analysis	Subnetwork: Number of index wells recommended	Subnetwork: Mean R^2 value	Subnetwork: Coverage of wells considered in R^2 analysis (percent)[1]
Water-table aquifer (west coast)	28	6	0.82	89
Lower Tamiami aquifer	19[3]	3	.83	100[2]
Sandstone aquifer	19[2]	6	.85	95[2]
Mid-Hawthorn aquifer	9	2	.86	78
Surficial aquifer system	36	8	.85	72
Biscayne aquifer	92	8	.81	78

[1]Based on R^2 value of at least 0.64 for each well.

[2]The well L-1996 was eliminated because its casing has been found to be open to multiple aquifers. Extent of hydrologic connection to each aquifer is unclear.

[3]The well C-492 was eliminated because its casing has been found to be open to the water-table aquifer. Extent of hydrologic connection to the lower Tamiami aquifer is unclear.

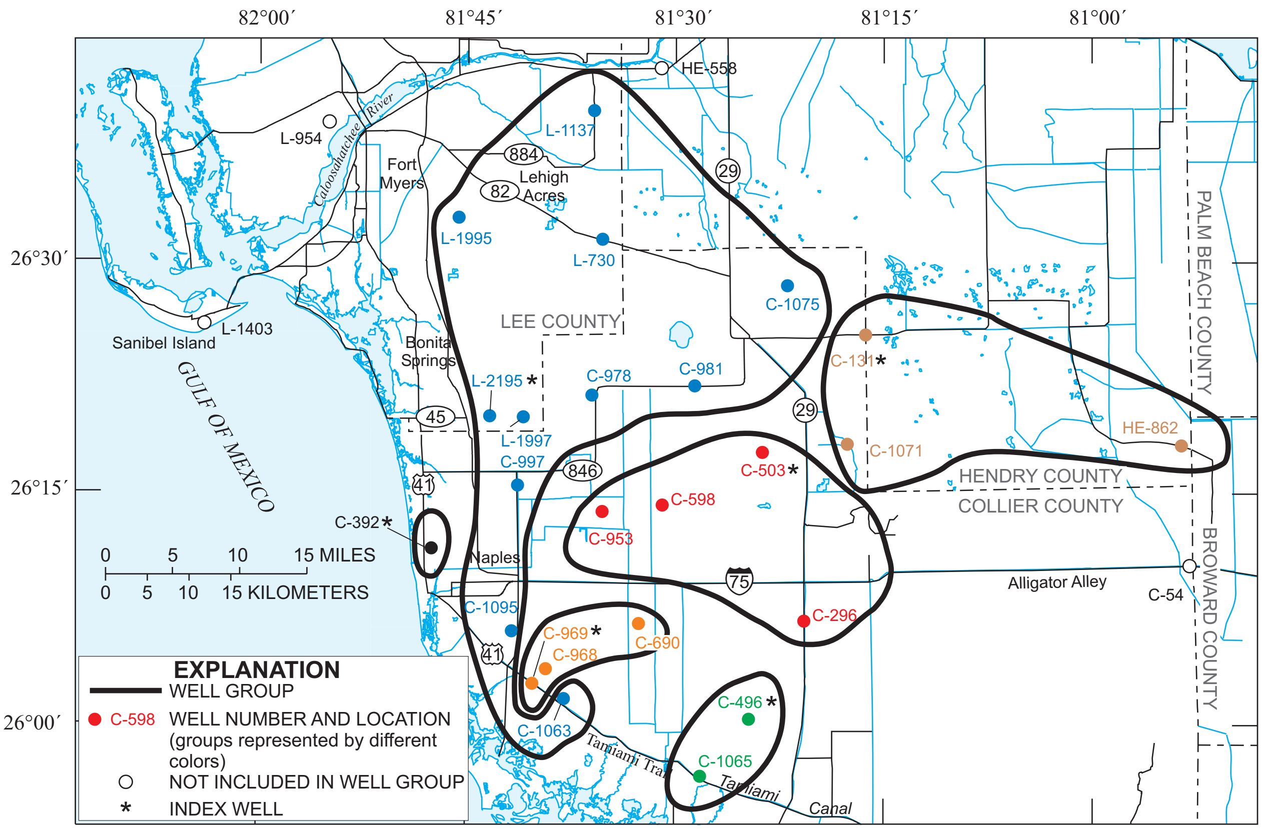

Figure 12. Network coverage defined by R^2 analysis using index wells in the water-table aquifer.

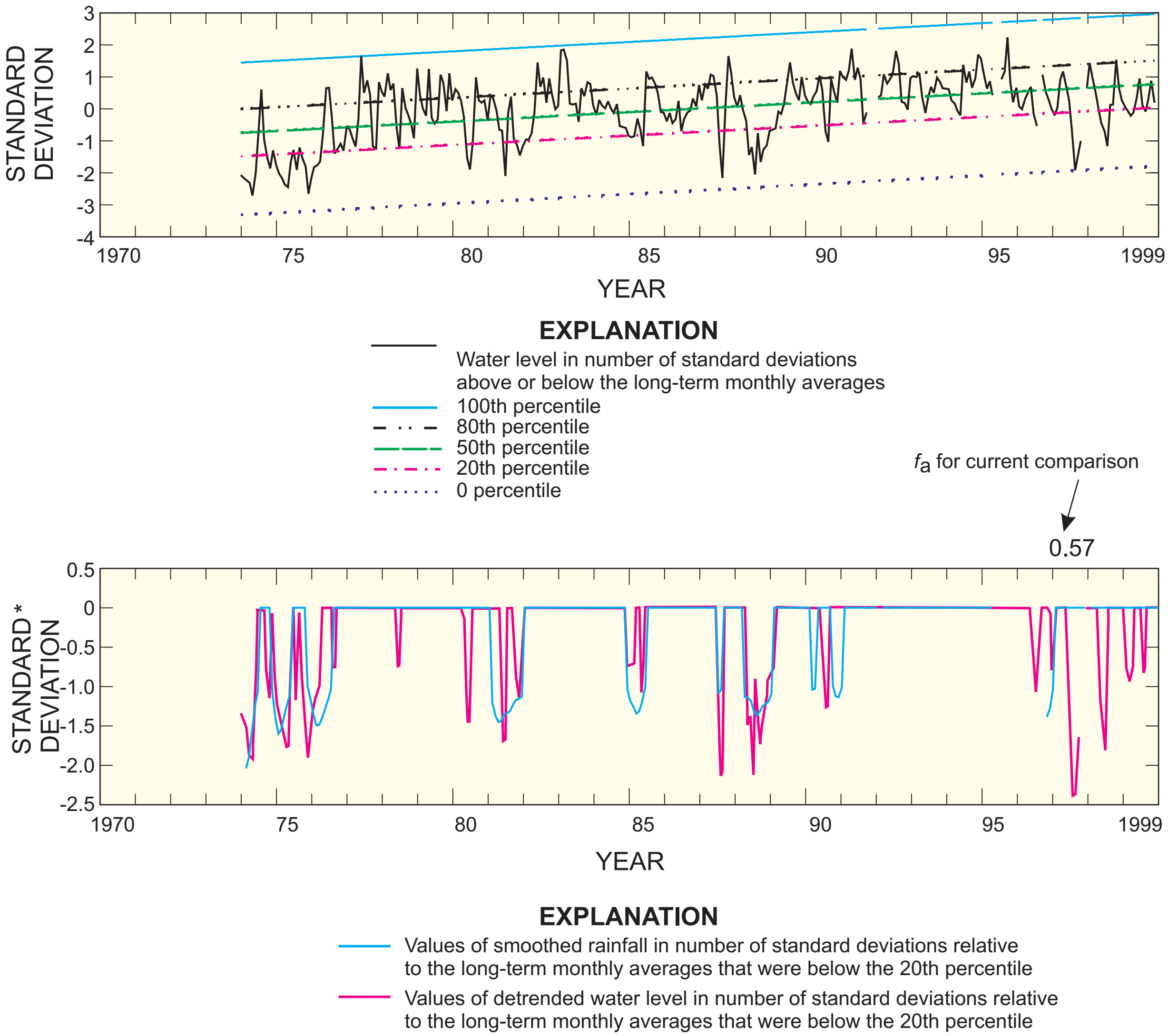

Figure 13. Comparison of smoothed average rainfall deviations (f-value = 1/26) and trend adjusted water-level deviations in well C-392. The fraction of agreement (f_a) for the lowest 20th percentile of the data was 0.57. For this comparison, water level was trend adjusted using a linear regression and lagged relative to smoothed rainfall deviations by 2 months. Asterisk represents standard deviation below the long-term monthly averages of water level and rainfall. These values for rainfall have been multiplied by 3 so that the resulting rainfall values can be readily compared to the water-level results. This multiplication does not affect the f_a.

The first 4 wells of this network (C-131, C-503, C-969, and L-2195) can be used to estimate water levels at 19 other wells in the water-table network (table 5). Index well C-392 has been included in this network because it provides better coverage close to the coast where minimum water levels have been near sea level. Well C-969 was also selected because it is near well C-1063 (fig. 12) where an upward trend in chloride concentration has been determined (table 3). Considering the period of data available for comparison, water-level data from well C-392 showed one of the best agreements with extreme rainfall minimums. The f_a determined was 0.57 (fig. 13 and table 2).

The total depth measurements performed at potential index wells indicated that wells C-131, C-392, and C-496 are not at the full depths indicated in the construction logs. Well C-496, which should be 57 ft deep (app. I), is currently 36 ft deep (relative to land surface). This well is still open to the aquifer from 7 to 36 ft below land surface (app. 1). The casing of well C-392 ends at a depth of 24 ft below land surface.

Several inches below the end of the casing of the well has filled with sand. Well C-131 may never have been drilled to the depth indicated in the construction logs (54 ft). The casing extends to a depth of 19 ft below land surface, and the bottom of the well is just below that depth (app. 1). There is a very thin layer of sediment at the bottom of this well, but the material beneath this sediment is hard and does not appear to have resulted from borehole collapse. Attempts to clear any loose material at the bottom of the well have been unsuccessful. Despite the well depth discrepancies, these wells are all open to the water-table aquifer (west coast) and appear to be good index wells. Basic well construction and analysis results for the index wells selected and the potential replacement well, C-997, are listed in table 7.

Table 7. Basic well construction and statistical information for potential index wells in southern Florida

[Top of aquifer elevation for the lower Tamiami and sandstone aquifers estimated from contour maps of Wedderburn and others (1982) and Knapp and others (1986). Open intervals reflect the original construction of the well and have not been changed to show the effect of obstructions or partial collapses. These problems are noted in the comments column of the table. Annotations: NS, no statistically significant trend for the period analyzed; *, well not included in final network; --, insufficient data for analysis; ?, information is unknown; WT, water-table well]

Well number	Daily value record (years)	Lowest measured water level (feet, relative to land surface)	Top of aquifer (feet, relative to land surface)	Top of open interval (feet, relative to land surface)	Bottom of open interval (feet, relative to land surface)	Existing satellite telemetry (yes or no)	Long-term trend	Period analyzed for trend	Comments
Water-Table Aquifer (West Coast)									
C-131	38.9	-11.18	WT	-19[1]	-54 (see comments)	No	NS	1974-95	Adds coverage at two wells. Casing ends and the bottom of the well is at a depth of 19 feet. The original construction notes may have been wrong, but the well is still functional.
C-392	26.3	-7.00	WT	-24[1]	-30	No	+0.04	1974-99	Improves coverage near a major well field. Most of the open hole portion of this well has filled with sand, but the well is still functional.
C-496	26.3	-9.21	WT	-7[1]	-57 (see comments)	No	+.03	1974-99	Adds coverage at one well. About 21 ft of the open-hole portion of this well has collapsed, but the well is still functional.
C-503	14.4	-15.30	WT	-8	-20.4	No	NS	1974-81	Adds coverage at four wells.
C-969	11.6	-4.90	WT	-25	-72	No	NS	1989-95	Improves coverage near a major well field.
C-997*	14.0	-8.80	WT	-12	-22	No	NS	1989-99	Possible substitute for C-503.
L-2195	22.3	-12.12	WT	-14	-15	No	NS	1989-99	Provides coverage for 57 percent of the network.
Lower Tamiami Aquifer									
C-391	26.1	-16.60	-50	-70	-75 (see comments)	No	+0.11 -.17	1974-99 1989-99	Provides coverage in an area of the aquifer that has increasing chloride concentrations. Partially obstructed, but functional.
C-462	23.0	-11.43	-80	-50	-110	No	NS	1974-95	Replaces C-492, which has been found to be open to multiple aquifers. Provides coverage at two wells.
C-492[2]	24.2	-5.15	-70	-19	-64 (see comments)	Yes	NS	1989-99	Casing has been found to be open to the water table aquifer at a depth of 19 ft[1].
L-738*	7.9	-14.67	-40	-61	-76	Yes	--	--	Can replace L-2194, if needed, but only has 8 years of record.
L-2194	22.2	-17.1	-55	-77[1]	-132[1]	No	NS	1989-99	Can be used to estimate water-level record for 74 percent of network.

Table 7. Basic well construction and statistical information for potential index wells in southern Florida (Continued)

[Top of aquifer elevation for the lower Tamiami and sandstone aquifers estimated from contour maps of Wedderburn and others (1982) and Knapp and others (1986). Open intervals reflect the original construction of the well and have not been changed to show the effect of obstructions or partial collapses. These problems are noted in the comments column of the table. Annotations: NS, no statistically significant trend for the period analyzed; *, well not included in final network; --, insufficient data for analysis; ?, information is unknown; WT, water-table well]

Well number	Daily value record (years)	Lowest measured water level (feet, relative to land surface)	Top of aquifer (feet, relative to land surface)	Top of open interval (feet, relative to land surface)	Bottom of open interval (feet, relative to land surface)	Existing satellite telemetry (yes or no)	Long-term trend	Period analyzed for trend	Comments
					Sandstone Aquifer				
C-989*	11.8	-24.26	-250	-234[1]	-270 (see comments)	No	+0.38	1986-95	Can replace C-1079, if needed. Provides coverage at most of the same wells. The open interval of this well has collapsed, but the well is still functional.
C-1079	13.1	-22.18	-265	-298	-390 (see comments)	No	+0.31	1986-99	Replaces L-1996, which was found to be open to multiple aquifers. Objects are partially obstructing the well casing, but the well is still functional.
HE-556	23.2	-26.3	-140	-163[1]	-175[1] (see comments)	Yes	NS	1986-99	Improves quality of coverage in this portion of the aquifer. Objects are partially obstructing the well casing, but the well is still functional. Depth in orignal construction notes was incorrect.
L-729	22.5	-22.83	-60	-81.5[1]	-107.5 (see comments)	No	-.24	1986-99	Can provide coverage for 67 percent of existing network. Well was listed in construction records as having a depth of 103 ft. Borehole camera inspection revealed a depth of -107.5 ft.
L-731	26.2	-33.05	-195	-163[1]	-243 (see comments)	Yes	-.27 +.75	1974-99 1986-99	Improves quality of coverage in this area. Objects are partially obstructing the well casing, but the well is still functional.
L-1996[3]	20.7	-15.37	-115	-65	-295 (see comments)	No	NS	1986-95	Well casing has been found to be open to multiple aquifers. Well is also partially obstructed.
L-1998	24.3	-59.06	-70	-102.4[1]	-160 (see comments)	Yes	-1.02 -1.50	1974-99 1986-99	Only well that can provide coverage of this portion of the aquifer. About 26 ft of the open-hole portion of well has collapsed, but the well is still functional.
L-2186	18.9	-35.25	-80	-133	-160	Yes	NS	1986-95	Adds coverage at two wells. Improves coverage at three wells.
					Mid-Hawthorn Aquifer				
L-581	26.3	-59.41	-160	-107[1]	-177 (see comments)	Yes	-.70 -1.16	1974-99 1984-99	Can be used to estimate water levels for 67 percent of the network. A small portion (7 ft) of the open interval has collapsed.
L-742	26.0	-87.88	-134	-136[1]	-225 (see comments)	No	NS -1.34	1974-99 1984-99	Adds coverage in an area where none exists. Lowest water levels in the network. About 25 ft of the open-hole portion of the well has collapsed, but the well is still functional.
L-2644*	20.2	-26.53	-177	-128	-180	Yes	-1.17	1984-99	Possible replacement for L-742.
L-4820	New Recorder	-30.10	-139	-128	-190	Yes	--	--	Provides real-time conductivity information in an area with increasing chloride concentrations.

Table 7. Basic well construction and statistical information for potential index wells in southern Florida (Continued)

[Top of aquifer elevation for the lower Tamiami and sandstone aquifers estimated from contour maps of Wedderburn and others (1982) and Knapp and others (1986). Open intervals reflect the original construction of the well and have not been changed to show the effect of obstructions or partial collapses. These problems are noted in the comments column of the table. Annotations: NS, no statistically significant trend for the period analyzed; *, well not included in final network; --, insufficient data for analysis; ?, information is unknown; WT, water-table well]

Well number	Daily value record (years)	Lowest measured water level (feet, relative to land surface)	Top of aquifer (feet, relative to land surface)	Top of open interval (feet, relative to land surface)	Bottom of open interval (feet, relative to land surface)	Existing satellite telemetry (yes or no)	Long-term trend	Period analyzed for trend	Comments
Surficial Aquifer System									
M-1004	14.7	-5.47	WT	-17	-17	Yes	NS	1991-99	Adds coverage at three wells.
PB-99	46.8	-9.42	WT	-16	-18.3	No	+.05	1974-99	Can be used to estimate water levels for up to 14 percent of the network.
PB-565	26.4	-13.77	WT	-21.9	-21.9	Yes	NS	1974-99	Improves coverage at one well in addition to itself.
PB-689	9.7	-2.76	WT	-17	-17	No	--	--	Adds coverage at six wells.
PB-732	25.3	-8.5	WT	-100	-100	No	NS	1974-99	Adds coverage at two wells.
PB-1491	15.8	-21.54	WT	-88	-138 (see comments)	No	NS	1991-99	Could add coverage at one well (itself). Well has filled with sand to a depth of 80 feet, but is still functional.
STL-41	34.6	-7.08	WT	-13	-17 (see comments)	No	--	--	Adds coverage at four wells. Well is plugged. A replacement well may be drilled.
STL-125	8.6	-6.05	WT	-11.8	-11.8	Yes	--	--	Could add coverage at two wells, but has only seven years of data.
Biscayne Aquifer									
F-239	26.3	-9.44	WT		-53	No	+0.07	1974-99	Could add coverage at Miami-Hialeah well field. Unusual water-level record due to historic changes.
F-291	45.3	-9.00	WT	-105[1]	-107[1] (see comments)	Yes	+.01	1974-99	Adds coverage for 12 wells. Casing of the well is partially corroded through from land surface to a depth of 9 ft.
G-580A	39.8	-8.62	WT	-4	-22 (see comments)	Yes	+.04	1974-83	Adds coverage for nine wells. Also in the vicinity of an area with changing chloride concentrations. About 10 ft of the open interval of this well has collapsed, but the well is still functional.
G-620	40.9	-3.8	WT	-3.2[1]	-13[1]	Yes	+.03	1974-99	Adds coverage for the remote areas of the aquifer in the Everglades.
G-975	41.2	-0.37	WT	-10	-15	Yes	NS	1974-99	Adds coverage for 12 wells.
G-1221	22.7	-5.43	WT	11.5	-20 (see comments)	Yes	NS	1983-92	Monitors an area with increasing chloride concentrations. The well has partially filled with sand from the formation, but is still functional.
G-1260	26.4	-10.42	WT	-59.5[1]	-90[1] (see comments)	Yes	+.08	1974-99	Adds coverage for five wells. Also in northern Broward County. About 5 ft of the open interval of this well has collapsed, but the well is still functional.
S-196A	46.2	-11.97	WT	0	-19	Yes	+.04	1974-99	Can be used to estimate water levels for up to 23 percent of the network.

[1]Depth has been adjusted slightly based on results of borehole camera examination.

[2]Well C-492 was eliminated from consideration because its casing has been found to be open to the water-table aquifer. Extent of hydrologic connection to the lower Tamiami aquifer is unclear.

[3]Well L-1996 was eliminated from consideration because its casing has been found to be open to multiple aquifers. Extent of hydrologic connection to the mid-Hawthorn, sandstone, and lower Tamiami aquifers is unclear.

Lower Tamiami Aquifer

The lowest monthly mean of daily maximum water levels in the lower Tamiami aquifer was 5.07 ft below sea level at well L-1691 in Bonita Springs (app. III). During the period of record, water levels at wells in a large area of this aquifer have at times reached minimum values that are well below sea level. Twelve of the 20 continuous monitoring wells in this aquifer have had monthly means of daily maximum water levels that were below sea level (app. III). These wells are: C-391, C-409A, C-460, C-998, C-1004, C-1083, L-738, L-1691, L-2194, L-5727, L-5745, and L-5747. All are located in an area that extends from Naples in the south to Bonita Springs in the north (fig. 4). The Pelican Bay and Naples Well Fields are located in this area (fig. 14). The first quartiles of water levels at wells L-738 and L-5747 are near or below sea level for much of the period of record for each well (app. III; 1992 to present at well L-738; 1997 to present at well L-5747). Water-level variation in this aquifer, expressed as the interquartile range in feet, is about 3 ft on average and ranges from 1.11 ft at well C-600 to 5.60 ft at well L-1691 (app. III).

Water-Level and Chloride Concentration Trend and Correlation Results

Water levels in a large part of the lower Tamiami aquifer increased by 0.15 to 0.80 ft/yr during the 1989-95 period. This increase is apparent in the water-level data from wells C-460, C-462, C-492, C-600, C-1004, C-1074, L-1691, and L-2194 (fig. 14 and app. II). This may have contributed to the decrease in chloride concentrations observed in four monitoring wells (table 3; wells C-975, C-1083, L-5725 and L-5727). Yet, chloride concentrations in water at five wells (C-489, C-492, C-525, C-528, and L-738) have increased (table 3). Chloride concentrations in wells C-489, C-525, and C-528 have increased by +1.5, +8.9, and +0.5 mg/L per year, respectively (table 3 and fig. 15A), despite the water-level increase of 0.11 ft/yr in nearby monitoring well C-391 during 1974-99 (app. II). Because of the proximity of these wells to the Gulf of Mexico, increased chloride concentrations in these wells may be caused by lateral intrusion of saltwater. Closer examination of the long-term water-level trend at well C-391 reveals that water levels have decreased by 0.17 ft per year for the 1989-99 period (app. II). This decrease may have contributed to the trend of increased chloride concentrations in the nearby wells.

The upward trend in chloride concentration observed at monitoring well L-738 (fig. 15B) may have been caused by leakage of saltwater from lower aquifers. Schmerge (2001) reports that a nearby well (L-2310) open to the Upper Floridan aquifer had a poorly sealed annular space, which may have allowed saltwater to intrude into the lower Tamiami aquifer in this area. Well L-2310 was plugged in 1999.

The water-level and chloride concentration correlation analysis indicated that only three wells (C-528, C-975, and L-5747) in the lower Tamiami aquifer showed a significant correlation between chloride concentration and water level. Spearman's r for wells C-528, C-975, and L-5747 was -0.32, -0.80, and 0.32, respectively, whereas Pearson's r for these wells was -0.29, -0.64, and 0.24, respectively (table 4).

Discussion of Well Coverage

Regression analysis alone of water-level data indicated that three monitoring wells (C-391, C-492, and L-2194) in the lower Tamiami aquifer could be used to estimate water level at the remaining 20 monitoring wells in this aquifer, with an average R^2 value of 0.78. In addition to the coverage that these three wells provide, the value of these wells is supported by the correspondence of minimum water levels at well L-2194 to droughts and the proximity of well C-391 to wells C-489, C-525, and C-528 where chloride concentrations have been increasing. The f_a determined, using the 22 years of water-level data from well L-2194, is 0.54. The only wells in this aquifer where better agreements were indicated had less than 13 years of data available for examination.

Furthermore wells C-391 and L-2194 are nested with wells C-392 and L-2195, respectively (fig. 4). These are two of the wells that have been selected to monitor the water-table aquifer (west coast) (table 5). The cost of installation of satellite telemetry can be reduced when monitoring nested wells because only one satellite transmitter is required.

Owing to problems with well C-492, another well (C-462) is the recommended substitute index well for a proposed network that also includes index wells C-391 and L-2194 (table 5). Well C-492 is already equipped with satellite telemetry, and construction records indicate that the well is 64 ft deep and cased to a depth of 60 ft below land surface (app. I and table 7). However, a total depth measurement using a borehole camera indicated that the well was only 21 ft deep. Attempts were made to clear this well.

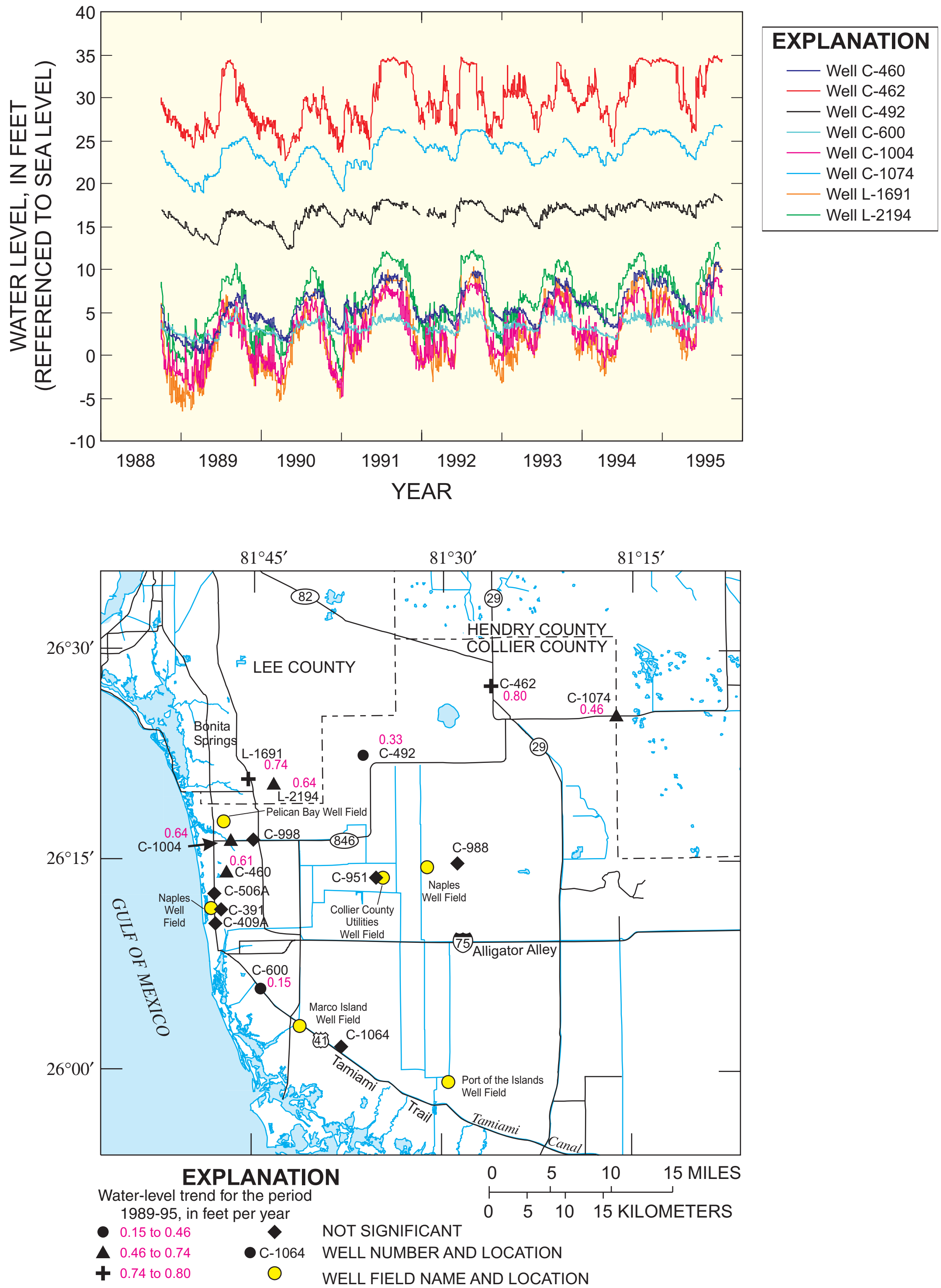

Figure 14. Statistically significant trends in water level at selected wells in the lower Tamiami aquifer.

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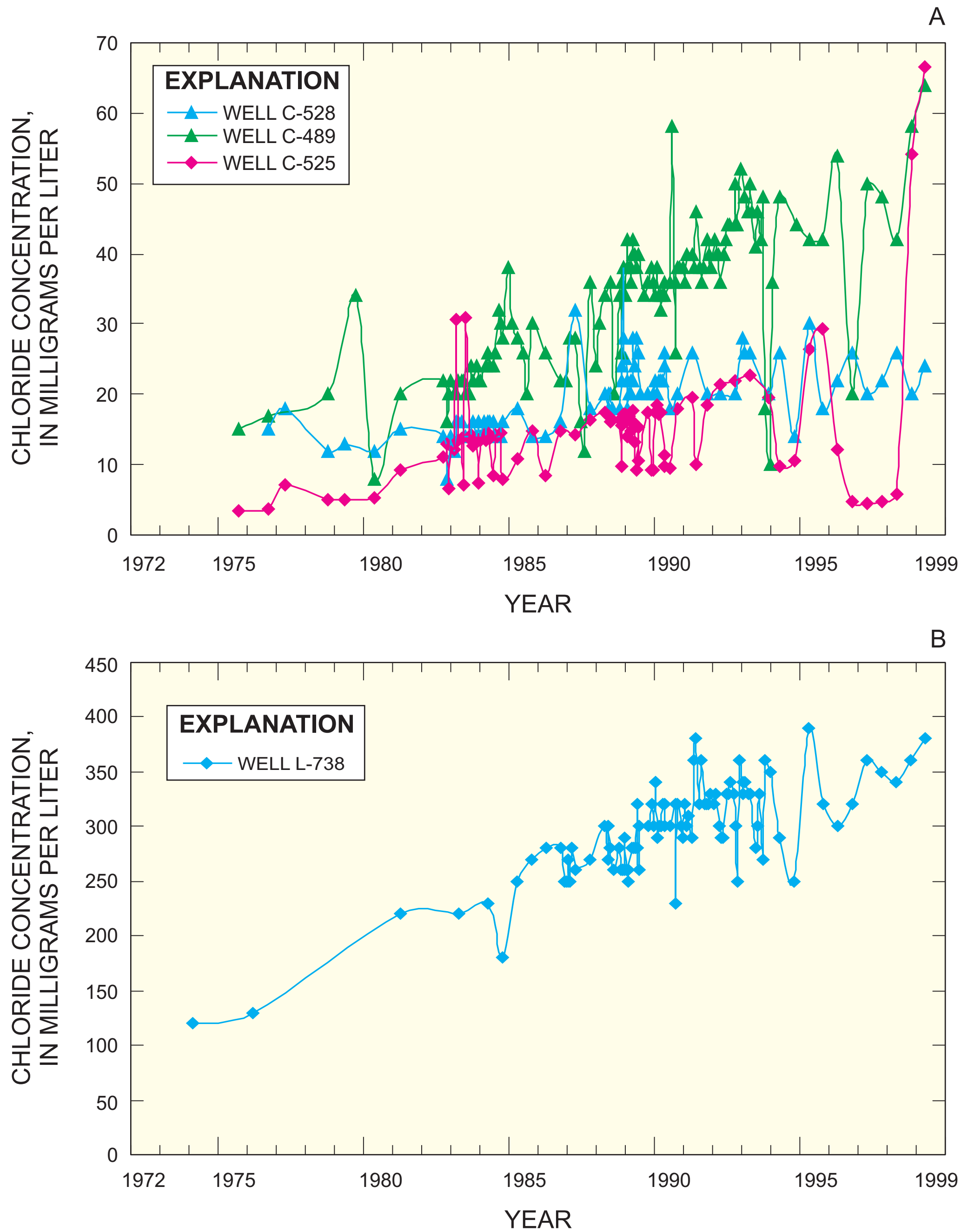


Figure 15. Chloride concentration trends at wells C-489, C-525, and C-528 and L-738.

Borehole videos showed that the well is open to the water-table aquifer (west coast) 19 ft below land surface and has apparently collapsed to a depth of 21 ft. The casing may have separated and collapsed, or the construction records may have been incorrect. As a result, this well can no longer be considered to monitor only the lower Tamiami aquifer. Because of this, it is necessary to substitute monitoring well C-462 for well C-492 (table 7). The average R^2 value for the network actually improves slightly to 0.83 because well C-492 is no longer considered (tables 5 and 6). Figure 16 shows (spatially) the parts of the network that could be estimated by using index wells C-391, C-462, and L-2194.

Although, regression analysis has shown that water levels at well L-2194 are most representative of

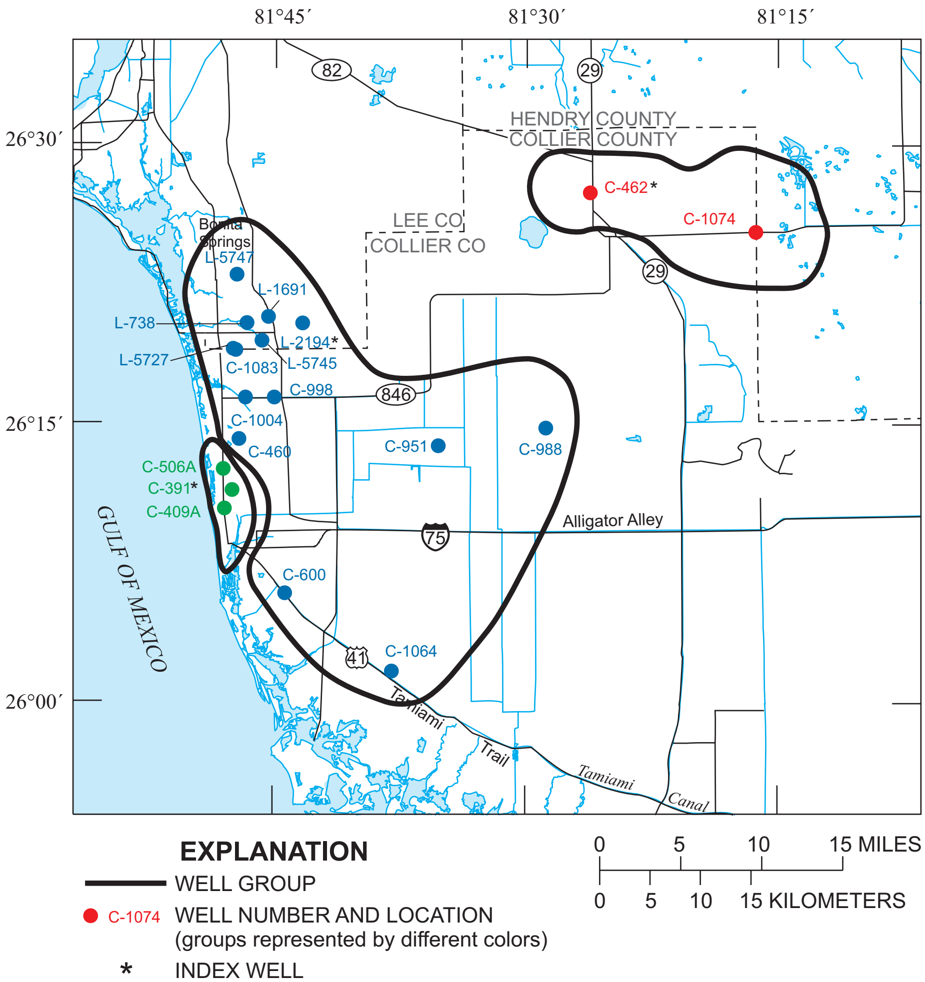


Figure 16. Network coverage defined by R^2 analysis using index wells in the lower Tamiami aquifer.

the majority of continuous monitoring wells in the lower Tamiami aquifer (table 5), well L-738 has already been equipped with satellite telemetry. This well also is monitored for chloride concentration, and there has been a statistically significant (+6.7 mg/L per year) upward trend in chloride concentration over the last 25 years (fig. 15B and table 3). Geographically, well L-738 is one of the closest wells to well L-2194. Regression analysis indicated that water-level data from well L-738 could be used to estimate water levels at 14 other wells with an R^2 value of 0.64 or greater. This included all of but one of the wells where water levels could be estimated using data from well L-2194. Well L-738 has daily water-level record for only about 8 years (app. I), and as such, was not evaluated for water-level trends. Despite this lack of long-term water-level data, the increasing chloride concentrations in this well provide a good reason for considering it to be a key indicator site. However, because this trend was likely caused by leakage in a well that has now been plugged (Schmerge, 2001), chloride concentrations in this area may decrease. Well L-2194 is, therefore, still considered to be the best of the two possible index wells. Table 7 provides information concerning well construction and analysis results for the three proposed index wells and wells C-492 and L-738.

Sandstone Aquifer

During the period of record, monthly mean water levels in the sandstone aquifer averaged 14 ft above sea level (app. III), but there is a broad area in north-central Collier County and southeastern Lee County where monthly mean water levels have reached as low as 0.26 to 31.81 ft below sea level (app. III; wells C-989, C-1079, L-731, L-1998, and L-2215). The lowest monthly mean water level (-31.81) was determined at well L-1998.

Water-Level and Chloride Concentration Trend and Correlation Results

Water levels at wells L-731 and C-1079 increased during 1986-99, but decreased during this same period in a large part of the sandstone aquifer at wells L-729, L-1994, and L-1998 near Lehigh Acres (fig. 17). Well L-1998 is close to the center of a major cone of depression in the sandstone aquifer. Effects of municipal water withdrawals are pronounced in monitoring well L-1998, which probably explains why water-level data from other monitoring wells cannot be used to estimate water levels in this well with any degree of certainty. Well L-1998 has the largest statistically significant water-level trend observed in this aquifer. The Seasonal Kendall Slope Estimator (SKSE) for well L-1998 was -1.02 ft/yr from 1974

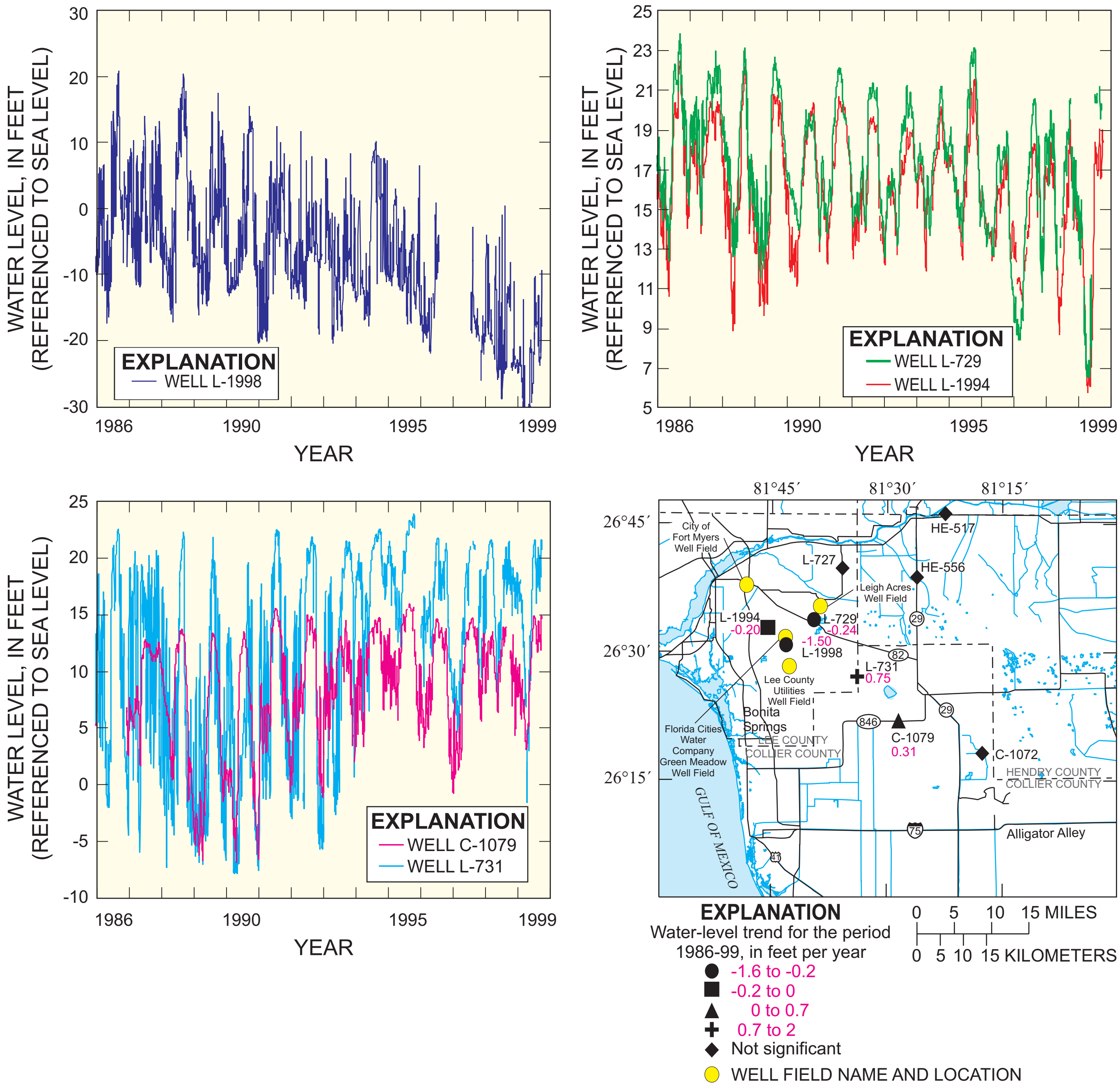


Figure 17. Statistically significant trends in water level at selected wells in the sandstone aquifer.

to 1999 (app. II). From 1986 to 1999, the estimate was -1.50 ft/yr. The top of the sandstone aquifer near well L-1998 (app. III) is about 40 ft below sea level (estimated from a structural contour map by Wedderburn and others, 1982). Because monthly mean water levels of -31.81 ft have already been observed in well L-1998 (app. III), and if the trend of -1.5 ft/yr were to continue, water levels would drop below the top of the aquifer during droughts beginning in 2005.

Long-term analysis of chloride concentration trends at three wells in the sandstone aquifer indicated one downward trend (table 3; -6.67 mg/L per year at well C-303) and one upward trend (table 3;+0.56 mg/L per year in well C-688). No correlation between water levels and chloride concentrations was found at the wells analyzed in the sandstone aquifer.

Discussion of Well Coverage

In the sandstone aquifer, wells HE-556, L-727, L-731, L-1998, L-2186 and L-2215 are currently equipped with satellite telemetry. The network R^2 value for the existing Data Collection Platforms (DCP) network is 0.83, and it would cover 85 percent of the wells in the continuous monitoring network.

Regression analysis, consideration of existing satellite telemetry, and analysis of water- level trends and minimums indicated that water-level data from 6 monitoring wells in the sandstone aquifer could be used to estimate water levels or provide direct coverage for 95 percent of the 19 continuous monitoring wells (excluding L-1996) with an R^2 value of 0.85 on average. This proposed network includes index wells C-1079, HE-556, L-729, L-731, L-1998, and L-2186 (tables 5 and 6).

Monitoring well L-1996 was considered as a possible index well. Preliminary regression analysis indicated that this well would have been a better index well than well C-1079. However, investigation of the construction of well L-1996 using a borehole camera and examination of well construction records indicated that this well was probably open to multiple aquifers, and therefore, would not be a good candidate for an index well. Implementing the proposed network by transferring the satellite telemetry from wells L-727 and L-2215 to wells L-729 and C-1079 improves overall network coverage by 10 percent, improves average period of record per monitoring index well from 20 years on average to 21 years on average, and improves the average network R^2 value from 0.83 to 0.85 (tables 5 and 6).

Water-level data from well L-729 can be used to estimate water levels at well L-2215 with an R^2 value of 0.95 (table 5). This relation is shown in figure 18. The advantage of using well L-729 in lieu of well L-2215 is that well L-729 has a much longer period of record (app. I) and indicates a significant downward trend in water levels during 1986-99 (app. II).

Water-level data from either well C-1072 or well HE-556 can be used to estimate water levels for the same group of wells. The average R^2 value for these comparisons is much better for well C-1072 (0.83) than for well HE-556 (0.76); however, well HE-556 has 23 years of data, compared to the 13 years of data

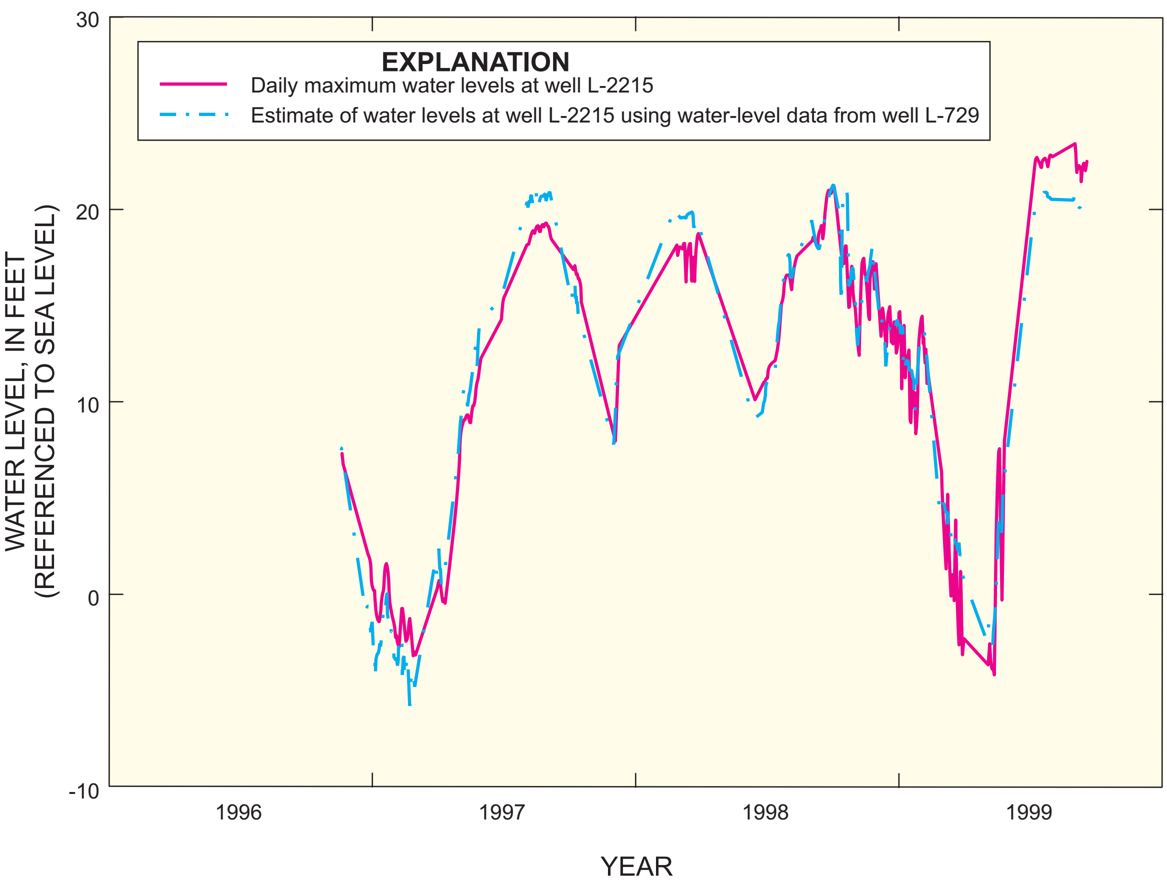


Figure 18. Comparison of water levels at well L-2215 and water levels estimated at well L-2215 using water-level data from well L-729.

available for well C-1072 (app. I). Therefore, well HE-556 would be a better index well based on the longer period of record.

The satellite telemetry for well L-727 is redundant because the water-level data from well L-2186 can be used to estimate water levels at well L-727 with an R^2 value for the regression of 0.89 (table 5). This relation is shown in figure 19.

Water levels at wells HE-517 and L-1998 could not be fit with an R^2 value of 0.64 or greater by any of the other monitoring wells that had at least 10 or more years of data on which to base a comparison. Of all the wells in this aquifer that had substantial record, water levels at well HE-517 showed the clearest relation with extreme minimums in rainfall (table 2). The best f_a (0.60) was obtained for the comparison of the lowest 20 percent of smoothed average rainfall deviations and trend adjusted water-level deviations. For this comparison, water-level data were trend adjusted using a linear regression and were not lagged relative to smoothed rainfall deviations (f-value = 1/26) (fig. 20). Because of this relation and because water-level data from other wells in the aquifer could not be used to create a satisfactory estimate of water levels in well HE-517, it would be useful to install satellite telemetry for this well. However, regression analysis indicated that water-level data from well HE-517 was not representative of water levels in other wells. As such, well HE-517 was not proposed as an index well.

Well construction logs indicate that wells L-729 and L-1998 were constructed to have open-hole intervals 22 and 60 ft in length, respectively (app. I). However, the borehole camera logs revealed that the open interval for well L-729 is actually 26 ft and that about 26 ft of the open interval of L-1998 has collapsed. Both wells are open to the aquifer and monitor the water-level changes that occur. Because of this, these wells are still considered to be valuable index wells.

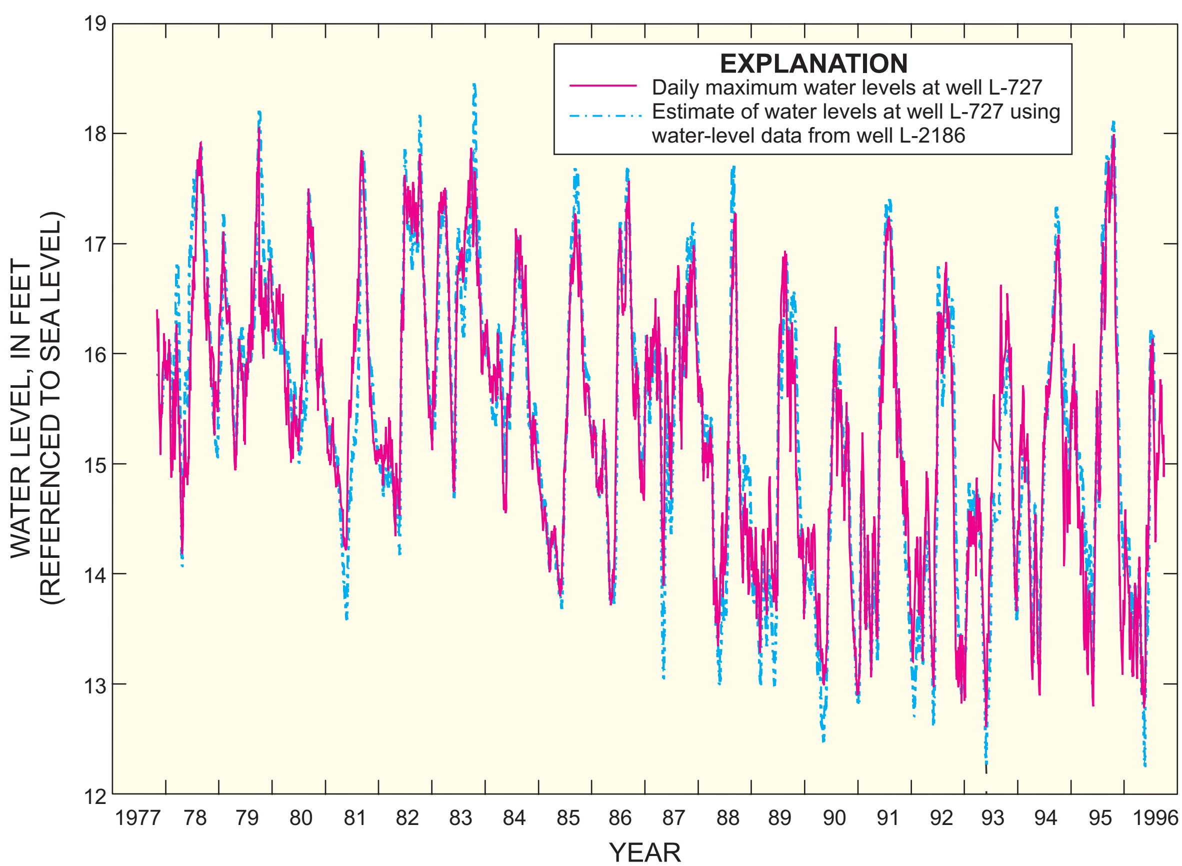


Figure 19. Comparison of water levels at well L-727 and water levels estimated at well L-727 using water-level data from well L-2186.

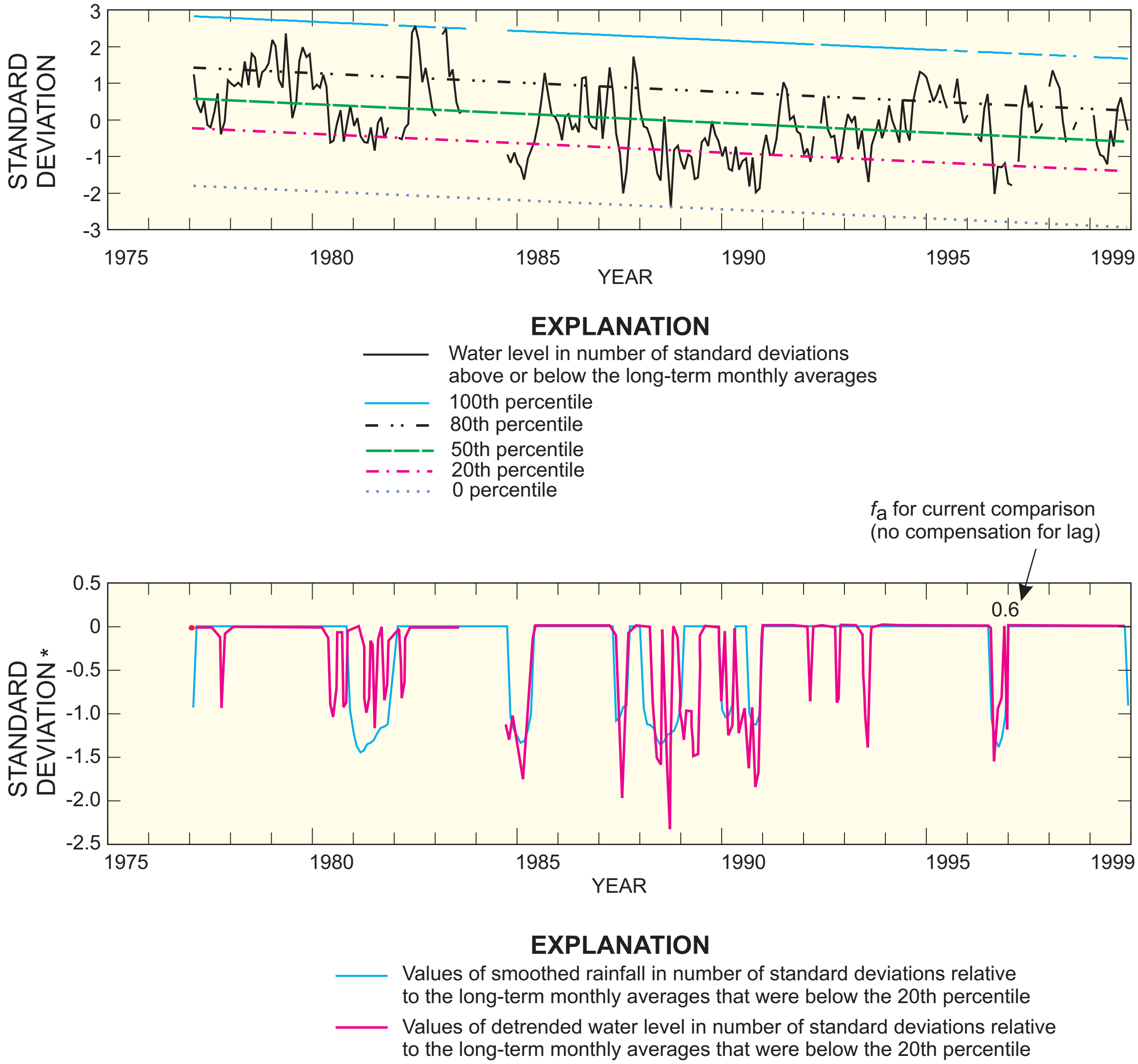


Figure 20. Comparison of smoothed average rainfall deviations (f-value = 1/26) and trend adjusted water-level deviations in well HE-517. The fraction of agreement (f_a) for the lowest 20th percentile of the data was 0.60. For this comparison, water level was detrended using a linear regression and was not lagged relative to smoothed rainfall. Asterisk represents standard deviation below the long-term monthly averages of water level and rainfall. These values for rainfall have been multiplied by 3 so that the resulting rainfall values can be readily compared to the water-level results. This multiplication does not affect the f_a.

Wells C-1079, HE-556, L-731, and L-1996 are all partially obstructed by floats, float tapes, or sampling equipment (table 7 and app.1). Borehole camera examination clearly shows that the majority of the screened interval of well HE-556 is still free of obstruction or defect, and the well is 20 ft deeper than indicated in construction notes. A sampling hose in well L-731 obstructs the well at the depth that the open-hole segment should occur. It is likely that the open- hole segment of this well has collapsed around the sampling hose, which has caused it to become lodged in the well. The borehole camera could not maneuver around the obstruction in well C-1079. If additional examination were to indicate that well C-1079 is not functional, monitoring well C-989 could be used as a replacement without impairing real-time network coverage. The open interval of well C-989 has almost completely collapsed, but the well is still open to the sandstone aquifer.

Figure 21 shows the parts of the network that could be covered by index wells C-1079, HE-556, L-729, L-731, L-1998 and L-2186. Table 7 summarizes basic well construction and analysis results for the proposed index wells and wells C-989 and L-1996.

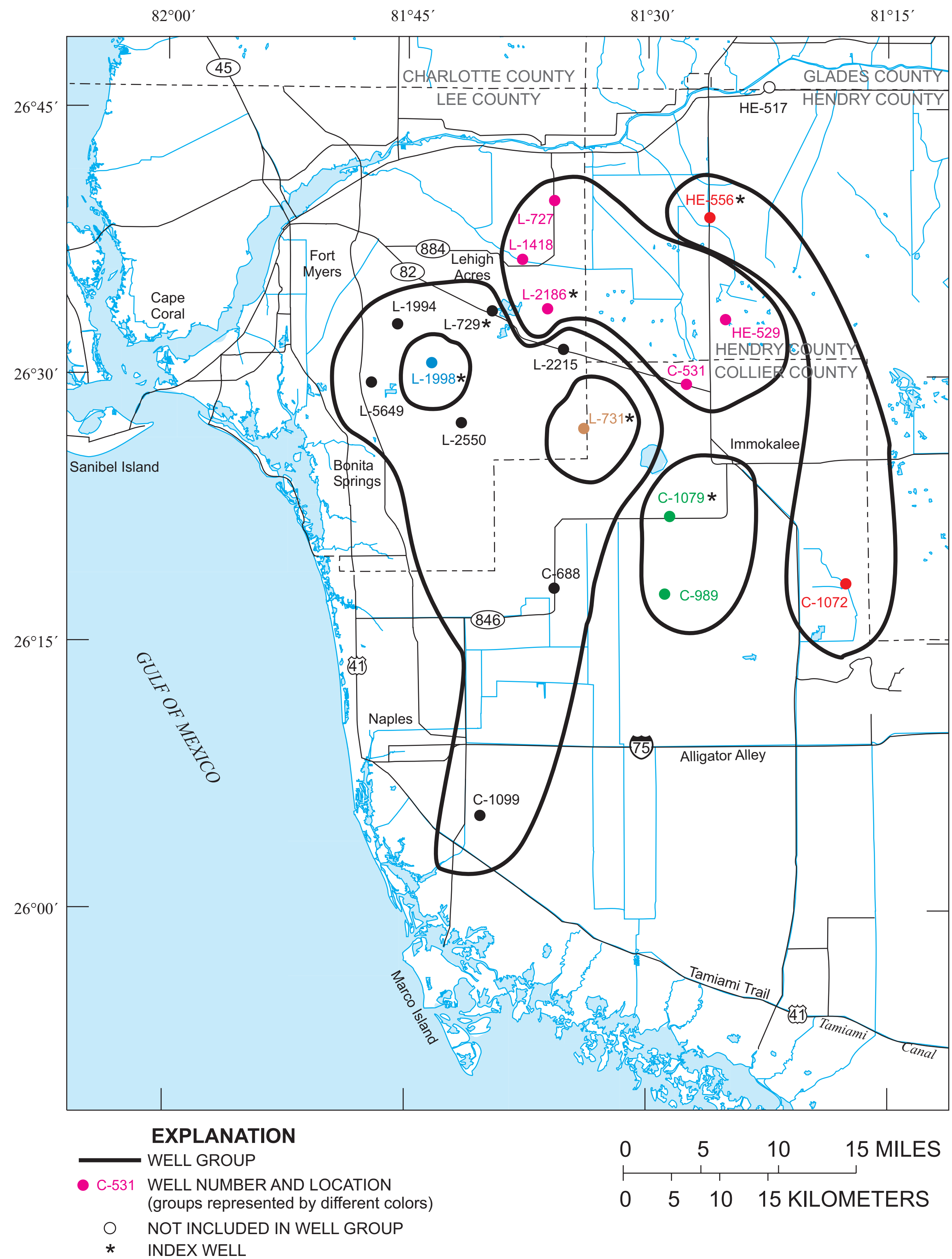


Figure 21. Network coverage defined by R^2 analysis using index wells in the sandstone aquifer.

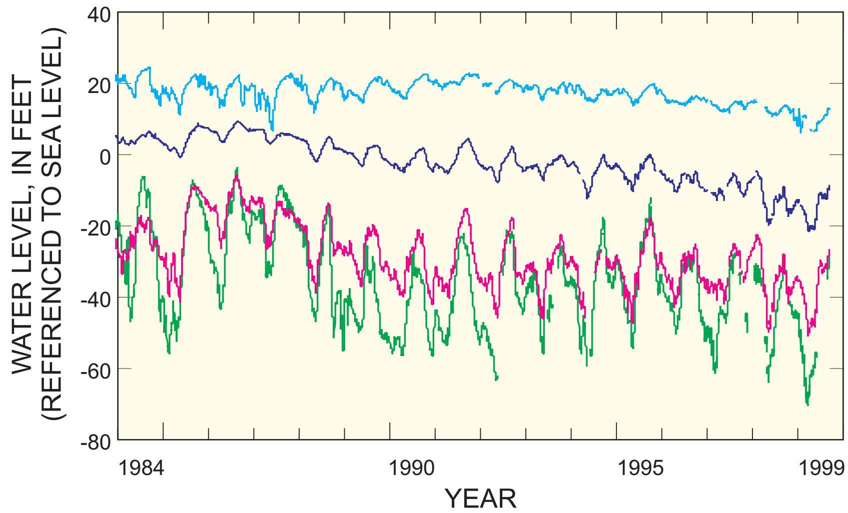
Mid-Hawthorn Aquifer

For the period examined (1974-99), the lowest monthly mean water level recorded was 76.02 below sea level at well L-742 (app. III). Monthly mean water levels averaged about 15 ft below sea level. The interquartile range of monthly mean water levels at monitoring wells in the mid-Hawthorn aquifer averaged about 11 ft and ranged from 5.00 ft in well L-2193 to 23.18 ft at well L-742 (app. III). Because the period of record for each well was highly variable, these statistics are probably not as representative of aquifer conditions as would be provided by longer records.

Water-Level and Chloride Concentration Trend and Correlation Results

There are strong downward trends in water levels at wells L-581, L-742, L-1993 and L-2644 for the 1984-99 period (fig. 22). During this period, water-level decreases at these wells averaged close to 1 ft/yr (app. II). The rate of decline was lowest at well L-1993 (-0.39 ft/yr) and highest at well L-742 (-1.34 ft/yr). The water-level recorder at monitoring well L-2703 was discontinued in 1996, and therefore, the well could not be analyzed for the full period (1984-99). However, from 1984 to 1995, this well also indicated a decline in water levels of 1.03 ft/yr (app. II).

Chloride concentrations at the majority of locations sampled in the mid-Hawthorn aquifer have declined or do not show any significant trend. The largest declines in chloride concentration were found at monitoring wells L-735 (-35.0 mg/L per year over 19 years), L-2702 (-3.92 mg/L per year over



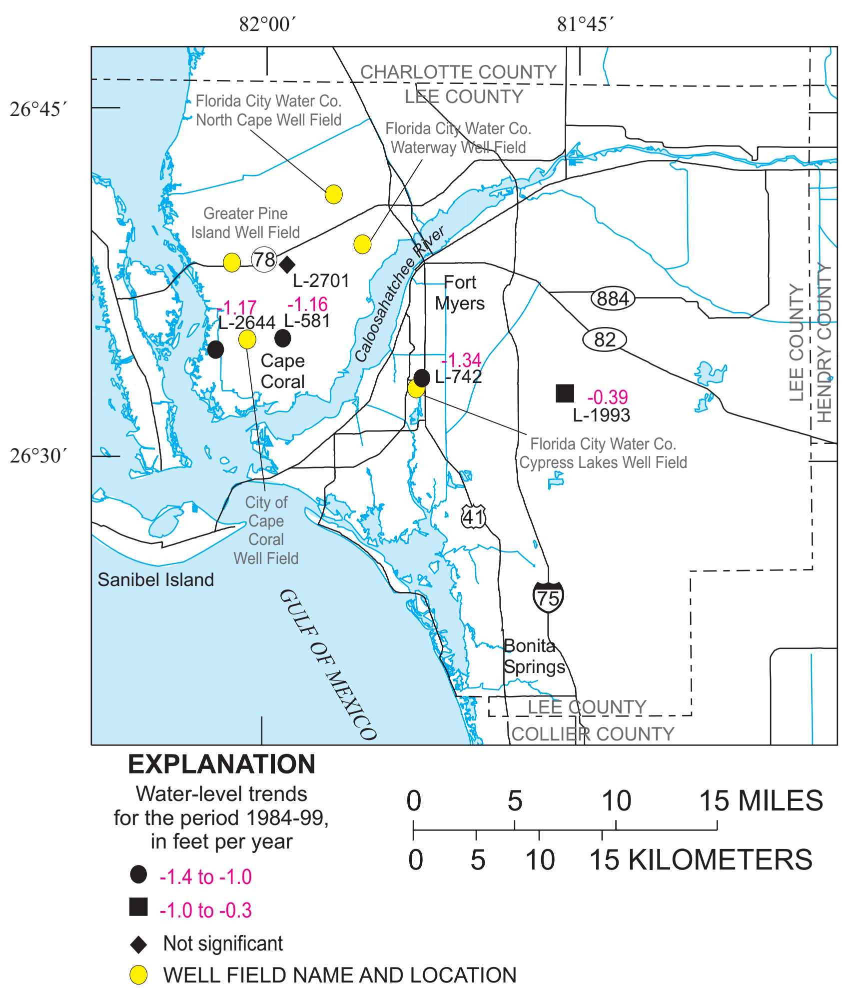


Figure 22. Statistically significant trends in water level at selected wells in the mid-Hawthorn aquifer.

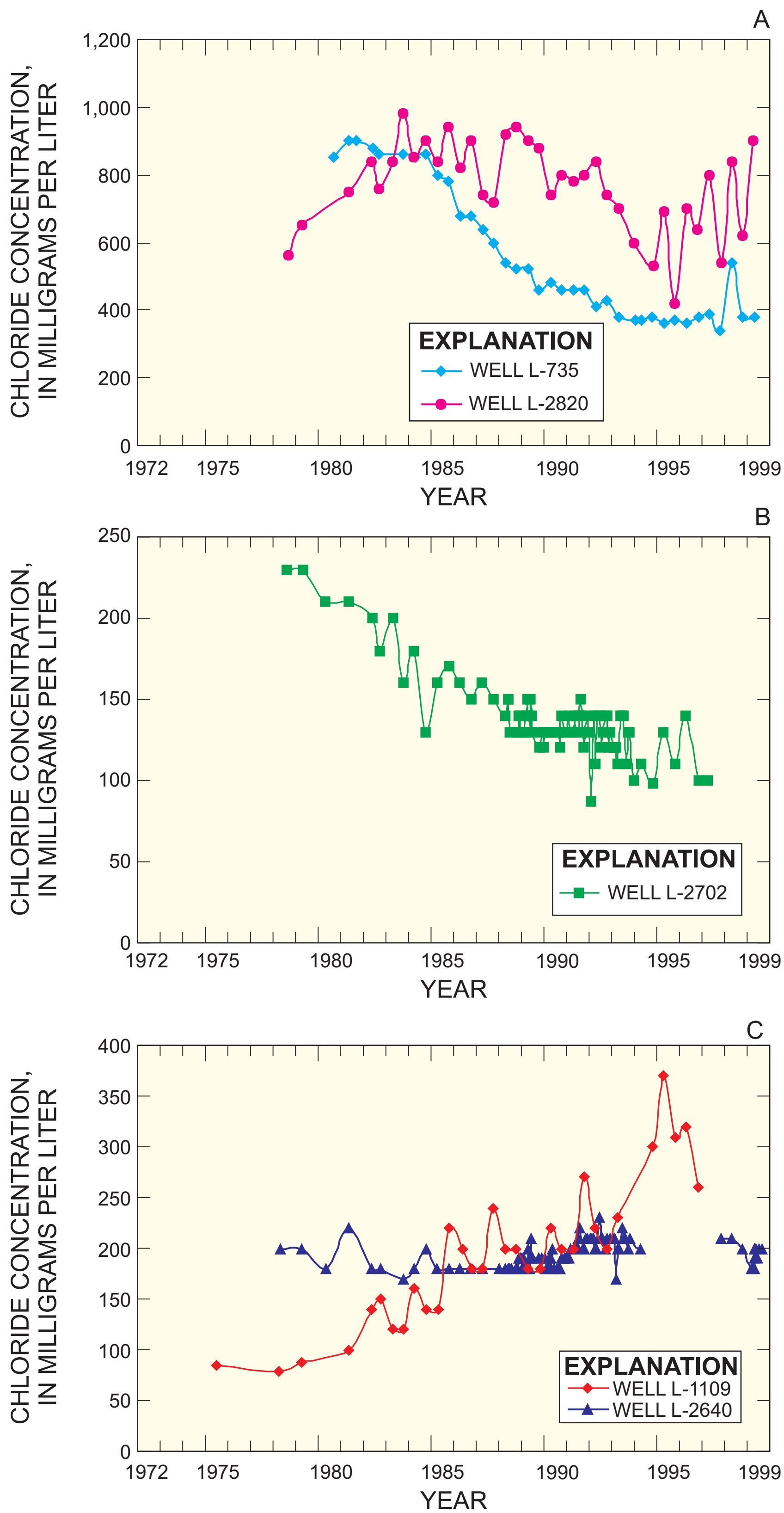


Figure 23. Chloride concentration trends at wells L-735, L-2820, L-2702, L-1109 and L-2640 in the mid-Hawthorn aquifer.

20 years), and L-2820 (-15.6 mg/L per year over 21 years) (fig. 23A-B and table 3). Chloride concentrations in water at well L-735 were initially near 900 mg/L and have declined to about 400 mg/L. Changes in chloride concentrations in well L-2820 have been more variable. Changes in chloride concentration between water samples of about 200 mg/L are common. However, between 1993 and 1999, chloride concentrations in water at well L-2820 increased from about 700 to 900 mg/L.

Chloride concentrations have increased at three wells; the largest increases were 10 mg/L per year at well L-1109 (with 23 years of data) and 2.5 mg/L per year at well L-2640 with 18 years of data (fig. 23C and table 3). Unfortunately part of the open interval of well L-1109 collapsed (from 230 to 80 ft apparently in 1996), which prevented additional chloride water samples from being collected. In both cases, chloride concentrations have been near or greater than the 250-mg/L limit for drinking water (Florida Department of Environmental Protection, 1993), so increases in chloride concentration in these areas is a concern. A minimal increase in chloride concentration (+1.0 mg/L per year) occurred at well C-1080, but this well only has 13 years of data.

Fitzpatrick (1986) indicated that a major cause of saltwater contamination in the mid-Hawthorn aquifer was leakage through nearly 8,000 (2-in. diameter) steel-cased wells that were drilled into the aquifer. As pumpage in the mid-Hawthorn aquifer increased and head in the aquifer fell below that of overlying aquifers, leakage in many of these wells permitted downward movement of saline water from overlying aquifers.

Other wells were open to both the lower Hawthorn aquifer and deeper saline aquifers. Saltwater was allowed to flow freely between these aquifers. A pilot well plugging program was initiated by the SFWMD in 1979 and established criteria to plug all flowing wells by 1992 (Burns, 1983). The subsequent declines in chloride concentration observed may be the result of this well plugging program. La Rose (1990) documents a slight decrease in chloride concentrations in part of the mid-Hawthorn aquifer where well plugging had been completed. The increases found at wells L-1109 and L-2640 could be the result of movement of the existing saltwater contamination within the aquifer.

Water levels and chloride concentrations were positively correlated at wells L-735 and L-2244 (table 4). Spearman's r coefficients were 0.74 and 0.52 respectively. Pearson's r values for these wells were 0.74 and 0.53, respectively. At well L-735, this relation may be caused by corresponding long-term declines in both chloride concentration (table 3) and water level (Prinos and Overton, 2000). As previously discussed, the decline in chloride concentration may be related to the well-plugging program.

Discussion of Well Coverage

Regression analysis alone indicated that water levels for 78 percent of the mid-Hawthorn continuous ground-water level monitoring network (nine wells) could be approximated by two monitoring wells (L-581 and L-2644), with an average R^2 value of 0.82. Data from well L-581 alone can approximate water levels or provide direct water-level measurements for 67 percent of the wells in the aquifer (table 5). In the mid-Hawthorn aquifer, wells L-581 and L-2644 are already equipped with satellite telemetry. Well L-4820 is equipped with a conductivity probe so that changes in chloride concentration in this area of the aquifer can be monitored in real time. Well L-4820 is about 1 mi east of well L-1109 and about 4 mi northwest of L-2640 (fig. 10) where increases in chloride concentration have been observed (table 3).

When minimum water levels in relation to the mid-Hawthorn and overall coverage are considered, well L-742 (instead of well L-2644) and well L-581 are the preferred choices for index wells in the proposed network. Well L-742 is the lowest point of the cone of depression in the mid-Hawthorn aquifer defined by the USGS water-level monitoring network. The lowest maximum daily water level recorded for this well was 78.61 ft below sea level on May 16, 1974, and water levels of about 70 ft below sea level were reached in the 1999 water year (Prinos and Overton, 2000). Estimating from the structural contour map of Wedderburn and others (1982), the top of the mid-Hawthorn aquifer is about 125 ft below sea level at well L-742. The top of the aquifer varies in depth from 125 to 175 ft below sea level at wells L-581, L-2644, and L-2703. Because minimum water levels at well L-742 are closer to the top of the aquifer, this is considered to be a more valuable index well than well L-2644. The percentage of network coverage is the same (78 percent), but the mean R^2 value for the proposed network increases to 0.86 (tables 5 and 6). This is because the R^2 value from the regression of data from well L-2644 against that of well L-742 is only 0.65, whereas data from well L-581 provided an excellent fit when regressed against the data of well L-2644 (R^2 value = 0.93; table 5). Thus, overall coverage would be improved by the addition of well L-742, which cannot be estimated as accurately as well L-2644 using data from well L-581.

When well L-742 was constructed, it was cased to a depth of 136 ft below land surface and open to the mid-Hawthorn aquifer from 136 to 225 ft (app. 1); however, 25 ft of the open-hole section of this well has collapsed. Well L-581 is cased to a depth of 107 ft below land surface and was originally open to the aquifer from 107 to 177 ft. The bottom 7 ft of this open-hole interval has collapsed. In both of these wells, most of the open interval is still open and water levels still represent changes occurring in the aquifer; these problems should not adversely affect water-level monitoring at these wells. Figure 24 shows parts of the network that can be estimated using wells L-581 and L-742. Table 7 includes basic well construction and analysis results for the wells discussed.

Surficial Aquifer System

As indicated in the discussion of the hydrogeologic setting, the surficial aquifer system in this part of the study area is not differentiated into locally named aquifers. For the period of record examined (1974-99), the lowest monthly mean water level recorded in this aquifer system was 2.50 ft below sea level at well PB-1491 (app. III). In comparison to the deeper aquifers of southwestern Florida, the surficial aquifer system in Martin, Palm Beach, and St. Lucie Counties does not show much variation in the monthly means of daily maximum water levels. Interquartile ranges for these wells vary from 3.23 ft at well PB-1491 to only 0.33 ft at well PB-900 (app. III). Average monthly mean water level for the aquifer was 14.48 ft above sea level; however, this average includes data from many wells that do not have data for the full period examined.

Water-Level and Chloride Concentration Trend and Correlation Results

Of the nine wells that had enough record for examination of water-level trends during 1974-99, four wells (44 percent) showed upward trends. Trends ranged from +0.05 to +0.13 ft/yr at wells PB-683, PB-809, PB-831, and PB-99 (app. II). None of the wells examined for this full period indicated any downward trends in water levels. Downward trends, however, were found at several wells for shorter periods. Water levels at wells PB-445 and PB-732 decreased by 0.02 and 0.28 ft/yr, respectively, during 1974-81 (app. II). Wells PB-565 and PB-900 showed water-level declines of 0.23 and 0.03 ft/yr, respectively, during 1981-91 (app. II). Water levels at well PB-445 declined by 0.07 ft/yr during 1991-99.

Fourteen wells located in the surficial aquifer system in Martin and Palm Beach Counties were tested for chloride concentration trends, with the results indicating that three (21 percent) of the wells showed downward trends (table 3). Trends of -3, -300, and -2 mg/L per year were determined at wells M-1052, PB-595, and PB-1669, respectively. There was not enough chloride concentration data from St. Lucie County to perform a trend analysis. No statistically significant correlation between water levels and chloride concentrations was found for the wells examined in the surficial aquifer system.

Discussion of Well Coverage

In the surficial aquifer system in the northeastern part of the study area, water levels at many of the

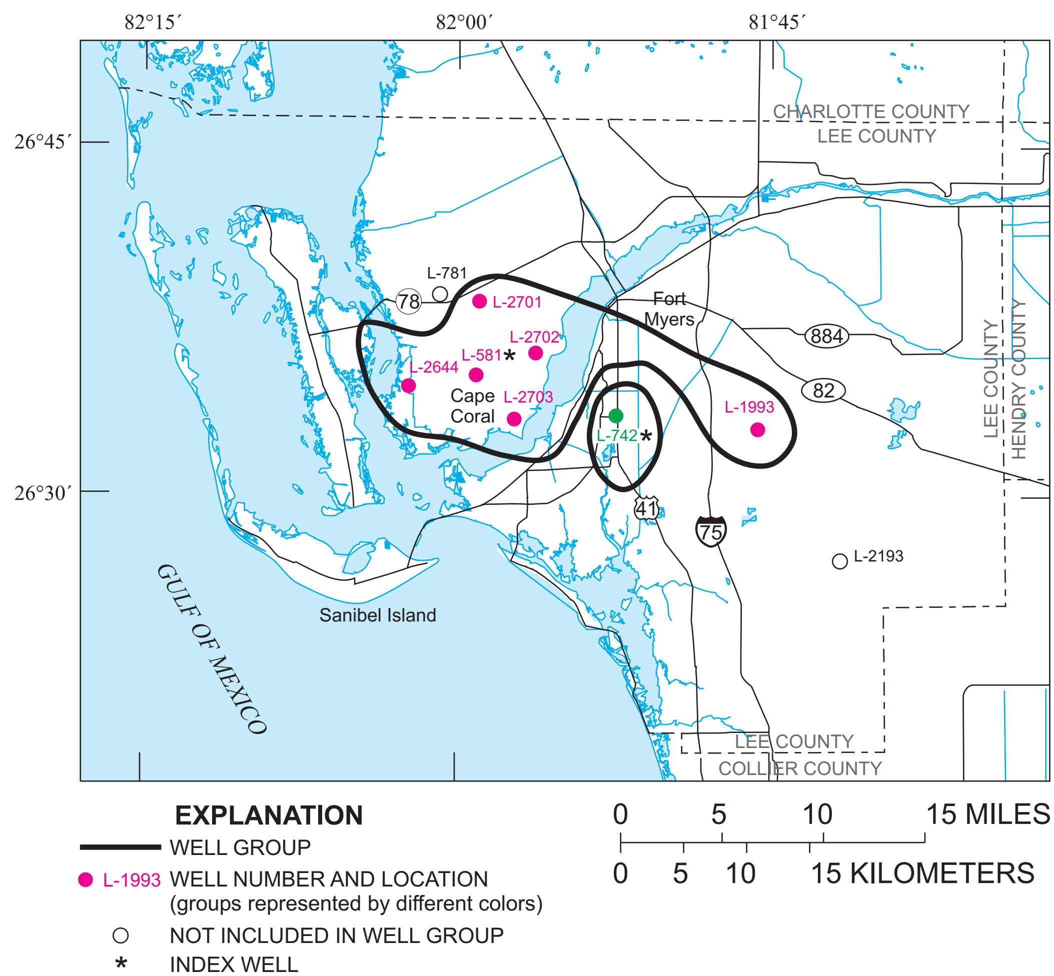


Figure 24. Network coverage defined by R^2 analysis using index wells in the mid-Hawthorn aquifer.

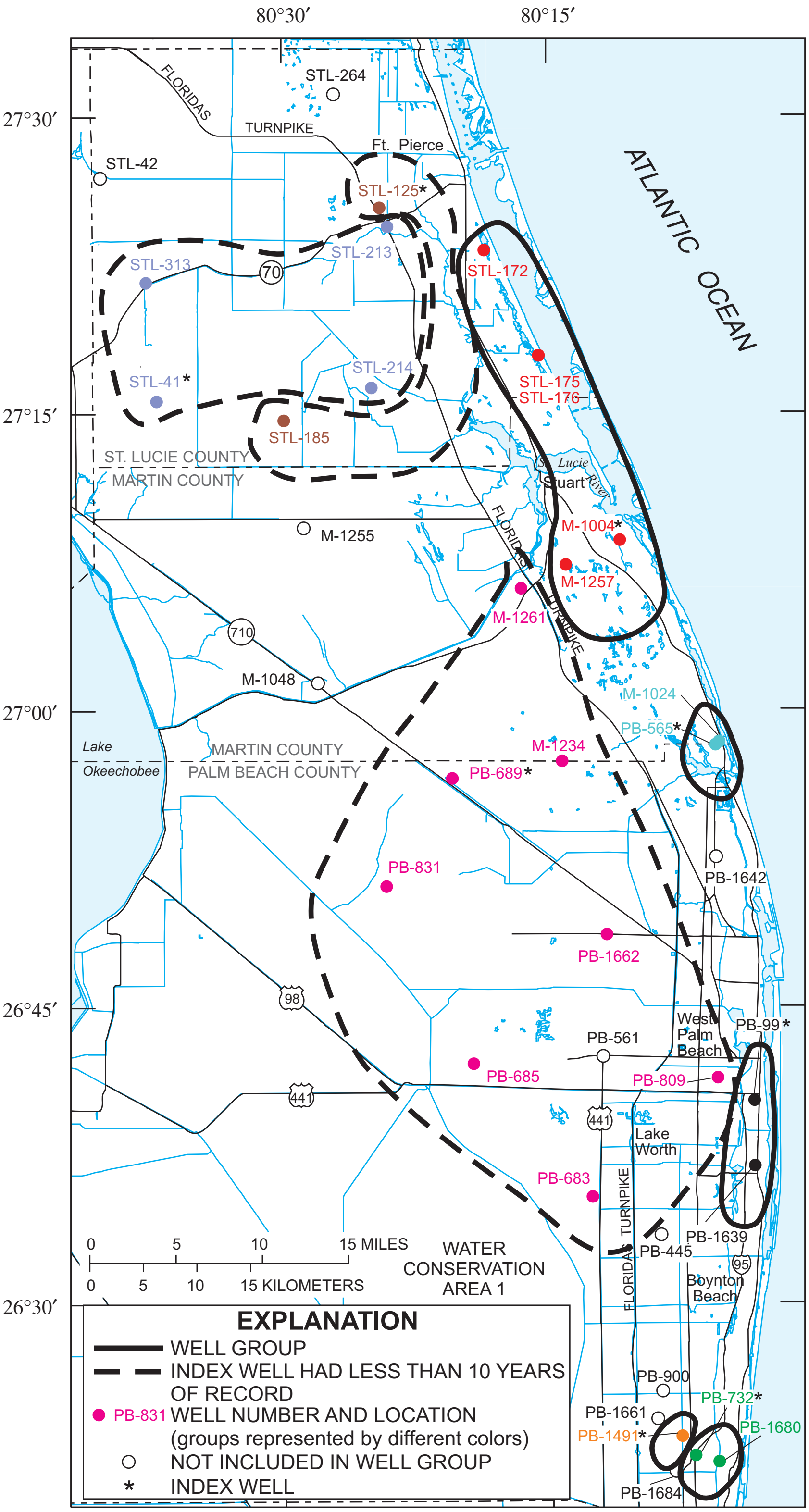


Figure 25. Network coverage defined by R^2 analysis using index wells in the surficial aquifer system. Wells STL-125, STL-41, and PB-689 have less than 10 years of data and normally would not be considered as potential index wells. However, few ground-water monitoring wells in these areas have additional data.

wells could not be estimated as accurately as in other aquifers. More index wells were needed in this area than in other aquifers, and even with these additional index wells, the average R^2 value for the resulting network was lower, and overall coverage was less. Considering the regression analysis alone, six monitoring wells (M-1004, PB-99, PB-689, PB-732, STL-41, and STL-125) could be used to provide or estimate water levels with an average R^2 of 0.82 at 26 of the 36 network wells examined. This corresponds to about 72 percent of the wells examined.

The proposed real-time network also includes wells PB-565 and PB-1491 as index wells, which improves coverage by providing better estimates of water levels. With these two wells added, the average R^2 value for the network is 0.85. The average period of record for these eight index wells is 23 years. The first four wells in this list actually provide the majority of the network coverage (table 5; 61 percent). The remaining four wells only add the ability to estimate water levels at a few additional wells (fig. 25; tables 5 and 6).

A -3 mg/L chloride concentration trend was indicated at well M-1052 (table 3). However, considering the normal variation in chloride concentration data from this well, the trend is minimal and does not require the addition of real-time monitoring.

This proposed real-time network includes wells to aid in the assessment of minimum water levels, agreement with decreased rainfall, and water-level and chloride concentration trends. This network also would involve considerably less effort to initiate than other possible networks because it makes use of the existing satellite telemetry. For example, well PB-565 is less than 0.5 mi from well PB-595 (figs. 5 and 10) where chloride concentrations have substantially decreased (table 3).

During a drought period on April 14, 1989, maximum daily water levels at well PB-1491 reached an elevation of 3.04 ft below sea level (Prinos and Overton, 2000). As previously mentioned, during this same drought, monthly mean water levels declined to 2.50 ft below sea level (app. III). Well PB-1491 is near the coast where sustained water levels below sea level can lead to saltwater intrusion. Of the wells that had more than 10 years of record (after considering missing record), well PB-1491 showed the greatest agreement with reductions in rainfall. The f_a determined for this relation was 0.63 (table 2). Even though there are a number of continuous monitoring wells near this well, none of the other wells in the surficial aquifer system with more than 10 years of record could be used to estimate water levels at well PB-1491 with an R^2 value greater than 0.64 (table 5). As a result, well PB-1491 would be a useful index well.

Of the potential index wells in this area, four already have satellite telemetry installed. These are wells M-1004, PB-565, STL-125, and STL-175. All but one of these, well STL-175, is included in the alternate network. Water levels at well STL-175 can be estimated using data from well M-1004 with an R^2 value for the regression of 0.70 (fig. 26 and table 5). Well M-1004 has a longer period of record than well STL-175 (app. I), and would, therefore, be the more useful of the two.

Water levels at well PB-565 could be estimated using data from well PB-689, but well PB-565 has a much more extensive period of record (table 5 and app. I). Because of this, the satellite telemetry for well PB-565 is still beneficial. Data from well PB-565 can also be used to estimate water levels at some, but not all, of the wells estimated using data from well PB-99.

Water levels at well STL-125 could not be estimated using data from any other well that had 10 years or more of data. Unfortunately, many wells in this area do not have much data available for analysis. Well STL-125 has about 9 years of data available (table 7 and app. I). Based on these limited data, water levels at several other

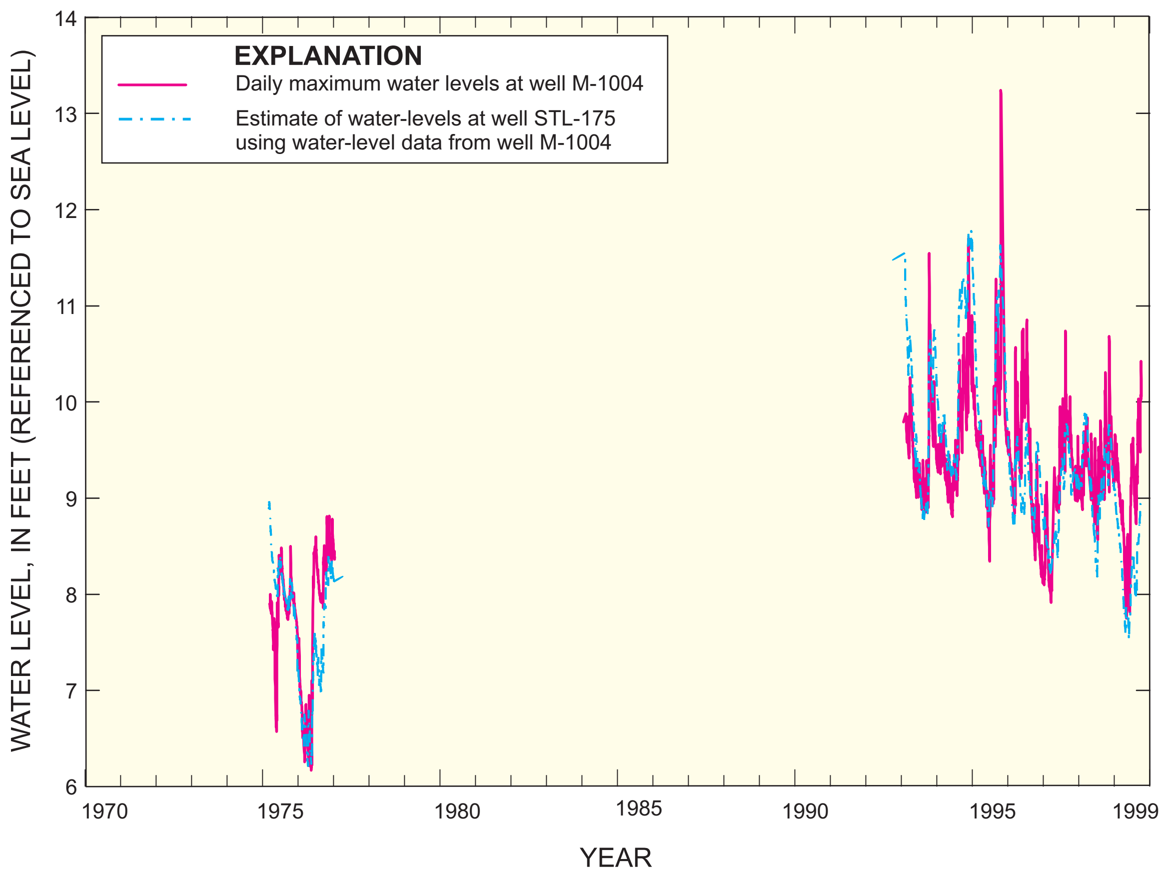


Figure 26. Comparison between water-level data from well STL-175 and estimation of water levels using data from well M-1004.

wells may be estimated using data from well STL-125. Analysis showed relatively good agreement with wells M-1261, PB-683, PB-689, STL-185, and STL-213. Well STL-125 could potentially be used to increase network coverage to 72 percent (table 5). Although this well has only about 9 years of data, it already has satellite telemetry, and the water-level data are not redundant. Therefore, well STL-125 has been suggested as a real-time index well in the proposed network. Basic well construction and statistical information for the proposed index wells is listed in table 7.

In 2001, index well STL-41 became plugged by clay from the formation (table 7 and app. I). Prior to this problem, the well was responding to changes in water levels in the surficial aquifer system and was representative of changes occurring in several wells. A replacement well is needed. A float and float tape were found to be obstructing well PB-1491 at a depth of 80 ft below land surface. These obstructions were removed, but the casing has filled with sand from the formation up to a depth of 80 ft (table 7 and app. I). This sand does not impede the changes in water levels at this well. Therefore, the well is still functional.

Biscayne Aquifer

The lowest monthly mean of daily maximum water levels in the Biscayne aquifer was 13.86 ft below sea level and was recorded at well G-2395 near the City of Fort Lauderdale Prospect Well Field (fig. 27). Water levels at this well have dropped to about 15 ft below sea level several times since 1992 (Prinos and Overton, 2000). The average interquartile range of the monitoring wells examined in the

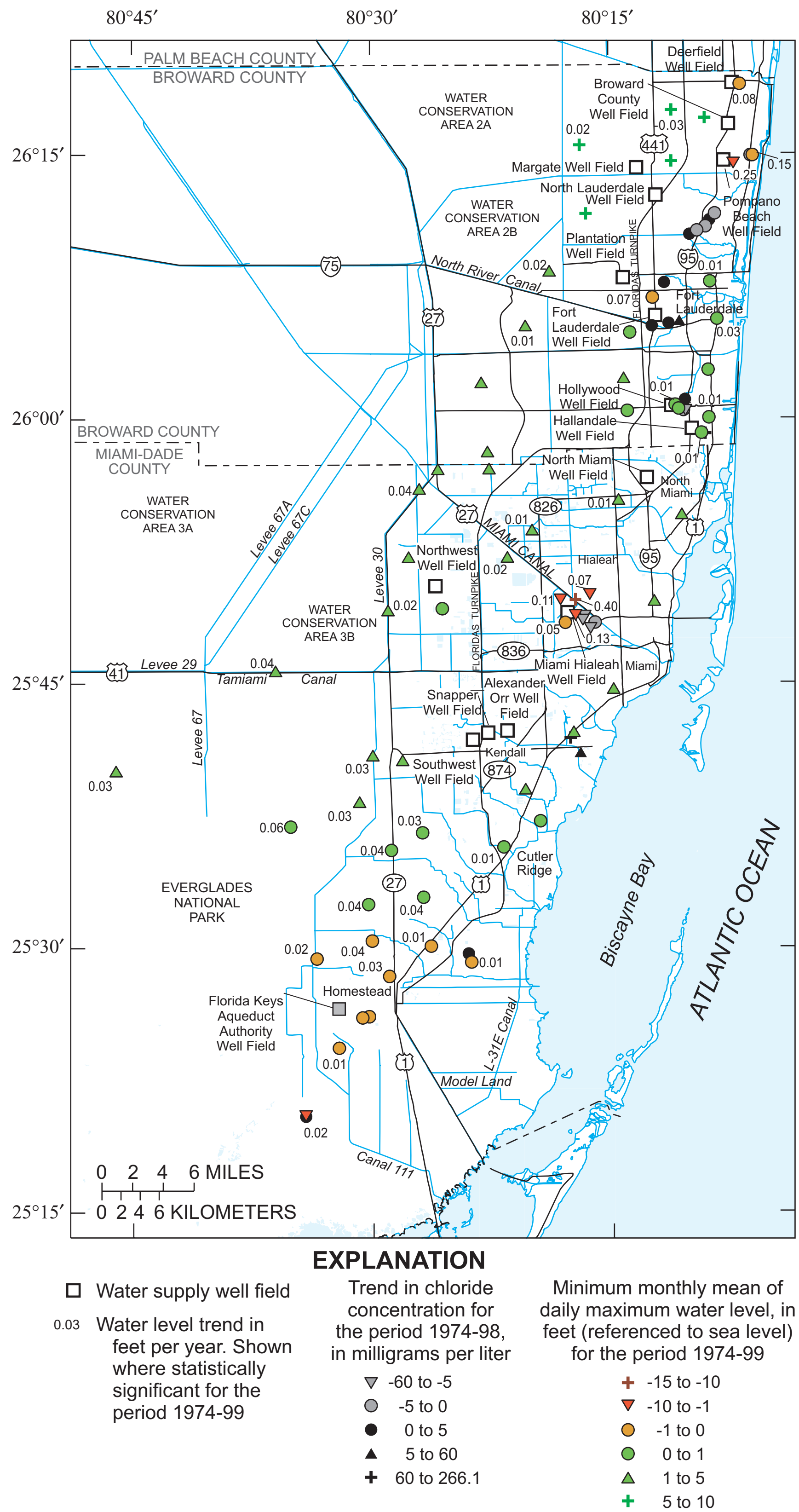


Figure 27. Comparison of minimum monthly means of maximum daily water levels and long-term trends in water level and chloride concentration in the Biscayne aquifer.

Biscayne aquifer was 1.15 ft and ranged from 11.36 to 0.27 ft (app. III). Mean water levels tend to be highest in the north and in the water-conservation areas. They are lowest near the coast and in the southern part of the aquifer. Near most of the major well fields in the Biscayne aquifer, water-level minimums below sea level have been recorded (fig. 27). Of the 133 monitoring wells examined, 28 wells had recorded monthly means of daily maximum water levels that were below sea level (app. III). Nine of these wells are located in a broad area around Homestead (fig. 27).

Water-Level and Chloride Concentration Trend Results

Of the 60 wells that have water-level data for the1974-99 period, 67 percent showed a significant upward trend in water level (app. II and fig. 27). Only one of the wells tested for this period, G-1213, indicated a downward trend (app. II; -0.03 ft/yr). Generally upward trends of 0.01 to 0.02 ft/yr occur near the coast. In and around Everglades National Park, water levels have increased by 0.01 to 0.06 ft/yr. The largest increases in water levels occurred in northern Broward County (0.25 ft/yr in well G-853) and near the Hialeah-Miami Springs Well Field in Miami-Dade County (fig. 27) where water levels increased by as much as 0.40 ft/yr (in well G-1368A). The actual trends near the Miami Springs-Hialeah Well Field were not linear, instead water levels increased sharply in late 1983.

Nine of the wells analyzed show strong influence from historical changes in pumpage at the Hialeah-Miami Springs Well Field. Between 1984 and 1992, pumpage in this well field was reduced because of industrial contamination in the supply wells (Sonenshein and Koszalka, 1996). As a result of this change in pumpage, water levels in surrounding monitoring wells follow a pattern that is unique to this area (fig. 28A).

Because many of the wells in the Biscayne aquifer had only partial record during 1974-99, more wells could be analyzed when trends were assessed during shorter periods. During 1974-83, it was possible to examine water-level data from 65 wells for trends (app. II). For this shorter period, fewer wells (28) indicated statistically significant trends, but the trends observed during this period were generally much larger than determined during 1974-99 (app. II). Twenty of the wells, which indicated statistically significant upward trends during 1974-99, generally also indicated a much larger upward trend during 1974-83. These wells increased by 0.22 ft, on average, more in the 10 years from 1974 to 1983 than during the 26-year period from 1974-99. At least some of these increases could probably be attributed to the implementation (1976-84) of an improved conveyance system that was designed to increase the quantities of water from Water Conservation Areas 3A and 3B into southern Miami-Dade County (Klein and Waller, 1985).

Thirty-four (68 percent) of the 50 wells in the Biscayne aquifer tested for chloride concentration trends showed significant trends, with 20 wells (40 percent) having upward trends and 14 (28 percent) having downward trends (table 3). Four of the wells (fig. 10; G-432, G-896, G-901, and G-1180) for which statistically significant increases in chloride concentration were recorded are located near the approximate location of the saltwater interface as determined by Sonenshein (1997).

Chloride concentrations in the Hialeah-Miami Springs Well Field area (fig. 27; wells G-548, G-571, G-1351, and G-1354) increased up until about 1976 because of contamination from the Miami-Tamiami Canal basin. In 1976, a salinity control structure was installed in the Tamiami Canal just east of Le Jeune Road. This structure and another structure on the Miami Canal at N.W. 36th Street allow higher heads to be maintained in this area (Klein and Ratzlaff, 1989). As a result, chloride concentrations in these four wells have been declining (fig. 28B).

The largest upward trends in chloride concentration in the Biscayne aquifer occurred at wells G-432, G-854, G-901, G-1241, and G-1435 (table 3). Wells G-432 and G-901 are located in Miami-Dade County, about 3 mi east of the Alexander Orr Well Field (fig. 27). From 1976 to 1995, chloride concentrations in water at these two wells increased from about 30 to 2,200 mg/L (mostly between 1988 and 1995). Beginning in 1995, chloride concentrations in water at both wells began to decrease. By 1999, chloride concentrations in water at wells G-432 and G-901 decreased to 640 and 1,600 mg/L, respectively (fig. 29). Although the trend analysis described in this report was only performed on data collected up to 1998, it is useful to note that during 2000 and 2001, chloride concentrations in water at both wells increased once again as drought conditions were experienced. At well G-432, a chloride concentration of 2,350 mg/L was measured in April 2001. This was

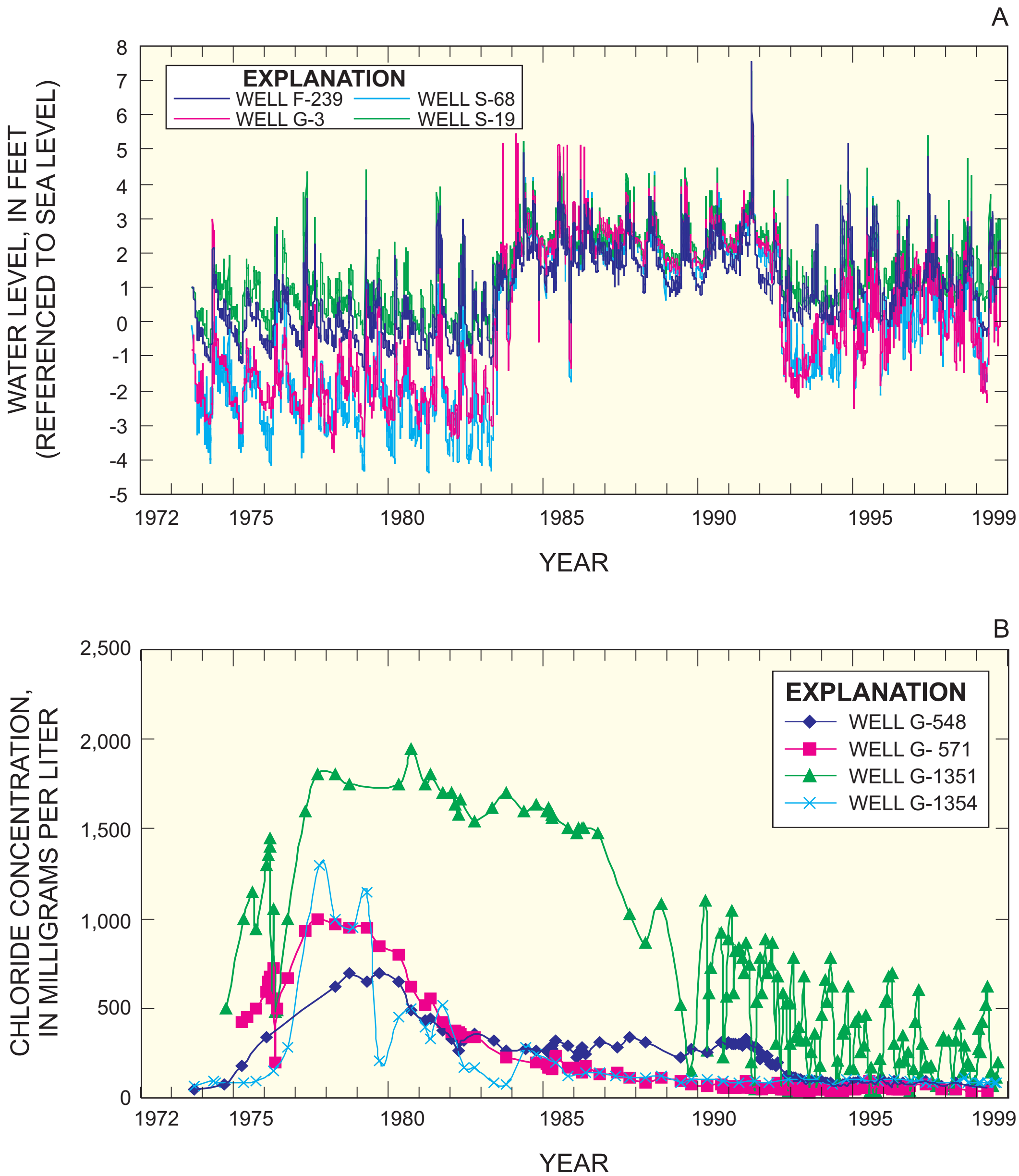


Figure 28. Water-level and chloride concentration trends in selected wells near the Hialeah-Miami Springs Well Field.

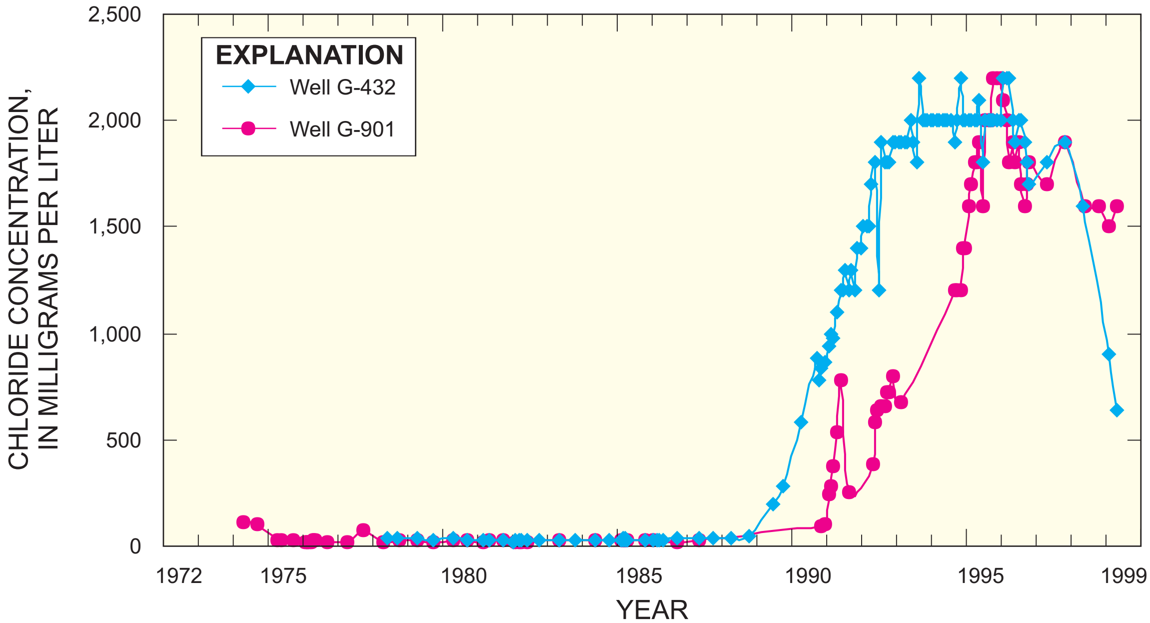


Figure 29. Chloride concentration in wells G-432 and G-901 near the Alexander Orr Well Field.

higher than any previous measurements taken at this well. Chloride concentration in water at well G-901 increased to 2,050 in October 2001. Sonenshein (1997) suggested that the landward movement of the saltwater interface in this area of the Biscayne aquifer could be caused by: (1) decline in water levels at the Alexander Orr Well Field, (2) lowering of water levels in the Coral Gables Canal as a result of reconstruction of the tidal control structure, or (3) combination of both factors.

Wells G-1241 and G-1435 are located in Broward County near Hallandale (fig. 10). Chloride concentrations in water at well G-1435 have increased by 266 mg/L per year on average during 1974-98 (table 3). Koszalka (1995) indicated landward movement of the saltwater interface at well G-1435 and indicated that the interface near the Hallandale Well Field (fig. 27) was between wells G-1435 and G-1473. The landward movement of this interface has continued, and chloride concentrations in water at well G-1435 have increased from 5,500 to almost 8,000 since 1990. Chloride concentrations in water at well G-1473, however, actually declined slightly during 1980-98 (table 3), so the interface remains between these two wells in this area.

Chloride concentration in water at well G-1241 increased from about 70 mg/L in 1981 to about 4,500 mg/L in 1993. Between 1993 and 1998, chloride concentrations in water at this well decreased to as low as 380 mg/L, but by 1999 had risen again to about 1,700 mg/L. Trend tests conducted on chloride concentration data from wells G-2410 and G-2478 also in the Hallandale area indicate increases of about 3 mg/L per year on average over their respective periods of record (fig. 30 and table 3). This trend for well G-2410, however, is not linear. Chloride concentrations in water at well G-2410, for example, increased much more during 1996-99 than during the preceding period.

Chloride concentrations in water at well G-854 near Fort Lauderdale have increased from about 1,000 mg/L in 1975 to about 2,400 mg/L in 1999 (fig. 31A). Other wells a little farther inland of well G-854 and closer to the Fort Lauderdale Well Field have also shown increases over their respective periods of record (fig. 31). Chloride concentrations in water at wells G-1343, G-2125, G-2130, and G-2352 have increased by about 1.5, 0.3, 0.4, and 7.0 mg/L per year, respectively (fig. 31B-C and table 3).

Water-Level and Chloride Concentration Correlation Analysis

Only 4 (10 percent) of the 39 wells located in the Biscayne aquifer in Broward County, for which correlation analyses were performed, demonstrated a statistically significant correlation between chloride concentrations and water levels (table 4). All showed a negative correlation with Spearman's ρ ranging from -0.20 to -0.51 and Pearson's *r* ranging from -0.22 and -0.51. Of 21 wells located in the Biscayne aquifer in Miami-Dade County, 7 wells (33 percent) showed a significant correlation between water levels and chloride concentrations (table 4). At five wells, chloride concentrations and water levels were inversely correlated; at two wells, chloride concentrations and water levels were positively correlated. For the inversely correlated wells, Spearman's ρ ranged from -0.21 to -0.65 and Pearson's ρ ranged from -0.15 to -0.55. For the two positively correlated wells, G-571 and G-548, Spearman's *r* was 0.24 and 0.42, respectively. Pearson's *r*, however, was negative for well G-571 and positive for well G-548.

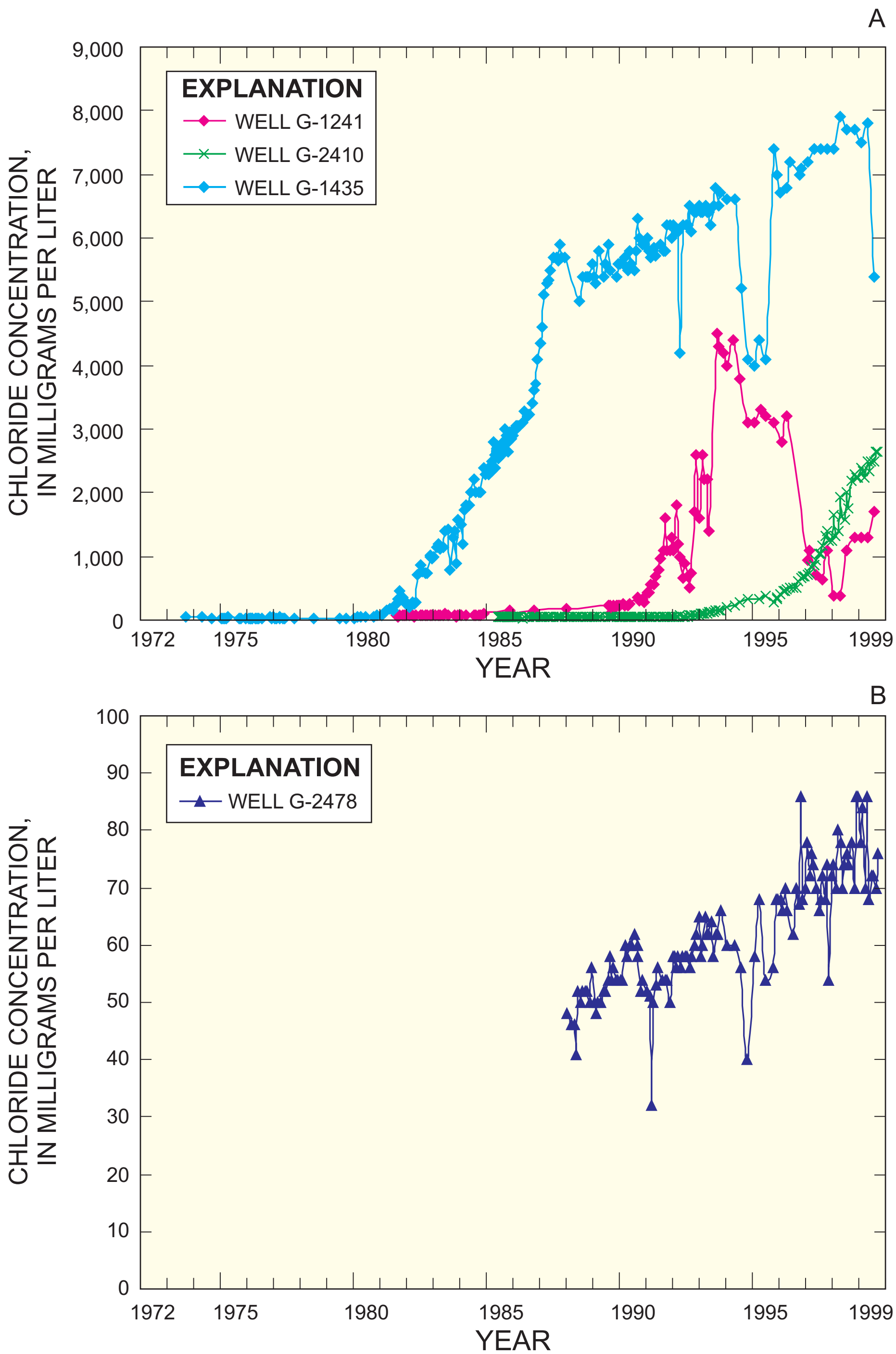


Figure 30. Chloride concentration in wells G-1241, G-1435, G-2410, and G-2478 near the Hallandale Well Field.

Generally, during drought periods, the reduced freshwater head resulting from deficient rainfall and increased municipal pumping increases the potential for further inland encroachment of the saltwater/freshwater interface. This would logically be manifested in an inverse relation between chloride concentrations and water levels. As previously mentioned, however, not all of the correlations were negative. The two wells (G-571 and G-548), which exhibited positive correlations between chloride concentrations and water levels, are located in north-central Miami-Dade County (fig. 10)-an area that is highly influenced by municipal pumping at the Hialeah-Miami Springs and Northwest Well Fields (Sonenshein and Koszalka, 1996). Both wells are also in relatively close proximity to the coastal control structures at the Miami (S-26) and Tamiami (S-25B) Canals. The combined effects of municipal pumping and operation of the coastal control structures may account for the positive correlation existing between chloride concentrations and water level in these two wells.

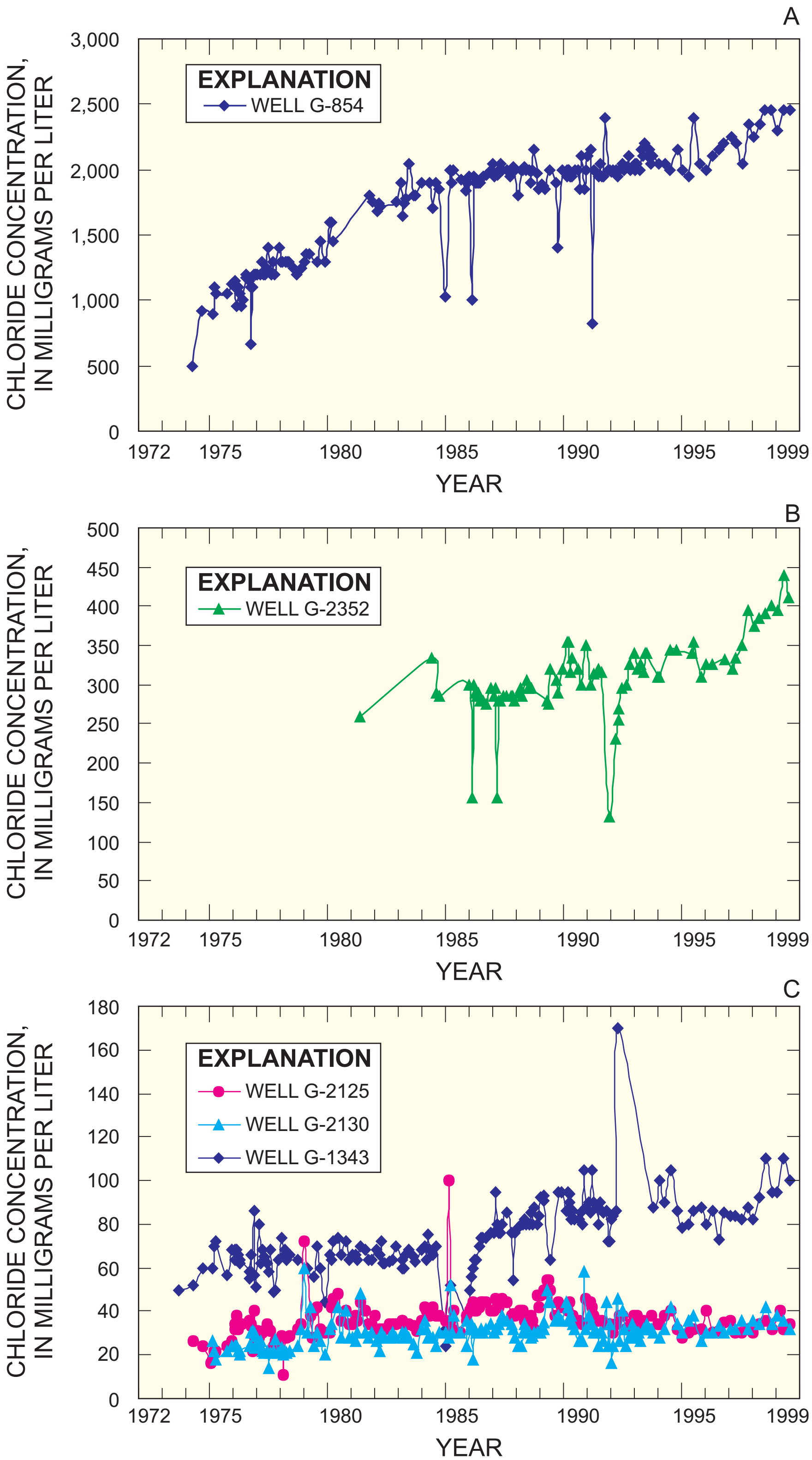


Figure 31. Chloride concentration in wells G-854, G-2352, G-1343, G-2125, and G-2130 near the Fort Lauderdale municipal well field.

Of the 11 wells in the Biscayne aquifer that showed correlation between water levels and chloride concentrations,4 wells had median chloride concentrations under 100 mg/L, 5 wells had median concentrations from 110 to 210 mg/L, 1 well had a median concentration of 708 mg/L, and 1 well had a median concentration of 2,500 mg/L. Chloride concentrations greater than 100 mg/L are generally indicative of saltwater contamination (Sonenshein, 1997). Many of the wells that showed chloride/water-level correlations in Miami-Dade County were located near the approximate location of the saltwater interface as determined in 1995.

Discussion of Well Coverage

There are 92 active continuous ground-water monitoring wells that have 10 or more years of data in the Biscayne aquifer in Miami-Dade and Broward Counties. Because of this unusually extensive coverage, regression analysis was only performed on the wells that had 10 years or more of data. This analysis alone indicated that water-level data from 12 wells can be used to provide and estimate water levels for 88 percent of the 92 wells analyzed. The average period of record for each indicator well was 34 years, and the R^2 value averaged 0.80.

Seven of the of the 12 index wells are already equipped with satellite telemetry (F-291, G-580A, G-620, G-975, G-1221, G-1260, and S-196A,). These 7 wells and 1 additional well, F-239, are the proposed index wells, which could be used to provide or estimate water levels for the 72 wells in the proposed network. The average R^2 value for this network is 0.81, and 78 percent of the 92 long-term Biscayne aquifer continuous monitoring wells would be covered (tables 5 and 6). Of the 12 wells, the remaining 4 wells generally added the ability to estimate water levels at only 1 or 2 other wells in each case. Considering this, additional satellite telemetry would be more beneficial in other aquifers.

In addition to the spatial coverage provided by these eight wells, many can provide additional assessment of aquifer conditions during droughts. Well G-580A provided an f_a of 0.55 for the comparison of rainfall and water-level minimums (table 2). This was not as high as the f_a value obtained for well G-3264A (0.80). The f_a determined for well G-580A, however, was based on 23 years of data, whereas well G-3264A only had 16 years of record available for this analysis (app. I).

Well S-196A provides coverage near Homestead where minimum water levels below sea level have been recorded in numerous wells during the 1970's. Index wells F-291, G-580A, and G-1221 provide coverage near the Hallandale, Alexander Orr, and Fort Lauderdale (Dixie) Well Fields, respectively, where chloride concentrations have increased dramatically during the period examined. Water levels at well F-239 are representative of water levels in the eight other wells affected by changes in pumpage at the Hialeah-Miami Springs Well Field.

Figure 32 shows parts of the network that are covered by index wells F-239, F-291,

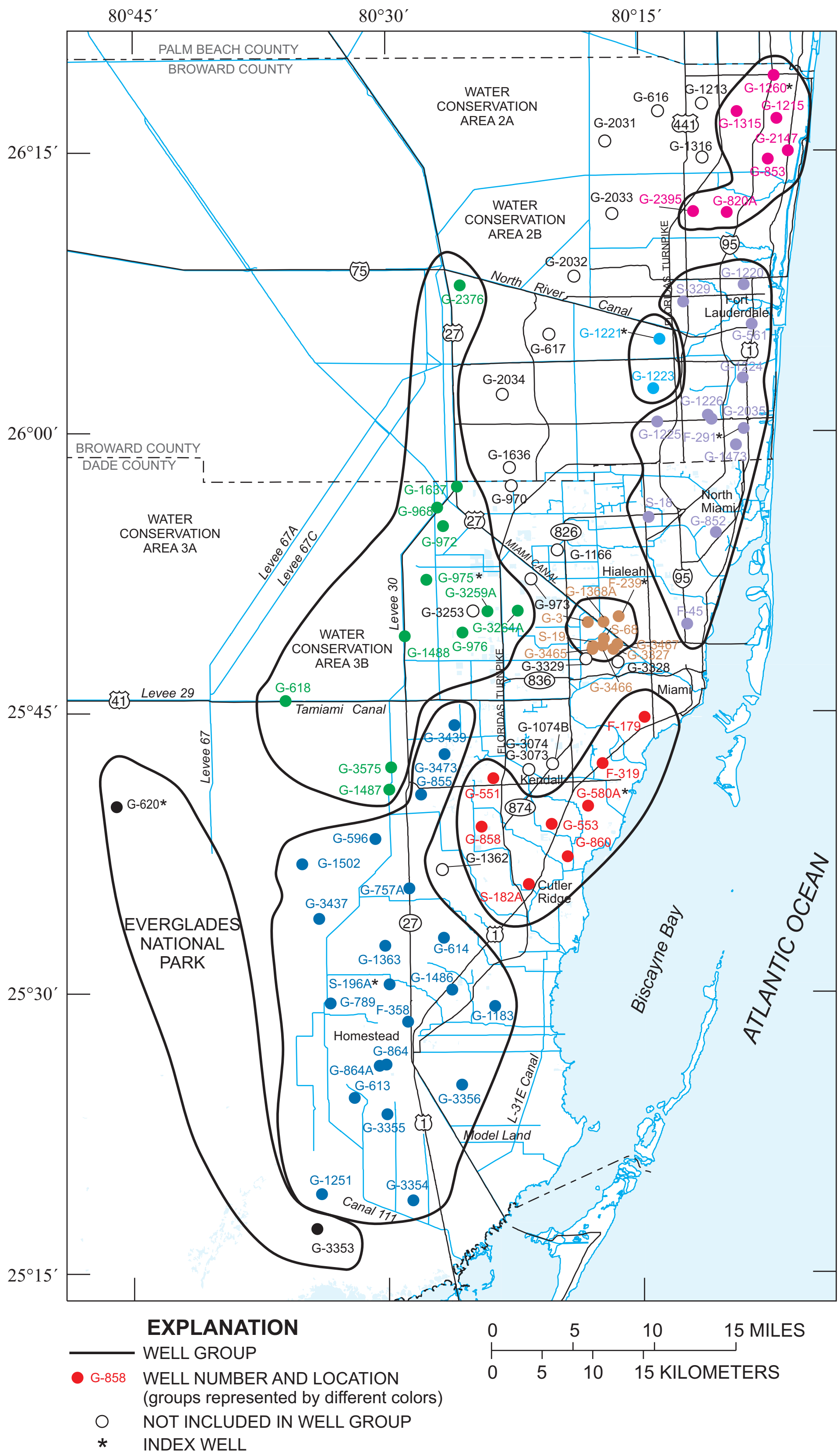


Figure 32. Network coverage defined by R^2 analysis using index wells in the Biscayne aquifer.

G-580A, G-620, G-975, G-1221, G-1260, and S-196A. Table 7 provides basic statistical and well construction information for the potential index wells discussed.

Of the proposed index wells in the Biscayne aquifer, three are in fair but acceptable condition. The casing of well F-291 has corroded to the point that small roots are growing into the well from land surface to a depth of 9 ft below land surface. The casing of well G-1221 has filled with sand to within about 5 ft of land surface. About 10 ft of the open-hole interval of well G-580A (originally 18 ft long) has collapsed. In each of these cases, the wells are still responding to changes in water levels in the Biscayne aquifer, and these conditions should not substantially affect the ability of each well to properly record water levels.

PORTRAYAL OF REAL-TIME GROUND-WATER LEVEL DATA

Water managers and others need readily accessible information from the real-time ground-water level monitoring network. Software programs have been created that automatically analyze data and portray the results on the real-time prototype website (http://www.sflorida.er.usgs.gov/ddn_data/index.html). Data from the real-time network is presented in graphs and maps that have been designed for easy access and interpretation while retaining the content necessary to support water-management decisions. The software developed for the site utilizes many of the statistical analyses that were used for the well network analysis. These analyses include: use of the Seasonal Kendall trend test, mathematical removal of long-term trends using linear or polynomial regressions, and frequency analysis of data. Where needed, these analytical techniques have been modified to reflect the website focus on the relation of current data to historical data.

Although this website is specifically designed to present ground-water data from the real-time ground-water level monitoring network, a select group of surface-water monitoring stations can add valuable information to aid in analysis. Using an extensive canal network, water from Lake Okeechobee can be used to recharge surficial aquifers in many areas of southern Florida. When the water level in Lake Okeechobee falls below 12 ft; however, a minimal amount of water is available to provide this recharge. During past droughts, water levels in Lake Okeechobee remained below 12 ft for extended periods. To aid in assessing drought severity and the effects that these droughts may have on aquifers, water levels from 11 surface-water monitoring stations (fig. 33) in southern Florida also are presented on this website.

Basic Depiction of Data

When evaluating data for a given well, it is useful to compare current values to those that occurred in previous water years. These comparisons create a framework for understanding the data from the current year and aid in rapid assessment of the status of the aquifer near each indicator well. For this reason, the prototype website includes a page presenting background information and current water-level and salinity data where available for each network station.

The most basic graphic generated by the prototype website shows the long-term chloride data for a well (fig. 34). Chloride water samples are only collected in a few of the real-time monitoring wells, but when these data are available, it can provide direct assessment of saltwater intrusion at a monitoring well. Chloride samples are not collected continuously at most sites, but one real-time monitoring well (L-4820), has been equipped with conductivity probes. The prototype website provides plots of the conductivity data.

Another basic method of depicting data is to use hydrographs that show changes in water level through time. The website software generates hydrographs for time periods of 30 and 90 days, current water year to date, and 25 years. The first three hydrographs shown on the webpage include water-level data from previous years and descriptive statistics (weekly maximum and minimums) for comparison with the most recent data from the current year. Representations of these types of hydrographs are shown in figure 35A-C. Descriptive statistics are computed for the last 25 years. The current year water-level data shown in the 30- and 90-day graphs are hourly values, which are collected and updated every 4 hours. For these short-period hydrographs, hourly data are used to show the daily water-level cycles that occur at many ground-water monitoring wells. The current year water-level data shown in longer duration hydrographs are

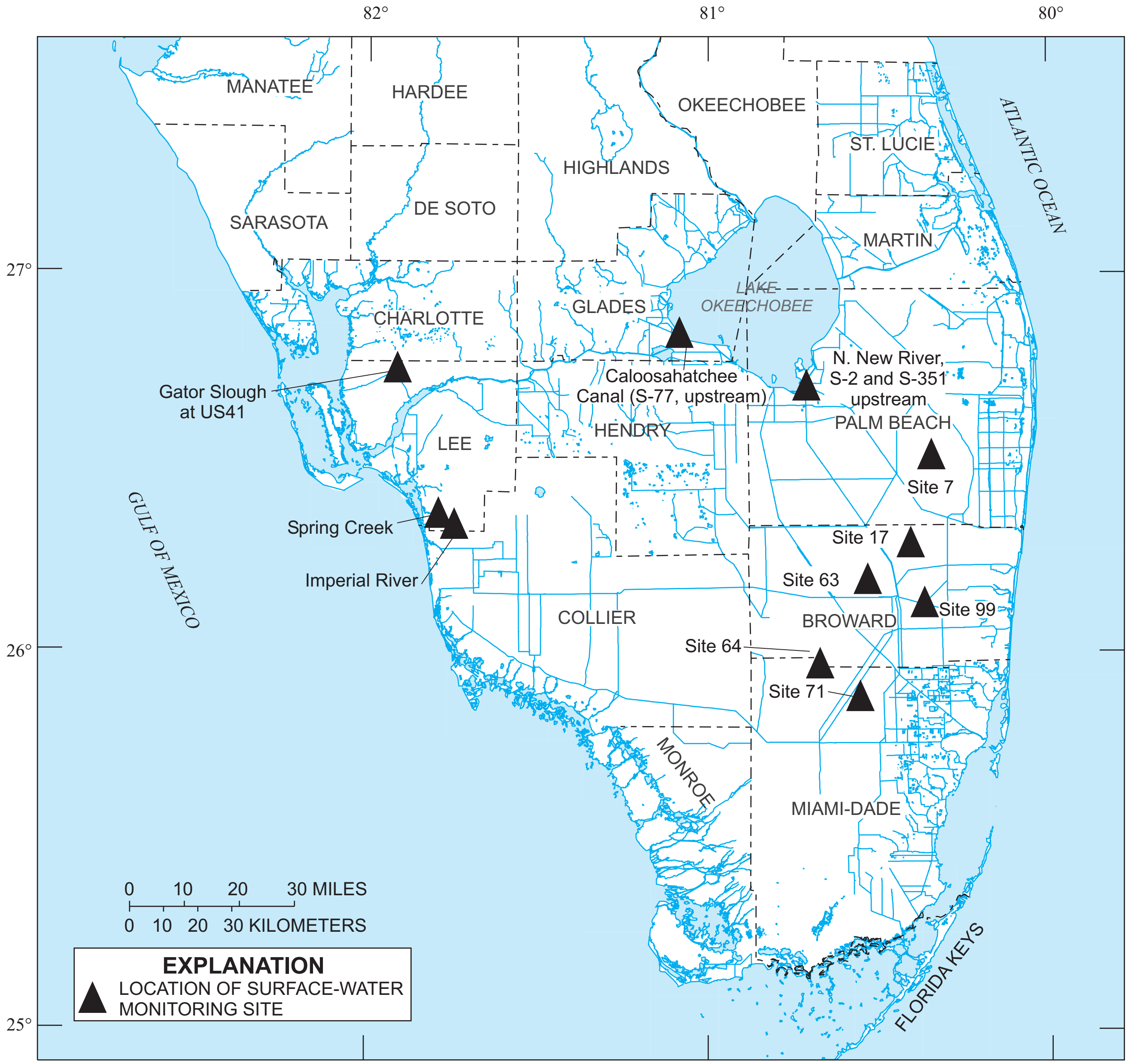


Figure 33. Locations of surface-water monitoring sites shown on the real-time prototype website.

daily maximum water levels for ground-water monitoring wells and daily mean water levels for surface-water monitoring stations. For those wells where water levels are near the top of the aquifer, the elevation of the top of the aquifer is also shown on the 25-year hydrographs.

Daily water levels from selected previous years are included on the first three hydrographs to provide a reference to historical water levels during significant events, such as droughts or unusually wet periods. The water-level data from a dry year (1989) and a wet year (1995) are used to provide historical reference. For those stations that do not have daily water-level data for previous years, instantaneous water-level measurements are used, if available. To aid in the analysis of the two monitoring stations on Lake Okeechobee, regulation schedules (U.S. Army Corps of Engineers, 1999) for the lake are also shown on these hydrographs.

Regression and Frequency Data

Examining current water-level data in light of historical data provides a valuable tool for water managers. Yet, because of the presence of strong long term trends in water levels, these simple comparisons may not be the best tools for trying to assess the effect of drought conditions. Long-term trends can mask water-level changes that may occur during short-term conditions such as droughts or floods.

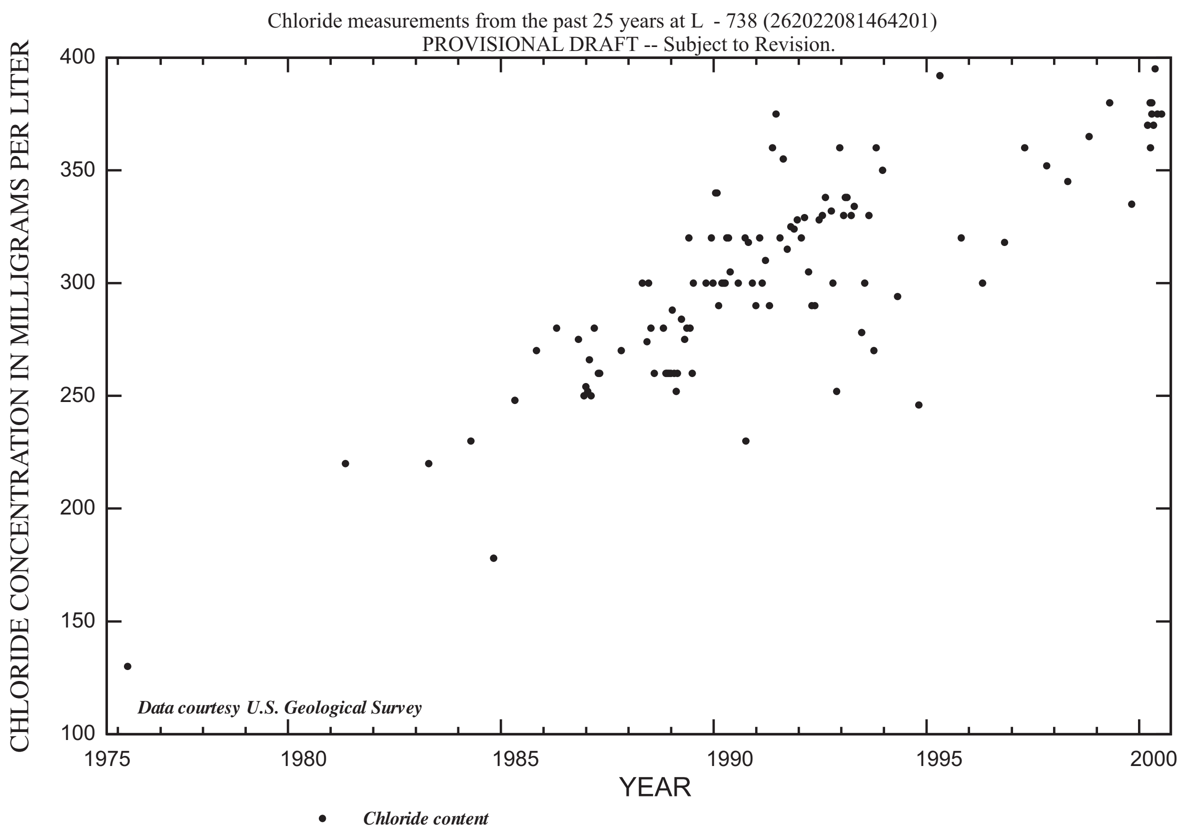


Figure 34. Long-term chloride concentrations in well L-738, March 24, 1976, to July 11, 2000 (from prototype website).

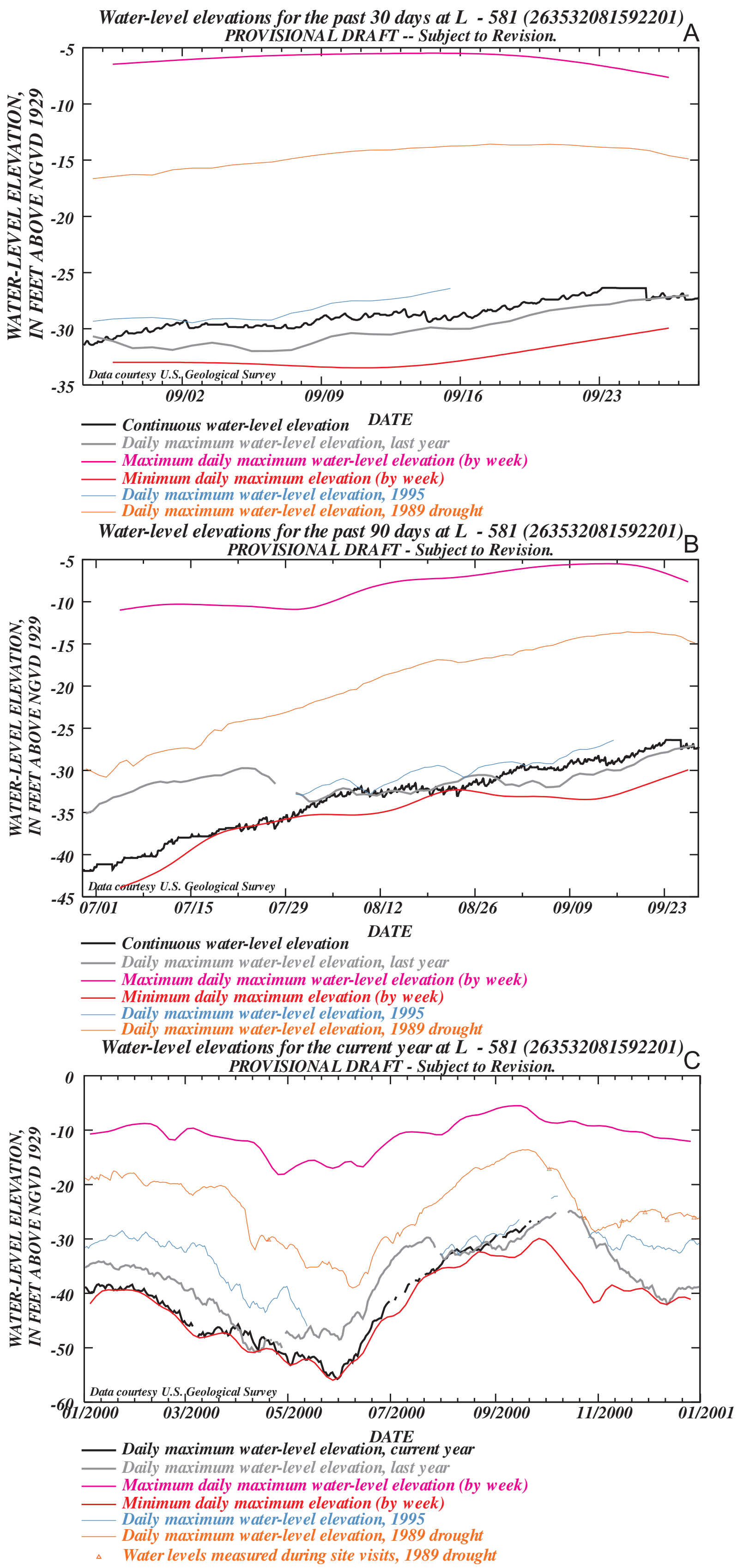


Figure 35. Water-level data for the previous 30 days, 90 days, and current year and comparison with the long-term data of well L-581 in the mid-Hawthorn aquifer, September 27, 2000 (from prototype website).

As an example, figure 35A-C shows that as of September 27, 2000, the water levels for the period shown at monitoring well L-581 were very low relative to the historical reference levels. However, water levels at this monitoring well have declined by about 20 ft over the last 25 years (fig. 36). Therefore, water levels for the current year should be expected to be below many historical reference levels. Direct historical comparisons therefore, may not represent the full picture of current hydrologic conditions throughout the aquifer because of bias introduced by long-term effects. Furthermore, these plots show that the spread between historical water-level highs and lows can be increased by a long-term trend. Because of this, it is difficult to quantify the significance of departures from historical conditions based solely on direct historical comparison. Detailed assessment of ground-water conditions requires a quantifiable knowledge of long-term, as well as short-term, changes in water levels.

To address the potential effects of long-term trends, historical water-level data are reviewed annually for long-term trends using a modified Seasonal Kendall trend test. If a statistically significant long-term trend is identified, the website support software runs a series of linear and polynomial regressions to obtain a best-fit regression of water level against time. The regression characteristics and Kendall trend test results are then stored for further reference. The derived trend line is plotted on the 25-year hydrograph (fig. 36). A zero-slope line representing the period of record mean water level is plotted on the 25-year hydrograph if a statistically significant trend was not identified.

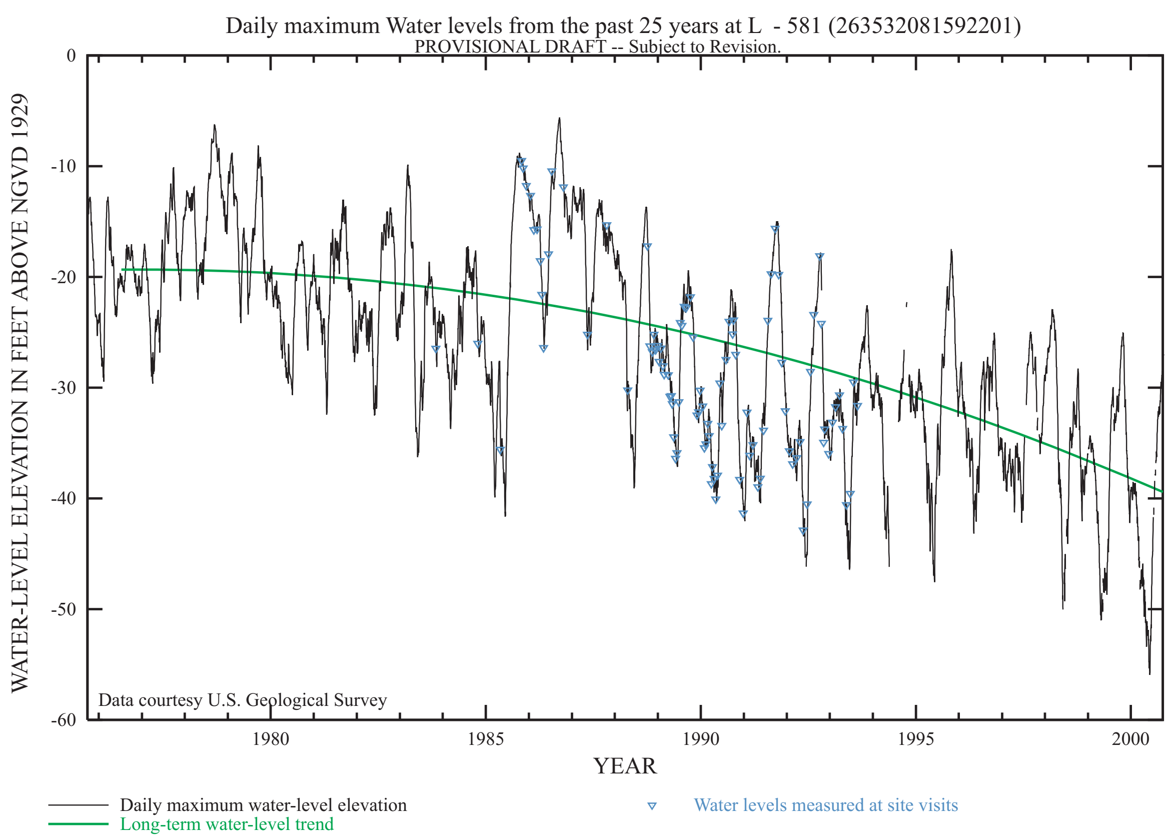


Figure 36. Daily maximum water level in well L-581, September 28, 1975, to September 27, 2000 (from prototype website).

For sites with identified long-term trends, regression residuals are used for performing a frequency analysis of the available data, grouped by the week of the year collected. If a statistically significant long-term trend was not identified, residuals from the period of record mean water level are used for the frequency analysis. The regression result (or mean) is combined with the results of the frequency analysis to generate expected weekly water-level frequencies for the current year. The most recent 365 days of water-level data are then plotted against this prediction (fig. 37). The frequency prediction displays a tighter range in water-level variation for the current year than would have been obtained had long-term trends not been considered. Using this prediction, it is much easier to accurately identify variation in the current year's data that may be caused by such factors as meteorologic droughts.

Data from the regression and frequency analyses are used to classify water-level monitoring sites. Maps are produced for each county and aquifer in addition to a map depicting the study area. For each site, symbols and colors are used to show the results of a comparison of the 7-day average of daily water levels to the weekly frequency predictions. Figure 38 is a representation of the water-level comparison carried out for the real-time monitoring network in Lee County on September 27, 2000.

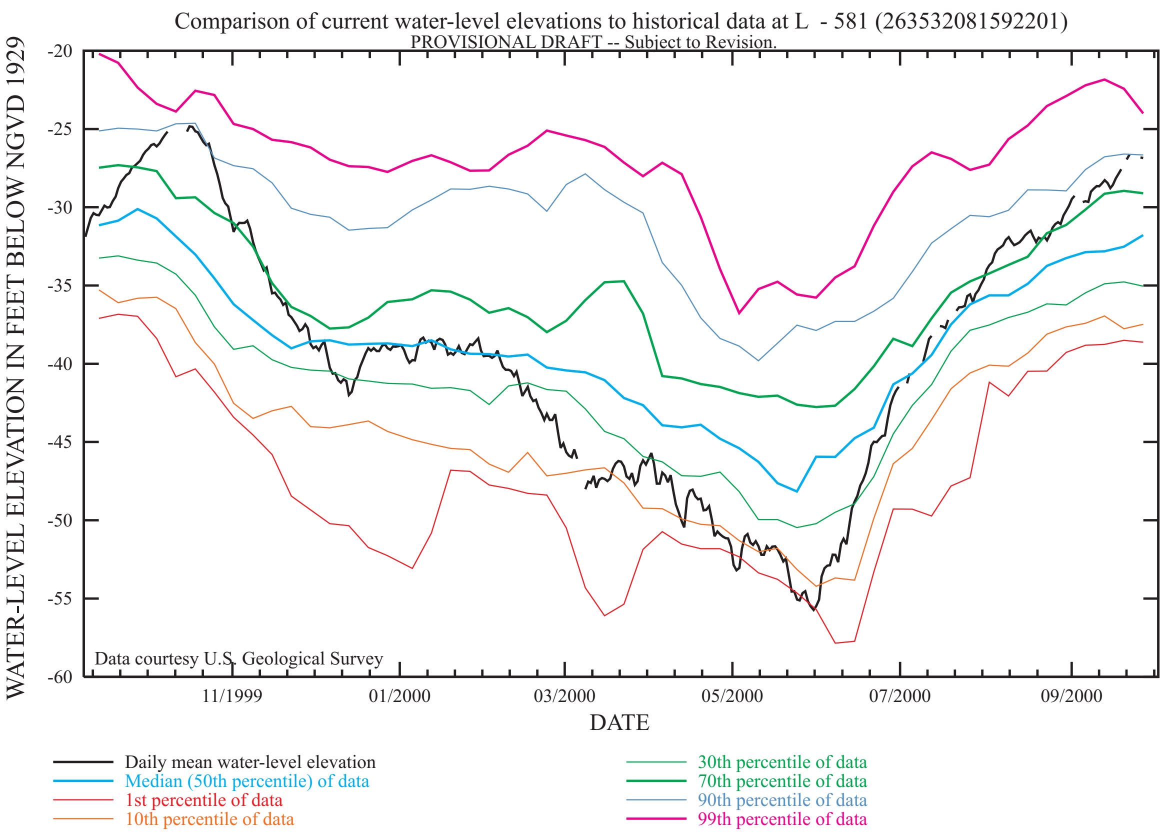


Figure 37. Current and historical water levels in well L-581, September 16, 1999, to September 27, 2000 (from prototype website).

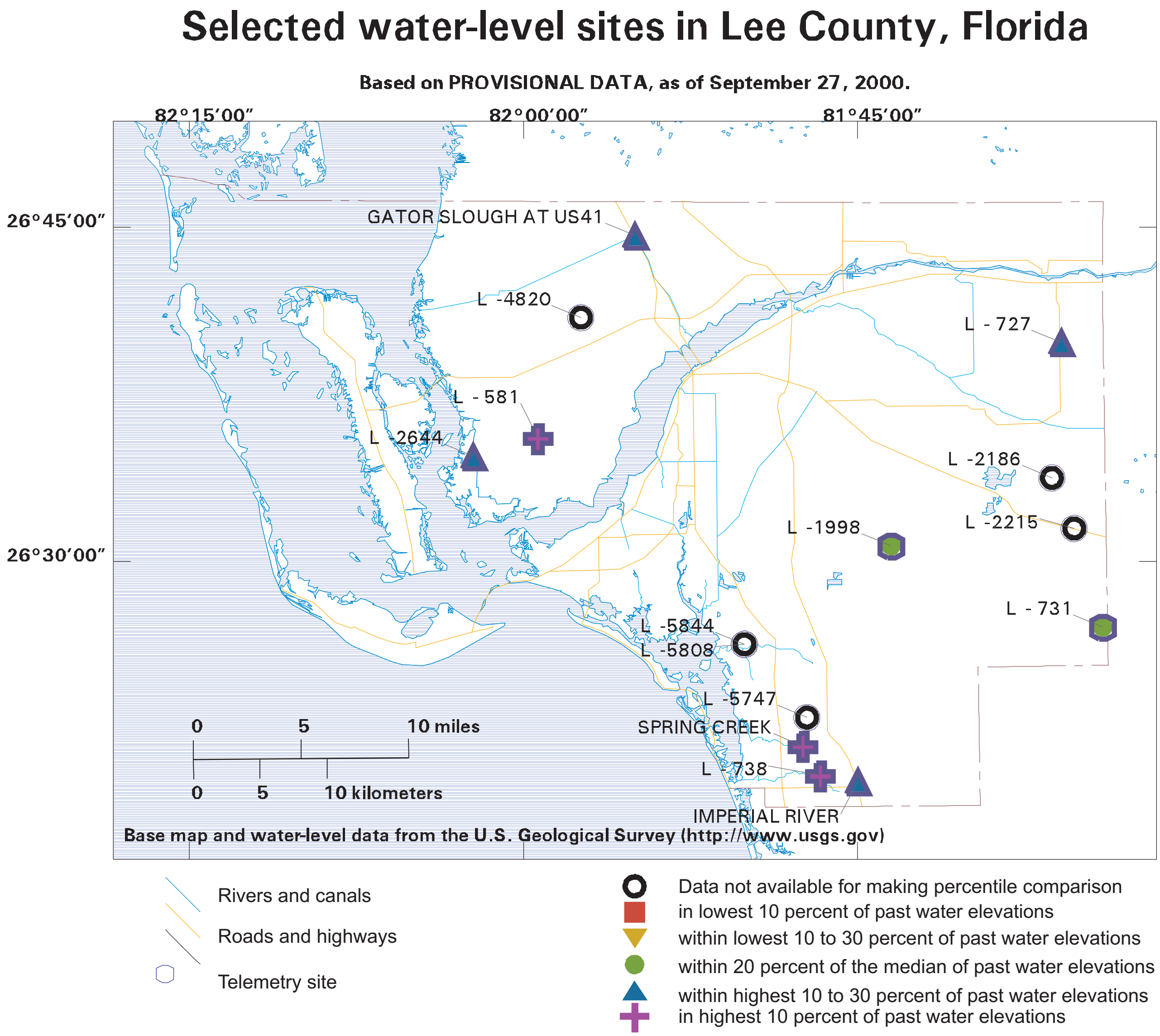


Figure 38. Water levels in selected wells in Lee County, September 27, 2000 (from prototype website). Because of rainfall from Hurricane Gordon on September 18, 2000, water levels in some wells are in the highest 10th to 30th percentile of the trend adjusted historical data. As water levels change relative to long-term trends, the symbols and colors will change on the map.

SUMMARY AND CONCLUSIONS

The USGS collects and computes data from over 200 continuous ground-water level recorders and performs salinity monitoring at 138 wells in southern Florida. These data are critical to decisions concerning water management in southern Florida. As the population in southern Florida has increased, ground-water withdrawals have increased, and in some instances have resulted in saltwater intrusion and loss of pumpage at privately owned water-supply wells.

Estimates of population for the 1980-98 period indicate increases of 34 percent in Miami-Dade and Broward Counties; 109 percent in Collier, Hendry, and Lee Counties; and 82 percent in Martin, Palm Beach, and St. Lucie Counties. These increases correspond to increases in ground-water usage of 26, 99, and 91 percent, respectively. In Miami-Dade and Broward Counties, the population increases have been sustained with minimal effect on the potentiometric surface of the Biscayne aquifer. This partially is because the Biscayne aquifer contains areas with transmissivities on the order of 1,000,000 ft^2/d. Aquifers in southwestern Florida, however, have transmissivities that are generally less than 134,000 ft2/d. As a result, increased water withdrawals have formed large cones of depression in the mid-Hawthorn aquifer, lower Hawthorn producing zone, and sandstone aquifer, and areas of every aquifer in southwestern Florida have occasionally been drawn down below sea level.

Water managers need to constantly assess ground-water levels and salinity so that they can evaluate ground-water conditions and take measures to minimize adverse effects. Because of the extensive time required to process, quality assure, and publish water-level and chloride concentration data, the entirety of these data is often not available when timely water-management decisions must be made. A real-time ground-water level monitoring network has been designed and a prototype website (http://www.sflorida.er.usgs.gov/ddn_data/index.html) has been built to provide data in a timely manner for evaluation of ground-water resources, particularly during periods of decreased recharge to the aquifer during meteorologic droughts.

This network is designed to consist of ground-water monitoring wells equipped with satellite telemetry that can transmit data to the USGS every 4 hours. Two of the most important factors considered in the design of this network were period of continuous ground-water level record available for each well considered and well construction. These two primary factors determined whether results of the statistical analyses used to design the network were significant or not. Short-term agreement between two indicator wells or between a monitoring well and precipitation may appear to be "statistically significant." These statistically significant agreements, however, are far more relevant if they occur during periods when the aquifer is under the most stress, such as during meteorologic droughts, which both cause a reduction in recharge and an increase in withdrawals from the aquifer for irrigation.

Four methods of statistical analysis were used to examine the water-level data monitoring wells included in the real-time ground-water level monitoring network. These methods are described below.

- The Seasonal Kendall trend test was used to examine long term trends in each aquifer. These tests showed areas where each of the aquifers was changing the most. In many cases, the trend tests that were conducted with data spanning 26 years showed statistically significant increases in aquifer water levels over time. Most of the wells with data for this period are completed in the Biscayne aquifer. Only 14 wells in aquifers in southwestern Florida and 9 wells in the surficial aquifer system in Martin and Palm Beach Counties had data for the period of record. Thus, several shorter periods were evaluated to compensate for many monitoring wells that did not have data for the entire period. The trend tests revealed small but statistically significant upward trends in most aquifers; however, large and localized downward trends occurred in the sandstone and mid-Hawthorn aquifers.
- Summary statistics were computed for all wells examined. These statistics provided information regarding the minimum monthly levels recorded and the measures of the amount of variation in water levels.
- Linear and polynomial regressions, LOWESS smoothing, and frequency analyses were combined to establish the relation between each candidate ground-water monitoring well and precipitation over the region. Focus was on the timing of extreme lows in precipitation and water level and determining which candidate monitoring wells most strongly showed aquifer-wide changes caused by reductions in recharge during meteorologic droughts. Analyses were performed on water-level data from 246 wells. Of this total, 104 wells had periods of record greater than 20 years (after considering missing record) and could be compared against several drought periods. After lag, seasonal cyclicity, and cumulative functions were considered, the timing of minimum values of water level from 15 wells and average minimum rainfall values were in agreement 57 to 62 percent of the time over 20 to 26 years. On average, the timing of water-level and rainfall minimums were in agreement about 52 percent of the time (and only about 29 percent of the time in some instances).
- A regression analysis was used to evaluate daily water levels from 203 monitoring wells that are currently, or recently had been, part of the network. The mean R^2 value was determined from a series of stepwise regressions between each candidate monitoring well and

every other candidate monitoring well in the aquifer. In each case, the explanatory variables included the water-level data of the candidate well, the water level squared, and time. The mean R^2 value provided a good indicator of how representative of the other wells in the network the candidate well is. Additionally, the individual R^2 values from each step-wise regression were used to determine the coverage that the single candidate well would provide. Coverage was defined using R^2 values of 0.64 or greater, which correspond to a correlation coefficient of 0.80. This degree of correlation was considered to be sufficient for an interim assessment of aquifer conditions. Results indicated that 35 wells had 10 years or more of data and could be used to directly monitor water levels or to estimate water levels at 180 of 203 wells (89 percent of the network).

The relation between water levels and chloride concentrations in 114 ground-water wells was examined using Spearman's r and Pearson's r correlation coefficients. Statistically significant results included both positive and negative relations. These analyses, however, have limitations in that they do not portray a regional assessment of saltwater intrusion, but indicate the relation between chloride concentrations and water levels at specific well locations. Regional assessments of saltwater intrusion have been made in the past, and these chloride/water-level analyses may be used to select wells that may be appropriate for drought monitoring. There were no statistically significant correlations between chloride concentrations and water levels in the water-table aquifer (west coast). Only three wells in the lower Tamiami aquifer showed significant correlation between chloride concentrations and water levels. No correlation existed between chloride concentration and water levels in the sandstone aquifer. Chloride concentrations and water levels were positively correlated in two wells in the mid-Hawthorn aquifer. There were no wells in the surficial aquifer system for which correlation between chloride concentrations and water levels existed; however, seven wells in the Biscayne aquifer showed statistically significant correlations between chloride concentrations and water levels.

The Seasonal Kendall trend test was also used to examine trends in chloride concentration in 113 wells. Of these, a total of 61 wells showed statistically significant trends. Fifty-six percent of the observed trends in chloride concentration were upward (34 of 61 wells), and 44 percent (27 of 61 wells) were downward.

Of the 61 wells that had statistically significant results, data were from 4 wells in the water-table aquifer (west coast), 11 wells in the lower Tamiami aquifer, 2 wells in the sandstone aquifer, 7 wells in the mid-Hawthorn aquifer, 34 wells in the Biscayne aquifer, and 3 wells in the surficial aquifer system. Upward trends were found in data from 3 wells in the water-table aquifer (west coast), 7 wells in the lower Tamiami aquifer, 1 well in the sandstone aquifer, 3 wells in the mid-Hawthorn aquifer, and 20 wells in the Biscayne aquifer. Downward trends were found in data from 1 well in the water-table aquifer (west coast), 4 wells in the lower Tamiami aquifer, 1 well in the sandstone aquifer, 4 wells in the mid-Hawthorn aquifer, 14 wells in the Biscayne aquifer, and 3 wells in the surficial aquifer system.

Statistical analyses of water levels and chloride concentrations combined with consideration of period of water-level record, completeness of water-level data, well construction, and prior existence of satellite telemetry indicated that a total of 33 water-level monitoring wells (17 already instrumented with satellite telemetry) would provide good coverage of ground-water conditions in southern Florida during times when the data from the full ground-water level monitoring network are unavailable. These 33 wells are not intended to replace the existing continuous monitoring wells because statistical analyses conducted by other investigators have previously indicated that a much more extensive network would be needed to fully assess conditions. However, these 33 wells can provide very useful real-time updates for changes in each of the principal aquifers in southern Florida.

The prototype website (http://www.sflorida.er.usgs.gov/ddn_data/index.html), developed to portray the data from the real-time ground-water level monitoring network, utilizes many of the same concepts that were originally used to design the network, including use of the Seasonal Kendall trend test, removal of long term trends using linear or polynomial regressions, and duration analysis of data (which originated from the frequency analysis used in network design). This prototype website also aids in the examination of chloride data by presenting long-term plots as well as the water-level data whenever possible.

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APPENDIX I
Well Construction and Period of Record

Appendix I. Well construction and period of record

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Water-Table Aquifer (West Coast)														
C-54	261000080520001	261021	0805300	1951	2000	46.5	8.5	--	0	7.2	6	7.2	8.5	Open
C-131	262521081161901	262520	0811619	1956	1996	38.9	54[1]	--	0	19[2]	6	19[2]	54[1]	Open
C-296	260640081204301	260645	0812042	1973	2000	14.3	45	--	0	8	4	8	45	Open
C-392	261124081470101	261125	0814729	1973	2000	26.3	30[4]	--	0	24[2]	8	24[2]	30[4]	Open
C-492	262228081361901	262228	0813619	1973	2000	24.2	64[1]	Open hole	3.96	19[2]	6	19[2]	64[1]	Open
C-496	260111081243901	260023	0812439	1973	2000	26.3	57[5]	Open hole	0	7[2]	6	7[2]	57[5]	Open
C-503	261741081235401	261742	0812343	1973	2000	14.4	20.4	Open hole	0	8	6	8	20.4	Open
C-598	261417081305402	261416	0813054	1980	1996	15.8	36.5	Screen	-3.2	32.5	4	32.5	36.5	Screen
C-690	260632081324702	260634	0813235	1980	2000	17.7	48	--	0	43	4	43	48	Open
C-953	261347081351201	261348	0813512	1984	2000	15.0	40	--	0	12	6	12	40	Open
C-968	260334081391601	260337	0813915	1984	2000	15.2	23	--	0	8	6	8	23	Open
C-969	260238081401401	260239	0814013	1985	1996	11.6	72	Open hole	-2.3	25	6	25	72	Open
C-978	262121081355501	262123	0813559	1996	2000	3.3	40	Open end	0	15	6	15	40	Open
C-981	262158081283401	262200	0812836	1996	2000	3.3	60	--	0	40	6	40	60	Open
C-997	261530081412001	261531	0814118	1985	2000	14.0	22	Screen	0	12	4	12	22	Screen
C-1063	260137081375901	260140	0813756	1996	2000	3.1	55	Open hole	0	30	4	30	55	Open
C-1065	255637081281401	255640	0812809	1996	2000	3.3	50	Open hole	0	27	4	27	50	Open
C-1071	261823081171901	261814	0811737	1986	2000	13.3	35	Screen	0	20	4	20	35	Screen
C-1075	262822081213201	262831	0812157	1997	2000	2.8	28	Screen	0	8	4	8	28	Screen
C-1095	260628081411601	260628	0814116	1994	1995	.7	50	Screen	0	50	4	47	50	Screen
HE-558	264235081310602	264236	0813104	1977	1996	14.6	14	--	--	--	--	--	--	--

Appendix I. Well construction and period of record (Continued)

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Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Water-Table Aquifer (West Coast)--Continued														
HE-862	261735080534002	261809	0805335	1977	2000	16.5	11	--	--	--	--	--	--	--
L-730	263138081545801	263129	0813516	1974	2000	25.2	19	--	0	18.7	4	18.7	19	Open
L-954	263903081550401	263901	0815500	1973	1996	22.5	14	--	--	--	--	--	--	--
L-1137	263950081355402	263950	0813554	1973	1996	23.0	20	P,S	0	15	4	15	20	P,S
L-1403	262549082035301	262555	0820355	1973	2000	26.3	12	--	0	2.9	4	2.9	12	Other
L-1995	263251081452803	263252	0814537	1975	2000	25.0	24	--	0	14	4	14	24	Screen
L-1996	261954081410101	261954	0814056	1975	1996	20.7	295[3]	Open hole	-2.84	65	4	65	295[3]	Open
L-1997	261954081410102	261956	0814056	1975	1996	21.4	20	--	--	--	--	--	--	--
L-2195	261957081432202	262000	0814321	1977	2000	22.3	15	--	0	14	4	14	15	Open
Lower Tamiami Aquifer														
C-391	261124081470301	261124	0814730	1973	2000	26.1	75[3]	--	0	70	4	70	75[3]	Open
C-409A	261024081480101	261024	0814757	1984	1996	11.7	73	--	-3.6	63	2	63	73	--
C-460	261405081465501	261406	0814706	1984	2000	14.9	66	Open end	0	64	2	64	66	Open
C-462	262724081260701	262726	0812612	1973	1996	23.0	110	--	0	50	8	50	110	Open
C-506A	261233081480201	261232	0814802	1984	1996	12.0	54	Open hole	0	--	2	50	--	Open
C-600	260549081441901	260552	0814419	1980	1996	16.0	52	GP	0	48	4	48	52	Other
C-951	261347081351202	261349	0813513	1984	2000	15.3	170	--	0	120	6	120	170	Open
C-988	261444081284901	261447	0812849	1984	2000	14.4	160	Open end	0	95	4	95	160	Open
C-998	261620081450201	261622	0814500	1990	1996	6.3	62	Screen	0	52	4	52	62	Screen
C-1004	261620081464401	261621	0814643	1985	2000	14.6	60	--	0	52	4	52	60	Open
C-1064	260137081375902	260141	0813757	1986	1996	9.9	120	Open hole	0	84	4	84	120	Open
C-1074	262519081162102	262520	0811619	1986	1996	9.9	130	Open hole	0	100	4	100	130	Open

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Lower Tamiami Aquifer--Continued														
C-1083	261805081473302	261820	0814729	1992	2000	7.7	74	Open hole	0	58	4	58	74	Open
L-738	262022081464201	262023	0814640	1992	2000	7.9	76	Open hole	0	61	4	61	76	Open
L-1691	262042081455001	262042	0814521	1973	1996	23.0	69	Open hole	0	--	4	58	69	Open
								--	0	58	4	--	--	--
L-2194	261957081432201	262000	0814321	1977	2000	22.2	132[2]	--	0	77[2]	4	77[2]	132[2]	Screen
L-5727	261859081481902	261859	0814729	1992	1996	4.5	100	--	--	--	--	--	--	--
L-5745	261900081454602	261926	0814545	1991	1997	5.9	105	Open hole	0	57	4	57	105	Open
L-5747	262258081471802	262259	0814716	1997	2000	2.9	105	Open hole	0	59	4	59	105	Open
Sandstone Aquifer														
C-531	262859081273001	262933	0812735	1976	1996	19.5	240	Screen	-2.6	210	4	210	240	Screen
C-688	261802081354801	261803	0813546	1996	2000	3.2	242	--	0	220	4	220	242	Open
C-989	261733081285502	261738	0812854	1984	1996	11.8	270[6]	Open hole	0	234[2]	6	234[2]	270[6]	Open
C-1072	261823081171902	261814	0811737	1986	2000	13.1	260	Open hole	0	140	4	140	260	Open
C-1079	262158081283404	262200	0812836	1986	2000	13.1	390[3]	Open hole	0	298	4	298	390[3]	Open
C-1099	260517081430302	260521	0814257	1993	1996	2.9	124	Screen	0	114	4	114	124	Screen
								--	124	125	4	--	--	--
HE-517	264623081213601	264614	0812228	1977	2000	22.0	136	Screen	-2.1	128	8	128	136	Screen
HE-529	263310081250901	263311	0812509	1976	1996	19.0	155		--	--	--	--	--	--
HE-556	263845081260702	263847	0812609	1976	2000	23.2	175[1,3]	Screen	-2.44	163[2]	4	163[2]	175[3]	Screen
L-727	263850081365401	263950	0813551	1973	2000	26.1	71	--	0	67	4	67	71	Open
L-729	263335081394301	263337	0813943	1977	1999	22.5	107.5[1,2]	Open hole	0	81.5[2]	4	81.5[2]	107.5[1,2]	Open
L-731	262703081340201	262704	0813400	1973	2000	26.2	243[6]	Open hole	0	163[2]	4	163[2]	243[3]	Open
L-1418	263630081375301	263631	0813751	1973	1996	22.3	62	Open hole	0	55	8	55	62	Open

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Sandstone Aquifer--Continued														
L-1994	263251081452802	263252	0814537	1975	2000	25.0	155	--	0	70	4	70	100	Screen
								--	100	125	--	125	155	Open
L-1998	263041081433102	263042	0814329	1974	2000	24.3	160[5]	--	-2.61	102.4[2]	4	102.4[2]	160[5]	Open
L-2186	263344081361703	263345	0813616	1977	1996	18.9	160	--	0	133	4	133	160	Screen
L-2215	263127081351602	263129	0813515	1996	2000	3.1	149	--	0	99	4	99	149	Screen
L-2550	262711081413701	262712	0814137	1992	2000	7.7	134	Open hole	0	67	6	67	134	Open
L-5649	262934081495801	262934	0814714	1982	1996	14.3	128	--	0	118	4	118	128	Screen
Mid-Hawthorn Aquifer														
L-581	263532081592201	263533	0815920	1973	2000	26.3	177[5]	Open hole	-3.40	107[2]	8	107[2]	177[5]	Open
L-742	263323081522401	263325	0815225	1973	2000	26.0	225[8]	Open hole	0	136[2]	8	136[2]	225[5]	Open
L-781	263834082005301	263835	0820053	1973	1996	23.0	290	Open hole	0	--	6	82	--	Open
L-1993	263251081452801	263251	0814535	1975	2000	24.8	242	--	0	190	4	190	242	Open
L-2193	262713081414401	262712	0814142	1992	2000	7.8	298	--	0	220	4	220	292	Screen
L-2640	263813081552801	263814	0815527	1997	2000	2.4	180	--	0	128	4	128	180	Open
L-2644	263440082022001	263444	0820214	1978	2000	20.2	180	--	0	128	4	128	180	Open
L-2701	263819081585801	263819	0815857	1978	2000	21.1	206	--	0	175	4	175	206	Open
L-2702	263621081563701	263607	0815616	1978	1997	18.5	155	--	--	--	--	--	--	--
L-2703	263357081575602	263359	0815756	1978	1996	17.4	159	--	--	--	--	--	--	--
Lower Hawthorn Producing Zone														
L-588	262538082045701	262543	0820455	1997	2000	2.8	557	--	0	403	4	403	557	Open
L-2434	263526082010201	263526	0820102	1981	2000	17.8	700	--	0	353	4	353	700	Open

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Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Surficial Aquifer System														
M-1004	270835080105801	270835	0801058	1973	2000	14.7	17	Open end	-3	17	6	--	--	Open end
M-1024	265822080052701	265822	0800527	1975	2000	10.4	83	--	--	--	--	--	--	--
M-1048	270124080280202	270124	0802802	1974	2000	25.1	80	--	--	--	--	--	--	--
M-1234	265725080141801	265725	0801418	1989	2000	10.5	18	--	--	--	--	--	--	--
M-1255	270913080284901	270913	0802849	1993	2000	7.0	28.4	Screen	-1.54	26.6	2	21.6	26.6	Screen
M-1257	270720080140202	270720	0801402	1992	1996	3.9	20	GS	-2.9	19.8	6	16.8	19.8	Screen
M-1261	270609080163401	270609	0801634	1993	2000	7.1	20	GS	-3.62	19.8	6	16.8	19.8	Screen
PB-99	264005080233501	264014	0800335	1948	2000	46.8	18.3	--	--	--	--	16	18	--
PB-445	263328080085201	263328	0800852	1948	2000	30.2	11.4	Open end	0	11.4	4	--	--	--
PB-565	265812080053901	265812	0800539	1973	2000	26.4	21.9	Open hole	-3.24	21.9	6	--	--	Open end
PB-683	263524080124301	263524	0801243	1973	2000	24.4	17	Open end	0	17	6	--	--	--
PB-685	264208080192201	264208	0801922	1973	2000	9.7	17	Open end	0	17	6	--	--	--
PB-689	265633080203001	265633	0802030	1973	2000	9.7	17	Open end	-3	17	6	--	--	Open end
PB-732	262218080070101	262218	0800701	1974	2000	25.3	100	Open end	-1.5	100	6	--	--	Open end
PB-809	264123080053801	264123	0800538	1975	2000	24.8	150	Screen	0	145	4	--	--	--
PB-831	265106080241402	265106	0802414	1974	2000	25.3	25	GS	0	21	4	--	--	--
PB-900	262534080085102	262534	0800851	1976	1996	20.9	63	Open hole	0	63	6	--	--	--
PB-1491	262317080074601	262317	0800746	1984	2000	15.8	138[4]	Screen	-1.81	88	6	88	138[4]	Screen
PB-1639	263656080033502	263656	0800335	1989	2000	10.5	25	GS	0	25	4	20	25	Screen
PB-1642	265233080054001	265233	0800540	1993	2000	6.3	21	GS	0	20	4	20	21	Screen
PB-1661	262410080090801	262410	0800908	1989	2000	10.2	25	Screen	0	25	4	15	25	Screen
PB-1662	264839080115001	264839	0801150	1991	2000	8.3	23	P,S --	-4 -4	18 3	4 15	18 --	23 --	P,S --

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Surficial Aquifer System--Continued														
PB-1680	262159080054201	262159	0800542	1993	2000	6.3	40	P,S	3	35	4	35	40	P,S
PB-1684	262130080080701	262130	0800807	1993	2000	6.3	40	P,S	3	35	4	35	40	P,S
STL-41	271538080371401	271538	0803706	1950	2000	34.6	17[8]	GS	0	13[8]	6	13[8]	--	Screen
STL-42	272655080401601	272655	0804016	1950	2000	35.9	18	GS	0	--	6	13	--	Screen
STL-125	272524080242801	272524	0802428	1973	2000	8.6	12	Open end	-2.92	12	4	--	--	Open end
STL-172	272313080182701	272315	0801834	1975	2000	10.1	30	Open end	-3.9	26	6	26	30	Open
STL-175	271755080153001	271755	0801530	1975	2000	11.1	200	Open end	-3	68	6	68	200	Open
STL-176	271755080153002	271755	0801530	1975	2000	11.0	30	Open end	-3.4	26	6	26	30	Open
STL-185	271413080311201	271440	0802955	1993	2000	7.1	115	Open end	-2.46	113	4	113	115	Open
STL-213	272427080240201	272427	0802402	1993	2000	7.0	115	P,S	0	75	2	75	115	P,S
STL-214	271618080245801	271618	0802458	1993	2000	6.9	70	P,S	0	40	2	40	70	P,S
STL-264	273109080270301	273109	0802703	1993	2000	7.0	90	Screen	0	60	2	60	90	Screen
STL-313	272138080374103	272138	0803741	1993	2000	7.1	122	Open end	-2.55	40	6	40	122	Open
Biscayne Aquifer														
F-45	254943080121501	254943	0801215	1960	2000	26.6	84.9	Open hole	-1.8	--	6	--	--	--
F-179	254444080144801	254444	0801448	1940	2000	59.0	77	--	0	--	6	--	--	--
F-239	255008080161801	255008	0801618	1973	2000	26.3	52.8	--	0	--	6	--	--	--
F-291	260010080085001	260010	0800850	1948	2000	45.3	107[7]	Open hole	0	105[7]	6	105[7]	107[7]	Open
F-319	254217080171801	254217	0801718	1956	2000	43.1	17	Open hole	0	--	6	--	--	--
F-358	252829080285101	252829	0802851	1956	2000	41.3	54		0	--	6	--	--	--
G-3	254950080180801	254950	0801808	1951	2000	31.3	20	Open hole	0	11.7	6	11.7	--	Open
G-551	254130080234501	254130	0802345	1955	2000	15.8	80	P,S	0	29	24	29	72	P,S
								--	29	72	18	--	--	--

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-553	253902080202501	253902	0802019	1956	2000	43.0	91	Open hole	0	36	24	79	--	Open
								--	36	79	18	--	--	--
G-561	260545080082001	260545	0800820	1956	2000	43.3	20.3	Open hole	0	19.7	6	19.7	20.3	Open
G-580A	254000080181001	254000	0801810	1949	1997	39.8	22[5]	Open hole	-2.5	4	6	4	22[5]	Open
G-594	255250080270801	255250	0802708	1987	1995	7.2	20	Open hole	0	13.9	6	13.9	20	Open
G-596	253937080304001	253816	0803044	1949	2000	50.3	16	Open hole	0	--	6	10.8	--	Open
								Open end	0	16	6	--	--	--
G-613	252425080320001	252425	0803200	1956	2000	43.0	20.5	Open hole	0	17.9	6	17.9	--	Open
G-614	253258080264301	253258	0802643	1956	2000	43.7	20	Open hole	0	18.1	6	18.1	--	Open
G-616	261710080135001	261710	0801350	1952	1995	39.2	23.7	GS	0	19	6	19	23.7	Screen
G-617	260515080202101	260515	0802021	1956	1999	43.8	29	Open hole	-3.5	28	6	28	29	Open
G-618	254500080360001	254540	0803600	1956	2000	43.7	20	Open hole	-2.8	11	6	11	20	Open
G-620	254000080460001	254000	0804600	1956	2000	40.9	13[2]	Open hole	-3.03	3[2]	6	3[2]	13[2]	Open
G-757A	253537080284401	253537	0802844	1973	2000	26.3	33	Open hole	-3.5	12.4	6	12.4	--	Open
G-789	252928080332401	252928	0803324	1956	2000	41.4	20	Open hole	-3	10	6	10	20	Open
G-820A	261144080094601	261144	0800946	1968	1995	21.1	100	Open hole	0	99	4	99	100	Open
G-852	255437080103201	255437	0801032	1973	2000	26.3	20	Open hole	0	10.5	6	--	--	--
G-853	261434080071901	261434	0800719	1959	2000	38.9	27	Open end	-3	27	4	27	--	Open end
G-855	254038080280201	254038	0802802	1961	2000	37.2	20	Open hole	0	10	6	10	--	Open
G-858	253854080242801	253854	0802428	1973	1993	19.7	20	Open hole	0	--	6	10.5	20	Open
G-860	253718080192301	253718	0801923	1973	2000	26.3	20	Open hole	0	10.5	6	10.5	--	Open
G-864	252612080300701	252612	0803007	1973	2000	26.3	20	--	--	--	6	--	--	--
G-864A	252619080310201	252608	0803032	1973	2000	26.2	20	Open hole	0	10	9	7	--	Open

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Lati-tude	Longi-tude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diame-ter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-968	255600080270001	255600	0802700	1960	2000	39.6	50	Open hole	0	--	16	--	--	--
G-970	255709080223701	255709	0802237	1971	2000	26.7	15	Open hole	0	10	6	10	--	Open
G-972	255522080261401	255500	0802640	1958	1996	37.9	15	Open hole	0	10	6	10	--	Open
G-973	255209080212801	255209	0802128	1973	2000	26.3	15		-3	--	6	--	--	--
G-975	255208080274001	255208	0802740	1958	2000	41.2	15	Open hole	0	10	6	10	15	Open
G-976	255023080202301	254918	0802533	1958	2000	41.7	15	Open hole	0	10	6	--	--	--
G-1074B	254215080201503	254215	0802015	1983	2000	16.3	45		--	--	--	--	--	--
G-1166	255342080195501	255342	0801955	1973	2000	26.1	18	Open end	0	10.5	6	--	--	--
G-1183	252918080234201	252918	0802342	1973	2000	26.2	47	Open hole	0	--	9	--	--	--
G-1213	261734080111301	261734	0801113	1963	2000	36.0	15	Open hole Open hole	0 0	11.5 12	5 5	11.5 12	20 15	Open Open
G-1215	261645080064701	261645	0800647	1973	1996	22.2	20	Open hole	0	14	5	14	20	Open
G-1220	260752080084701	260752	0800847	1963	2000	36.6	20	Open hole	-1.92	12.1	5	12.1	20	Open
G-1221	260458080134801	260458	0801348	1973	2000	22.7	20[4]	Open hole	-2.5	11.5	5	11.5	4	Open
G-1223	260219080141101	260219	0801411	1973	2000	26.3	20	Open hole	-2.35	12	5	12	20	Open
G-1224	260252080085301	260252	0800853	1973	2000	26.3	20	Open hole	0	12	5	12	20	Open
G-1225	260032080135701	260032	0801357	1973	2000	25.8	20	Open hole --	-2.32 --	11 --	5 --	11 145	20 --	Open Screen
G-1226	260053080105701	260053	0801057	1973	2000	26.3	20	Open hole	0	14	5	14	20	Open
G-1251	251922080340701	251916	0803357	1965	2000	33.1	59	Open hole	0	5	6	5	--	Open
G-1260	261903080065601	261903	0800656	1973	2000	26.4	90[5]	Open hole	-2.5	59.5[2]	6	59.5[2]	90[5]	Open
G-1315	261708080090801	261708	0800908	1973	2000	26.1	14	Open hole	0	--	4	--	--	--
G-1316	261441080111301	261441	0801113	1973	2000	22.0	16	Open hole	0	--	4	--	--	--

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-1359	254720080253001	254720	0802530	1968	1999	8.5	33	Open hole	0	11	6	11	--	Open
G-1362	263630080264801	253637	0802647	1969	1999	30.5	33	Open hole	0	11	6	11	33	Open
G-1363	253233080301001	253233	0803010	1973	2000	26.3	33	Open hole	0	12	6	12	--	Open
G-1368A	254950080171202	254950	0801712	1974	2000	25.8	39	Open hole	-3.3	38.4	6	38.4	39	Open
G-1473	255918080091801	255918	0800918	1973	2000	26.3	132	Open hole	0	126	8	126	132	Open
G-1486	253012080261401	253012	0802614	1973	2000	25.5	32	Open hole	0	--	6	--	--	--
G-1487	254054080295401	254054	0802954	1970	2000	22.7	20	Open hole	0	--	6	--	--	--
G-1488	254830080284201	254907	0802857	1970	1999	29.5	20	Open hole --	0 0	-- --	6 2	-- --	-- --	-- --
G-1502	252656080350301	253656	0803503	1970	2000	29.3	31	Open hole	-0.7	11	6	11	--	Open
G-1636	255807080224301	255807	0802243	1972	2000	26.6	24	Open end	-3	24	6	24	24	Open
G-1637	255707080255001	255707	0802550	1972	2000	26.3	26	Open end	3	26	6	26	26	Open
G-2031	261534080165801	261534	0801658	1973	2000	26.3	22	Open hole	0	21	6	21	22	Open
G-2032	260821080185101	260821	0801851	1973	2000	26.8	22	Open hole	0	21	6	21	22	Open
G-2033	261141080163401	261141	0801634	1973	2000	26.3	23	Open hole	0	21	6	21	23	Open
G-2034	260653080184901	260202	0802307	1973	2000	26.3	22	Open hole	0	21	6	21	22	Open
G-2035	260040080104401	260040	0801044	1973	2000	26.3	52	Open hole	0	50	4	50	52	Open
G-2147	261501080060701	261501	0800607	1974	2000	28.4	16	Open hole	0	--	6	--	--	--
G-2376	260753080253701	260753	0802537	1984	1997	13.0	15	--	--	--	--	--	--	--
G-2395	261147080114501	261147	0801145	1984	2000	15.6	73	Open hole	0	71	2.5	71	73	Open
G-2739	261831080151301	261831	0801513	1991	2000	8.2	21	--	0	21	4	--	--	--
G-2852	261938080101001	261938	0801010	1995	2000	4.3	140	Screen	0	130	2	130	140	Screen
G-2866	261641080064801	261641	0800648	1996	2000	3.6	20	Screen	-3	20	6	15	20	Screen

Appendix I. Well construction and period of record (Continued)

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Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-3073	254157080214001	254157	0802140	1977	1995	18.3	20	Open hole	0	20	6	--	--	--
G-3074	254157080214002	254157	0802140	1977	2000	22.3	40	Open hole	0	40	6	--	--	--
G-3253	255027080245501	255027	0802455	1981	2000	17.8	20	Open hole	0	18	6	18	20	Open
G-3259A	255026080240302	255026	0802403	1983	2000	16.8	60	Open hole	0	20	4	20	60	Open
G-3264A	255027080221602	255027	0802216	1984	2000	15.6	50	Open hole	0	20	4	20	50	Open
G-3272	253952080321501	254000	0803420	1983	2000	6.2	10	Open hole	0	7.5	4	7.5	10	Open
G-3327	254823080163701	254823	0801637	1984	2000	15.8	54	--	--	--	--	--	--	--
G-3328	254741080162101	254741	0801621	1984	2000	15.9	54	--	--	--	--	--	--	--
G-3329	254752080181501	254752	0801815	1984	2000	16.2	54	--	--	--	--	--	--	--
G-3353	251724080341401	251724	0803414	1985	1999	14.1	8	--	--	--	--	--	--	--
G-3354	251855080283401	251855	0802834	1985	1999	13.3	8	--	--	--	--	--	--	--
G-3355	252332080300501	252332	0803005	1985	2000	14.5	13	--	--	--	--	--	--	--
G-3356	252502080253901	252506	0802541	1985	2000	14.4	13	--	--	--	--	--	--	--
G-3437	253400080340401	253400	0803404	1986	2000	13.3	12.5	Open end	0	12.5	5	--	--	--
G-3439	254421080260201	254421	0802602	1987	2000	12.7	12	Open hole	0	10	4	10	12	Open
G-3465	254823080175201	254823	0801752	1988	2000	12.2	28.8	Open end	-3.01	28.8	4	--	--	Open end
G-3466	254834080171601	254834	0801716	1988	2000	12.0	19.5	Open end	0	19.5	4	--	--	--
G-3467	254839080162301	254839	0801623	1988	2000	12.1	27.5	Open end	0	27.5	4	--	--	--
G-3473	254248080263801	254248	0802638	1991	2000	8.3	20.4	--	0	20.4	4	--	--	--
G-3549	252933080210001	252933	0802100	1994	2000	5.9	11	Screen	-3	6	4	--	--	--
G-3550	252906080213101	252906	0802131	1994	2000	5.8	13	Screen	-4.5	8	4	--	--	--
G-3551	254158080294501	254158	0802945	1994	2000	5.8	18.3	Screen	-2.6	13.3	5	--	--	--
G-3552	254138080284401	254138	0802844	1994	2000	5.8	19.4	Screen	-2.6	14.4	5	--	--	--

Appendix I. Well construction and period of record (Continued)

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Name	USGS identifier	Latitude	Longitude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diameter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-3553	254152080282101	254152	0802821	1994	2000	6.1	19.9	Screen	-2.6	14.9	5	--	--	--
G-3554	254152080274501	254152	0802745	1994	2000	5.2	20	Screen	-3.24	15	5	--	--	--
G-3555	254111080272501	254111	0802725	1994	2000	5.9	19	Screen	-2.62	14	5	--	--	--
G-3556	254213080281501	254213	0802815	1994	2000	5.5	19.1	Screen	-2.72	14.1	5	--	--	--
G-3557	254112080294201	254112	0802942	1994	2000	5.9	19.5	Screen	-2.4	14.5	5	--	--	--
G-3558	254334080284401	254334	0802844	1994	2000	5.9	19	Screen	-2.8	14	5	--	--	--
G-3559	254445080295001	254445	0802950	1994	2000	5.9	19.5	Screen	-2.5	14.5	5	--	--	--
G-3560	254108080231301	254108	0802813	1994	2000	5.8	19.5	Screen	-2.8	14.5	5	--	--	--
G-3561	254022080263601	254022	0802636	1994	2000	6.0	19	Screen	-2.8	14	5	--	--	--
G-3562	255112080151901	255112	0801519	1994	2000	5.4	18.6	Screen	-3	13.6	5	13.6	18.6	Screen
G-3563	254340080203601	254340	0802036	1994	2000	5.4	18.1	Screen	-3.15	13.1	5	13.1	18.1	Screen
G-3564	254917080143301	254917	0801433	1994	2000	5.4	18.8	Screen	-2.68	13.8	5	13.8	18.8	Screen
G-3565	254218080241801	254218	0802418	1994	2000	5.3	19	Screen	-3.56	14	5	14	19	Screen
G-3566	254951080194901	254951	0801949	1994	2000	5.3	18	Screen	-3	13.2	5	13.2	18.2	Screen
G-3567	255358080260901	255358	0802609	1994	2000	5.4	18.7	Screen	-3.6	13.7	5	13.7	18.7	Screen
G-3568	254657080214401	254657	0802144	1994	2000	5.3	16.8	Screen	-3.5	11.8	5	11.8	16.8	Screen
G-3570	254536080172601	254536	0801726	1994	2000	5.4	18.7	Screen	-3.1	13.7	5	13.7	18.7	Screen
G-3571	255616080180301	255616	0801803	1994	2000	5.3	18.5	Screen	-3	13.5	5	13.5	18.5	Screen
G-3572	254432080240401	254432	0802404	1994	2000	5.4	19.4	Screen	-3.02	14.4	5	14.4	19.4	P,S
G-3573	254032080093301	254032	0800933	1994	1995	1.1	12.2	Screen	-3.2	10.4	4	7.2	12.2	Screen
G-3574	254446080295501	254446	0802955	1995	2000	5.1	6.8	Open end	-2.85	6.8	4	--	--	--
G-3575	254206080294701	254206	0802947	1995	2000	5.1	8.95	Open end	-2.85	8.95	4	--	--	--
G-3576	254442080305201	254442	0803052	1995	2000	5.0	9.64	Open end	-3.44	9.64	4	--	--	--

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Lati-tude	Longi-tude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diame-ter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-3577	254207080300201	254207	0803002	1995	2000	5.0	8.04	Open end	-3.05	8.04	4	--	--	--
G-3578	254210080304801	254210	0803048	1995	2000	5.0	5.99	Open end	-3.22	5.99	4	--	--	--
G-3579	255130080291601	255130	0802916	1996	1997	1.0	82	Open hole	0	80	4	80	82	Open
G-3580	255130080291602	255130	0802916	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3581	255130080291301	255130	0802913	1996	1996	.9	32	Open hole	0	30	4	30	32	Open
G-3582	255130080291302	255130	0802913	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3583	255130080291303	255130	0802913	1996	1996	.9	11	Open hole	0	9	4	9	11	Open
G-3584	255130080291101	255130	0802911	1996	1996	.9	32	Open hole	0	30	4	30	32	Open
G-3585	255130080291102	255130	0802911	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3586	255130080291103	255130	0802911	1996	1996	.9	12	Open hole	0	10	4	10	12	Open
G-3587	255130080291104	255130	0802911	1996	1996	.9	82	Open hole	0	80	4	80	82	Open
G-3588	255130080290601	255130	0802906	1996	1996	.9	10	Open hole	0	9	4	9	10	Open
G-3589	255130080290602	255130	0802906	1996	1996	.9	32	Open hole	0	30	4	30	32	Open
G-3590	255130080290603	255130	0802906	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3591	255130080290605	255130	0802906	1996	1996	.9	82	Open hole	0	80	4	80	82	Open
G-3592	255130080290604	255130	0802906	1996	1996	.9	52	Open hole	0	50	4	50	52	Open
G-3593	255130080290401	255130	0802904	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3594	255130080290402	255130	0802904	1996	1996	.9	7	Open hole	0	5	4	5	7	Open
G-3595	255130080290403	255130	0802904	1996	1996	.9	32	Open hole	0	30	4	30	32	Open
G-3596	255130080290404	255130	0802904	1996	1996	.9	52	Open hole	0	50	4	50	52	Open
G-3597	255130080290405	255130	0802904	1996	1996	.9	82	Open hole	0	80	4	80	82	Open
G-3598	255130080290101	255130	0802901	1996	1996	.9	17	Open hole	0	15	4	15	17	Open
G-3599	255130080290102	255130	0802901	1996	1996	.9	82	Open hole	0	80	4	80	82	Open

Appendix I. Well construction and period of record (Continued)

[Examination of well construction using a borehole camera indicated that the depths originally listed in the construction records were sometimes measured relative to the top of the well casing. For wells where borehole camera examination revealed this discrepancy, depths were adjusted to be relative to the land surface, and the correction has been noted in this table. Borehole camera examinations were not performed on all wells listed in this table. Annotations: GP, gravel with perforations; GS, gravel screen; PC, porous concrete; P,S, perforated or slotted; --, no data]

Name	USGS identifier	Lati-tude	Longi-tude	Begin year	End year	Daily value record (years)	Well depth (feet)	Type of finish	Depth to top of casing (feet)	Depth to bottom of casing (feet)	Casing diame-ter (inches)	Depth to top of open interval (feet)	Depth to bottom of open interval (feet)	Type of opening
Biscayne Aquifer--Continued														
G-3619	252243080335501	252243	0803355	1996	2000	3.9	12	P,S	-3	12	10	10.8	12	P,S
G-3620	252312080320301	252312	0803203	1996	2000	3.9	12	P,S	-3	12	10	10.8	12	P,S
G-3621	252115080293701	252115	0802937	1996	2000	3.9	12	P,S	-3	12	10	10.8	12	P,S
G-3622	252955080340701	252955	0803407	1996	2000	3.7	12	P,S	-3	12	10	10.8	12	P,S
G-3626	253708080304201	253708	0803242	1996	2000	3.7	12	P,S	-3	12	10	10.8	12	P,S
G-3627	253632080321101	253632	0803011	1996	2000	3.7	12	P,S	-3	12	10	10.8	12	P,S
G-3628	253539080320501	253539	0803205	1996	2000	3.7	12	P,S	-3	12	10	10.8	12	P,S
G-3660	254209080294801	254209	0802948	1998	2000	1.8	57	PC	0	47	6	47	57	Screen
PB-561	264230080120501	264230	0801205	1973	2000	24.3	11.3	Open hole	0	11.3	6	--	--	--
S-18	255526080143001	255526	0801430	1944	2000	49.8	52		0	--	8	--	--	--
S-19	254832080175001	254832	0801750	1956	2000	43.2	95	Open hole	0	91	6	--	--	--
S-68	254857080171101	254857	0801711	1950	2000	31.5	61		0	--	6	--	--	--
S-182A	253549080214101	253549	0802141	1956	2000	42.1	51		0	--	6	--	--	--
S-196A	253029080295601	253029	0802956	1950	2000	46.2	19[2]	Open hole	0	0	8	0	19	Open
S-329	260657080122301	260657	0801223	1946	2000	52.6	68		0	--	4	--	--	--

[1]Borehole camera examination indicates that the reported depth may be incorrect.
[2]Depth indicated by borehole camera examination (relative to land surface).
[3]Well is partially obstructed.
[4]Well has partially filled with sand.
[5]Open hole portion of the well has partially collapsed.
[6]Open hole portion of the well has completely collapsed.
[7]Casing of the well is breached at one or more depths.
[8]Well is plugged.

APPENDIX II

Results of Seasonal Kendall Trend Tests of Continuous Water-Level Data

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Water-Table Aquifer (West Coast)						
C-54	261000080520001	8	0.52	0.05	No	1974-81
		22	.32	.01	No	1974-95
		26	.79	.00	No	1974-99
		9	.85	.01	No	1981-89
		7	.64	.04	No	1989-95
		11	.34	-.03	No	1989-99
C-131	262521081161901	8	.51	-.10	No	1974-81
		22	.68	.01	No	1974-95
		9	.34	-.17	No	1981-89
		7	.04	.57	Yes	1989-95
C-296	260640081204301	8	.67	.02	No	1974-81
C-392	261124081470101	8	.04	.19	Yes	1974-81
		22	.00	.06	Yes	1974-95
		26	.00	.04	Yes	1974-99
		9	.89	.01	No	1981-89
		7	.06	.05	No	1989-95
		11	.55	-.02	No	1989-99
C-496	260111081243901	8	.11	.07	No	1974-81
		22	.01	.03	Yes	1974-95
		26	.01	.03	Yes	1974-99
		9	.16	-.10	No	1981-89
		7	.02	.23	Yes	1989-95
		11	.09	.08	No	1989-99
C-503	261741081235401	8	.42	-.04	No	1974-81
C-598	261417081305402	9	.26	-.13	No	1981-89
		7	.05	.46	No	1989-95
C-690	260632081324702	9	.31	-.09	No	1981-89
		7	.25	.23	No	1989-95
		11	.95	.01	No	1989-99
C-953	261347081351201	7	.04	.25	Yes	1989-95
		11	.32	.06	No	1989-99
C-968	260334081391601	7	.05	.15	No	1989-95
		11	.03	.17	Yes	1989-99
C-969	260238081401401	7	.06	.15	No	1989-95
C-997	261530081412001	7	.07	.39	No	1989-95
		11	.27	.13	No	1989-99
C-1071	261823081171901	7	.01	.98	Yes	1989-95
		11	.04	.44	Yes	1989-99
HE-558	264235081310602	7	1.00	.00	No	1989-95
HE-862	261735080534002	7	.71	-.02	No	1989-95
		11	.12	-.05	No	1989-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Water-Table Aquifer (West Coast)--Continued						
L-730	263138081545801	8	0.31	0.08	No	1974-81
		22	.71	.01	No	1974-95
		26	.71	-.01	No	1974-99
		9	.96	-.01	No	1981-89
		7	.10	.10	No	1989-95
		11	.85	.01	No	1989-99
L-954	263903081550401	8	.98	-.01	No	1974-81
		22	.76	-.01	No	1974-95
		9	.63	-.06	No	1981-89
		7	.07	.36	No	1989-95
L-1137	263950081355402	8	.84	-.02	No	1974-81
		22	.18	-.03	No	1974-95
		9	.88	.01	No	1981-89
		7	.07	.16	No	1989-95
L-1403	262549082035301	8	.12	.07	No	1974-81
		22	.24	.02	No	1974-95
		26	.21	.02	No	1974-99
		9	.23	-.09	No	1981-89
		7	.03	.19	Yes	1989-95
		11	.11	.08	No	1989-99
L-1995	263251081452803	8	.75	-.07	No	1974-81
		22	.26	.02	No	1974-95
		26	.14	.02	No	1974-99
		9	.75	.03	No	1981-89
		7	.07	.19	No	1989-95
		11	.12	.09	No	1989-99
L-1997	261954081410102	8	.14	.13	No	1974-81
		22	.82	-.01	No	1974-95
		9	.07	-.21	No	1981-89
		7	.02	.50	Yes	1989-95
L-2195	261957081432202	9	.25	-.16	No	1981-89
		7	.02	.39	Yes	1989-95
		11	.26	.14	No	1989-99
Lower Tamiami Aquifer						
C-391	261124081470301	8	.10	.25	No	1974-81
		22	.00	.14	Yes	1974-95
		26	.00	.11	Yes	1974-99
		9	.32	.14	No	1981-89
		7	.94	.00	No	1989-95
		11	.02	-.17	Yes	1989-99
C-409A	261024081480101	7	.49	.03	No	1989-95
		11	.93	.00	No	1989-99
C-460	261405081465501	7	.03	.61	Yes	1989-95
		11	.23	.22	No	1989-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Lower Tamiami Aquifer--Continued						
C-462	262724081260701	8	0.33	-0.18	No	1974-81
		22	.05	-.11	No	1974-95
		9	.32	-.25	No	1981-89
		7	.02	.80	Yes	1989-95
C-492	262228081361901	8	.28	.08	No	1974-81
		7	.01	.33	Yes	1989-95
		11	.08	.14	No	1989-99
C-506A	261233081480201	7	.22	.13	No	1989-95
		11	.39	.08	No	1989-99
C-600	260549081441901	9	.29	-.05	No	1981-89
		7	.04	.15	Yes	1989-95
C-951	261347081351202	7	.15	.19	No	1989-95
		11	.58	-.05	No	1989-99
C-988	261444081284901	7	.05	.59	No	1989-95
		11	.29	.10	No	1989-99
C-998	261620081450201	7	.07	.63	No	1989-95
C-1004	261620081464401	7	.02	.64	Yes	1989-95
		11	.40	.12	No	1989-99
C-1064	260137081375902	7	.09	.13	No	1989-95
C-1074	262519081162102	7	.03	.46	Yes	1989-95
L-1691	262042081455001	8	.08	-.19	No	1974-81
		22	.00	-.19	Yes	1974-95
		9	.04	-.53	Yes	1981-89
		7	.05	.74	Yes	1989-95
L-2194	261957081432201	9	.11	-.28	No	1981-89
		7	.03	.64	Yes	1989-95
		11	.31	.16	No	1989-99
Sandstone Aquifer						
C-531	262859081273001	10	.43	.22	No	1986-95
C-989	261733081285502	10	.05	.38	Yes	1986-95
C-1072	261823081171902	10	.09	.38	No	1986-95
C-1072	261823081171902	14	.30	.17	No	1986-99
C-1079	262158081283404	10	.05	.57	Yes	1986-95
		14	.04	.31	Yes	1986-99
HE-517	264623081213601	10	.34	.06	No	1986-95
		14	.31	.04	No	1986-99
HE-529	263310081250901	10	.34	.04	No	1986-95
HE-556	263845081260702	10	.15	.23	No	1986-95
		14	.26	.12	No	1986-99
L-727	263850081365401	13	.65	-.01	No	1974-86
		22	.00	-.06	Yes	1974-95
		26	.00	-.06	Yes	1974-99
		10	.60	-.03	No	1986-95
		14	.36	-.03	No	1986-99
L-729	263335081394301	10	.34	-.08	No	1986-95
		14	.01	-.24	Yes	1986-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Sandstone Aquifer--Continued						
L-731	262703081340201	13	0.00	-0.81	Yes	1974-86
		22	.00	-.57	Yes	1974-95
		26	.01	-.27	Yes	1974-99
		10	.13	.91	No	1986-95
		14	.03	.75	Yes	1986-99
L-1418	263630081375301	13	.27	-.04	No	1974-86
		22	.00	-.07	Yes	1974-95
		10	.21	-.07	No	1986-95
L-1994	263251081452802	13	.10	-.21	No	1974-86
		22	.04	-.10	Yes	1974-95
		26	.00	-.14	Yes	1974-99
		10	.90	-.01	No	1986-95
		14	.03	-.20	Yes	1986-99
L-1996	261954081410101	10	.15	.31	No	1986-95
L-1998	263041081433102	13	.00	-1.70	Yes	1974-86
		22	.00	-.86	Yes	1974-95
		26	.00	-1.02	Yes	1974-99
		10	.01	-1.03	Yes	1986-95
		14	.00	-1.50	Yes	1986-99
L-2186	263344081361703	10	.15	-.25	No	1986-95
L-5649	262934081495801	10	.36	-.12	No	1986-95
Mid-Hawthorn Aquifer						
L-581	263532081592201	11	.35	-.35	No	1974-84
		22	.00	-.65	Yes	1974-95
		26	.00	-.70	Yes	1974-99
		12	.00	-1.35	Yes	1984-95
		16	.00	-1.16	Yes	1984-99
L-742	263323081522401	11	.01	3.68	Yes	1974-84
		22	.02	1.14	Yes	1974-95
		26	.06	.73	No	1974-99
		12	.10	-1.39	No	1984-95
		16	.02	-1.34	Yes	1984-99
L-781	263834082005301	11	.25	-.86	No	1974-84
		22	.30	-.26	No	1974-95
		12	.85	.09	No	1984-95
L-1993	263251081452801	11	.02	-.26	Yes	1974-84
		22	.00	-.45	Yes	1974-95
		26	.00	-.51	Yes	1974-99
		12	.35	-.12	No	1984-15
		16	.00	-.39	Yes	1984-99
L-2644	263440082022001	12	.00	-1.02	Yes	1984-95
		16	.00	-1.17	Yes	1984-99
L-2701	263819081585801	12	.11	-.79	No	1984995
		16	.08	-.47	No	1984-99
L-2702	263621081563701	12	.07	-.75	No	1984-95
L-2703	263357081575602	12	.01	-1.03	Yes	1984-95

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Surficial Aquifer System						
M-1004	270835080105801	9	0.09	-0.09	No	1991-99
		26	.75	.01	No	1974-99
		11	.20	-.13	No	1981-91
		9	.38	-.10	No	1991-99
		8	.56	.15	No	1974-81
M-1234	265725080141801	9	1.00	.00	No	1991-99
PB-99	264005080233501	26	.01	.05	Yes	1974-99
		11	.78	-.02	No	1981-91
		9	.48	-.03	No	1991-99
		8	.11	.15	No	1974-81
PB-445	263328080085201	26	.20	.01	No	1974-99
		11	.09	.02	No	1981-91
		9	.05	-.07	Yes	1991-99
		8	.02	-.02	Yes	1974-81
PB-561	264230080120501	10	.56	.05	No	1974-83
		26	.09	.04	No	1974-99
		10	.39	-.12	No	1983-92
		8	.81	.03	No	1992-99
PB-565	265812080053901	26	.17	.05	No	1974-99
		11	.02	-.23	Yes	1981-91
		9	.06	.20	No	1991-99
		8	.05	.28	No	1974-81
PB-683	263524080124301	26	.00	.13	Yes	1974-99
		11	.23	.11	No	1981-91
		9	.12	-.03	No	1991-99
		8	.70	-.02	No	1974-81
PB-732	262218080070101	26	.90	.00	No	1974-99
		11	.90	-.01	No	1981-91
		9	.80	-.01	No	1991-99
		8	.01	-.28	Yes	1974-81
PB-809	264123080053801	26	.00	.08	Yes	1974-99
		11	.56	.04	No	1981-91
		9	.50	-.02	No	1991-99
		8	.07	-.19	No	1974-81
PB-831	265106080241402	26	.00	.12	Yes	1974-99
		11	.07	.16	No	1981-91
		9	.34	.03	No	1991-99
		8	.71	-.04	No	1974-81
PB-900	262534080085102	11	.02	-.03	Yes	1981-91
PB-1491	262317080074601	9	.54	.08	No	1991-99
PB-1639	263656080033502	9	.14	.16	No	1991-99
PB-1661	262410080090801	9	.37	-.02	No	1991-99
PB-1662	264839080115001	9	.07	.09	No	1991-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer						
F-45	254943080121501	10	0.78	0.00	No	1974-83
		26	.39	.00	No	1974-99
		10	.77	-.01	No	1983-92
		8	.22	-.03	No	1992-99
F-179	254444080144801	10	.12	.02	No	1974-83
		26	.46	.00	No	1974-99
		10	.55	-.01	No	1983-92
		8	.25	-.02	No	1992-99
F-239	255008080161801	10	.42	.02	No	1974-83
		26	.01	.07	Yes	1974-99
		10	.79	.02	No	1983-92
		8	.86	.02	No	1992-99
F-291	260010080085001	10	.04	.02	Yes	1974-83
		26	.00	.01	Yes	1974-99
		10	.64	.01	No	1983-92
		8	.62	-.01	No	1992-99
F-319	254217080171801	10	.93	.00	No	1974-83
		26	.71	.00	No	1974-99
		10	.19	-.02	No	1983-92
		8	.91	.00	No	1992-99
F-358	252829080285101	10	.01	.10	Yes	1974-83
		26	.00	.03	Yes	1974-99
		10	.90	.01	No	1983-92
		8	.21	-.03	No	1992-99
G-3	254950080180801	10	.99	.00	No	1974-83
		26	.02	.11	Yes	1974-99
		10	.72	.03	No	1983-92
		8	.48	.07	No	1992-99
G-551	254130080234501	8	.56	-.08	No	1992-99
G-553	253902080202501	10	.02	.06	Yes	1974-83
		26	.29	.01	No	1974-99
		10	.14	-.04	No	1983-92
		8	.74	-.03	No	1992-99
G-561	260545080082001	10	.31	.02	No	1974-83
		26	.00	.03	Yes	1974-99
		10	.12	.02	No	1983-92
		8	.93	-.01	No	1992-99
G-580A	254000080181001	10	.02	.04	Yes	1974-83
		10	.36	-.02	No	1983-92
G-596	253937080304001	10	.00	.20	Yes	1974-83
		26	.02	.03	Yes	1974-99
		10	.16	-.06	No	1983-92
		8	.96	.00	No	1992-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
G-613	252425080320001	10	0.07	0.05	No	1974-83
		26	.02	.01	Yes	1974-99
		10	.61	-.01	No	1983-92
		8	.57	.01	No	1992-99
G-614	253258080264301	10	.01	.09	Yes	1974-83
		26	.00	.04	Yes	1974-99
		10	.27	-.03	No	1983-92
		8	.84	.01	No	1992-99
G-616	261710080135001	10	.53	-.12	No	1974-83
		10	.11	-.14	No	1983-92
G-617	260515080202101	10	.08	.02	No	1974-83
		26	.00	.01	Yes	1974-99
		10	.36	-.01	No	1983-92
		8	.42	.01	No	1992-99
G-618	254500080360001	10	.02	.05	Yes	1974-83
		26	.00	.04	Yes	1974-99
		10	.34	-.04	No	1983-92
		8	.19	.05	No	1992-99
G-620	254000080460001	10	.00	.12	Yes	1974-83
		26	.03	.03	Yes	1974-99
		10	.05	-.11	No	1983-92
		8	.27	.10	No	1992-99
G-757A	253537080284401	10	.01	.14	Yes	1974-83
		26	.00	.04	Yes	1974-99
		10	.41	-.02	No	1983-92
		8	.93	.00	No	1992-99
G-789	252928080332401	10	.01	.14	Yes	1974-83
		26	.01	.02	Yes	1974-99
		10	.13	-.03	No	1983-92
		8	.39	-.03	No	1992-99
G-820A	261144080094601	10	.12	.09	No	1983-92
G-852	255437080103201	10	.01	.10	Yes	1974-83
		26	.28	.01	No	1974-99
		10	.13	-.03	No	1983-92
		8	.80	.01	No	1992-99
G-853	261434080071901	10	.99	.01	No	1974-83
		26	.00	.25	Yes	1974-99
		10	.08	.29	No	1983-92
		8	.22	.15	No	1992-99
G-855	254038080280201	10	.02	.08	Yes	1974-83
		26	.01	.03	Yes	1974-99
		10	.36	-.05	No	1983-92
		8	.43	.02	No	1992-99
G-858	253854080242801	10	0.27	0.03	No	1974-83
		10	.95	-.01	No	1983-92

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
G-860	253718080192301	10	0.03	0.05	Yes	1974-83
		26	.13	.01	No	1974-99
		10	.35	-.02	No	1983-92
		8	.51	-.02	No	1992-99
G-864	252612080300701	10	.04	.08	Yes	1974-83
		26	.13	.01	No	1974-99
		10	.18	-.03	No	1983-92
		8	.97	.00	No	1992-99
G-864A	252619080310201	10	.12	.08	No	1974-83
		26	.19	.01	No	1974-99
		10	.58	-.02	No	1983-92
		8	.67	-.01	No	1992-99
G-968	255600080270001	10	.01	.18	Yes	1974-83
		26	.01	.04	Yes	1974-99
		10	.20	-.11	No	1983-92
		8	.34	.04	No	1992-99
G-970	255709080223701	10	.56	-.01	No	1974-83
		26	.53	.00	No	1974-99
		10	.16	-.02	No	1983-92
		8	.04	.07	Yes	1992-99
G-972	255522080261401	10	.00	.12	Yes	1974-83
		10	.05	-.11	No	1983-92
G-973	255209080212801	10	.53	.01	No	1974-83
		26	.04	.02	Yes	1974-99
		10	.81	-.01	No	1983-92
		8	.54	-.02	No	1992-99
G-975	255208080274001	10	.59	.02	No	1974-83
		26	.85	.00	No	1974-99
		10	.03	-.18	Yes	1983-92
		8	.59	.03	No	1992-99
G-976	255023080202301	10	.78	.01	No	1974-83
		26	.32	-.02	No	1974-99
		10	.09	-.18	No	1983-92
		8	.86	.02	No	1992-99
G-1074B	254215080201503	10	.04	-.59	Yes	1983-92
		8	.01	.55	Yes	1992-99
G-1166	255342080195501	10	.55	.01	No	1974-83
		26	.00	.01	Yes	1974-99
		10	.09	.02	No	1983-92
		8	.87	.00	No	1992-99
G-1183	252918080234201	10	.00	.05	Yes	1974-83
		26	.00	.01	Yes	1974-99
		10	.08	.02	No	1983-92
		8	.13	-.01	No	1992-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
G-1213	261734080111301	10	0.09	0.08	No	1974-83
		26	.04	-.03	Yes	1974-99
		10	.05	-.14	Yes	1983-92
		8	.14	-.06	No	1992-99
G-1215	261645080064701	10	.82	.07	No	1974-83
		10	.05	-.31	No	1983-92
G-1220	260752080084701	10	.08	.03	No	1974-83
		26	.04	.01	Yes	1974-99
		10	.39	-.02	No	1983-92
		8	.88	-.01	No	1992-99
G-1221	260458080134801	10	.22	.03	No	1983-92
		8	.88	-.01	No	1992-99
G-1223	260219080141101	10	.01	.03	Yes	1974-83
		26	.21	.01	No	1974-99
		10	.54	-.02	No	1983-92
		8	.82	-.01	No	1992-99
G-1224	260252080085301	10	.48	-.01	No	1974-83
		26	.30	.00	No	1974-99
		10	.97	.00	No	1983-92
		8	.29	.03	No	1992-99
G-1225	260032080135701	10	.01	.06	Yes	1974-83
		26	.06	.02	No	1974-99
		10	.25	-.05	No	1983-92
		8	.46	.03	No	1992-99
G-1226	260053080105701	10	.09	.02	No	1974-83
		26	.05	.01	Yes	1974-99
		10	.95	.00	No	1983-92
		8	.34	-.02	No	1992-99
G-1251	251922080340701	10	.01	.06	Yes	1974-83
		26	.00	.02	Yes	1974-99
		10	.20	-.03	No	1983-92
		8	.60	.02	No	1992-99
G-1260	261903080065601	10	.64	.05	No	1974-83
		26	.02	.08	Yes	1974-99
		10	.19	-.16	No	1983-92
		8	.31	.15	No	1992-99
G-1315	261708080090801	10	.66	.03	No	1974-83
		26	.29	-.02	No	1974-99
		10	.09	-.13	No	1983-92
		8	.48	.06	No	1992-99
G-1316	261441080111301	10	.09	-.11	No	1983-92
		8	.62	.01	No	1992-99
G-1362	263630080264801	10	.03	.08	Yes	1974-83
		26	.01	.03	Yes	1974-99
		10	.52	-.03	No	1983-92
		8	.81	.01	No	1992-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
G-1363	253233080301001	10	0.01	0.15	Yes	1974-83
		26	.00	.04	Yes	1974-99
		10	.44	-.02	No	1983-92
		8	.33	-.03	No	1992-99
G-1368A	254950080171202	10	.07	-.22	No	1974-83
		26	.04	.40	Yes	1974-99
		10	.90	-.01	No	1983-92
		8	.20	.36	No	1992-99
G-1473	255918080091801	10	.01	.04	Yes	1974-83
		26	.01	.01	Yes	1974-99
		10	.96	.00	No	1983-92
		8	.26	.03	No	1992-99
G-1486	253012080261401	10	.08	.07	No	1974-83
		26	.02	.01	Yes	1974-99
		10	.76	.00	No	1983-92
		8	.28	-.02	No	1992-99
G-1487	254054080295401	10	.50	.04	No	1983-92
		8	.13	-.07	No	1992-99
G-1488	254830080284201	10	.31	.03	No	1974-83
		26	.03	.02	Yes	1974-99
		10	.10	-.08	No	1983-92
		8	.22	.05	No	1992-99
G-1502	252656080350301	10	.00	.17	Yes	1974-83
		26	.00	.06	Yes	1974-99
		10	.20	-.09	No	1983-92
		8	.69	.02	No	1992-99
G-1636	255807080224301	10	.80	.00	No	1974-83
		26	.35	.01	No	1974-99
		10	.43	-.02	No	1983-92
		8	.10	.05	No	1992-99
G-1637	255707080255001	10	.81	-.01	No	1974-83
		26	.26	.01	No	1974-99
		10	.36	-.04	No	1983-92
		8	.77	.01	No	1992-99
G-2031	261534080165801	10	.08	-.05	No	1974-83
		26	.03	.02	Yes	1974-99
		10	.71	.02	No	1983-92
		8	.59	.02	No	1992-99
G-2032	260821080185101	10	.00	.07	Yes	1974-83
		26	.01	.02	Yes	1974-99
		10	.07	-.06	No	1983-92
		8	.56	.01	No	1992-99
G-2033	261141080163401	10	.08	.03	No	1974-83
		26	.16	.01	No	1974-99
		10	.06	-.08	No	1983-92
		8	.59	.03	No	1992-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
G-2034	260653080184901	10	0.78	0.01	No	1974-83
		26	.29	.01	No	1974-99
		10	.38	-.02	No	1983-92
		8	.33	-.04	No	1992-99
G-2035	260040080104401	10	.77	.00	No	1974-83
		26	.19	.01	No	1974-99
		10	.57	-.01	No	1983-92
		8	.92	.00	No	1992-99
G-2147	261501080060701	10	.22	.11	No	1974-83
		26	.00	.15	Yes	1974-99
		10	.53	.04	No	1983-92
		8	.36	.09	No	1992-99
G-2376	260753080253701	10	1.00	.00	No	1983-92
G-2395	261147080114501	10	.02	-.52	Yes	1983-92
		8	.62	.07	No	1992-99
G-2739	261831080151301	8	.54	-.01	No	1992-99
G-3073	254157080214001	10	.03	.09	Yes	1983-92
G-3074	254157080214002	10	.01	.44	Yes	1983-92
		8	.87	.01	No	1992-99
G-3253	255027080245501	10	.02	-.40	Yes	1983-92
		8	.70	.07	No	1992-99
G-3259A	255026080240302	10	.80	-.04	No	1983-92
		8	.66	.04	No	1992-99
G-3264A	255027080221602	10	.33	.06	No	1983-92
		8	.23	.07	No	1992-99
G-3327	254823080163701	10	.40	-.02	No	1983-92
		8	.67	.02	No	1992-99
G-3328	254741080162101	10	.19	-.02	No	1983-92
		8	.21	.02	No	1992-99
G-3329	254752080181501	10	.52	-.01	No	1983-92
		8	.61	.02	No	1992-99
G-3353	251724080341401	8	.38	.03	No	1992-99
G-3354	251855080283401	8	.61	.02	No	1992-99
G-3355	252332080300501	8	.79	.01	No	1992-99
G-3356	252502080253901	8	.98	.00	No	1992-99
G-3437	253400080340401	8	.84	-.01	No	1992-99
G-3439	254421080260201	8	.60	-.02	No	1992-99
G-3465	254823080175201	8	.46	.03	No	1992-99
G-3466	254834080171601	8	.64	.06	No	1992-99
G-3467	254839080162301	8	.42	.03	No	1992-99
G-3473	254248080263801	8	.79	.01	No	1992-99

Appendix II. Results of Seasonal Kendall trend tests of continuous water-level data (Continued)

Station name	Station identifier	Years of record examined	p-value	Slope (feet per year)	Statistically significant?	Period examined
Biscayne Aquifer--Continued						
S-18	255526080143001	10	0.05	0.02	Yes	1974-83
		26	.01	.01	Yes	1974-99
		10	.56	.00	No	1983-92
		8	.07	.02	No	1992-99
S-19	254832080175001	10	.36	-.03	No	1974-83
		26	.04	.05	Yes	1974-99
		10	.40	.03	No	1983-92
		8	.45	.06	No	1992-99
S-68	254857080171101	10	.23	-.03	No	1974-83
		26	.03	.13	Yes	1974-99
		10	.62	.03	No	1983-92
		8	.35	.15	No	1992-99
S-182A	253549080214101	10	.03	.03	Yes	1974-83
		26	.01	.01	Yes	1974-99
		10	.73	.01	No	1983-92
		8	.17	.03	No	1992-99
S-196A	253029080295601	10	.01	.15	Yes	1974-83
		26	.00	.04	Yes	1974-99
		10	.35	-.02	No	1983-92
		8	.65	-.02	No	1992-99
S-329	260657080122301	10	.06	.04	No	1974-83
		26	.00	.07	Yes	1974-99
		10	.94	.01	No	1983-92
		8	.20	.18	No	1992-99

APPENDIX III

Summary Statistics of Water-Level Data from Candidate Monitoring Wells

Water-Table Aquifer (West Coast)

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Mini-mum	Ist quartile (25th per-centile)	Mean	Median (50th per-centile	3rd quartile (75 per-centile)	Maxi-mum	Standard deviation	Inter-quartile range	
Summary Statistics									
Average	8.44	10.82	11.73	11.82	12.72	14.49	1.33	1.90	191
Maximum	25.85	27.65	28.80	29.23	30.21	30.85	2.42	3.58	308
Minimum	-1.70	.73	1.33	1.55	1.77	2.37	.63	.75	29
Individual Well Statistics									
C-54	8.31	10.39	10.90	10.82	11.52	13.12	0.84	1.13	308
C-131	16.81	22.27	23.35	23.49	24.69	26.39	1.72	2.42	270
C-296	6.43	9.33	10.34	10.66	11.66	12.63	1.50	2.33	162
C-392	3.40	6.09	6.63	6.70	7.29	8.39	.91	1.21	306
C-496	1.40	5.98	6.40	6.88	7.17	10.40	1.48	1.19	307
C-503	13.25	15.86	16.63	16.84	17.64	18.44	1.25	1.79	167
C-598	5.87	9.50	10.93	11.01	12.58	14.22	2.05	3.08	180
C-690	2.71	4.81	5.86	5.62	6.61	9.75	1.46	1.80	203
C-953	4.57	6.24	7.25	7.34	8.08	11.48	1.24	1.84	177
C-968	2.49	4.18	5.16	5.31	6.31	7.43	1.29	2.13	173
C-969	.61	1.59	2.67	2.54	3.69	4.76	1.19	2.10	138
C-978	14.77	16.07	16.93	17.15	17.74	18.52	1.15	1.67	38
C-981	12.27	13.81	14.08	14.38	14.57	15.00	.74	.75	36
C-997	5.94	8.18	9.35	9.37	10.47	13.27	1.61	2.29	161
C-1063	.76	2.59	3.21	3.24	4.18	4.74	1.03	1.59	33
C-1065	-.14	.83	1.33	1.55	1.77	2.37	.63	.94	37
C-1071	7.83	13.02	14.56	14.76	16.60	18.60	2.42	3.58	156
C-1075	25.85	27.65	28.80	29.23	30.21	30.85	1.63	2.56	29
HE-558	12.82	14.37	14.84	15.00	15.31	16.01	.63	.94	168
HE-862	8.87	11.06	12.01	11.92	12.77	16.79	1.39	1.71	183
L-730	24.29	26.04	26.77	26.74	27.54	29.67	1.04	1.49	298
L-954	-1.70	.73	2.16	1.98	3.63	7.19	2.01	2.90	256
L-1137	15.75	17.15	18.16	18.06	18.91	21.79	1.26	1.76	270
L-1403	-.52	.86	1.53	1.57	2.27	3.72	.94	1.41	304
L-1995	19.15	22.16	23.04	23.20	24.01	25.22	1.21	1.85	288
L-1997	8.90	11.71	12.91	13.07	14.19	16.36	1.69	2.48	256
L-2195	7.19	9.60	10.81	10.77	12.01	14.05	1.63	2.41	191

[1]Months that had less then 15 days of data were not used.

Lower Tamiami Aquifer

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Mini-mum	Ist quartile (25th per-centile)	Mean	Median (50th per-centile)	3rd quartile (75 percen-tile)	Maxi-mum	Standard deviation	Inter-quartile range	
Summary Statistics									
Average	2.02	5.75	7.26	7.33	8.97	11.50	2.16	3.22	156.4
Maximum	24.23	29.06	31.07	31.07	33.43	35.62	3.60	5.60	285
Minimum	-5.07	-.59	1.19	1.61	3.03	4.94	.77	1.11	32
Individual Well Statistics									
C-391	-4.08	1.81	2.97	3.06	4.25	6.81	1.77	2.44	285
C-409A	-.35	2.26	2.83	2.92	3.59	5.00	1.00	1.33	136
C-460	-.39	3.54	4.94	5.00	6.55	1.34	2.34	3.01	167
C-462	24.23	29.06	31.07	31.07	33.43	35.62	2.66	4.37	273
C-492	12.84	16.20	16.66	16.91	17.45	18.56	1.07	1.25	279
C-506A	2.24	4.30	5.19	5.20	6.18	8.44	1.30	1.88	139
C-600	1.59	2.78	3.30	3.25	3.89	4.98	.77	1.11	190
C-951	1.27	4.72	6.02	6.02	7.32	11.80	1.98	2.60	181
C-988	5.14	10.48	12.07	12.60	14.21	15.66	2.52	3.74	158
C-998	-3.17	2.63	4.69	4.24	7.35	10.37	3.02	4.72	73
C-1004	-3.39	.73	2.78	2.72	5.07	8.50	2.76	4.35	168
C-1064	1.09	2.50	3.48	3.44	4.59	5.61	1.23	2.09	118
C-1074	19.62	23.06	23.99	24.17	25.19	26.76	1.65	2.13	116
C-1083	-1.33	1.20	2.99	3.02	4.95	7.67	2.24	3.75	83
L-738	-2.87	.35	2.13	2.25	4.20	7.08	2.47	3.85	88
L-1691	-5.07	1.65	4.33	4.39	7.25	11.54	3.60	5.60	270
L-2194	-.56	4.55	6.86	6.98	9.52	12.78	3.17	4.97	257
L-5727	-.91	1.35	3.09	3.11	4.45	7.58	2.13	3.10	50
L-5745	-1.48	2.43	4.54	4.59	6.89	1.02	2.94	4.46	65
L-5747	-4.01	-.59	1.19	1.61	3.03	4.94	2.52	3.62	32

Sandstone Aquifer

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Mini-mum	Ist quartile (25th per-centile)	Mean	Median (50th per-centile	3rd quartile (75 percen-tile)	Maxi-mum	Standard deviation	Inter-quartile range	
Summary Statistics									
Average	4.08	11.56	13.87	14.29	16.66	20.90	3.63	9.33	197.79
Maximum	24.86	28.03	28.92	29.03	29.88	33.28	10.52	32.94	305
Minimum	-31.81	-10.31	-3.50	-3.31	3.25	4.92	1.08	2.79	22
Individual Well Statistics									
C-531	7.91	21.46	24.55	25.52	28.19	32.54	4.90	11.08	228
C-688	5.82	9.72	11.13	11.51	12.65	13.67	1.87	3.96	35
C-989	-.26	8.84	11.08	11.86	14.79	17.12	4.44	8.28	141
C-1072	8.12	13.15	14.75	14.91	16.65	19.08	2.43	5.93	145
C-1079	-4.69	6.09	8.46	9.29	12.21	15.54	4.76	9.46	152
C-1099	1.26	2.13	3.07	3.16	3.93	4.92	1.08	2.79	34
HE-517	8.27	10.05	10.86	10.87	11.64	13.57	1.11	3.52	250
HE-529	24.86	28.03	28.92	29.03	29.88	30.99	1.25	2.96	222
HE-556	11.02	19.03	21.23	21.75	23.66	28.09	3.39	9.07	267
L-727	11.06	14.44	15.37	15.53	16.20	17.93	1.23	3.49	305
L-729	6.89	16.07	18.23	18.53	20.78	24.42	3.22	8.35	261
L-731	-5.88	9.70	14.29	15.96	19.87	24.42	6.94	14.72	302
L-1418	13.30	15.19	16.29	16.23	17.23	21.10	1.54	5.91	255
L-1994	6.31	14.45	16.78	16.95	19.07	33.28	3.36	18.83	294
L-1996	.97	5.37	7.62	7.58	10.13	12.79	2.94	7.42	243
L-1998	-31.81	-10.31	-3.50	-3.31	3.25	22.63	10.52	32.94	271
L-2186	11.04	16.04	18.58	18.94	21.11	24.78	3.29	8.75	223
L-2215	-3.65	9.56	12.59	13.52	19.38	21.38	7.56	11.82	22
L-2550	7.69	11.68	13.80	14.10	16.39	18.85	3.04	7.17	84
L-5649	7.50	12.20	14.19	14.52	16.18	19.03	2.56	6.83	169

Mid-Hawthorn Aquifer

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Minimum	Ist quartile (25th percentile)	Mean	Median (50th percentile	3rd quartile (75 percentile)	Maximum	Standard deviation	Inter-quartile range	
Summary Statistics									
Average	-34.83	-20.18	-15.00	-14.74	-9.07	0.23	7.84	11.11	212.4
Maximum	6.64	16.92	20.14	20.08	24.55	26.68	16.40	23.18	308
Minimum	-76.02	-52.58	-40.70	-42.34	-29.40	-12.81	3.86	5.00	20
Individual Well Statistics									
L-581	-49.15	-31.28	-25.04	-24.34	-18.70	-6.57	8.58	12.58	308
L-742	-76.02	-52.58	-40.70	-42.34	-29.40	-3.64	16.40	23.18	293
L-781	-42.06	-18.12	-12.80	-11.64	-6.21	2.59	8.86	11.91	273
L-1993	6.64	16.92	20.14	20.08	24.55	26.68	4.54	7.63	290
L-2193	-9.77	-1.98	.20	.62	3.02	6.36	3.86	5.00	81
L-2640	-36.72	-26.15	-22.60	-22.35	-15.90	-12.81	6.92	10.25	20
L-2644	-20.74	-4.89	-1.05	-.46	4.42	9.04	6.49	9.30	214
L-2701	-34.00	-22.28	-18.19	-18.58	-13.92	-3.31	6.46	8.36	239
L-2702	-41.73	-29.99	-25.08	-24.23	-19.99	-10.02	7.61	9.99	208
L-2703	-44.78	-31.45	-24.87	-24.16	-18.55	-6.00	8.72	12.90	198

Surficial Aquifer System

Well number (if applicable)	Monthly mean water level (feet): Mini-mum	Ist quartile (25th per-centile)	Mean	Median (50th per-centile	3rd quar-tile (75 per-centile)	Maxi-mum	Standard deviation	Inter-quartile range	Months of data available (1974-99)[1]
Summary Statistics									
Average	12.05	13.82	14.48	14.48	15.16	16.75	1.00	1.34	156.25
Maximum	25.31	28.06	29.40	29.49	30.65	32.33	2.43	3.23	310
Minimum	-2.50	1.56	2.91	2.77	3.54	5.39	.29	.33	47
Individual Well Statistics									
M-1004	2.56	4.42	4.71	4.77	5.22	6.40	0.78	0.80	168
M-1024	.71	2.15	2.91	2.77	3.54	6.34	1.09	1.40	124
M-1048	25.31	28.06	29.40	29.49	30.65	32.33	1.64	2.59	291
M-1234	13.76	15.54	15.91	15.97	16.43	17.55	.74	.89	121
M-1255	23.29	24.11	24.42	24.47	24.73	25.58	.49	.62	80
M-1257	13.03	13.99	14.64	14.65	15.27	15.84	.77	1.28	47
M-1261	6.83	10.20	10.79	10.73	11.64	13.02	1.17	1.44	82
PB-99	5.70	7.14	7.86	7.77	8.52	10.83	1.00	1.38	303
PB-445	15.03	15.97	16.12	16.14	16.31	17.06	.32	.34	310
PB-561	11.15	13.84	14.62	14.80	15.66	17.05	1.32	1.82	286
PB-565	.42	2.05	3.18	3.07	4.12	7.43	1.46	2.07	309
PB-683	12.09	14.19	15.18	15.06	16.28	18.37	1.39	2.09	282
PB-685	11.76	13.51	14.60	14.34	15.70	17.53	1.45	2.20	111
PB-689	21.58	23.52	24.00	24.21	24.69	25.25	.89	1.18	112
PB-732	3.62	5.41	6.00	5.97	6.59	8.38	.88	1.18	291
PB-809	6.28	9.54	10.07	10.33	10.94	12.33	1.30	1.40	292
PB-831	17.43	19.90	20.76	20.72	21.77	22.93	1.22	1.87	294
PB-900	13.42	14.50	14.65	14.66	14.83	15.42	.29	.33	239
PB-1491	-2.50	1.56	3.23	3.39	4.79	9.48	2.43	3.23	181
PB-1639	2.83	4.53	5.49	5.24	6.45	9.60	1.49	1.92	123
PB-1642	4.82	6.69	7.24	7.21	7.71	9.59	.95	1.02	73
PB-1661	13.64	14.51	14.87	14.85	15.23	15.89	.48	.72	118
PB-1662	16.11	17.45	17.75	17.75	18.06	19.01	.57	.61	95
PB-1680	1.77	2.89	3.39	3.41	3.77	5.39	.77	.88	71
PB-1684	9.07	9.47	9.64	9.65	9.86	10.29	.31	.39	73
STL-41	22.77	24.69	25.54	25.59	26.49	28.04	1.23	1.80	139
STL-42	24.12	25.11	25.51	25.54	25.96	27.48	.67	.85	144
STL-125	14.87	15.85	16.68	16.44	17.20	20.22	1.15	1.35	92
STL-172	11.79	13.84	14.25	14.34	14.96	15.97	.93	1.12	118
STL-175	6.19	8.22	8.87	8.95	9.47	11.69	1.13	1.25	129
STL-176	10.69	13.52	14.26	14.51	15.19	16.67	1.28	1.67	126
STL-185	22.91	25.03	25.30	25.49	25.77	26.54	.72	.74	81
STL-213	9.52	10.92	11.95	11.90	12.87	14.94	1.20	1.95	80
STL-214	18.26	20.22	21.37	21.18	22.54	24.34	1.46	2.32	78
STL-264	18.42	18.96	19.19	19.15	19.35	20.05	.35	.39	78
STL-313	24.62	26.11	26.78	26.87	27.40	28.33	.87	1.29	84

Biscayne Aquifer

Well number (if applicable)	Monthly mean water level (feet): Minimum	Ist quartile (25th percentile)	Mean	Median (50th percentile	3rd quartile (75 percentile)	Maximum	Standard deviation	Interquartile range	Months of data available (1974-99)[1]
Summary Statistics									
Average	1.56	3.05	3.61	3.63	4.20	5.59	0.81	1.15	201
Maximum	9.79	11.75	12.20	12.23	12.82	14.04	5.48	11.36	312
Minimum	-13.86	-9.85	-8.26	-8.46	-6.73	-2.68	.19	.27	19
Individual Well Statistics									
F-45	1.39	1.85	2.25	2.12	2.57	4.87	0.56	0.72	311
F-179	1.27	1.89	2.25	2.19	2.52	4.06	.47	.63	310
F-239	-1.11	.13	.95	1.06	1.75	4.64	1.06	1.62	307
F-291	.52	1.25	1.66	1.55	1.98	4.04	.61	.73	309
F-319	1.46	2.12	2.30	2.32	2.49	4.00	.33	.37	308
F-358	-.43	2.28	2.68	2.67	3.24	4.31	.78	.96	310
G-3	-3.34	-1.62	.15	-.10	2.14	3.95	1.96	3.75	311
G-551	-2.06	.36	.97	1.01	1.76	3.56	1.03	1.41	167
G-553	1.50	2.94	3.41	3.40	3.92	5.32	.69	.98	295
G-561	.53	1.41	1.77	1.72	2.09	3.66	.58	.68	308
G-580A	1.06	2.27	2.57	2.57	2.91	3.79	.49	.65	279
G-594	3.68	5.25	6.05	6.19	6.80	7.44	.94	1.55	81
G-596	1.14	4.64	5.00	5.21	5.58	7.36	.96	.94	309
G-613	-.75	1.91	2.15	2.26	2.51	3.17	.57	.60	311
G-614	.05	2.56	3.10	3.09	3.69	5.55	.88	1.13	306
G-616	5.90	7.75	8.58	8.55	9.22	12.39	1.19	1.47	221
G-617	2.85	3.62	3.85	3.80	4.03	5.30	.39	.41	310
G-618	3.81	6.32	6.57	6.69	7.08	8.09	.76	.76	306
G-620	3.39	5.96	6.29	6.31	6.73	8.25	.76	.77	273
G-757A	.49	3.55	3.99	4.13	4.65	5.89	.92	1.11	307
G-789	-.38	3.03	3.43	3.50	4.07	5.44	.91	1.04	305
G-820A	-2.41	2.84	3.69	3.98	4.93	7.79	1.88	2.10	187
G-852	1.01	1.70	2.04	1.96	2.35	4.31	.49	.65	306
G-853	-5.14	-.55	1.39	.90	3.41	7.58	2.58	3.96	303
G-855	1.57	4.00	4.47	4.57	5.06	6.18	.82	1.06	305
G-858	1.30	3.33	3.81	3.89	4.40	5.34	.78	1.07	233
G-860	.93	2.39	2.68	2.74	3.06	3.66	.48	.68	312
G-864	-.39	2.04	2.54	2.52	3.05	4.21	.76	1.01	310
G-864A	-.53	1.94	2.41	2.42	2.92	4.17	.77	.99	304
G-968	3.21	5.78	6.34	6.68	7.07	8.13	1.08	1.29	309
G-970	2.03	2.60	2.85	2.80	3.03	4.61	.37	.43	302
G-972	3.16	4.41	4.85	4.99	5.43	5.77	.66	1.03	264
G-973	1.56	2.56	2.87	2.83	3.21	4.43	.50	.65	310
G-975	2.85	5.17	5.53	5.86	6.16	7.08	.89	1.00	302
G-976	.96	3.49	4.30	4.66	5.30	6.69	1.24	1.81	309
G-1074B	-8.94	-6.35	-4.10	-4.55	-2.18	3.13	2.86	4.16	188
G-1166	1.74	2.10	2.28	2.24	2.40	3.17	.24	.30	303
G-1183	-.25	1.78	2.02	1.97	2.36	3.21	.47	.58	307
G-1213	9.79	11.75	12.20	12.23	12.82	14.04	.87	1.07	309
G-1215	-1.79	1.37	2.98	3.00	4.48	8.98	2.19	3.11	262
G-1220	.60	1.44	1.88	1.85	2.25	3.77	.63	.81	310
G-1221	.91	1.76	2.15	2.13	2.45	3.97	.55	.69	265
G-1223	1.50	2.16	2.49	2.41	2.74	3.99	.46	.58	303
G-1224	.07	1.32	1.71	1.60	2.02	4.25	.60	.70	309
G-1225	.93	2.00	2.47	2.39	2.90	4.74	.71	.90	304
G-1226	.49	1.23	1.57	1.51	1.88	4.01	.53	.65	302
G-1251	-1.04	1.61	1.90	2.05	2.32	3.09	.61	.72	295
G-1260	-.53	2.11	3.34	3.42	4.62	7.56	1.65	2.52	312

Biscayne Aquifer (Continued)

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Minimum	Ist quartile (25th percentile)	Mean	Median (50th percentile	3rd quartile (75 percentile)	Maximum	Standard deviation	Interquartile range	
G-1315	6.38	9.46	10.02	10.23	10.77	12.38	1.11	1.31	307
G-1316	6.76	7.64	8.24	8.21	8.78	11.94	.77	1.15	256
G-1359	3.78	4.61	5.04	5.05	5.52	6.10	.64	.90	55
G-1362	.79	3.57	4.02	4.13	4.62	5.72	.86	1.05	305
G-1363	.03	3.21	3.68	3.72	4.37	5.79	.99	1.16	311
G-1368A	-13.38	-9.85	-3.90	-3.26	1.51	4.36	5.48	11.36	305
G-1473	.52	1.21	1.60	1.52	1.90	4.08	.60	.69	310
G-1486	-.10	2.20	2.61	2.56	3.12	4.04	.68	.92	301
G-1487	2.07	4.90	5.37	5.49	6.02	7.20	.96	1.13	227
G-1488	3.61	5.93	6.17	6.42	6.70	7.76	.84	.78	307
G-1502	.75	5.14	5.69	6.03	6.61	7.62	1.28	1.48	308
G-1636	2.20	2.77	3.07	3.01	3.31	4.90	.44	.54	308
G-1637	2.58	3.82	4.15	4.22	4.57	5.64	.58	.75	301
G-2031	5.97	7.06	7.39	7.42	7.75	8.39	.47	.69	310
G-2032	3.14	4.12	4.46	4.49	4.78	5.84	.49	.66	307
G-2033	5.36	6.38	6.66	6.66	6.93	7.98	.44	.55	304
G-2034	1.79	3.32	3.68	3.64	3.98	5.15	.53	.66	306
G-2035	.41	1.20	1.57	1.50	1.85	3.63	.55	.65	309
G-2147	-.75	1.37	2.69	2.72	3.92	6.83	1.57	2.56	302
G-2376	4.51	5.88	6.31	6.40	6.77	7.28	.61	.89	153
G-2395	-13.86	-9.78	-8.26	-8.46	-6.73	-2.68	2.36	3.05	167
G-2739	6.18	7.74	7.95	7.99	8.26	8.75	.44	.52	92
G-2852	4.03	6.27	6.97	7.04	7.77	9.35	1.10	1.50	50
G-2866	2.86	5.72	6.46	6.54	7.41	10.22	1.63	1.69	42
G-3073	.17	1.78	2.27	2.33	2.79	3.79	.73	1.01	218
G-3074	-2.46	-.30	1.06	1.50	2.32	3.56	1.55	2.62	264
G-3253	-4.40	-1.10	1.62	1.39	4.74	6.70	3.01	5.84	201
G-3259A	-1.09	1.37	3.00	2.97	4.99	6.67	2.02	3.62	199
G-3264A	1.13	2.80	3.48	3.32	4.33	6.23	1.02	1.53	183
G-3272	4.15	5.79	6.33	6.35	6.97	7.83	.77	1.18	71
G-3327	1.12	1.74	2.02	1.97	2.30	3.65	.41	.56	187
G-3328	1.44	1.94	2.13	2.11	2.32	3.24	.29	.38	185
G-3329	1.97	2.62	2.85	2.83	3.07	4.25	.36	.45	188
G-3353	-.09	1.03	1.25	1.33	1.51	2.25	.43	.48	164
G-3354	.86	1.56	1.86	1.90	2.20	2.75	.44	.64	153
G-3355	1.35	2.22	2.62	2.67	3.02	3.86	.53	.80	165
G-3356	1.18	1.83	2.20	2.18	2.52	3.08	.41	.69	167
G-3437	2.49	4.61	5.15	5.28	5.87	6.93	.97	1.26	158
G-3439	2.50	3.76	4.33	4.31	4.91	6.29	.84	1.15	137
G-3465	.55	1.47	2.04	1.98	2.53	4.41	.71	1.05	144
G-3466	-.34	.72	1.49	1.56	2.17	4.55	.99	1.45	129
G-3467	.90	1.45	1.83	1.78	2.17	3.70	.48	.72	142
G-3473	2.64	4.01	4.44	4.36	4.91	5.97	.61	.90	91
G-3549	1.42	1.71	1.83	1.80	1.98	2.24	.19	.27	62
G-3550	1.27	1.55	1.75	1.77	1.94	2.13	.23	.40	59
G-3551	4.62	5.57	5.88	5.94	6.28	7.07	.54	.71	67
G-3552	4.09	4.90	5.36	5.43	5.83	6.67	.59	.93	67
G-3553	3.93	4.70	5.17	5.22	5.68	6.35	.59	.98	69
G-3554	4.19	4.81	5.35	5.42	5.78	6.80	.63	.98	56
G-3555	3.62	4.40	4.81	4.84	5.31	6.05	.59	.92	67
G-3556	3.92	4.67	5.18	5.29	5.65	6.33	.61	.99	63
G-3557	4.67	5.37	5.84	5.88	6.29	7.20	.57	.92	68
G-3558	4.05	4.68	5.19	5.24	5.63	6.58	.59	.95	69

Biscayne Aquifer (Continued)

Well number (if applicable)	Monthly mean water level (feet)								Months of data available (1974-99)[1]
	Minimum	lst quartile (25th per-centile)	Mean	Median (50th per-centile	3rd quartile (75 percen-tile)	Maxi-mum	Standard deviation	Inter-quartile range	
G-3559	5.14	5.66	5.94	5.97	6.25	6.98	0.37	0.59	68
G-3560	4.00	4.79	5.17	5.22	5.53	6.42	.54	.74	61
G-3561	3.43	4.28	4.61	4.69	5.01	5.49	.54	.73	68
G-3562	2.78	3.35	3.82	3.66	4.26	5.72	.66	.91	64
G-3563	2.44	2.99	3.27	3.15	3.51	4.37	.41	.52	58
G-3564	1.11	1.67	2.07	1.89	2.43	3.84	.61	.76	62
G-3565	2.82	3.30	3.60	3.58	3.90	4.66	.44	.60	61
G-3566	2.61	2.99	3.42	3.30	3.78	4.90	.55	.79	62
G-3567	4.67	5.46	5.80	5.97	6.16	6.84	.52	.71	64
G-3568	2.90	3.27	3.60	3.49	3.94	4.74	.45	.67	63
G-3570	2.31	2.74	3.34	3.08	3.82	6.14	.77	1.08	64
G-3571	1.80	2.49	2.93	2.78	3.30	5.02	.64	.81	60
G-3572	3.13	3.64	3.91	3.78	4.23	4.80	.43	.59	63
G-3574	5.40	6.02	6.22	6.25	6.47	7.26	.37	.45	59
G-3575	4.80	5.88	6.11	6.27	6.54	7.31	.56	.66	59
G-3576	6.08	6.74	6.92	6.97	7.13	7.88	.37	.39	57
G-3577	4.96	6.24	6.51	6.68	6.93	7.73	.64	.69	58
G-3578	5.51	6.52	6.73	6.80	7.01	7.77	.47	.49	56
G-3619	1.61	2.51	2.64	2.76	2.89	3.30	.39	.38	45
G-3620	1.67	2.33	2.50	2.59	2.67	3.04	.34	.34	45
G-3621	1.17	1.99	2.22	2.28	2.47	3.03	.38	.49	44
G-3622	3.18	3.99	4.44	4.59	4.86	5.79	.64	.86	42
G-3626	4.19	4.60	4.85	4.86	5.04	6.06	.36	.44	42
G-3627	3.85	4.24	4.48	4.48	4.69	5.56	.35	.45	42
G-3628	4.02	4.55	4.96	5.05	5.29	6.37	.52	.74	42
G-3660	5.31	5.86	6.16	6.15	6.44	7.23	.44	.58	19
S-18	1.32	1.92	2.11	2.07	2.25	3.21	.29	.33	306
S-19	-.66	.69	1.48	1.41	2.29	4.43	1.00	1.60	310
S-68	-4.04	-1.84	-.02	-.02	1.96	4.49	2.08	3.80	310
S-182A	.85	2.40	2.63	2.63	2.91	4.10	.45	.51	311
S-196A	-.08	2.90	3.35	3.40	3.99	5.19	.90	1.10	312
S-329	-.93	.92	1.70	1.59	2.45	5.87	1.16	1.53	309