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# *SALTWATER INTRUSION AND THE MINIMUM AQUIFER LEVEL IN THE SOUTHERN WATER USE CAUTION AREA*

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## ISSUE PAPER:

# SALTWATER INTRUSION AND THE MINIMUM AQUIFER LEVEL IN THE SOUTHERN WATER USE CAUTION AREA

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# SALTWATER INTRUSION AND THE MINIMUM AQUIFER LEVEL IN THE SOUTHERN WATER USE CAUTION AREA

## 1.0 INTRODUCTION

Chapter 373 Florida Statutes requires the water management districts to annually update and submit a schedule for establishing minimum flows and levels (MFLs) on priority water bodies. In the SWFWMD it has been determined that saltwater intrusion in the Upper Floridan aquifer is occurring in coastal areas of the Southern Water Use Caution Area (SWUCA; SWFWMD, 1993). This is in response to reductions in coastal ground-water discharge caused by historical increases in ground-water withdrawals (SWFWMD, 1993; DOAH). The Governing Board of the SWFWMD has determined that saltwater intrusion is of regional significance and that the Upper Floridan aquifer in the SWUCA is a MFLs priority water body. They further concluded that a minimum aquifer level should be established to achieve the management goal of slowing the rate of movement of the freshwater/saltwater interface.

The purpose of this paper is to document the background and the methodology used to establish a minimum aquifer level to prevent significant harm caused by saltwater intrusion in the Upper Floridan aquifer within the SWUCA. The principal area of concern in the SWUCA is the coastal area of the Eastern Tampa Bay (ETB) WUCA located in southern Hillsborough, Manatee, and northern Sarasota counties and is shown in **Figure** 1. The organization of this paper is as follows: Section 2 provides a brief historical overview and general background of the area; Section 3 briefly discusses the hydrogeology of the area; Section 4 reviews assessments of saltwater intrusion that have been made; Section 5 summarizes the quantification of wells and water supply potentially at risk to future saltwater intrusion; and Section 6 documents and describes the methodology for calculating the proposed minimum aquifer level.

The analyses presented herein rely on more detailed reports that were prepared in support of the establishment of a minimum aquifer level for regional saltwater intrusion and are only briefly summarized here. Following is a list of significant references by topic:

| | |
|---|---|
| Hydrogeology: | SWFWMD (1993); Basso (2002). |
| Changes in coastal ground-water quality: | SWFWMD (1993); SWFWMD (1994); SWFWMD (2000); SWFWMD (2002). |
| Changes in ground-water levels: | SWFWMD (1993); SWFWMD (1994); Beach et al (2002b). |
| Regional ground-water flow system | SWFWMD (1993); Barcelo and Basso (1993); Beach et al (2002a) |
| Numerical modeling of saltwater intrusion | HydroGeoLogic (1994); HydroGeoLogic (2002); |
| Wells and water supply potentially at risk to saltwater intrusion | Beach and Kelley (1998); Beach and Schultz (2000); Barcelo et al (2002); HydroGeoLogic (2002) |

## 2.0 BACKGROUND

In the late 1980s it was noted that declines in ground-water levels had occurred in three regions of the District: Highlands Ridge, Northern Tampa Bay (NTB) and Eastern Tampa Bay (ETB). These declines were primarily caused by ground-water withdrawals. Regional impacts resulting from the lowered ground-water levels were: lowered lake and wetland levels in the NTB area; lowered lake levels in the Highlands Ridge area; and saltwater intrusion in the ETB area. In order to provide the technical framework for a management strategy in the region, the District initiated detailed hydrologic assessments of each of these areas to further examine cause and effect relationships and assess water availability. These assessments were referred to as Water Resource Assessment Projects (WRAPs).

In response to the lowered levels, the Governing Board declared each of the areas as water use caution areas (WUCA) in 1989. For the southern portion of the District, specific water use permitting rules were implemented in 1990 for the Highlands Ridge and Eastern Tampa Bay WUCAs. Major rule provisions emphasized water conservation and water use monitoring, including per capita goals for public suppliers, crop efficiency standards for agriculture and specific conservation plans for recreation, industrial and mining uses. Metering was required for all uses greater than 100,000 gallons per day. Also in 1990, the District designated the coastal area of the ETB WUCA as the “Most Impacted Area (MIA)” (SWFWMD, 2001b). The purpose for this designation was to initiate management actions to stabilize the long-term water level declines that had occurred and that had resulted in saltwater intrusion. Since the early 1990s, there has been no increase in permitted quantities from the Upper Floridan aquifer in the MIA.

The Eastern Tampa Bay WRAP was completed in 1993 (SWFWMD, 1993). The major conclusion of this study was that significant, regional saltwater intrusion was occurring and posed a limiting constraint on ground-water development in the area. The study indicated that ground-water withdrawals within the basin, but outside the ETB area, also contribute to water-level declines in the area and should be managed as well. Out of concern for impacts to water resources in the region, the Governing Board in 1992 established the SWUCA, encompassing both the Eastern Tampa Bay and Highlands Ridge WUCAs and all the area in between (**Figure** 1). Specifically, the SWUCA encompasses an area of about 5,100 square miles and covers the southern half of the District, including all of Manatee, Sarasota, Hardee and DeSoto counties and portions of Hillsborough, Charlotte, Highlands and Polk counties. In addition to the lowered lake levels along the Highlands Ridge and advancing saltwater intrusion in coastal regions of the Eastern Tampa Bay WUCA, other resource concerns in the SWUCA include the cessation of flow from Kissengen Spring and reduced baseflow to the upper Peace River in Polk County as a result of lowered ground-water levels.

### 2.1 Previous Work

The water resources and hydrogeology of the Eastern Tampa Bay WUCA and SWUCA have been discussed in detail in many reports. As it pertains to the Eastern Tampa Bay area, a detailed discussion can be found in the Eastern Tampa Bay Water Resources Assessment Project report (ETB WRAP; SWFWMD, 1993). Additional discussions can be found in SWFWMD(1994), HGL (1994), Basso (2002), Beach (2002a), Beach (2002b), and HGL (2002).

SWFWMD (1993) provides a comprehensive evaluation of water resources of the ETB WUCA. Historical changes in ground-water levels, quality, and withdrawals were analyzed, and ground-water flow and solute transport models were developed. The major conclusion of this study was that saltwater intrusion in coastal portions of the Upper Floridan aquifer was occurring in response to declining ground-water levels since the 1930s. The principal factor causing these declines was the historical increases in ground-water withdrawals.

Subsequent to completion of the ETB WRAP the District formed a team of technical experts to review the body of work that had been conducted and recommend improvements to the analyses where needed. This led to the compilation of a series of issue papers addressing the recommendations, as well as expanding the evaluations to include the entire SWUCA. These papers are contained in SWFWMD (1994), and are referred to as the "Supplemental Investigations." The investigations included analyses of water level and water quality trends, conceptual model of ground-water quality, summary of logging and sampling of water use permit wells, and examination of the origin of chlorides in the Floridan aquifer. One of the outcomes of the review was to revise the solute transport modeling documented in HydroGeoLogic (1991). The revised modeling is documented in HydroGeoLogic (1994a). In addition, a sharp-interface ground-water flow model developed by HydroGeoLogic (1994b) was applied to the region and compared to results of the solute transport modeling. The solute transport modeling investigations are summarized as part of the "Assessment of Saltwater Intrusion," discussed later in this report.

### 2.2 Previously Proposed Minimum Aquifer Level

Based on conclusions of the ETB WRAP, the District initiated development of a long-term water management strategy for the region. As part of the strategy, the District proposed a minimum aquifer level over the entire SWUCA to preserve the freshwater resources of the Floridan Aquifer and stabilize lake levels in Polk and Highlands counties. The strategy resulted in the promulgation of the SWUCA Rules. A fundamental underpinning of the strategy was the Board's acknowledgement that the water resource problems of the area had developed over the long-term and could not be corrected immediately without serious socioeconomic impacts. The principal concept integrated within the rules was to gradually reduce existing withdrawals while not allowing new withdrawals to take place, and building in a mechanism (reallocation) to redistribute existing permitted quantities to new uses and at new locations within the SWUCA.

The use of a minimum aquifer level to prevent the withdrawal of new quantities from the Floridan Aquifer was a key aspect of the proposed SWUCA rule. The minimum level was developed as a single value representing the annual-average potentiometric surface for 1991 over the entire SWUCA. The annual-average was derived as the average of the May and September 1991 potentiometric surfaces published by the U. S. Geological Survey. Though this level was found to be scientifically valid during a subsequent administrative hearing on the proposed rules, the level was withdrawn following the invalidation of other parts of the rule and because of previous agreements made with water users in the region.

## 3.0 HYDROLOGIC OVERVIEW

### 3.1 Hydrogeology

The hydrogeology of the Eastern Tampa Bay WUCA and SWUCA has been discussed in detail in many reports (SWFWMD, 1993; SWFWMD, 1994; Basso, 2002; Beach, 2002a et al; Miller, 1986; Ryder, 1985). A brief overview is given here.

Peninsular Florida consists of several ground-water basins (see **Figure** 2). The SWUCA lies within the Southern West Central Florida Ground-Water basin (SWCFGWB). The ground-water flow system of the SWCFGWB is comprised of three, vertically sequenced, aquifer systems: the unconfined surficial aquifer system (SAS); the confined intermediate aquifer system (IAS); and the Floridan aquifer system (FAS).

The geology underlying the west-central Florida area consists of a series of clastic sediments overlying carbonate rocks. Each strata differs in its ability to yield water to wells. In the ETB WUCA there are three recognized aquifer systems (**Table** 1). At the surface and extending several tens of feet thick is the unconfined surficial aquifer. It is generally comprised of unconsolidated sediments. Underlying the surficial is the confined IAS which consists of a series of thin, interbedded limestone and phosphatic clays of generally low permeability. Although there are permeable units within the IAS it is often categorized as a confining unit that separates the surficial and Upper Floridan aquifers (Basso, 2002).

The third aquifer system, which underlies the IAS, is the confined Floridan aquifer system (FAS). It is composed of a series of limestone and dolomite formations that can yield in excess of 2,000 gallons per minute from large diameter wells. The FAS is divided into the Upper Floridan aquifer (UFA) and the Lower Floridan aquifer (LFA), which are separated by a middle confining unit (MCU). The MCU consists of a thick, massive sequence of evaporite materials of extremely low permeability (Miller, 1986 ). Horizontal conductivities from five packer tests of the MCU ranged from 0.002 to 0.04 feet/day (Basso, 2002). Because the LFA is hydraulically isolated from the UFA, contains highly brackish water, and is not utilized, the UFA is the principal source of ground-water in the southern District area, as well as the remaining District areas.

The UFA ranges in thickness from about 1,000 feet in the northern portion to more than 1,400 feet in the southern portion of the basin. The aquifer is comprised of three hydrogeologic units. The upper flow, or permeability, zone (UPZ) includes most of the Suwannee Limestone and sometimes the overlying Tampa Formation of the Hawthorn Group. The permeability of this unit is principally intergranular with apparently minor contribution from secondary porosity (Basso, 2002). The UPZ is considered to be “moderately permeable” when discussing well yields and has transmissivities that range from about 1,400 $ft^2$/day to 290,000 $ft^2$/day. The Ocala Limestone acts as semi-confining unit ranging in thickness from about 200 feet in the north to over 500 feet in the south. Water levels in wells completed above and below this unit show little difference in value. The median horizontal conductivity for this unit is about 0.2 feet per day and the median vertical conductivity is about 0.02 feet per day (Basso, 2002). The lower flow, or ermeability, zone (LPZ) occurs principally in the Avon Park Formation and is sometimes referred to as the "high T zone" or the "highly permeable zone."

Table 1. Hydrogeologic framework of the Southern District Water Use Caution Area (from Basso, 2002).

<table>
<tr><th>Series</th><th colspan="3">Stratigraphic Unit</th><th colspan="2">Hydrogeologic Unit</th><th>Lithology</th></tr>
<tr><td>Holocene to Pliocene</td><td colspan="3">Undifferentiated Surficial Deposits</td><td colspan="2">Surficial Aquifer</td><td>Sand, silty sand, clayey sand, peat, and shell</td></tr>
<tr><td rowspan="5">Miocene</td><td rowspan="5">Hawthorn Group</td><td colspan="2" rowspan="2">Peace River Formation</td><td>UICU</td><td rowspan="5">Intermediate Aquifer System</td><td rowspan="3">Predominantly phosphatic clay, gray to green to brown, plastic, ductile, minor sand, residual limestone and dolostone</td></tr>
<tr><td>PZ 2</td></tr>
<tr><td colspan="2">Arcadia Formation</td><td>MICU</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Tampa Member</td><td>PZ 3</td><td rowspan="2">Limestone, gray to tan, sandy, soft, clayey, minor sand, phosphatic. Chert found locally</td></tr>
<tr><td>LICU</td></tr>
<tr><td>Oligocene</td><td colspan="3">Suwannee Limestone</td><td>UPZ</td><td rowspan="3">Upper Floridan Aquifer</td><td>Limestone,cream to tan, sandy, vuggy, fossiliferous</td></tr>
<tr><td rowspan="3">Eocene</td><td colspan="3">Ocala Limestone</td><td>SCU</td><td>Limestone,white to tan, friable to micritic, fine-grained, soft, abundant foraminifera</td></tr>
<tr><td colspan="3" rowspan="2">Avon Park Formation</td><td>LPZ</td><td rowspan="2">Limestone and dolomite. Limestone is tan, recrystallized. Dolomite is brown, fractured, sucrosic, hard. Peat found locally at</td></tr>
<tr><td colspan="2">Middle Confining Unit</td></tr>
</table>

The permeability of the LPZ is generally 5 to 10 times greater than the UPZ and is principally derived from secondary porosity formed through fracturing of recrystallized dolomite. There is, however, some uncertainty as to the vertical and, possibly, the spatial distributions of the "highly permeable zone" (Basso, 2002; Waterstone, 2001). Transmissivities of this zone range from about 5,000 $ft^2$/day to over 1,600,000 $ft^2$/day (Beach et al, 2002a). Yields from large diameter wells completed into this zone can reach 2,000 to 3,000 gallons per minute (gpm).

3.2 Ground-Water Flow and Levels

Within the SWCFGWB, ground-water flow in the UFA originates as rainfall that percolates downward from the surficial aquifer through the IAS. Recharge rates to the UFA are generally highest in the northern and eastern portions of the basin (Aucott, 1988). In the northeastern portion of the basin annual-average recharge can exceed 10 inches per year. As you move south and west in the basin, recharge diminishes. In the coastal and more southern areas of the basin, hydraulic heads in the UFA are generally higher than heads in the IAS and SAS and diffuse upward leakage (discharge) occurs.

The direction of ground-water flow in the UFA is generally west/southwest from the regional potentiometric high in the northeastern portion (Green Swamp) and the Lake Wales Ridge in the eastern portion of the basin, toward the coast. The predevelopment potentiometric surface of the UFA, defined as a period prior to when the effects of withdrawals were significant, is shown in **Figure** 3 (Johnston et al, 1980). Major features of the surface are the Green Swamp high and the tendency for the potentiometric contours to wrap around the eastern portion of Tampa Bay, indicating discharge to the bay. The annual-average potentiometric surface for 1999 is shown in **Figure** 4. Changes in ground water flow patterns are evident from a comparison of these figures. Long-term changes in ground-water levels can be illustrated by water levels collected from the Sarasota 9 Deep well located in northern Sarasota County (**Figure** 5; see **Figure** 22 for location). Of significance to saltwater intrusion is the increasing annual water level fluctuations and fairly steady decline that has occurred since the early 1930s. Within the ETB WUCA, seasonal ground-water fluctuations can exceed 50 feet for some years (SWFWMD, 1993).

A detailed discussion of long-term changes in ground-water levels can be found in SWFWMD, (1994) and Beach et al, (2002b). A brief overview is provided in Section 4.3 of this report.

3.3 Water use in the SWUCA

3.3.1 Overview

The majority of water supply in the SWUCA is derived from ground water, with the UFA being the principal source of supply for most uses. In 1999, total estimated water use from permitted users was 767 million gallons per day (Mgal/d) with 680 Mgal/d (89 percent) coming from ground water and 87 Mgal/d (11 percent) coming from surface water. Generally, about 90 percent of the ground-water use in the SWUCA is derived from the UFA with the remainder derived from the overlying intermediate aquifer system.
Major uses of ground water have historically been for agricultural irrigation and mining of phosphate ore. Locations of agricultural withdrawals tend to be distributed throughout the basin, whereas, phosphate mining has been concentrated in the areas of southeast Hillsborough, southwest Polk, and northern Hardee counties (**Figure** 6). Since the 1970s, there has been a

shift in water use from the mining industry to other water use types in other areas of the basin. As described in Beach et al (2002b), the 1990s was a period of water level recovery in the northern portion of the basin and continued water level decline in southern portions of the basin. This, in large part, was due to the migration of agriculture into the area. Decreased water use in the northern portion of basin was largely due to increased water conservation practices by the phosphate mining industry since the 1970s and other changes within the industry that occurred.

Agriculture continues to be the largest user of water. With respect to estimated ground-water use in 1999: 448 Mgal/d (67 percent) was used for agriculture; 42 Mgal/d (6 percent) was used for industrial/commercial; 35 (5 percent) Mgal/d was used for mining/dewatering; 136 Mgal/d (20 percent) was used for public supply; and 18 Mgal/d (2 percent) was used for recreation/asethetics.

3.3.2 Historical Ground-Water Use

The District estimates water use from permitted withdrawals within the District on an annual basis. These estimates are a combination of metered data and statistical estimates for those withdrawals without meters. This methodology was developed by Tsai et al (1994) and estimates by this method date to 1991. Estimates were made for 1989 and 1990 by Downing (1994, Draft) on a well by well basis which permitted the use of such data in the Eastern Tampa Bay Ground-Water Computer Model. From 1982 to 1988 estimates were made by the District based on permitted data, reported metered data for non-agricultural permittees permitted for greater than 100,000 gallons per day, and a small group of metered agricultural water users under the USGS Benchmark Farms Program (Duerr and Trommer, 1982). Prior to 1982, water use for the District was estimated irregularly by the USGS for various years back to 1970. The multiple methodologies used to generate these different estimates makes any meaningful comparison uncertain.

3.3.3 Historical Water Use 1989 - 1999 (water use estimates by SWFWMD)

Estimated ground-water withdrawals over the past eleven years from permitted uses averaged 663 Mgal/day in the SWUCA with a maximum of 832 Mgal/day and a minimum of 568 Mgal/day (**Figure** 7). The Eastern Tampa Bay WUCA ground-water withdrawals generally comprise between 25 and 30 per cent of the SWUCA totals.

3.3.4 Historical Water Use 1900 - 1988 (regression models)

In 2001, the District developed water use estimates extending back in time to near the beginning of ground-water development (Beach, 2002). These estimates were required for a solute-transport model of saltwater intrusion being developed by HydroGeoLogic, Inc., of Herndon, Virginia. The District used a series of historical water levels from six reference wells in the SWUCA and regressed estimated monthly ground-water withdrawals against the nearest monthly well water levels for the period 1989 through 1998. This regression was done on a county by county basis. Ground-water withdrawals were extrapolated for each county from the regression equations back to about 1950, based on the limit of available data. Prior to that time, water use was linearly interpolated back to zero in 1900. The results of these estimates are shown in **Figures** 8 and 9.

## 4.0 ASSESSMENT OF SALTWATER INTRUSION

This section defines saltwater intrusion, describes the District's conceptualization of coastal ground-water quality with respect to saltwater intrusion, and discusses the District's analyses of the risk of saltwater intrusion.

### 4.1 Definition

Saltwater intrusion is the movement of salty, or saline, water into regions of an aquifer previously occupied by fresher, less saline, water. For purposes of this discussion, salty, or saline, water consists of varying dilutions of seawater up to 100 per cent. The principal ion in seawater is chloride and it is the usual indicator of seawater intrusion. Seawater contains about 19,000 mg/L chlorides and about 34,500 mg/L dissolved solids (Goldberg, 1963). In coastal aquifers, saltwater forms a wedge below the fresh water (see **Figure** 10) of the terrestrial aquifers. This occurs because the density of saltwater is greater than freshwater. Along the top of the wedge, where the freshwater and saltwater meet, a transition zone is formed where the water changes gradually from freshwater to seawater. This transition zone is often referred to as the interface between saltwater and freshwater. The wedge of saltwater below the freshwater is a natural occurrence. It is the landward movement of the wedge that constitutes saltwater intrusion.

### 4.2 Description of Interface/Transition Zone based on well drilling

The principal source of data for describing and locating the saltwater-freshwater interface is to be found in the monitor well site reports for the Regional Observation and Monitor-Well Program (ROMP). The specific sites are ROMP TR9-2, ROMP TR9-3, ROMP TR-AB-1, ROMP TR-AB-3, ROMP TR8-1, ROMP TR-SA-1, ROMP TR-SA-3, ROMP TR4-1, ROMP 20, and ROMP 22. Reports describing the exploratory drilling, monitor well construction, and aquifer testing at these sites are available in the District files. The location of these wells are shown in **Figure** 11. There are more ROMP wells in the area but for various reasons exploration was not pursued across the interface. In most early cases (i.e. prior to 1989), the drilling was halted as a matter of policy when the 250 mg/L chloride concentration was encountered. More recently, other wells were drilled farther inland beyond the toe of the interface within the Upper Floridan aquifer.

The water quality of ground water in the coastal area of the SWUCA generally consists of three, vertically sequenced, water types. The upper most type is the calcium-bicarbonate type associated with recharge areas. The middle type is the calcium/magnesium-sulfate type which originates from the evaporitic materials deposited at the lower elevations of the Upper Floridan aquifer. It is quite common to see sulfate concentrations of 1,500 to 3,000 mg/L in inland areas, near the base of the Upper Floridan aquifer. These high sulfate concentrations are often accompanied by very low chloride concentrations, 25 mg/L or less. At ROMP 22, in Sarasota County, sulfate and chloride concentrations are 1,620 and 19 mg/L, respectively, at 1,440 feet below land surface. The lower type water is a sodium-chloride type similar to seawater, which was the original source of this water. Although the calcium/magnesium-sulfate water is a saline water, in this discussion, saltwater refers only to the sodium-chloride type water.

In the Avon Park Formation the saltwater-freshwater transition zone is relatively sharp in the northern half of the SWUCA and becomes more diffuse in the southern half. The transition zone, as a surface, is inclined about one or two degrees from the horizontal. The District uses the 1,000 mg/L chloride concentration as a convenient indicator of the interface. The actual transition zone is the interval between the apparent background concentration and seawater.

At ROMP TR9-2 near Apollo Beach, chloride concentrations began to increase during drilling at about 750 feet below land surface (bls). By 875 feet bls, chloride and sulfate concentrations were consistent with seawater. At the ROMP TR8-1 site near Rubonia (northern Manatee County), chloride concentrations began to increase at about 885 feet bls and continued increasing to seawater concentrations at about 1,060 feet bls. These data indicate that the transition zone is about 100 to 200 feet thick in south Hillsborough and northern Manatee Counties of the SWUCA.

At the ROMP 20 site near Osprey, chloride concentrations began to increase above background levels (approximately 100 mg/L) at about 600 feet bls. Concentrations steadily increased to 4,500 mg/L at about 1,400 feet bls and then increased suddenly to 85 percent of seawater at about 1,440 feet bls. Drilling was terminated at 1,480 feet bls where packer testing confirmed a chloride concentration of 17,800 mg/L. At ROMP TR4-1 near Venice, chloride concentrations began to increase above background (approximately 100 to 200 mg/L) at about 700 feet bls. Concentrations continued to increase to about 83 percent of seawater at about 1150 feet bls. Drilling was discontinued at 1174 feet bls. These data illustrate a very diffuse transition zone, about 600 to 800 feet thick in the southern end of the SWUCA.

The sharp interface or transition zone in the north and the availability of data from several wells along a transect permit the estimation of the slope of the transition zone in that area. The 1,000 mg/L chloride concentration was encountered at ROMP TR-AB-1 at about 660 feet bls. At ROMP TR9-2, about a mile away, the 1,000 mg/L concentration occurred at about 750 feet bls. At the ROMP TR-AB-3 site, another mile inland, the 1,000 mg/L concentration was encounterd about 850 feet bls. In both cases the slope is about 100 feet per mile or about 0.02 feet/foot. This is slightly more than one degree of slope. Similarly, the difference between the 1,000 mg/L chloride concentration elevation at the Sarasota sites of ROMP TR-SA-1 and TR-SA-3 is about 200 feet and the distance between about 2 miles. This results in a very similar slope to the interface in that area. In those parts of the aquifer with lower permeabilities, the slope will increase somewhat, but has not been measured in the SWUCA under such conditions.

### 4.3 “First Principle”

The principle of salt-water intrusion is relatively simple. The landward extent of the transition zone depends upon the amount of discharge at the coast. Salt-water intrusion occurs whenever there is a reduction in the rate of discharge. A reduction in discharge is generally caused by an increase in ground-water withdrawals.

Reductions in ground-water discharge, or flow, cannot be measured directly, but are evident in the reduced ground-water levels in monitor wells. It is a hydrogeologic fact that if ground-water levels, properly known as hydraulic potentials, are reduced above the interface, then salt-water intrusion must occur. This is the “First Principle” of salt-water intrusion.

Area-wide hydraulic-potential, or water level, declines can be seen in a comparison of the predevelopment potentiometric surface map of the Upper Floridan aquifer system with a more recent map, such as for the 1999 annual-average potentiometric surface (**Figure** 12). The predevelopment potentiometric surface (Johnston, et al, 1980) is based on water levels in wells as recorded, principally, by V.T. Stringfield (1936) in the early 1930s. Although Stringfield’s data does not represent true predevelopment conditions, water levels in the 1930s were much less affected when compared to today's levels. The average 1999 potentiometric surface map is generated by averaging the May and September 1999 potentiometric surface maps produced by the U. S. Geological Survey (USGS).

4.4 Local versus Regional Salt-water Intrusion

It is sometimes convenient to distinguish between local and regional salt-water intrusion. Local salt-water intrusion at a single well or a few closely located wells, completed above the interface, is due to the pumping of that/those specific well or wells. The phenomenon is often referred to as "upconing" because the interface is pulled up toward the well and the interface below the well takes the shape of a cone.

Regional salt-water intrusion is the upward movement of the plane of the interface over a large area in response to area wide potential declines in the aquifer. Regional intrusion is observable as increasing chloride concentrations in water-quality data from properly constructed monitor wells. However, the lack of increasing chloride concentrations over time from such monitor wells does not negate the "First Principle," but rather points to a failure to properly locate such monitor wells. Note that as the regional interface moves upward, it becomes more likely that a production well will produce "upconing" of the interface.

The District directs three different water-quality data collection programs: a hydrogeologic exploratory program; a long-term monitoring of dedicated monitor wells; and, water quality from permitted production wells. The Regional Observation and Monitor-Well Program (ROMP) collects water quality data at different depths during the exploratory phase of construction of dedicated monitor wells. These dedicated monitor wells are designed to monitor water levels and water quality within specific zones of the multiple aquifers within the District. The collection of water quality during drilling in the near coastal areas allows the District to locate the current position of the salt-water interface.

Long-term water-quality sampling of dedicated monitor wells under the District's Water Quality Monitoring Program (WQMP) Section permits the District to monitor movement of the salt-water interface. Water quality in these wells is considered to be responding predominately to the effects of regional intrusion in their area because the wells are not pumped except to collect a sample and are located away from production wells where possible. A plot of chloride concentration versus time from ROMP TR9-3 is considered to be indicative of regional intrusion in that area (**Figure** 13).

The District also collects water-quality data from selected permitted production wells as a condition of the water use permit for the well. The principal purpose of this data collection is to monitor the effect of withdrawals on local conditions. Such wells can experience extreme, local, salt-water intrusion. This was the case for a well in the Ruskin area, about two miles east of ROMP TR9-3 (**Figure** 11), several years ago. Chloride concentrations increased each spring and receded in the summer (**Figure** 14). Over a period of several years, the maximum chloride concentration increased each year due to the seasonal nature of the pumping. Eventually, the water quality deteriorated to the point that the permittee back plugged the well into the Suwannee Limestone of the Upper Floridan aquifer system.

4.5 Water Quality in Monitor Wells

The District's WQMP Section samples the designated wells in the District's ground-water quality network. The current network began as a U.S. Geological Survey project during the late 1980s and was taken over by the District in 1991. Past analyses examined the data for trends in the chemical ions of chloride and sulfate, as well as dissolved solids (TDS). More recently, the analysis for trends separated the wells into water types as well as aquifer groups.

### 4.5.1 The Monitoring Networks

The current network of wells is the CGWQMN-WUPNET. The CGWQMN is a carry over from the District's Coastal Ground-Water Quality Monitoring Network, a network of dedicated monitor wells and production wells assembled to monitor for evidence of saltwater intrusion. The CGWQMN consisted of 281 wells which were sampled yearly. A subset of 95 of these wells was sampled two additional times per year.

In 1999 and 2000, the CGWQMN was modified and reduced to be a sentinel well network for the Water Use Permitted (WUP) production wells. The new network was designed to "...provide statistically based network design to the confined aquifers of the SWUCA to monitor water quality trends" (SWFWMD, November 2001, Draft). The coastal monitoring mission was retained and the new network is known as the CGWQMN-WUPNET. The network consists of 250 wells subdivided by aquifer (**Table** 2). The sampling periods for the network are December through March for the entire network; and May through June and September through October for the subnetwork of 176 wells.

Table 2: Wells by aquifer and sample frequency in the CGWQMN-WUPNET.

| Sample Frequency/Year | Number of Wells | Intermediate Aquifer System | Suwannee / Tampa (UFA) | Avon Park / Ocala (UFA) |
|---|---|---|---|---|
| 1 | 74 | 32 | 33 | 9 |
| 3 | 176 | 75 | 61 | 40 |
| Total | 250 | 107 | 94 | 49 |

### 4.5.2 Water Quality Data Analyses

The last full report of water quality data and trends was produced in 2000 (SWFWMD, August 2000). Since that time, the data were re-analyzed to accommodate a revision to the network (SWFWMD, November 2001, Draft). The revision reclassified the wells according to the predominate water type: calcium-bicarbonate (Type 1), calcium/magnesium-sulfate (Type 2), or sodium-chloride (Type 3) (Environmental Resources Management, July 1999). The purpose of this revision was to group wells according to the type of water quality change that might be expected to occur in them. This was especially important, for example, in the monitoring for saltwater intrusion where inland wells in recharge areas were being sampled but their inclusion in saltwater intrusion analysis was not pertinent.

The data were divided into temporal groups, aquifer units, and water quality type, as described above. The data were analyzed for changes based on the exact form of the Wilcoxon Rank

Sum test, a non-parametric method of comparing data groups to test for statistically significant change in median values. Significance was based on a 95 percent confidence level. Because of the small number of samplings per year at each well, the data were grouped into sets of two years: 1993 - 1995, the base or reference set (A); 1999-2001, the current data set (D); and 1997-1999, the previous set of data (C). Two other temporal sets were created to accommodate the data which has only been sampled one time per year in the past: 1991-1996, the early set (E); and the 1996-2001, the late set (F).

The aquifer units for the analysis are the intermediate aquifer system (IAS), the Suwannee and Tampa Limestones unit of the Upper Floridan aquifer (UFA), and the Avon Park Formation and Ocala Limestone of the UFA. The higher transmissivity due to greater secondary porosity generally makes the Avon Park/Ocala unit most susceptible to saltwater intrusion.

In this summary, only chloride changes are discussed, although the data were tested for changes in sulfate. Among the Type 1 waters, calcium-bicarbonate, only the data from two wells showed an increasing chloride change: these wells were in the intermediate aquifer and from the sets E and F, of the five year sets. The other results for chloride changes are shown in **Table**s 3 and 4 below for Type 2 and Type 3 waters. The chloride changes are shown on maps in **Figures** 15 and 16. The IAS wells are excluded from this summary as there were generally few changes and the unit is not considered to be susceptible to regional saltwater intrusion.

Table 3: Water-quality trends in wells with a Type 2 water ($Ca/Mg\text{-}SO_4$).

| Time Groups | Aquifer Units | Increasing | Decreasing | No Trend | Totals |
|---|---|---|---|---|---|
| A vs D (1993 - 1995 vs 1999-2001) | Swnn / Tpa | 3 | 4 | 14 | 21 |
| | Av Pk / Ocala | 1 | 0 | 9 | 10 |
| | | | | | 31 |
| C vs D (1997 - 1999 vs 1999 - 2001) | Swnn / Tpa | 2 | 2 | 12 | 16 |
| | Av Pk / Ocala | 1 | 0 | 10 | 11 |
| | | | | | 27 |
| E vs F (1991 - 1996 vs 1996 - 2001) | Swnn / Tpa | 7 | 5 | 19 | 31 |
| | Av Pk / Ocala | 1 | 1 | 8 | 10 |
| | | | | | 41 |

Table 4: Water-quality trends in wells with a Type 3 water (Na-Cl).

| Time Groups | Aquifer Units | Increasing | Decreasing | No Trend | Totals |
|---|---|---|---|---|---|
| A vs D (1993 - 1995 vs 1999-2001) | Swnn / Tpa | 2 | 1 | 3 | 6 |
| | Av Pk / Ocala | 7 | 0 | 0 | 7 |
| | | | | | 13 |
| C vs D (1997 - 1999 vs 1999 - 2001) | Swnn / Tpa | 1 | 1 | 9 | 11 |
| | Av Pk / Ocala | 6 | 0 | 4 | 10 |
| | | | | | 21 |
| E vs F (1991 - 1996 vs 1996 - 2001) | Swnn / Tpa | 5 | 1 | 6 | 12 |
| | Av Pk / Ocala | 6 | 0 | 5 | 11 |
| | | | | | 23 |

In the wells with Type 3 water, the increasing chloride changes are predominately in wells completed into the Avon Park/Ocala unit. This is especially true when the data from the current period, D, are compared with that of the historical base period, A. In wells with a Type 2 water, most of the increasing chloride changes are in wells completed into the Suwannee/Tampa unit. This is most evident when the first half of the data, E, is compared to the second half of the data, F, and the data from 7 of 31 wells exhibits an increasing change. This is probably water that is in transition from a Type 2 to a Type 3.

## 4.6 Numerical Modeling

The District has contracted for numerical modeling of the saltwater interface of the Eastern Tampa Bay Water Use Caution Area (ETB WUCA) on several occasions. All previous simulations were performed by HydroGeoLogic, Inc. of Herndon, Virginia. The first effort (HydroGeoLogic, 1991a) examined the potential for future movement of the interface with two-dimensional models located at three key cross sections. These cross sections were located in Hillsborough (A-A'), Sarasota (C-C'), and along the Hillsborough-Manatee county line (B-B') and were oriented parallel to the generally persistent, hydraulic flow paths in the area (**Figure** 17). These models were based on the proprietary DSTRAM computer code (HydroGeoLogic, 1991b). The DSTRAM computer code can simulate two or three-dimensional conditions. It is more efficient, when possible, to simulate along cross sections (2-D). The results of these models demonstrated the movement of the entire interface, both vertical as well as lateral.

Two later modeling efforts were done in such a way as to be a check on one another. The first of these was a refinement of the 1991 models (HydroGeoLogic, 1994). These models, like the first, were based on the proprietary computer code, DSTRAM. The middle model (Hillsborough-Manatee county line, B-B') was dropped for these simulations as it did not provide significant additional information. The results of these models showed specific ranges of movement by the interface under various changes in pumping (**Table** 5). The models clearly showed that the LPZ, or Avon Park Formation, was at the greatest risk of saltwater intrusion (**Figure** 18). The figure shows the simulated position of the 1,000 mg/L chloride concentration for pre-development, current conditions, and after continued pumping of 600 Mgal/day from the SWUCA over the next 50 years. The number of wells at risk and the pumping and permitted quantities associated with them were later assessed by the District and are discussed below. The other simulation employed the computer code, SIMLAS (HydroGeoLogic, 1993), a quasi-three-dimensional, sharp-interface code. This code used the Eastern Tampa Bay flow model (Barcelo & Basso, 1993) as a base. The results of this model are characterized by measurements of lateral movement of the toe of the interface (**Table** 5). The column “Absolute Maximum” represents the SIMLAS simulated maximum lateral movement of the interface which was not at the location of the two cross sections, North and South.

Table 5. Comparison of simulated displacements of the 1,000 mg/L isochlor in the Upper Floridan aquifer (from HydroGeoLogic, 1994).

| **Simulation Description** | **Simulated Lateral Displacement (miles)** | | | | |
|---|---|---|---|---|---|
| | **SIMLAS** | | | **DSTRAM** | |
| | **North Section** | **South Section** | **Absolute Maximum** | **North Section** | **South Section** |
| Predevelopment to 1989 | 1.6 | 1.05 | 1.70 | 1.80 | 1.10 |
| Calendar Year 1989 – 2039 | | | | | |
| 600 Mgal/day | 1.08 | 0.90 | 1.40 | 1.75 | 1.25 |
| 800 Mgal/day | 1.30 | 1.05 | 1.60 | 2.50 | 1.50 |
| 1,000 Mgal/day | 1.54 | 1.25 | 2.25 | 3.25 | 1.75 |

Most recently, HydroGeoLogic, Inc. has produced a three-dimensional, density-dependent, solute transport model of the ETB WUCA (HydroGeoLogic, 2002). This model, the Eastern Tampa Bay Solute Transport Model (ETB-ST Model), is based on the computer code MOD-HMS (HydroGeoLogic, 2000) and the District’s ground-water flow model of the southern half of the District, the Southern District Ground-Water Flow Model (Beach, et al, 2002). The onshore model area is congruent with the ETB WUCA and extends offshore some 25 miles. The southern half of Pinellas County is also included in the model. The ETB-ST Model simulates ground-water flow and density-dependent, salt transport in the Upper Floridan aquifer only. The model was calibrated to the assumed steady-state condition of 1900 and then calibrated through a 100 year transient to 2000. Predictive scenarios included continued withdrawals for periods of 20 and 50 years from current conditions at a variety of pumping rates. The number of wells at risk and the pumping and permitted quantities associated with them are discussed below.

4.7 Previous Logging and Sampling of WUP Wells at Risk

In 1992 and early 1993, a number of Water Use Permitted wells that were believed to be completed into the Avon Park Formation and lie seaward of the toe of the interface were logged and sampled by the Water Quality Monitoring Program (WQMP). These wells were considered to be at risk of salt water intrusion based on 1992 estimates for the location of the toe of the interface. This program offered to reimburse well owners for costs associated with the removal and replacement, when necessary, of their pumps. Not all owners wished to participate. The logging program was to determine the current casing and total depth of these wells as reported depths are uncertain. Additionally, the wells would be sampled for chloride, sulfate, total dissolved solids, and conductivity.

There were 22 wells visited or scheduled for logging. The principal result was that seven of ten wells that were sampled and could be considered completed in the Avon Park Formation had chloride concentrations elevated to an extent that could be considered to be in the transition zone. The table of these results appears in the appendix to the Supplemental Investigation paper, “Logging and Sampling of Coastal Water-Use Permitted Wells Reported to be Completed into the Avon Park Formation” (Beach, 1994b).

## 5.0 WELLS AND WATER SUPPLY AT RISK TO SALTWATER INTRUSION

The District has undertaken several analyses to determine the number of wells at risk and the quantities of water, both permitted and estimated use, associated with those wells. The multiple assessments reflect the uncertainty in the assumptions, methods, and the problem. The collective result is to point toward an understandable range as to the severity of the problem. Two of the analyses (Beach and Kelley, 1998; and Beach and Schultz, 2000) used a graphical-analytical approach to apply estimated rates of movement from the numerical modeling results by HydroGeoLogic (1994). These results were later modified by Barcelo and ??? (2002). A more recent estimate of wells at risk used results directly from a fully three-dimensional solute transport model of the entire area created by HydroGeoLogic, Inc (2002).

5.1 Two dimensional modeling analysis and analytical approaches

In these analyses, the condition of being “at risk” was determined by a multi-step procedure. First the plane of the interface was assumed to be represented by the 1,000 mg/L isochlor. The interface was projected, as a line, on six cross-sections of the coastal hydrogeology. The projection of the interface on each cross section was based on interpolation and extrapolation of hydrogeologic and water quality data acquired during the construction of dedicated monitor wells in the vicinity of each cross-section. The locations of the cross-sections are shown in **Figure** 19. The point where the interface exited the base of the UFA was determined to be the toe of the interface (Beach and Kelley, 1998). The toe position for each cross section, a point, was placed on an areal map. The six points were connected by a continuous curve, which defined the landward extent of the saltwater interface in the UFA under current conditions.

The interface projection on each cross-section was moved from the current position to a position that the interface would achieve over the next 50 years at specified pumping levels. That movement of the interface was based on the modeling results (HydroGeoLogic, 1994) for the cases of pumping 600, 800, and 1,000 Mgal/day from the SWUCA. An additional case, 400

Mgal/day, was extrapolated from the HydroGeoLogic modeling results. Wells were considered to be “at risk” if they plotted coastward of the projected line on the areal maps and they were reported to be completed into the Avon Park Formation.

Subsequently, Beach and Schultz (2000) revisited the analysis above and revised the results. In that effort, the toe position was taken as the most landward extent of the interface in the “highly transmissive” zone of the Avon Park Formation. This very permeable zone is estimated to comprise only about 200 to 300 feet of the 500 to 600 feet of the Avon Park Formation thickness and usually above the midpoint of the formation. The zone is reported in a number of the ROMP reports of exploratory drilling in the Avon Park Formation. This slightly reduced the wells at risk when compared to the previous analysis.

Barcelo et al (2002) made another revision to the previous work. In that work, the projections were again extended to the base of the UFA and previous estimates of the angle of the interface with the horizontal were modified. The analysis also incorporated some adjustments to hydrostratigraphic horizon picks and assumptions about well completion depths where those data are unreported. The results of that analysis, reported as number of wells at risk, the withdrawals associated with those wells for 1998, and the year 2001 permitted quantities associated with those wells are given in **Table** 6.

Table 6. Number of wells at risk, the withdrawals associated with those wells for 1998, and the permitted quantities associated with those wells for the year 2001 (from Barcelo, et al, 2002).

| **Model** | | **Avon Park/Ocala Units** | | |
|---|---|---|---|---|
| **Pumping (Mgal/d)** | **Years** | **Wells** | **1998 Estimated Pumping (Mgal/d)** | **2001 Permitted Pumping (Mgal/d)** |
| Current | 0 | 50 | 8.0 | 19.9 |
| 400 | 50 | 66 | 9.1 | 23.4 |
| 600 | 50 | 75 | 11.1 | 27.1 |
| 800 | 50 | 87 | 12.9 | 30.5 |
| 1,000 | 50 | 97 | 13.3 | 34.6 |

5.2 Three dimensional modeling analysis

Based on the recent solute-transport modeling (HydroGeoLogic, 2002), the wells at risk of saltwater intrusion were determined. The condition of being “at risk” was assessed by two different thresholds for chloride concentration and at two future time periods. In the first case, wells with chloride concentrations greater than 500 mg/L were determined for a future period of 20 years and 50 years beyond the year 2000 (current conditions). In the second case, wells with chloride concentrations greater than 1,000 mg/L, as in previous analyses, were determined for the same future periods. Each case determined the number of wells at risk under four different pumping rates within the SWUCA: 400, 600, 800, and 1,000 Mgal/day. This also followed previous analyses. The increasing ground-water withdrawals were apportioned in the same ratios as the 1998 ground-water withdrawals in the SWUCA.

The use of the 500 mg/L chloride concentration as an alternative threshold had two purposes. First, was to provide a sensitivity test to the problem. Although the District has generally used the 1,000 mg/L threshold as an indicator of the interface position, water quality of lower chloride concentrations is limiting for some uses. Secondly, the well concentrations in the transport model are reflective of blended waters where such wells are opened to multiple producing zones in the UFA. In previous analyses, a well that intercepted a zone with 1,000 mg/L chloride concentration water was considered to be at risk of saltwater intrusion. However, wells intercepting a high chloride concentration zone may produce water with chloride concentrations less than 1,000 mg/L when mixed with waters from lower chloride concentration zones.

The results indicate that if the threshold were 500 mg/L, there are currently 154 wells at risk of saltwater intrusion (**Table** 7). This total includes wells completed in the Avon Park Formation and the Ocala and Suwannee Limestones. If only the Avon Park is considered there are 37 wells at risk (**Table** 8). In the previous analyses, only wells completed in the Avon Park Formation were considered to be at risk. If the threshold is increased to 1,000 mg/L, the total number of wells currently at risk declines to 63, with 19 of those reported to be completed in the Avon Park Formation.

Table 7. Results of three-dimensional solute transport scenarios for saltwater intrusion in all units of the Upper Floridan aquifer.

| Regional Pumping (Mgal/d) | Years | Threshold (mg/L) | Number of Wells at Risk | 1995-1999 Average Annual Use (Mgal/d) | 1999 Permitted Pumping (Mgal/d) | Change from Current Conditions # of Wells at Risk | Change from Current Conditions Ann. Use (Mgal/d) | Change from Current Conditions Permitted (Mgal/d) |
|---|---|---|---|---|---|---|---|---|
| **Current** | **0** | **>500** | **154** | **15.84** | **22.20** | **0** | **0.00** | **0.00** |
| 400 | 20 | >500 | 151 | 15.22 | 21.61 | -3 | -0.62 | -0.58 |
| 600 | 20 | >500 | 162 | 16.02 | 23.18 | 8 | 0.19 | 0.99 |
| 800 | 20 | >500 | 169 | 16.47 | 23.85 | 15 | 0.63 | 1.66 |
| 1000 | 20 | >500 | 183 | 17.60 | 26.24 | 29 | 1.77 | 4.05 |
| 400 | 50 | >500 | 159 | 15.27 | 21.49 | 5 | -0.56 | -0.71 |
| 600 | 50 | >500 | 188 | 17.09 | 25.49 | 34 | 1.26 | 3.30 |
| 800 | 50 | >500 | 204 | 18.34 | 27.52 | 50 | 2.50 | 5.33 |
| 1000 | 50 | >500 | 224 | 19.95 | 31.05 | 70 | 4.11 | 8.86 |
| **Current** | **0** | **>1000** | **63** | **6.35** | **8.31** | **0** | **0.00** | **0.00** |
| 400 | 20 | >1000 | 71 | 7.72 | 10.13 | 8 | 1.38 | 1.82 |
| 600 | 20 | >1000 | 82 | 8.77 | 12.08 | 19 | 2.43 | 3.77 |
| 800 | 20 | >1000 | 91 | 10.14 | 13.98 | 28 | 3.80 | 5.67 |
| 1000 | 20 | >1000 | 104 | 12.22 | 17.99 | 41 | 5.88 | 9.68 |
| 400 | 50 | >1000 | 79 | 9.18 | 11.83 | 16 | 2.84 | 3.52 |
| 600 | 50 | >1000 | 104 | 12.02 | 17.40 | 41 | 5.67 | 9.10 |
| 800 | 50 | >1000 | 126 | 14.00 | 20.90 | 63 | 7.64 | 12.60 |
| 1000 | 50 | >1000 | 147 | 15.33 | 23.24 | 84 | 8.98 | 14.93 |

Table 8. Results of three-dimensional solute transport scenarios for wells at risk to saltwater and reported to be completed into the Avon Park Formation.

| Regional Pumping (Mgal/d) | Years | Threshold (mg/L) | Number of Wells at Risk | 1995-1999 Avg. Annual Use (Mgal/d) | 1999 Permitted Pumping (Mgal/d) | Change from Current Conditions | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | # of Wells at Risk | Ann. Use (Mgal/d) | Permitted (Mgal/d) |
| **Current** | **0** | **>500** | **37** | **5.81** | **7.26** | **0** | **0.00** | **0.00** |
| 400 | 20 | >500 | 34 | 5.12 | 6.61 | -3 | -0.69 | -0.65 |
| 600 | 20 | >500 | 41 | 5.84 | 8.06 | 4 | 0.03 | 0.80 |
| 800 | 20 | >500 | 46 | 6.18 | 8.67 | 9 | 0.37 | 1.41 |
| 1000 | 20 | >500 | 55 | 7.22 | 10.82 | 18 | 1.41 | 3.56 |
| 400 | 50 | >500 | 34 | 4.94 | 6.26 | -3 | -0.87 | -1.00 |
| 600 | 50 | >500 | 50 | 6.55 | 9.85 | 13 | 0.74 | 2.59 |
| 800 | 50 | >500 | 62 | 7.58 | 11.54 | 25 | 1.77 | 4.28 |
| 1000 | 50 | >500 | 74 | 9.05 | 14.26 | 37 | 3.24 | 7.00 |
| **Current** | **0** | **>1000** | **19** | **3.33** | **3.47** | **0** | **0.00** | **0.00** |
| 400 | 20 | >1000 | 21 | 3.42 | 3.69 | 2 | 0.09 | 0.22 |
| 600 | 20 | >1000 | 30 | 4.45 | 5.62 | 11 | 1.12 | 2.15 |
| 800 | 20 | >1000 | 37 | 5.79 | 7.23 | 18 | 2.46 | 3.76 |
| 1000 | 20 | >1000 | 45 | 6.29 | 9.33 | 26 | 2.96 | 5.86 |
| 400 | 50 | >1000 | 22 | 3.43 | 3.71 | 3 | 0.10 | 0.24 |
| 600 | 50 | >1000 | 40 | 6.03 | 8.49 | 21 | 2.70 | 5.02 |
| 800 | 50 | >1000 | 51 | 6.61 | 9.94 | 32 | 3.28 | 6.47 |
| 1000 | 50 | >1000 | 62 | 7.59 | 11.67 | 43 | 4.26 | 8.20 |

Previous analyses estimated wells at risk in the future based on a 50 year scenario and a chloride threshold of 1,000 mg/L. Current ground-water withdrawals are slightly more than 600 Mgal/day. If that withdrawal rate is continued for an additional 50 years, then slightly more than 41 wells would be at risk of saltwater intrusion of which 21 would be wells reported to be completed into the Avon Park Formation. Other scenarios and conditions are reported in **Table**s 7 and 8.

## 6.0 METHODOLOGY FOR ESTABLISHING A MINIMUM AQUIFER LEVEL

As previously discussed, declining ground-water levels in the SWUCA over the past several decades have reduced coastal ground-water discharge resulting in regional saltwater intrusion. Concerns regarding saltwater intrusion are principally related to impacts to the freshwater resource and existing water supplies. District staff have demonstrated and quantified the potential risks associated with continued saltwater intrusion in the region. The Governing Board of the SWFWMD has determined that it is unacceptable to allow the rate of regional saltwater intrusion to increase beyond the current rates of movement. The methodology to establish a minimum aquifer level to protect against regional saltwater intrusion was thereby developed to achieve the management goal of slowing the rate of saltwater intrusion. The first step in management efforts to slow the rate of movement would be to stabilize regional water level declines.

Section 373.042(3)(1996 supp.) of Florida Statutes requires the District to establish MFLs in priority water bodies. Although there are water quality concerns in other areas of the basin, the District has determined that the priority area is the coastal portion of the SWUCA in southern Hillsborough, Manatee, and northern Sarasota counties. This is largely because the Upper Floridan aquifer in the area is highly productive, well confined and generally contains good quality water. In addition, the area is in close proximity to naturally occurring poor water quality in coastal portions of the aquifer and long-term withdrawal stresses within and adjacent the area are high. Because of this, the recent technical work that has been conducted has tended to focus on this area. Minimum aquifer levels to address water quality concerns in other portions of the basin will be addressed in the future on an as-needed basis.

The process of establishing a minimum aquifer level begins with identification of a resource problem, developing cause and effect relationships, and determining the consequences of different courses of action. Once an understanding of the problem has been developed, a decision on what is an acceptable level of impact can be made.

As previously discussed, the administrative law judge presiding over the hearing on the District's SWUCA rules upheld the District's scientific efforts and concluded that saltwater intrusion in the region was occurring (DOAH). He further concluded that basing the previously proposed minimum level on the annual-average potentiometric surface for 1991 was one of several possibilities and that socioeconomic factors could be considered in establishing a minimum level for saltwater intrusion. With respect to the current effort, the goal is to provide a minimum aquifer level that can be used in long-term management efforts to slow the rate of regional saltwater intrusion in the ETB MIA. As was done previously and is discussed below, the approach to establishing the minimum aquifer level is to determine a single value, average potentiometric surface over the area of interest. Basing the minimum level on a single average value addresses the regional nature of the problem in the SWUCA and avoids the potential for localized lowering of a "minimum level" to trigger a regulatory response. This is in contrast to the approach employed in the NTB area where it was concluded that saltwater intrusion was occurring at a more localized scale and that at current and anticipated future levels of pumping saltwater intrusion does not appear to be a regional concern (Hancock and Basso, 1999). For that area, minimum levels were established at individual wells along transects adjacent major ground-water withdrawals in coastal areas.

## 6.1 Area of Resource Concern

In the previous effort to establish a minimum aquifer level in the region, the District proposed a single value representing the average potentiometric surface for 1991 over the entire SWUCA, as well as separate levels for the ETB and Highlands Ridge WUCAs. Requests for new withdrawals would not be considered unless the levels in each of the three areas were above the respective minimum levels. Based on experience gained during establishment of MFLs in the NTB area, the District decided the objective for this effort would be to establish a minimum aquifer level over the principal area of "resource concern" and not the entire SWUCA.

With respect to saltwater intrusion, the area of concern for which the minimum aquifer level is being established is the ETB MIA (**Figure** 20). The ETB MIA is an area of about 708 square miles that encompasses the coastal portions of southern Hillsborough, Manatee, and northern Sarasota counties. The area was designated the ETB "Most Impacted Area" in response to the long-term declines in ground-water levels and increasing evidence and concerns over saltwater intrusion in that area. The goal of establishing the MIA was to stabilize declining ground-water levels. Since 1990, permitted ground-water withdrawals from the Upper Floridan aquifer in the area have been capped. In 1999, permitted ground-water withdrawals were 250 Mgal/d whereas, the estimated, “actual” ground-water withdrawals were 98.6 Mgal/d.

The original delineation of the ETB MIA in the early 1990s was based on circumscribing the area over which the closed zero potentiometric surface contour generally occurred landward of the coast. If the closed zero contour were allowed to persist on an annual basis landward of the coast, the entire thickness of the Upper Floridan aquifer beneath the north-south axis of the depression would eventually become saline, though this would take on the order of centuries to occur. The estimated location of the toe of the freshwater/saltwater interface, as defined by the 1,000 mg/l isochlor (**Figure** 20) is also located within the ETB MIA. With respect to future saltwater intrusion, establishing a minimum aquifer level over this area can be used to support management efforts in slowing the rate of regional saltwater intrusion by ensuring fresh ground-water flows to the interface are maintained at or above current levels.

6.2 Minimum Level Reference Period

Though the change in fluid pressure in the aquifer occurs rapidly, regional movement of saltwater can take on the order of centuries to complete. The ability for saltwater to move through the aquifer matrix is dependent on the aquifer characteristics and duration of head declines. Though short-term head changes can temporarily affect rates of movement, it is the sustained lowering of ground-water levels, and corresponding reductions in coastal discharge, that affect the long-term regional movement of the interface in the ETB MIA. .

In selecting the reference period to base the calculation of the minimum aquifer level, it was necessary to review water levels to assess recent hydrologic conditions. Because of the long-term nature of regional saltwater intrusion it was decided to evaluate changes in long-term water levels as represented by 10-year moving averages. The basis for using 10-years to represent “long term” was because, it is a period of sufficient length to incorporate high and low rainfall years and it is not too long so that the period average is leveraged with data from earlier years when withdrawals were occurring under different management goals. In addition, and since regional saltwater intrusion occurs slowly, 10 years is sufficiently long so that management decisions are not unduly influenced by “short term” events.

Annual-average and ten-year moving average ground-water levels for 16 wells within and adjacent to the MIA are presented in **Figure** 21. Locations for these wells are shown in **Figure** 22. As noted in Beach et al (2002b) and evident from review of these levels, the period immediately preceding the 1990s was a period of water level decline throughout the region. In the mid-1990s, the declines somewhat stabilized and in several wells water levels began to increase. Over the 1990s and early 2000s, the highest ten-year average water levels generally occurred during the period from 1990 to 1999. As it relates to saltwater intrusion, water levels for this period represent a slowing or reduction in the rate of saltwater intrusion as compared to other ten-year periods ending in the 1990s and early 2000s. In addition, ten-year average water levels for 1990 to 1999 were slightly higher than annual-average water levels for 1991, which formed the basis for the previously proposed minimum aquifer level. Because this period is recent and represents a reduction in the rate of saltwater intrusion, as compared to other 10-year periods ending after the early 1990s, the reference period for which the minimum aquifer level was calculated was the period 1990 to 1999. Ground-water withdrawals for permitted uses over the period averaged about 645 Mgal/d in the SWUCA. Though not reported for the beginning of this period, ground-water withdrawals averaged 182 Mgal/d in the ETB WUCA for the period 1993 to 2000 and averaged 98 Mgal/d in the ETB MIA for the period 1998 to 2000.

Factors contributing to the higher 10-year average water levels for the reference period include:

- Beginning in 1989, the water management district initiated a series of actions to limit ground-water withdrawals in the region
- Water use permitting rules went into effect in the Highlands Ridge and ETB WUCAs in 1990. These rules included increased conservation measures and metering of all uses permitted for greater than 100,000 gal/d.
- The ETB MIA went into effect in 1990 and continues to serve as a permitting standard for saltwater intrusion. There has been no increase in total permitted quantities from the Upper Floridan aquifer since 1990 (SWFWMD, 2001b).
- The period does not include the extreme conditions experienced during the drought years of 1989, 2000 and 2001.

6.3 Calculation of the Minimum Aquifer Level

The goal of the minimum level calculation is to determine a single value representing the average elevation of the potentiometric surface of the Upper Floridan aquifer over the Eastern Tampa Bay Most Impacted Area (MIA). Basing the minimum aquifer level on a single average value addresses the regional nature of saltwater intrusion in the SWUCA and is similar to the previously proposed minimum aquifer level. Since saltwater intrusion is a regional problem, calculating the minimum level this way minimizes the potential for localized lowering of water levels to trigger a regulatory response if minimum aquifer levels were to be assigned to individual wells. The reference period for which the minimum aquifer level will be calculated was determined to be the period from 1990 through 1999. The resulting value would represent the District's estimate of the conditions that would be required to slow the rate of saltwater intrusion in the area below the rates occurring during other 10 year periods ending since the early 1990s. Important to this process is not that the absolute “true” average is determined but rather, that an objective process is established that can be used in future calculations to determine the status of the resource.

There are two general ways of calculating the average elevation. The first is to take an unweighted average of the data from individual monitor wells within the MIA. The second approach uses the same monitor wells, along with some additional wells outside the MIA, to estimate a potentiometric surface over the the MIA. The target average elevation would be calculated from the estimated surface that covers the MIA.

Although the area of interest is the MIA, it is desirable to include data from outside the MIA for the construction of a surface representing the UFA to overcome edge effects in areas where data within the MIA are limited. In order to accomplish this, data from the entire Eastern Tampa Bay Water Use Caution Area (WUCA) was examined. Wells from the ETB WUCA and MIA were selected using Arc/INFO®. A total of 212 Upper Floridan aquifer wells were identified from the District's data base. The site numbers of these wells were then used to query the District's Water Management Data Base (WMDB) to identify which of these wells had water level data for the period of 1990 through 2001 and examine the overall quantity of data each well had for that period. The data search found that 60 of the wells had at least some data for the desired period.

Of the sixty wells only eight had complete data sets, that is, 12 months of data for each year over the ten year period of 1990 - 1999. While eight wells might be adequate it was decided to relax the data requirements slightly in order to increase the size of the data set and improve spatial coverage. Wells having at least 90 percent of the potential full data set were next included. In other words, over the ten year period there are potentially 120 months of data, if a well had 90 percent of this value or 108 months it was included. This increased the potential data set to 19 wells. After examination, four of the wells were eliminated from the data set. Exclusion of a well could occur for one or more reasons. For example, the ROMP 50 Avon Park well (site 394) was removed because it is actually a Middle Confining Unit well. In another case, a site contained two nested wells, in which case only one was retained.

The final list consisted of 16 wells, 10 from within the MIA and the remaining 6 from within the WUCA. (**Table** 9., **Figure** 22.) These wells were then used to construct the decadal average Upper Floridan potentiometric surface of the WUCA. The first step was to extract the monthly water level data for each of the wells and calculate the annual average elevation for each of the years 1990 through 1999. For years with missing data, the annual average was calculated as the average of existing monthly data. The annual averages over the period were then used to calculate the decadal average for the period. An Arc/INFO® point coverage was created from this data. Fields included in the coverage include the annual average elevation, 1990-1999, 1991-2000, 1992-2001, decadal elevations, the well site number, sequence number, and site name. The additional decadal averages were calculated for possible later comparisons.

Using this coverage as input, and the Arc/INFO® Triangular Irregular Network (TIN) routine an estimated potentiometric surface was created. Just as it was necessary to include additional wells inland from the MIA to minimize edge effects, additional data were needed seaward for the same reason. Since there are no offshore wells, an artificial line with an assigned constant potential value of 10 feet was placed five miles offshore from the coast. The actual TIN surface was constructed using the well data point coverage and the five-mile 10 feet potential line, and then clipped by the boundary of the MIA.

The final step before calculating the average elevation for the MIA was to superimpose a regular grid of points over the estimated potentiometric surface TIN. A grid spacing of 1,000 meters was used and elevations were assigned to each point by linear interpolation of the estimated potentiometric surface. Within the MIA there are 1,750 points which were then used to calculate the basic statistics including the average elevation. For comparison purposes, the same statistics were calculated using the 10 wells located within the MIA. Results are shown in Table 10.

Table 9: Wells from which water levels were used in construction of decadal averages.

| Site Number | Site Name | Formation | Total Depth (ft) | Casing Depth (ft) |
|---|---|---|---|---|
| 142 | EDGEVILLE 3 DEEP | FLADN | 600 | 487 |
| 623 | FLORIDA CITIES TEST 1 | COMBN | 446 | 104 |
| 653 | FLORIDA POWER AT PINEY PT | FLADN | 950 | 104 |
| 564 | KIBLER DEEP | COMBN | 1123 | 208 |
| 87 | ROMP 123 HAWTHORN/OCALA | COMBN | 620 | 117 |
| 503 | ROMP 32 L OCALA/AVON | FLADN | 1215 | 909 |
| 489 | ROMP 48 AVON PARK | FLADN | 815 | 780 |
| 10914 | ROMP 50 TAMPA/OCALA | FLADN | 562 | 200 |
| 10880 | ROMP 61 SUWANNEE/AVON PARK | FLADN | 1000 | 300 |
| 10883 | ROMP TR 10-2 TAMPA | FLADN | 125 | 115 |
| 10870 | ROMP TR 11-2 SUWANNEE | FLADN | 315 | 300 |
| 287 | ROMP TR 7-1 TAMPA | FLADN | 340 | 320 |
| 10926 | ROMP TR 7-4 SUWANNEE/OCALA | FLADN | 800 | 560 |
| 10909 | ROMP TR 9-3 SUWANNEE/OCALA | FLADN | 525 | 289 |
| 561 | SARASOTA 9 DEEP | COMBN | 730 | 101 |
| 456 | VERNA T 0-4 | COMBN | 500 | 140 |

Table 10. Comparison of average values from the estimated potentiometric surface vs individual wells for the Reference Period

| Average Upper Floridan Aquifer Potentiometric Surface (1990 to 1999) | | |
|---|---|---|
| **Statistic** | **Estimated Surface (ft.)** | **Individual Wells (ft.)** |
| Mean | 12.83 | 12.21 |
| Minimum | 4.01 | 3.83 |
| Maximum | 22.98 | 19.86 |
| Standard Deviation | 3.21 | 5.02 |

It is apparent the results are quite similar. The major difference is that the average from the estimated potentiometric surface tends to smooth out the elevations resulting in a smaller standard deviation.

Water levels since 1970 for the 16 wells used to calculate the proposed minimum aquifer level are shown in **Figure** 21. In addition to the annual water levels, the decadal average for the period 1990 - 1999 is shown along with ten-year moving averages for each well. Though somewhat variable, the highest ten-year average of well water levels in the 1990s occurred in 1999. Using the methodology outlined above, **Table** 11 provides a comparison of ten-year average potentiometric surfaces for the MIA. The average potentiometric surface for 1991, the period used for the previously proposed minimum aquifer level, is also shown.

Table 11. Comparison of Ten Year Average Potentiometric Surfaces versus the average of individual wells for the ETB MIA

| Average Upper Floridan Aquifer Potentiometric Surface | | |
|---|---|---|
| **Period** | **Estimated Surface (Ft.)** | **Individual Wells (Ft.)** |
| **1990 to 1999** | **12.8***| **12.2** |
| **1991 to 2000** | **12.6** | **12.0** |
| **1992 to 2001** | **12.0** | **11.4** |
| **1991** | **12.6** | **12.2** |

* - Proposed minimum aquifer level.

6.4 Proposed Implementation of the Minimum Aquifer Level

The minimum aquifer level will be used to gage the status of the ground-water resource with respect to saltwater intrusion in the region. Determining the status of the resource will be based on comparison of the average water level over the MIA for 10-year moving windows of time with the minimum level. The 10-year average water level for a particular year will be calculated as the average water level for that year and the previous nine (9) years. The process of calculating the 10-year average is the same as described above for calculating the minimum level.

The objective of the District's management efforts is for the 10-year moving average to fluctuate in a range above the minimum level. It is proposed that, the minimum level will have been achieved if the 10-year moving average has fluctuated above the minimum level for a minimum of 5 consecutive years. The goal is to ensure that the system is truly fluctuating above the minimum level and it is not the result of random chance. It is proposed that, the minimum level has not been met when the 10-year moving average has fallen below the minimum level for more than 2 consecutive years.

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# FIGURES

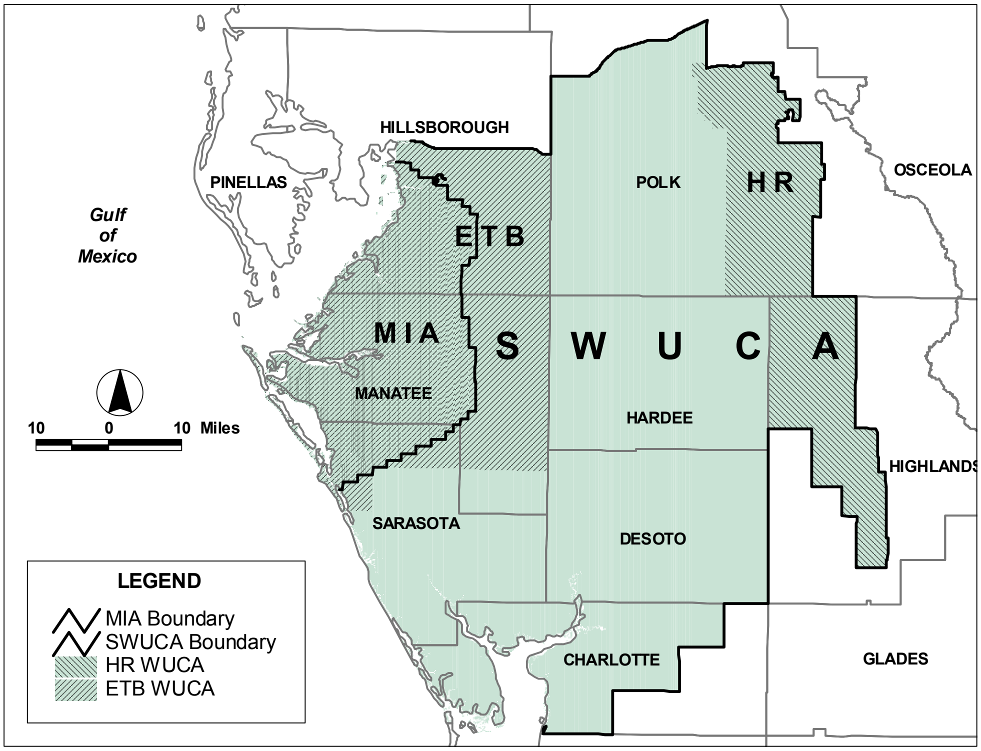


**Figure 1: Location of WUCAs in the SWFWMD.**

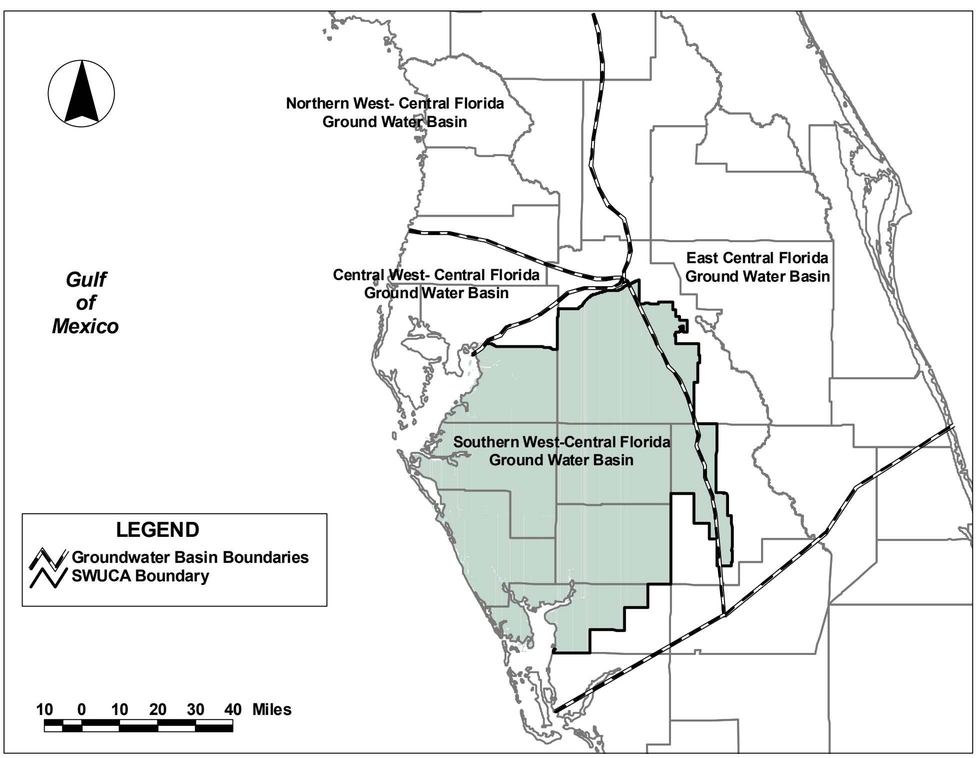


**Figure 2: Location of Ground-Water Basins in Peninsular Florida.**

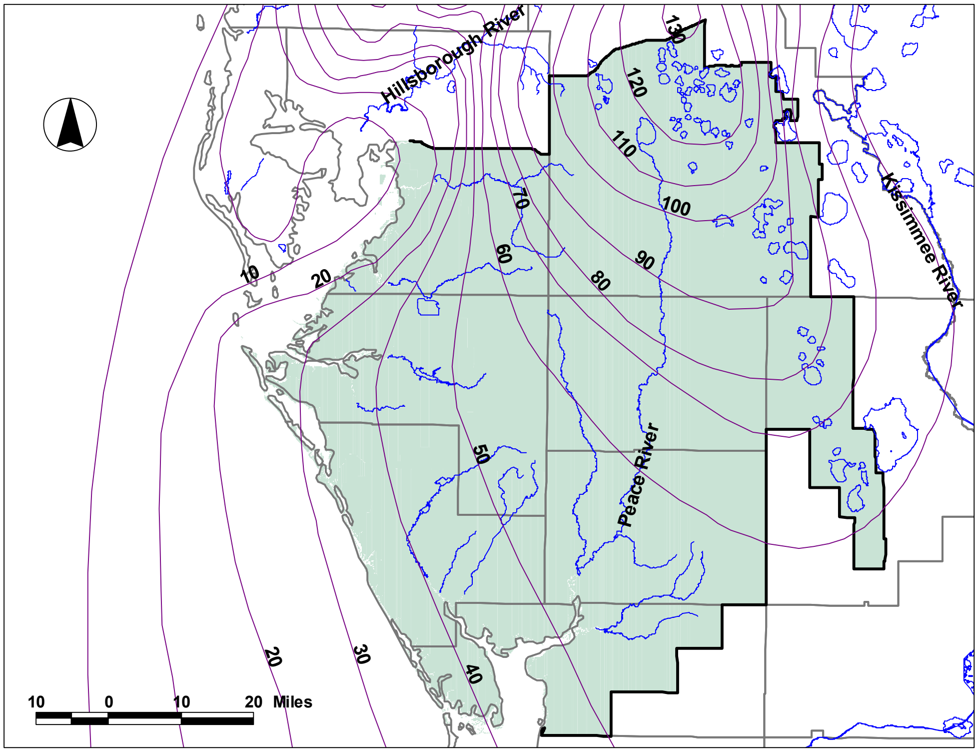


**Figure 3: Pre development Potentiometric Surface of the Upper Floridan aquifer (Johnson, et. al, 1980).**

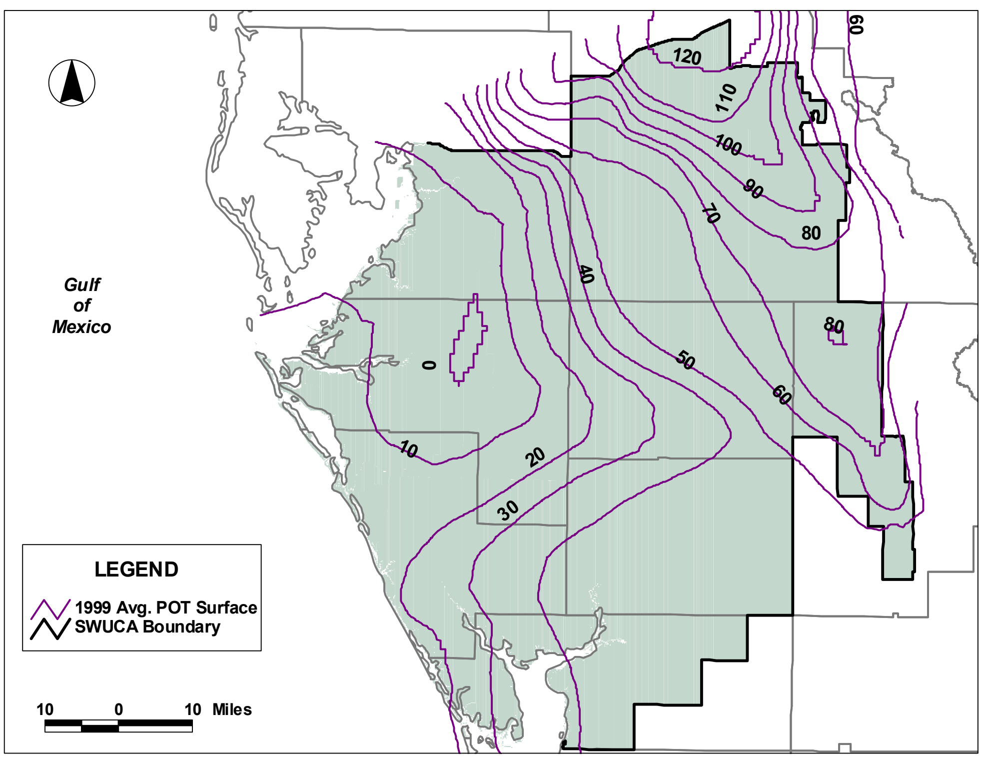


**Figure 4: annual average potentiometric surface of the Upper Floridan aquifer.**

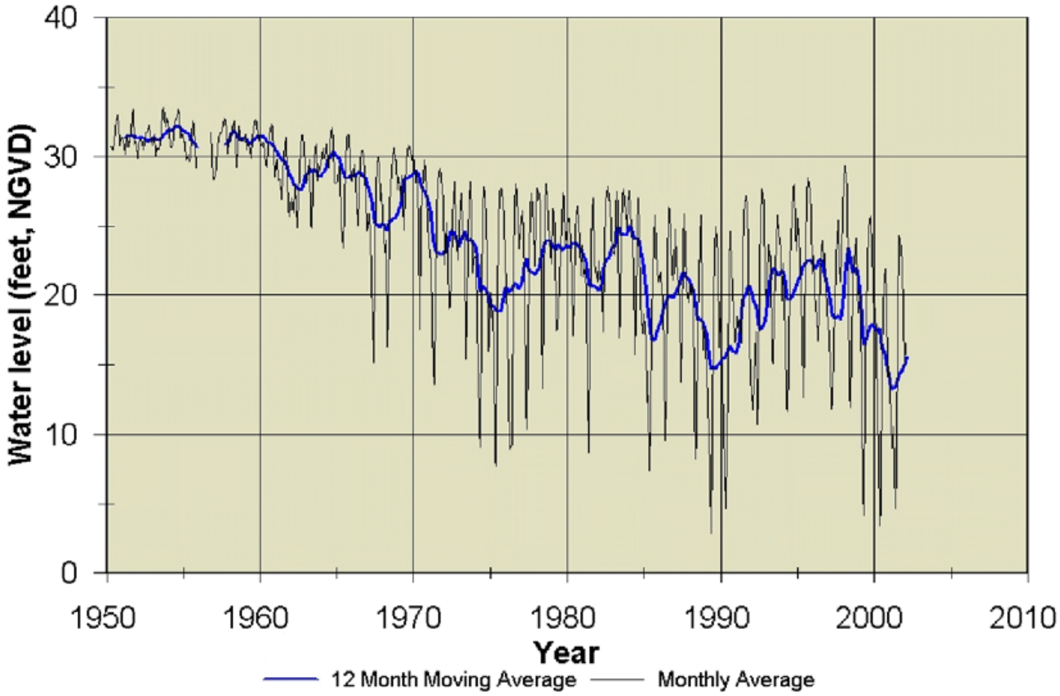


**Figure 5: Monthly and 12 month moving average for the Sarasota 9 Deep well.**

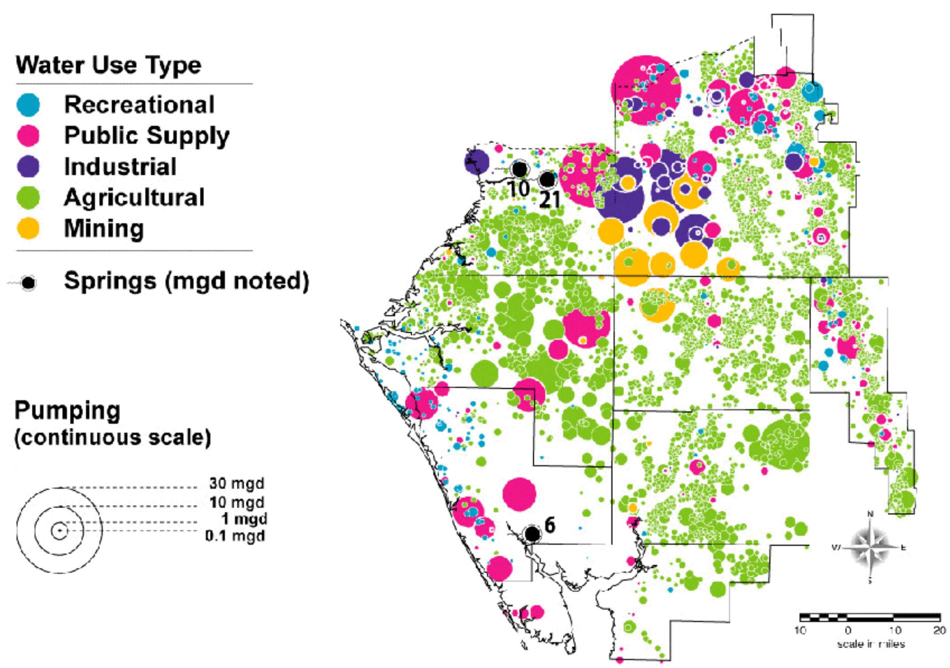


**Figure 6: Estimated ground-water use and locations of permitted ground-water users in the SWUCA.**

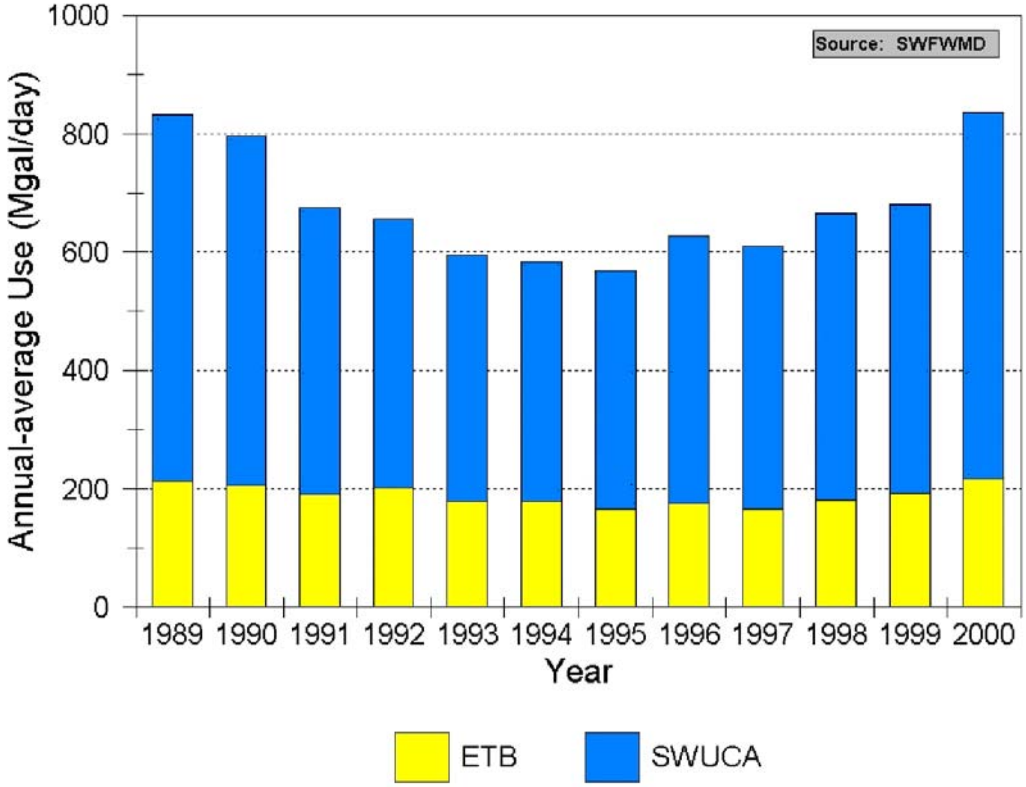


**Figure 7: Ground-water withdrawals in the SWUCA for the period of 1989 – 2000.**

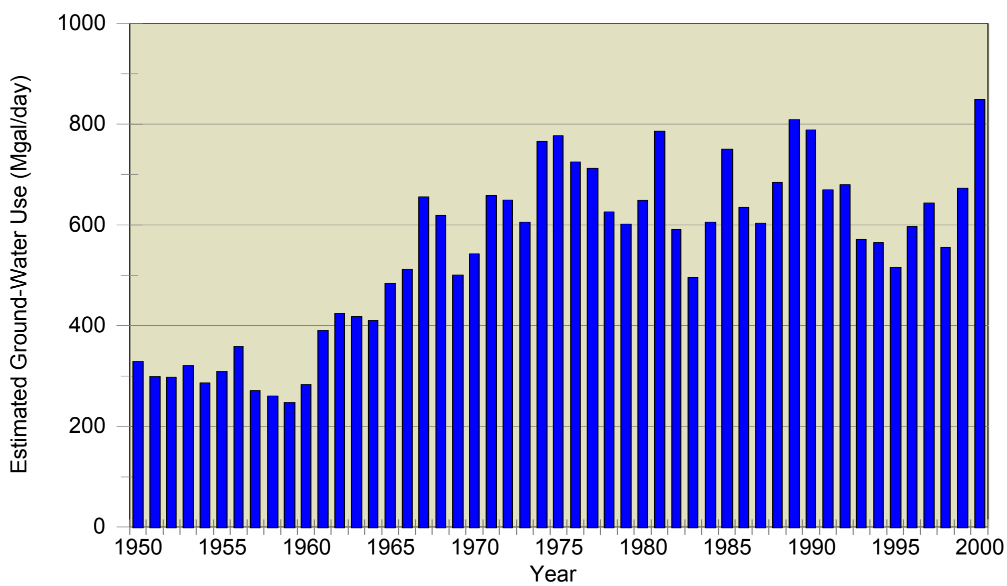


**Figure 8: Historical estimates for ground-water withdrawals in the SWUCA since 1950.**

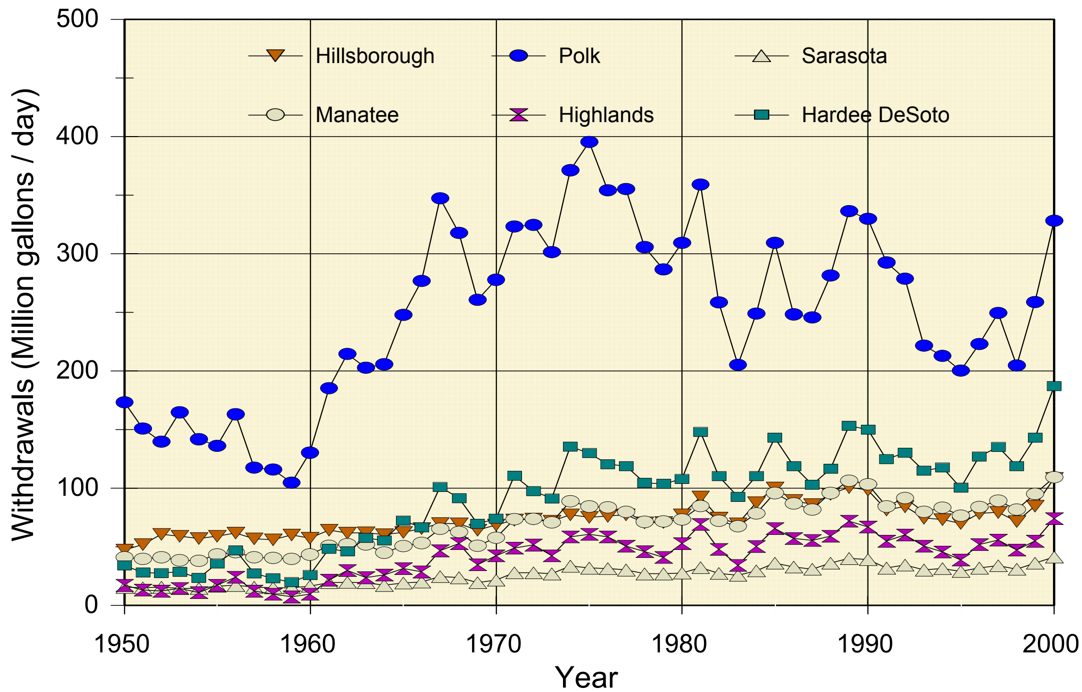


**Figure 9: Historical estimates for ground-water withdrawals in those counties, or portions of counties, lying in the SWUCA since 1950.**

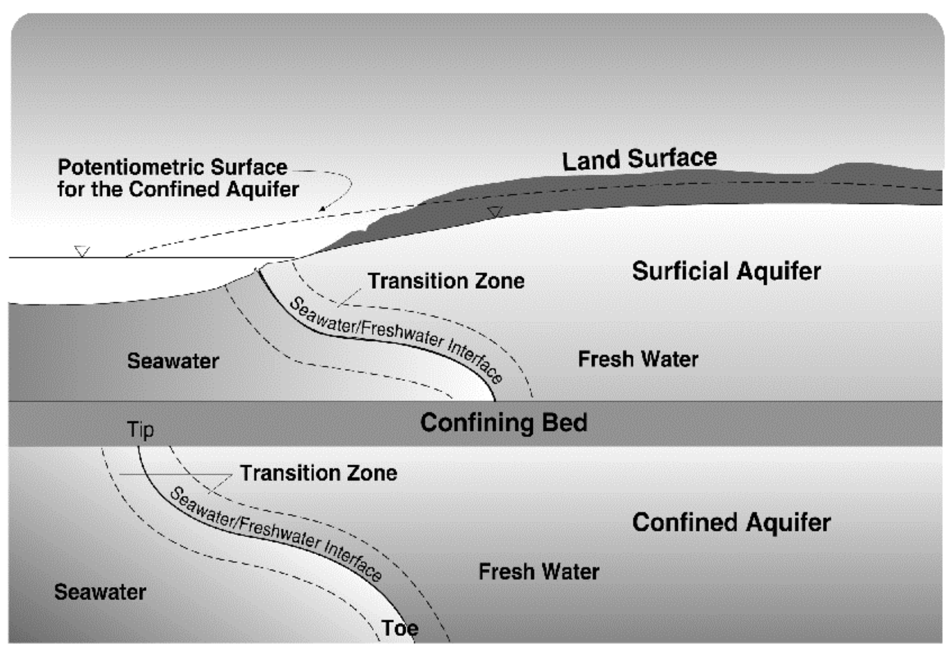


**Figure 10: Schematic of saltwater-freshwater interface.**

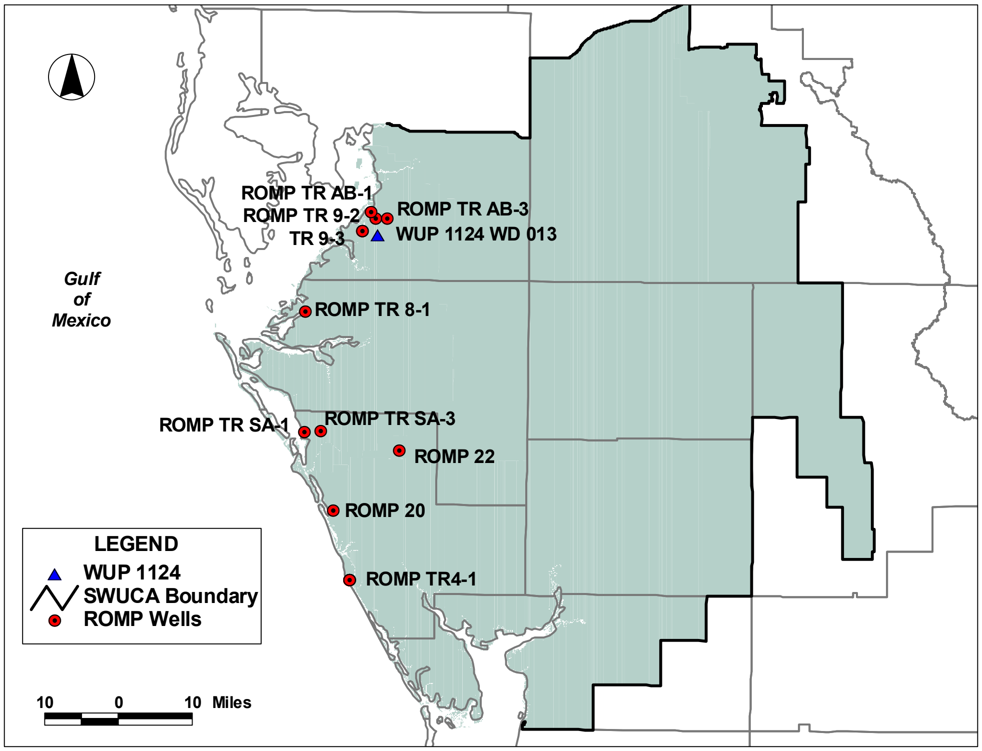


**Figure 11: Map of selected ROMP locations.**

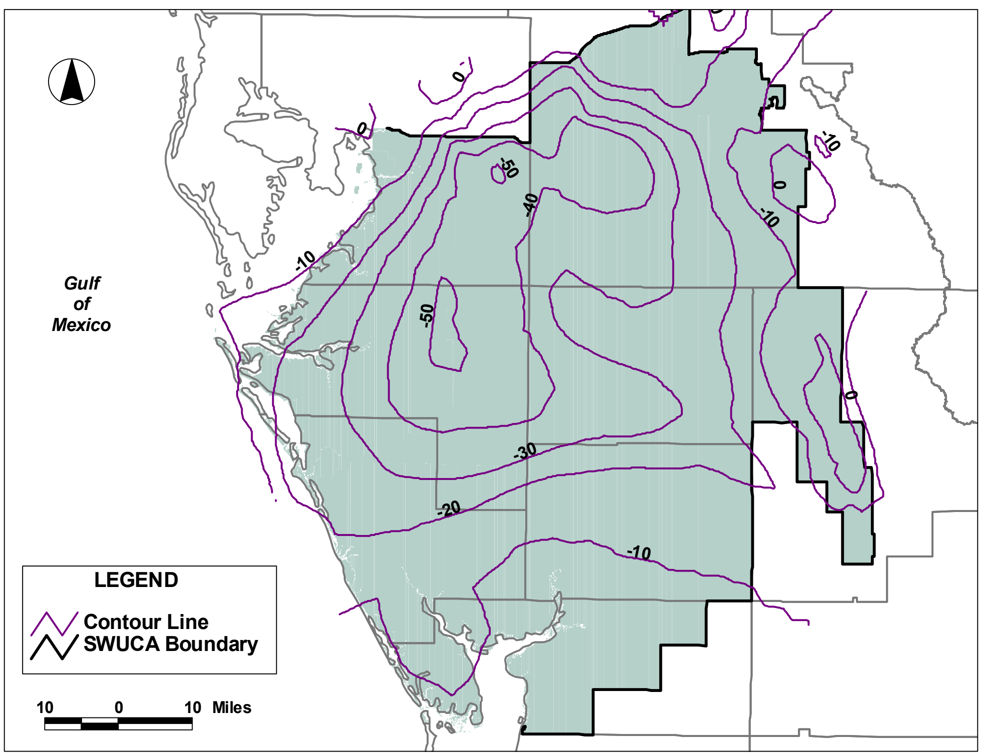


**Figure 12: change in the Upper Floridan aquifer potentiometric surface from predevelopment to 1999.**

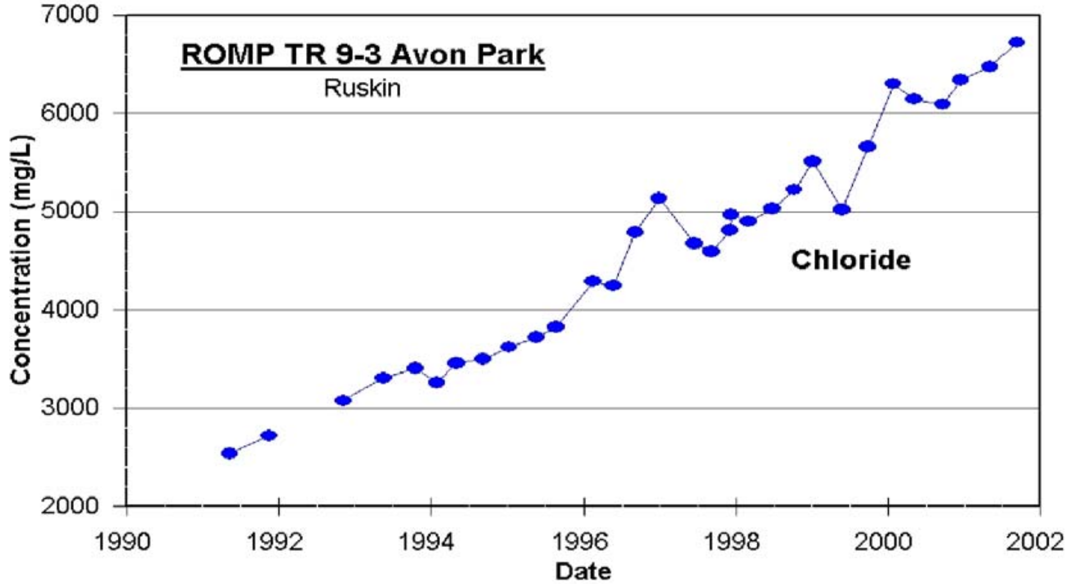


Figure 13: Chloride concentration vs. time for ROMP TR9-3 Avon Park well.

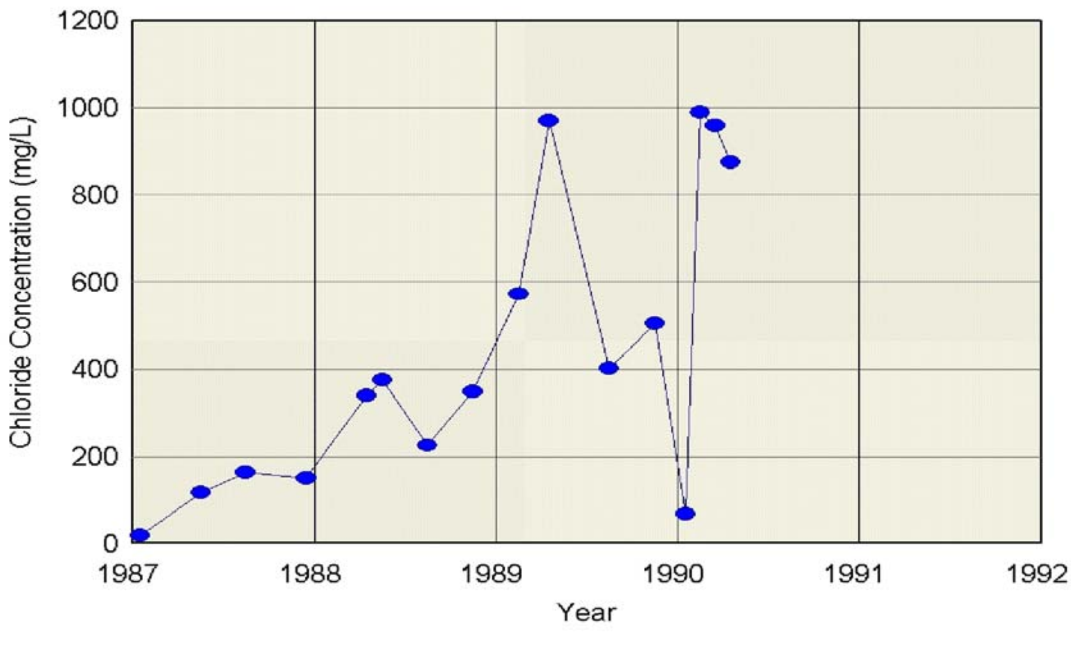


Figure 14: Chloride concentration vs. time for WUP 20114 well WD 013.

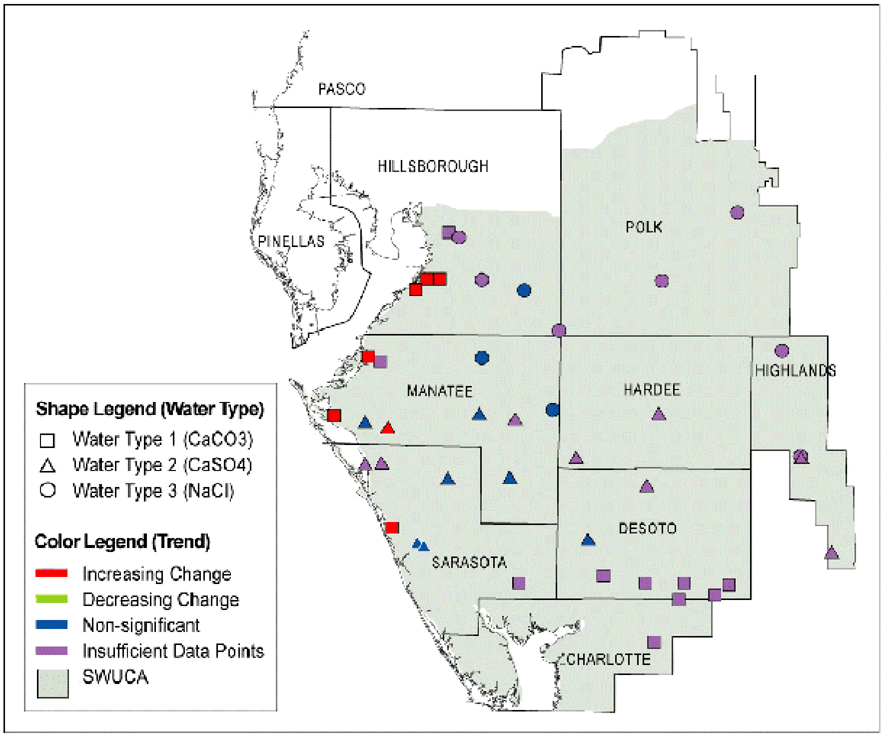


**Figure 15: Chloride trends for wells completed in the Ocala to Avon Park formations. Comparison of Group A (April 20, 1993 - April 19, 1995) and Group D (April 20, 1993 - April 20, 2001).**

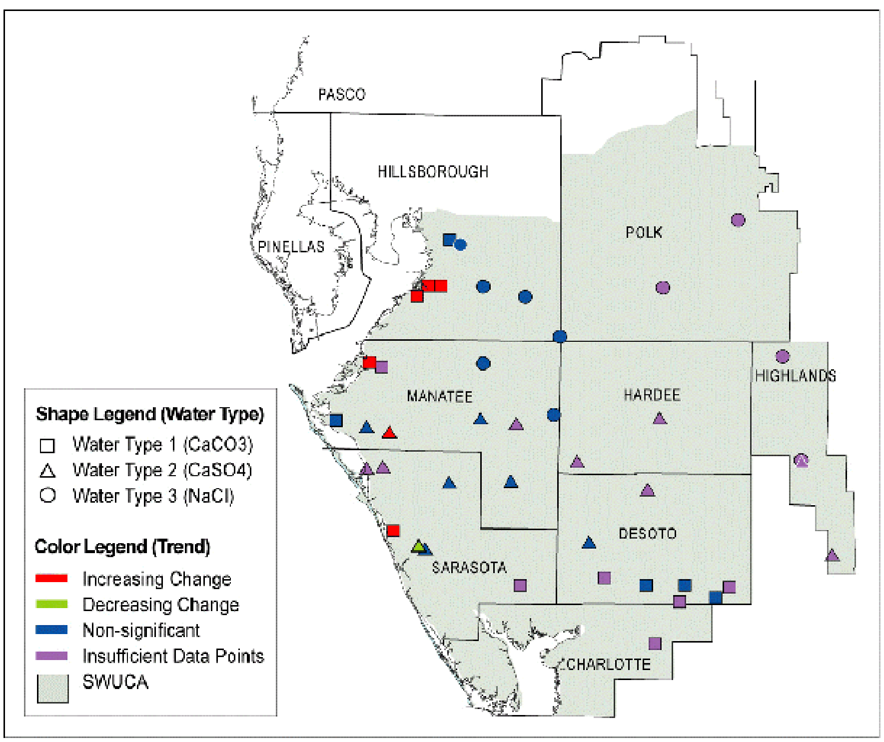


**Figure 16: Chloride trends for wells completed in the Ocala to Avon Park formations. Comparison of Group E (January 1, 1991 - April 19, 1996) and Group F (april 20, 1996 - April 20, 2001).**

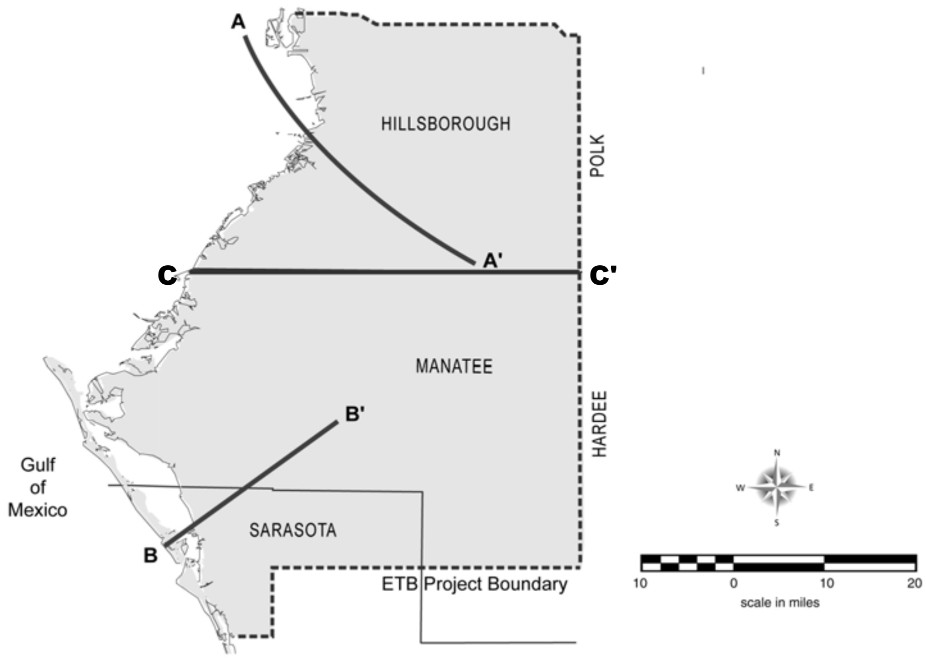


**Figure 17: Locations for the solute transport model cross-sections used by Hydrogeologic Inc., for DSTRAM saltwater-freshwater interface modeling.**

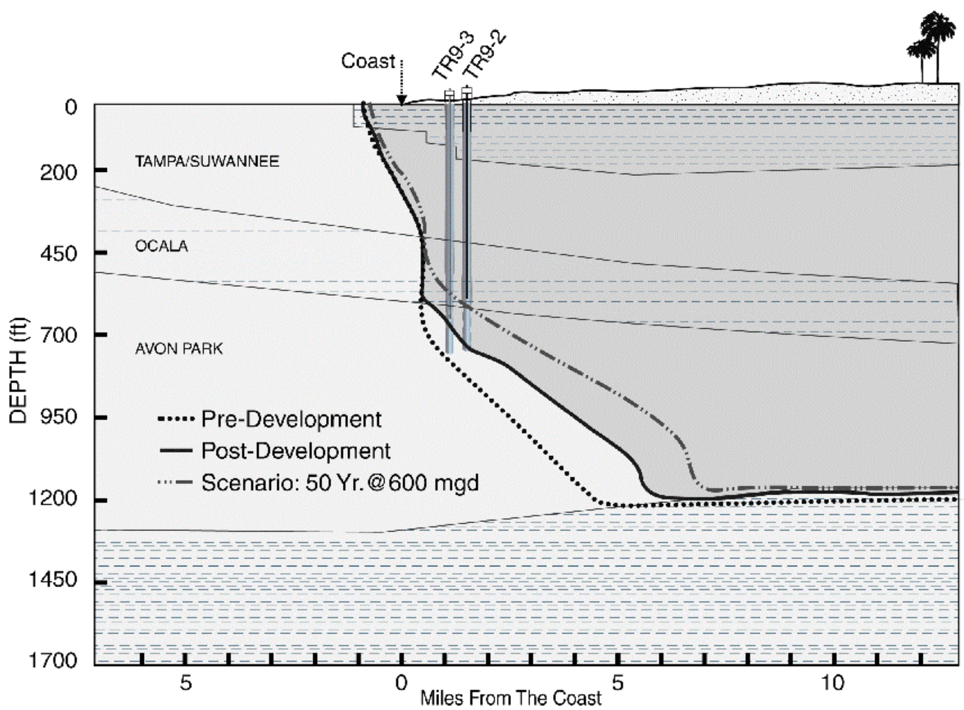


**Figure 18: Simulation of the 1000 mg/l chloride concentration at section A-A' for predevelopment, post development (current), and future if 600 Mg/d are withdrawn from the SWUCA over the next 50 years (Based on Hydrogeologic Inc., 1954).**

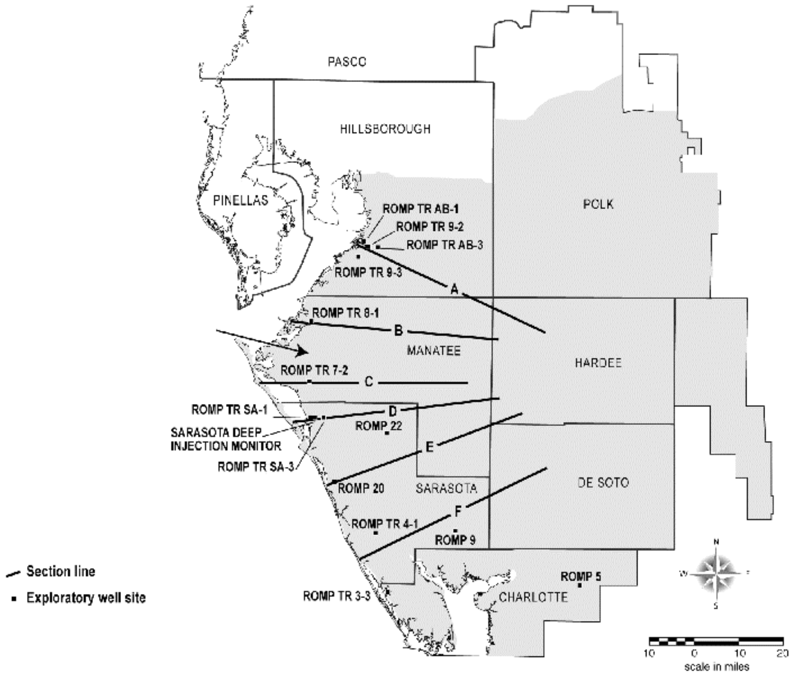


**Figure 19: Locations for cross sections used to analyze wells at risk for saltwater intrusion.**

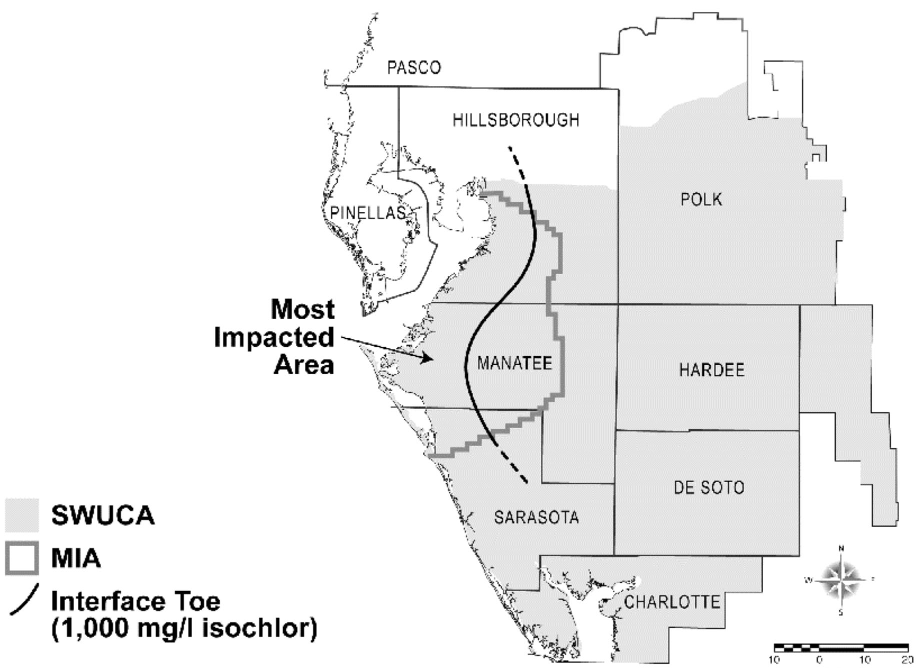


**Figure 20: Location of the toe of the interface in the Upper Floridan aquifer within the ETB WUCA and MIA.**

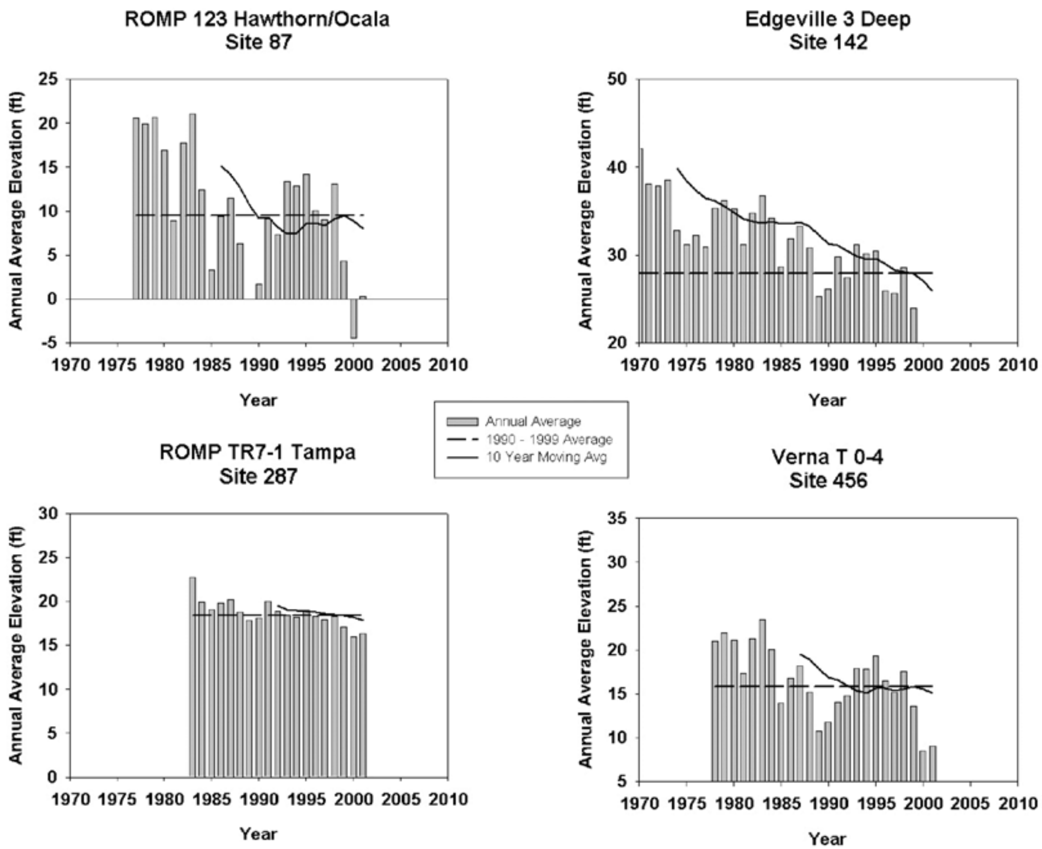


**Figure 21: Annual average and 10 year moving average water levels for wells used to calculate the minimum aquifer levels.**

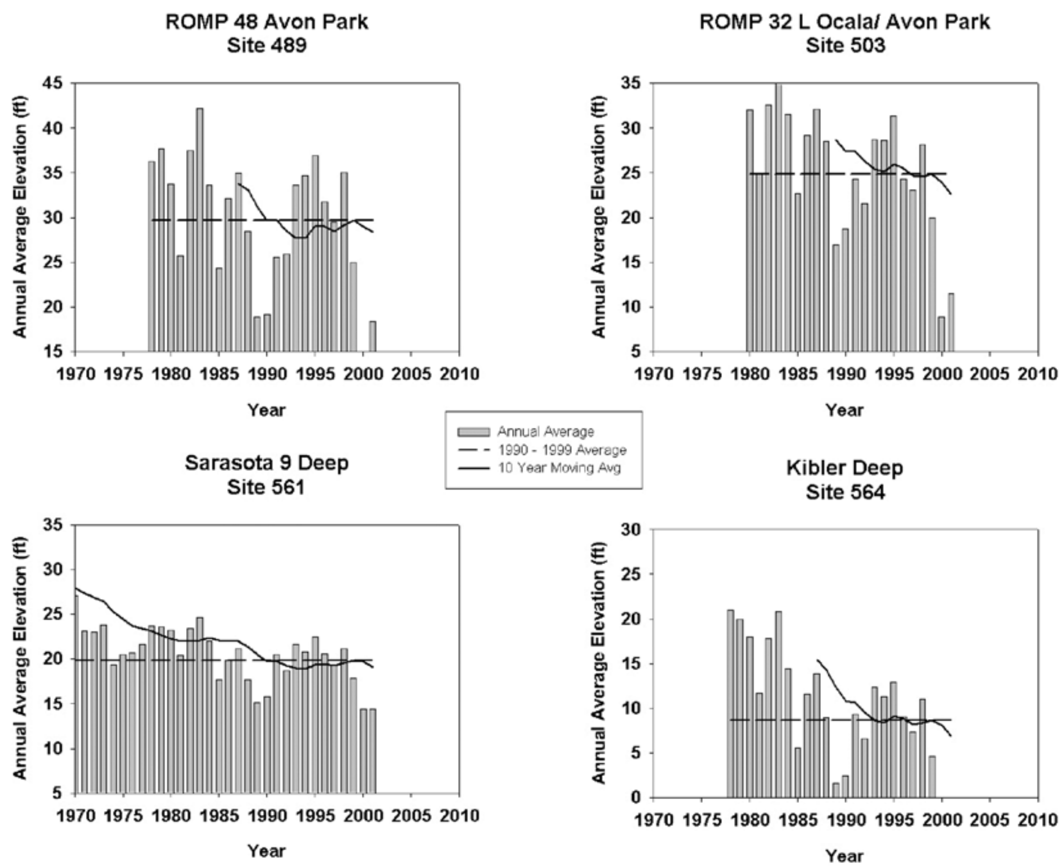


**Figure 21: Annual average and 10 year moving average water levels for wells used to calculate the minimum aquifer levels.**

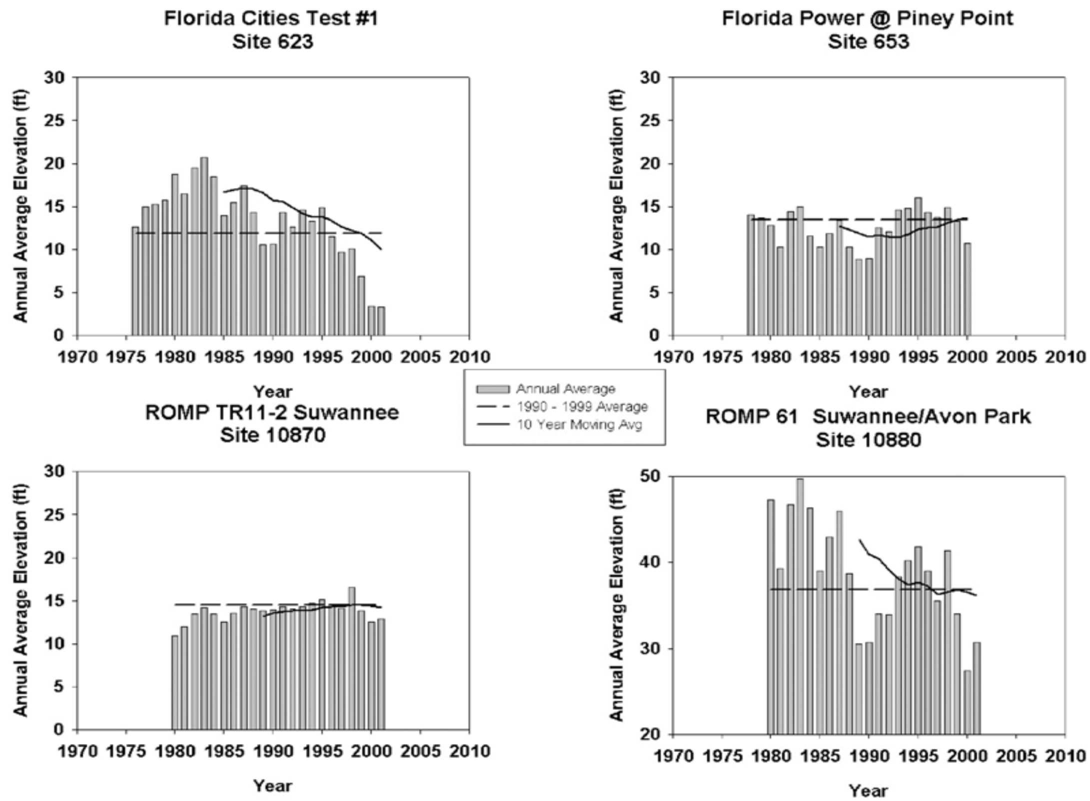


**Figure 21: Annual average and 10 year moving average water levels for wells used to calculate the minimum aquifer levels.**

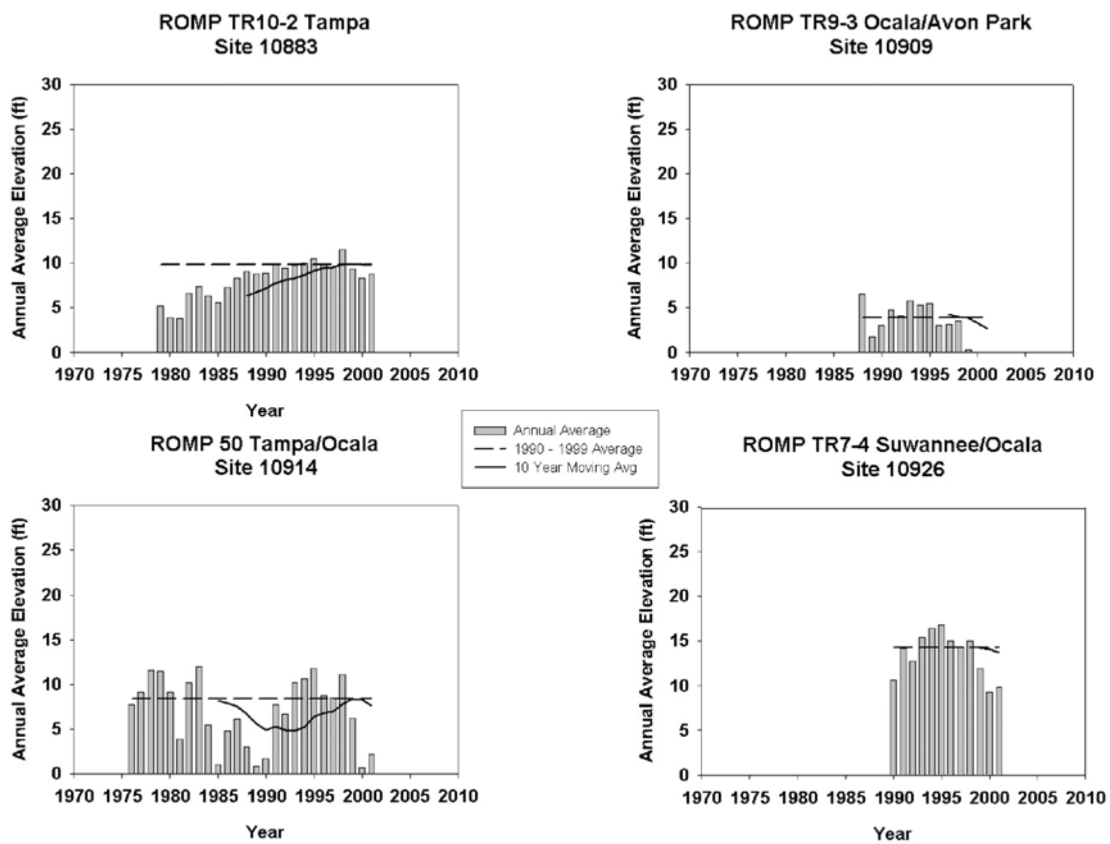


**Figure 21: Annual average and 10 year moving average water levels for wells used to calculate the minimum aquifer levels.**

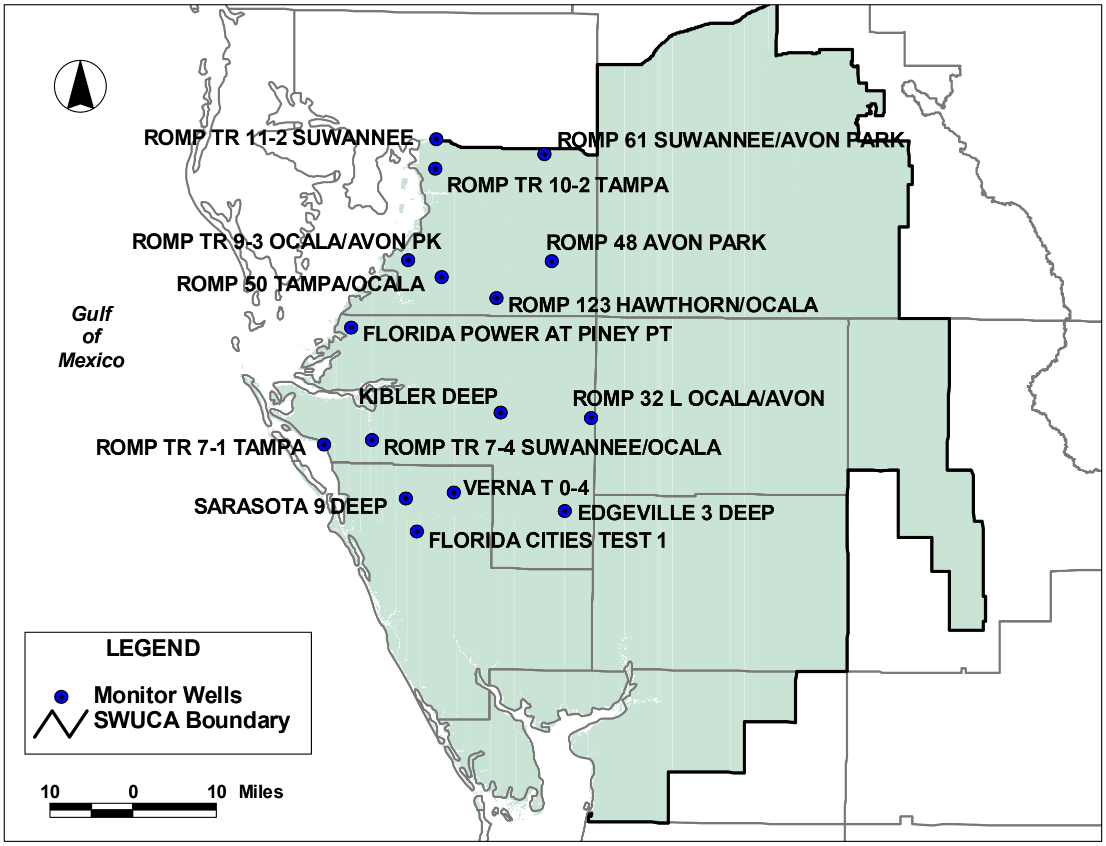


**Figure 22: Location of monitor wells used to calculate the minimum level.**