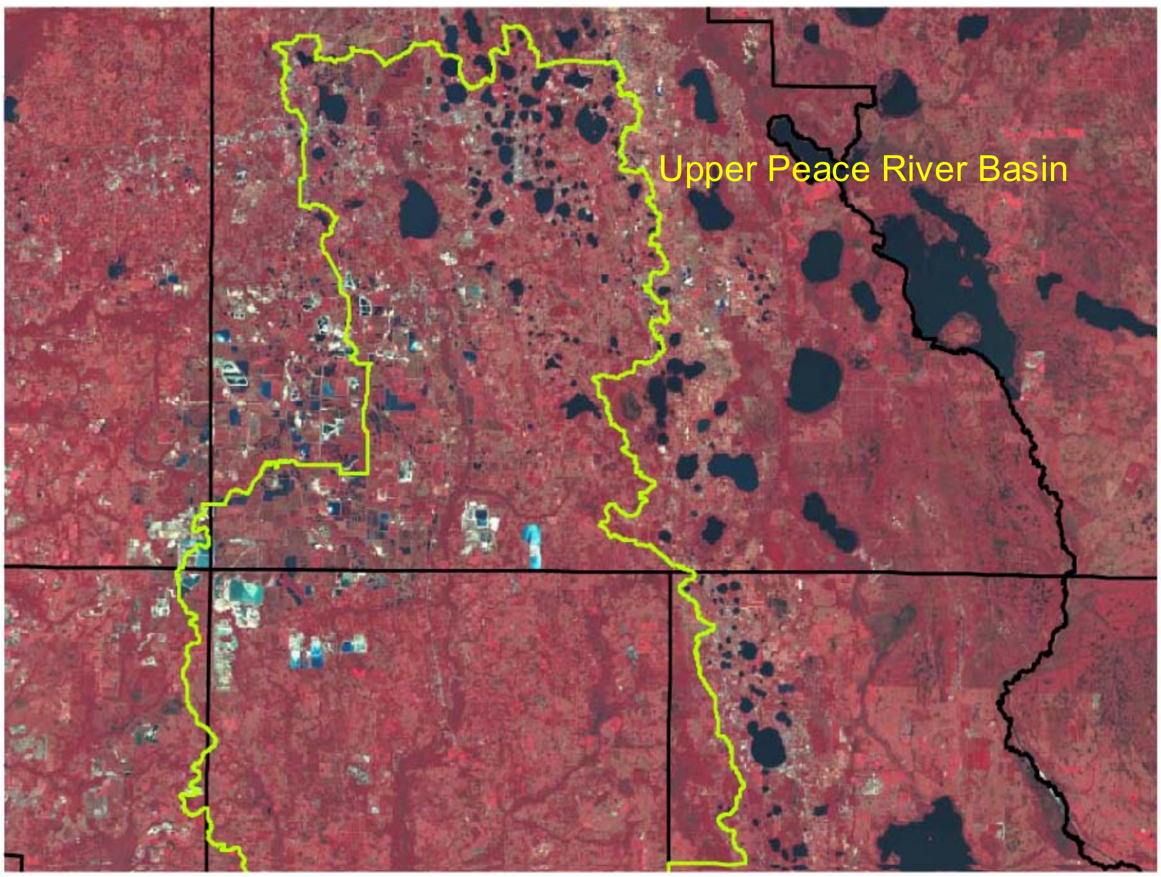
Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals



Hydrologic Evaluation Section
Southwest Florida Water Management District

July 2003

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The geological evaluation and interpretation contained in the report entitled *Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals* has been prepared by or approved by a Certified Professional Geologist in the State of Florida, in accordance with Chapter 492, Florida Statutes.

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Date: ______________________________

Contents

Figures

Tables

Predicted Change in the Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals

By Ron Basso, P.G.

1.0 INTRODUCTION

Ground-water withdrawals for mining, agriculture, and public supply have lowered the potentiometric surface of the Upper Floridan aquifer over 40 feet since the 1930's in south-central Polk County. Kissengen Spring, located on the upper Peace River, historically discharged about 15 to 20 million gallons per day (mgd) during the 1930s. Due to increasing ground-water withdrawn from the Upper Floridan aquifer in the area, flow gradually declined from the Spring until it ceased completely in 1950. The Peace River, where flows have declined over the last 60 years at the Bartow, Zolfo Springs, and Arcadia gage sites, may also be adversely effected by declining ground-water levels (Lewelling and others, 1998).

In response to these concerns and to assist in the evaluation of minimum low flows on the upper Peace River, the Hydrologic Evaluation Section of the Southwest Florida Water Management District (SWFWMD) conducted a study to examine the Peace River/ground-water system interaction from the headwaters near Lake Hancock to the Zolfo Springs gaging station located in central Hardee County. Previous investigations by Peek (1951) and Kaufman (1967) determined that ground-water withdrawals in the region had directly affected springflow and baseflow contributions to the upper section of the river.

The report is divided into four main sections. The first section provides background information detailing the physical and hydrogeologic framework of the upper Peace River basin. The second section of the report is a review of historic changes and trends in springflow and Upper Floridan aquifer potentiometric levels. The third section focuses on the impact of ground-water withdrawals and subsequent declining flows, and the final part of the report evaluates the effect of reductions in pumping on the possible reestablishment of flow at Kissengen Spring and the return of upward head potential along the Peace River.

1.1 Purpose and Scope

The purpose of this study is to characterize hydrogeologic conditions along the upper Peace River and quantify the likely hydrologic response due *solely* to reductions in existing ground-water use. Projected changes in the hydrologic system are based on graphical analysis and numerical modeling simulations. At the conclusion of the report, recommendations for future work are included that address data limitations.

This study represents an initial assessment until more information is gained through additional drilling and testing along the river. It is not intended to address all of the factors that have affected Peace River flow. The SWFWMD is currently examining several factors related to changes in streamflow over the entire basin under the *Peace River Cumulative Impact Study*, scheduled for release during late 2003.

1.2 Previous Investigations

The hydrologic and hydrogeologic conditions of the upper Peace River basin have been extensively studied. Peek (1951) described the cessation of flow of Kissengen Spring and Stewart (1966) discussed the ground-water resources of Polk County. The hydrologic effects of groundwater pumpage in the Peace and Alafia River Basins from 1934 through 1965 was reported by Kaufman (1967). The hydrology of the Lakeland Ridge along the extreme northern part of the Peace River basin was described by Robertson (1973). Hutchinson (1978) examined shallow ground-water resources in the Alafia and upper Peace River basins. Barr (1992) examined the potential for ground-water contamination in Polk County and Lewelling and others (1998) analyzed the hydraulic connection between ground-water and the Peace River. Rainfall studies included Palmer and Bone (1977) and Coastal Engineering (1997). Hammett (1990) and Flannery and Barcelo (1997) examined surface water flow and rainfall. Recently, Ross and others (2001) completed a 10-year surface water model simulation that included the Peace River basin. Other reports and studies that are more regional in scope that cover the upper Peace River basin include Wilson and Gerhart (1980), Barcelo and Basso (1993), Ryder (1985), Miller (1986), Duerr and others (1988), Scott (1988), and Yobbi (1996).

2.0 BACKGROUND CONDITIONS

2.1 Description of Study Area

The Peace River basin comprises about 2,350 square miles in the southern half of the SWFWMD (Figure 1). At the confluence of Peace Creek Canal and Saddle Creek in the north, the river stretches 75 miles southward through Bartow, Zolfo Springs, and Arcadia where it finally empties into the Gulf of Mexico at Charlotte Harbor. Major tributaries include Bowlegs Creek in Polk County, Payne Creek and Charlie Creek in Hardee County, and Horse Creek in De Soto County. Mean annual flow varies from 224 cubic feet per second (cfs) (145 mgd) at Bartow, 626 cfs (404 mgd) at Zolfo Springs, and 1,060 cfs (685 mgd) at Arcadia for the period-of-record at each gaged site.

The study area is defined as the northern extent of the Peace River drainage basin, bounded at the north by the cities of Lakeland and Lake Alfred, extending south to Zolfo Springs in central Hardee County (Figure 2). This represents 840 square miles (mi^2) or about 36 percent of the total drainage area.

Drainage to the upper portion of the river, located from Bartow to Ft. Meade, is mostly limited to phosphate-mine releases and reclaimed stream channels. Much of the pre-mining hydrography has been altered. Numerous clay-settling areas, which individually may cover several hundred acres, are the dominant reclaimed land form type located along this section of the river (Lewelling and others, 1998). Further southward, surface drainage to the river is from naturally formed tributaries. About 25 facilities have permits from the Florida Department of Environmental Protection (FDEP) to discharge domestic effluent to the Peace River and its tributaries. The combined design capacity for all domestic discharges is about 20 mgd (Hammett, 1990).

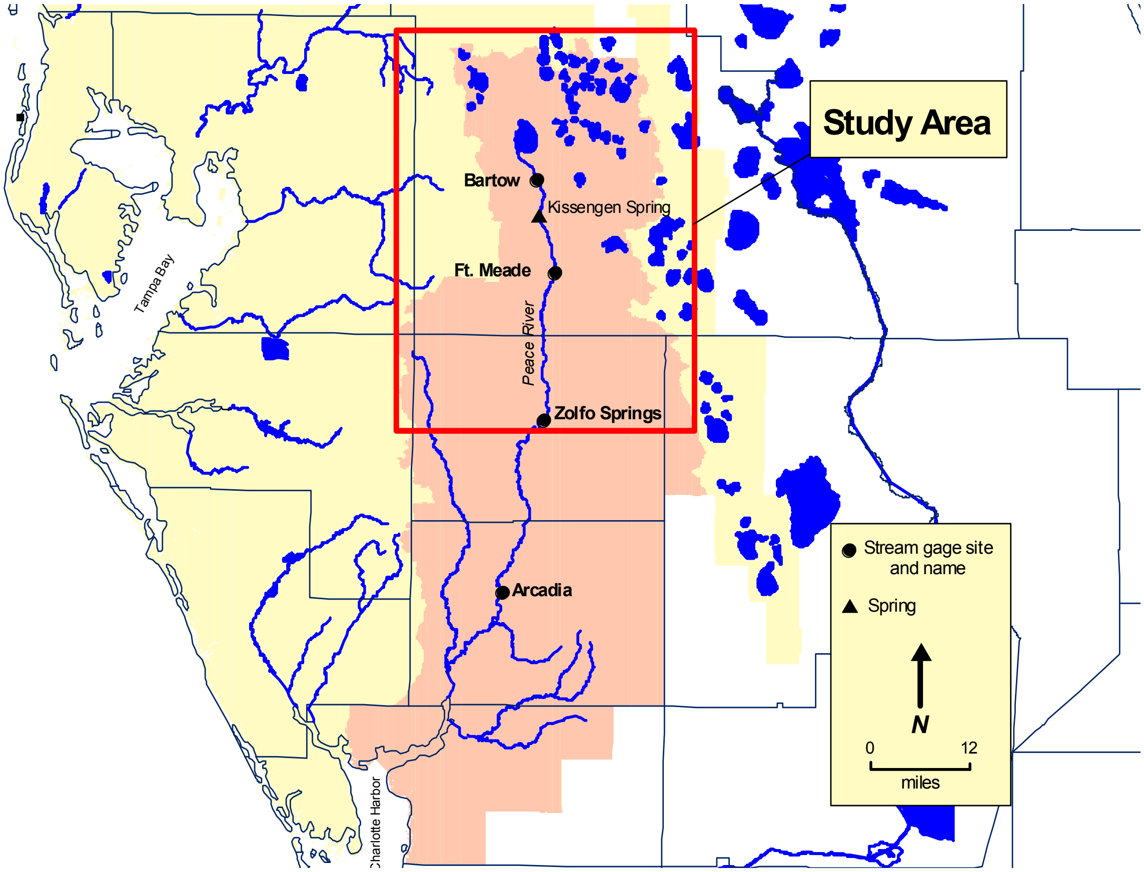

Figure 1. Location of the study area, the Peace River drainage basin, and stream gage sites.

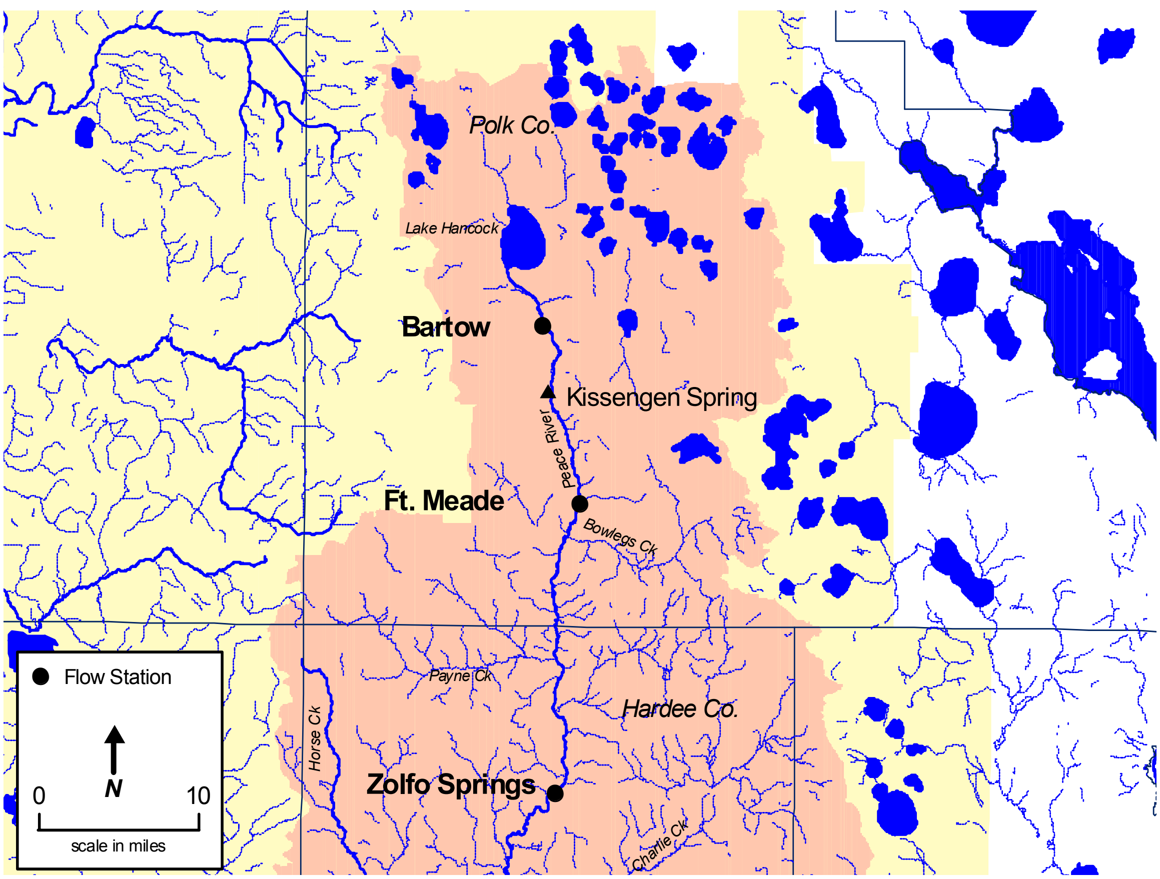

Figure 2. Location of the upper Peace River basin study area.

Land use/land cover in the upper Peace River basin consists predominantly of agriculture (citrus, pasture, and row crops), mining, rangeland, and urban area (Figure 3). Major cities include Lakeland, Winter Haven and Bartow. As of 2001, approximately 300 square miles in the upper Peace River basin have been mined for phosphate (Orlando Rivera, FDEP, personal communication). This represents about 36 percent of the basin above Zolfo Springs.

The major use of ground-water in the Peace River Basin has historically been for agricultural irrigation and activities associated with the mining and processing of phosphate ore. Peek (1951) estimated annual ground-water withdrawals of 22 mgd in southwest Polk County by 1940 which increased to 90 mgd by 1950. He attributed about 70 percent of the total ground-water withdrawn to phosphate mining use. Ground-water withdrawals continued to increase in Polk County reaching about 230 mgd in 1960 and over 410 mgd by 1975. Water-conserving practices in agriculture and mining have reduced Polk County ground-water use by about 100 mgd since the mid-1970s. Currently, ground-water withdrawals average between 300 and 400 mgd from Hardee and Polk Counties (Table 1).

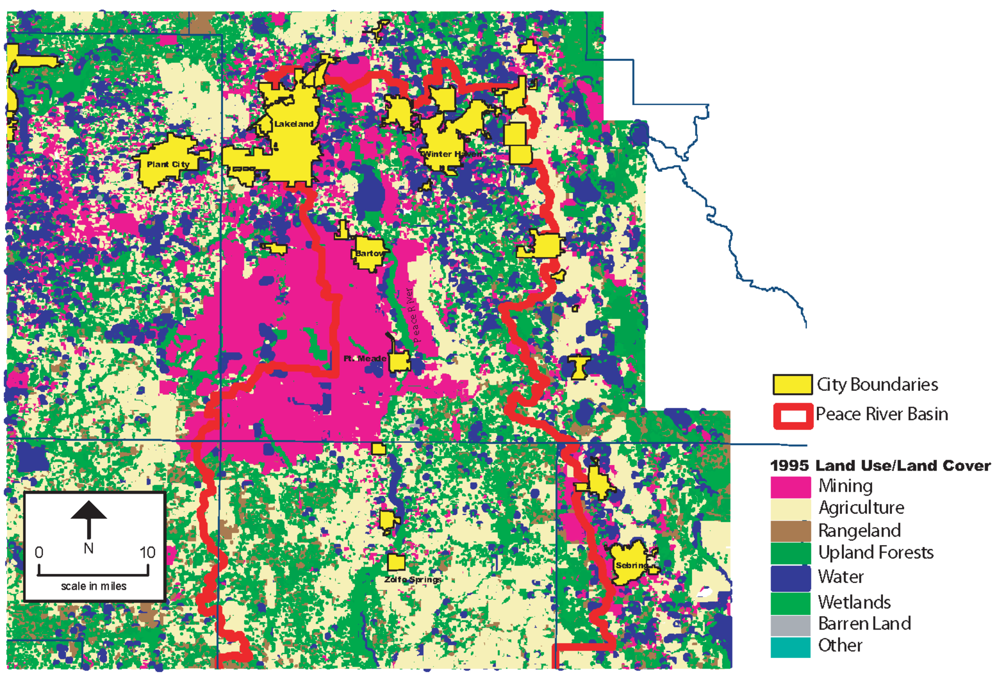

Figure 3. 1995 land use/land cover in the upper Peace River basin.

Table 1. Ground-water use in Hardee and Polk Counties, Florida (1985-2000).

Category	Polk County				Hardee County			
	1985	1990	1995	2000	1985	1990	1995	2000
Agriculture	106	112	93	149	86	61	44	82
Mining/Ind.	207	150	92	81	5	0.1	3	6
Public Supply	70	82	65	84	3	3	3	2
Recreational	(1)	7	9	11	(1)	0	0.1	0.3
Total:	383	351	259	325	94	64	50	90

Note: (1) Recreational included with Agriculture.
All units in million gallons per day (mgd).
Source: SWFWMD Water Use Estimate Reports.

The physiography of the upper Peace River basin transitions from an upland, internally-drained lake district in the north and northeastern portion, dominated by several highland ridges, to a poorly-drained upland region that extends south of Bartow to central Hardee County (Lewelling and others, 1998). A distinct ancient shoreline at 100-ft NGVD, formed by past sea level changes, separates the upland regions from the De Soto plain located in southern Hardee County (Figure 4). Land surface elevation ranges from greater than 200 ft NGVD along the Lakeland and Winter Haven ridges to around 100 ft NGVD in central Hardee County (Figure 5).

Specific, local physiographic features that influence the hydrologic system include the Bartow Embayment, an internally-drained, local erosional basin that has been partially infilled with phosphate-rich siliclastic deposits (Lewelling and others, 1998). It extends from north of Lake Hancock to Homeland (Brooks, 1981). The headwaters of the Peace River occupies the Embayment with sand ridges rising up to the east and west. The area lying southward along the river from Homeland to Zolfo Springs corresponds to the Bone Valley Uplands where land surface elevations are generally greater than 130 ft NGVD (Brooks, 1981). This region is characterized by pine flatwoods, wetlands, and lakes that occupy a poorly-drained plateau. In this region upstream from the Polk-Hardee County line, much of the natural drainage system has been altered by phosphate mining activity.

2.2 Hydrogeologic Framework

In general, the geology underlying the west-central Florida area consists of a series of clastic sediments overlying carbonate rocks (Table 1). In the upper Peace River basin there are three recognized aquifer systems. At the surface and extending up to several tens of feet thick is the unconfined surficial aquifer. It is generally comprised of unconsolidated quartz sand, silt, and clayey sand. Underlying the surficial is the confined intermediate aquifer system (IAS) which consists of a series of thin, interbedded limestone and phosphatic clays of generally low permeability. The third aquifer system, which underlies the IAS, is the confined Floridan aquifer system. It is composed of a series of limestone and dolomite formations. The location of two hydrostratigraphic cross-sections depicting the subsurface flow system are shown in Figure 6. Individual cross-sections are illustrated in Figures 7 and 8.

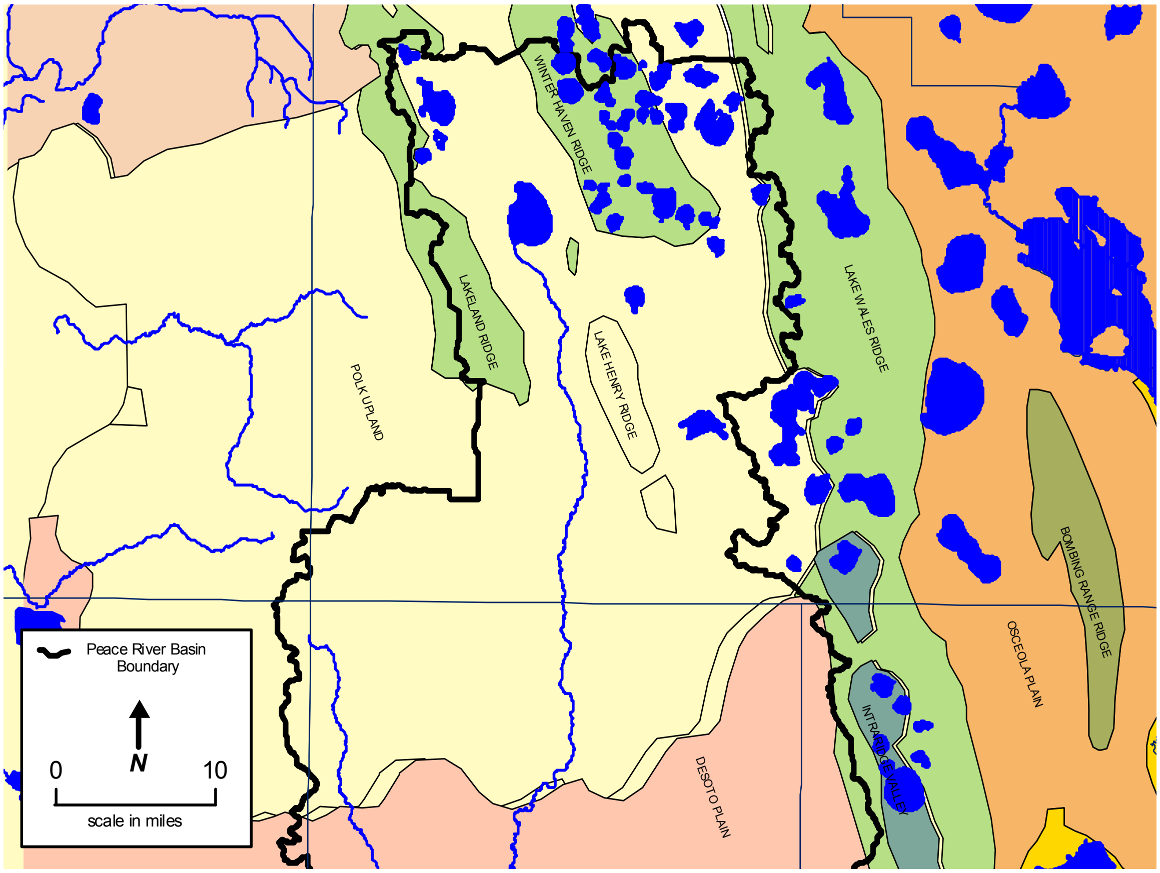

Figure 4. Physiographic regions within the upper Peace River basin.

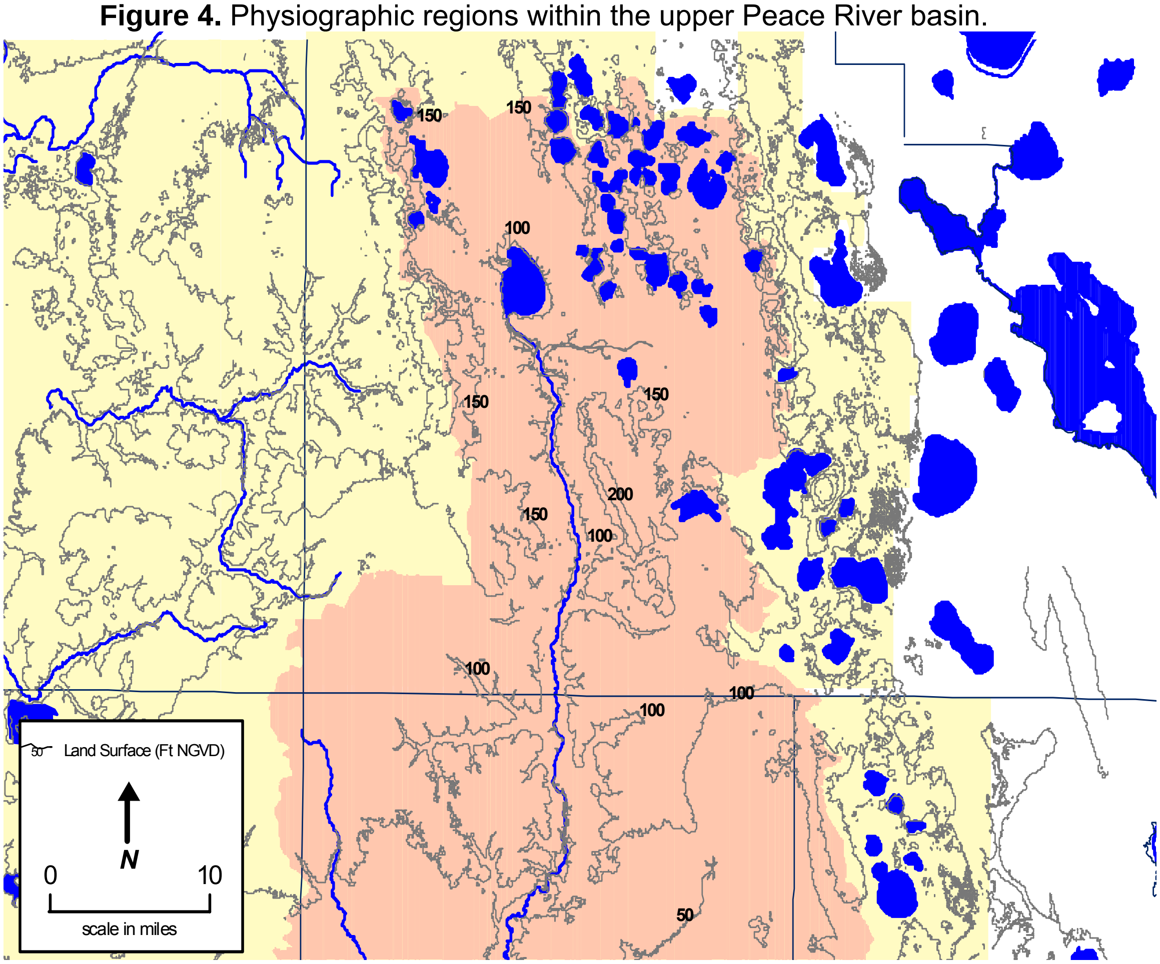

Figure 5. Elevation of land surface in the upper Peace River basin.

Table 2. Hydrogeology of the Peace River Basin (modified from Miller,1986, Barr, 1996, and Tihansky and others, 1996).

Series	**Stratigraphic Unit**		**Hydrogeologic Unit**		**Lithology**
Holocene to Pliocene	Undifferentiated Surficial Deposits		Surficial Aquifer		Sand, silty sand, clayey sand, peat, and shell
Miocene	Hawthorn Group	Bone Valley Member	Confining Unit	Intermediate Aquifer System	Predominantly phosphatic clay, gray to green to brown, plastic, ductile, minor sand, phosphatic gravel, residual limestone and dolostone
		Peace River Formation	PZ 2		
			Confining Unit		
		Arcadia Formation			
Miocene / Oligocene		Tampa or Nocatee Member	PZ 3		Limestone, gray to tan, sandy, soft, clayey, minor sand, phosphatic. Chert found locally
			Confining Unit		
Oligocene	Suwannee Limestone		Upper Permeable Zone	Upper Floridan Aquifer	Limestone,cream to tan, sandy, vuggy, fossiliferous
Eocene	Ocala Limestone		Semi-Confining Unit		Limestone,white to tan, friable to micritic, fine-grained, soft, abundant foraminifera
	Avon Park Formation		Lower Permeable Zone		Limestone and dolomite. Limestone is tan, recrystallized. Dolomite is brown, fractured, sucrosic, hard. Peat found locally at top. Interstitial gypsum in lower part.
			Middle Confining Unit		

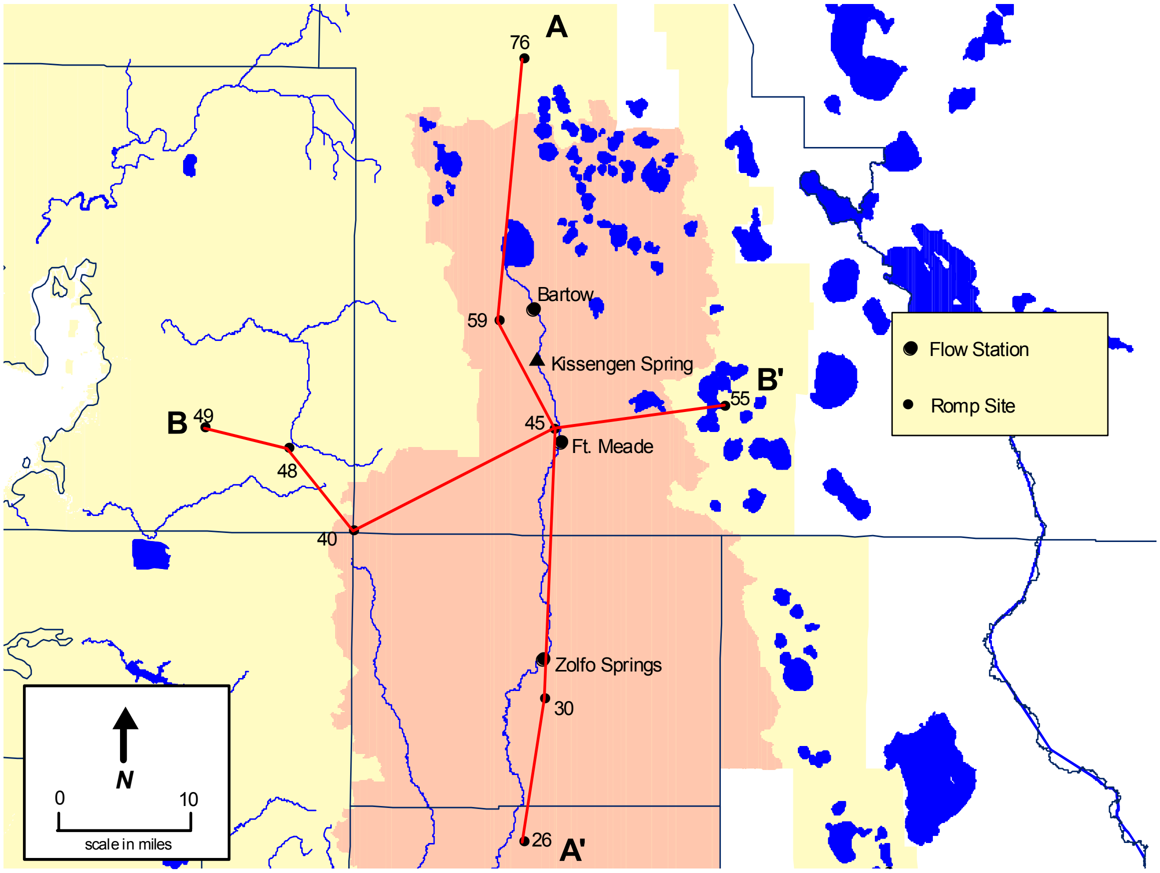

Figure 6. Location of hydrogeologic cross-sections A-A' and B-B'.

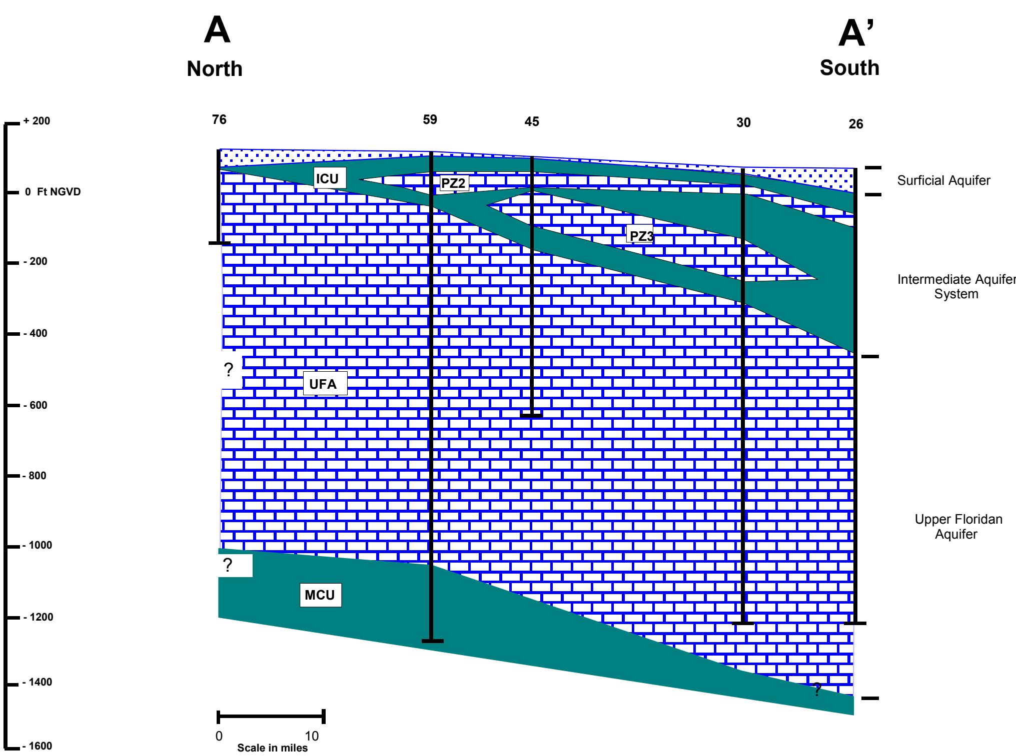

Figure 7. Hydrogeologic cross-section A-A'.

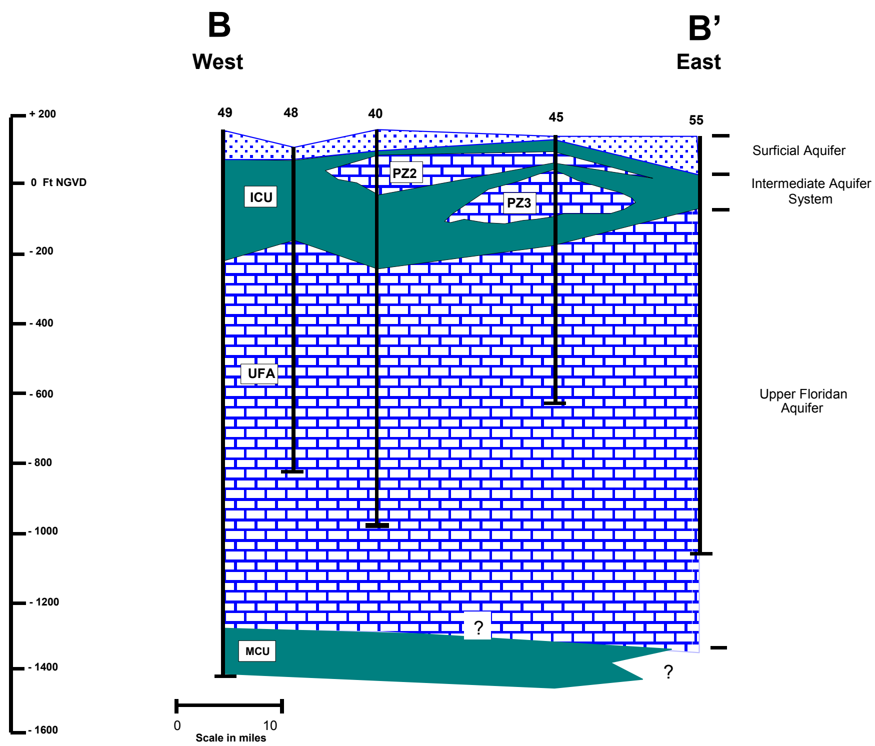

Figure 8. Hydrogeologic cross-section B-B'.

The Floridan aquifer system is further divided into the Upper Floridan and Lower Floridan aquifers which are separated by a middle confining unit (MCU) consisting of a thick, massive sequence of evaporite materials of extremely low permeability (Miller, 1986). The Lower Floridan aquifer is comprised of interbedded dolomite and anhydrite, hydraulically isolated from the Upper Floridan aquifer, generally low in permeability, and is brine-saturated. Because of it's poor water quality, deep depth, and limited ability to yield water, the Lower Floridan aquifer has only been used for disposal of industrial waste through deep well injection in west-central Florida.

In the following sections, hydrostratigraphic units within the upper Peace River basin have been determined based upon review of lithologic logs from SWFWMD Regional Observation and Monitoring-Well Program (ROMP) sites. The elevation and thickness maps contained in this report should be interpreted from a generalized or regional perspective. Appendix A contains specific hydrostratigraphic information for each ROMP site.

2.3 Surficial Aquifer

The unconfined surficial aquifer consists primarily of fine-to-medium grained quartz sand, clayey sand, silt, and minor shell and its thickness ranges from less than 50 feet over the western two-thirds of the basin to greater than 100 feet along the Lake Wales Ridge located in Highlands County (Figure 9). Near Bartow and Ft. Meade, surficial sand thickness averaged less than 10 feet. Minor amounts of organic material, gravel, and phosphate also are present in the surficial aquifer. Along the banks of the Peace River, this strata exists as thin sand units within the streambed and exposed cut banks ranging from several feet to more than 20 feet in thickness (Lewelling and others, 1998).

The surficial aquifer produces relatively small quantities of water in the upper Peace River basin and is rarely used for more than lawn irrigation or domestic water supply. The deposits are composed of undifferentiated sediments formed during the Holocene and Pleistocene epochs.

The base of the surficial aquifer consists of Pliocene age clays and clayey sands that form the top of the IAS. The surficial aquifer is unconfined and in the project area, the depth to the water table ranges from near land surface in swampy, poorly drained areas, to more than ten feet below land surface on higher sand ridges. Water levels are typically lowest in the spring and highest in late summer. Local ground-water flow direction within the surficial aquifer usually follows the topography.

Hydraulic properties for the surficial aquifer vary with saturated thickness and lithology. Based on 15 aquifer tests on the surficial aquifer in the upper Peace River basin, horizontal hydraulic conductivity values varied from less than one to 102 feet/day (ft/d). The median value of hydraulic conductivity was 22 ft/d (SWFWMD, 1994). Specific yield values ranged from 0.01 to 0.3.

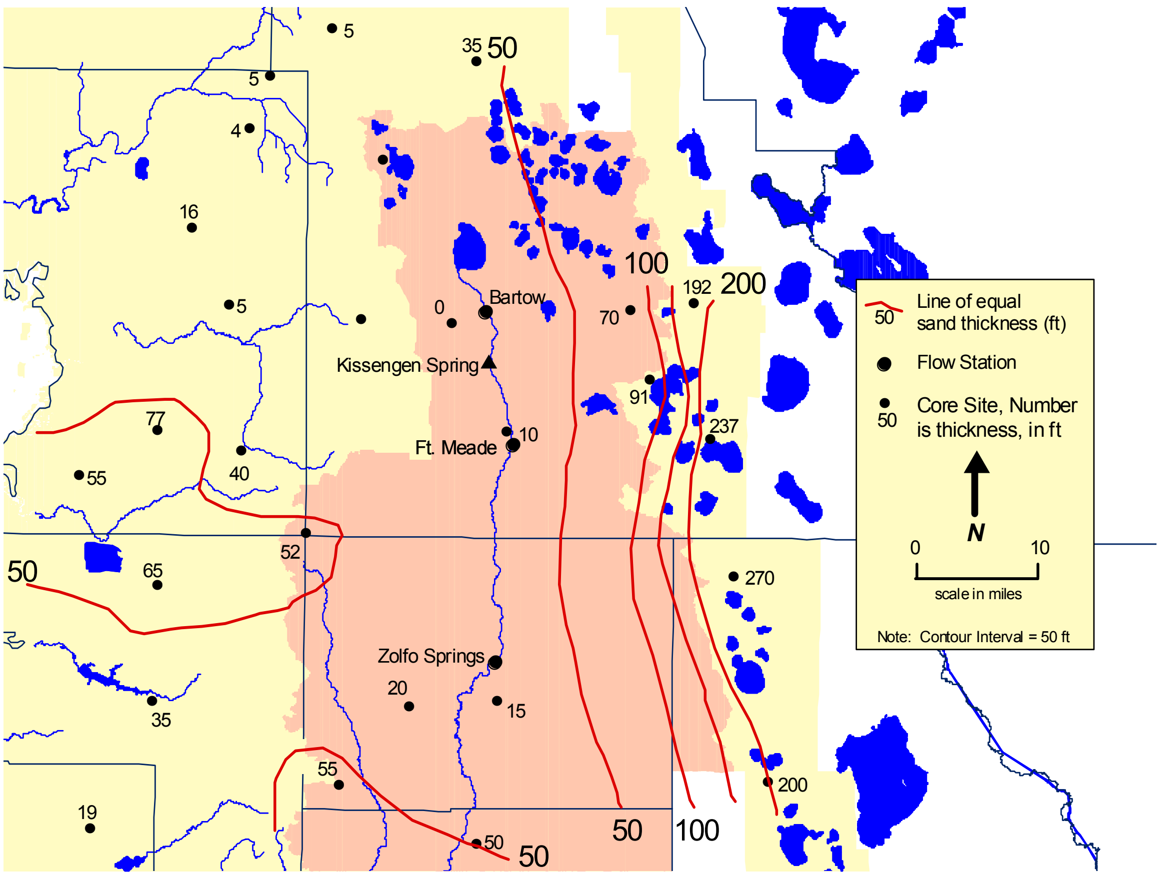

Figure 9. Sand thickness of the surficial aquifer.

2.4 Intermediate aquifer system (IAS)

Underlying the unconfined surficial aquifer is a series of interbedded phosphatic clays, sands, gravels, dolomite and thin limestone beds named the IAS. As a whole, the entire system can often be categorized as a confining unit that separates the surficial aquifer from the Upper Floridan aquifer, although permeable units occur within the clay matrix. In the upper Peace River basin, the aquifer(s) within the system eventually "pinch-out' toward the north. Based on analysis of ROMP data, the transition from an aquifer system (with associated confining units) to a confining unit appears to occur from a line extending from southwest Hillsborough County to north-central Polk County (Figure 10). This position is slightly south of the extent mapped by Duerr and others (1988). It must be noted, however, that thin, discontinuous producing zones may locally exist north of the position mapped in this report. The entire IAS dips toward the south-southwest and thickens to more than 450 feet in northern DeSoto County (Figures 11 and 12).

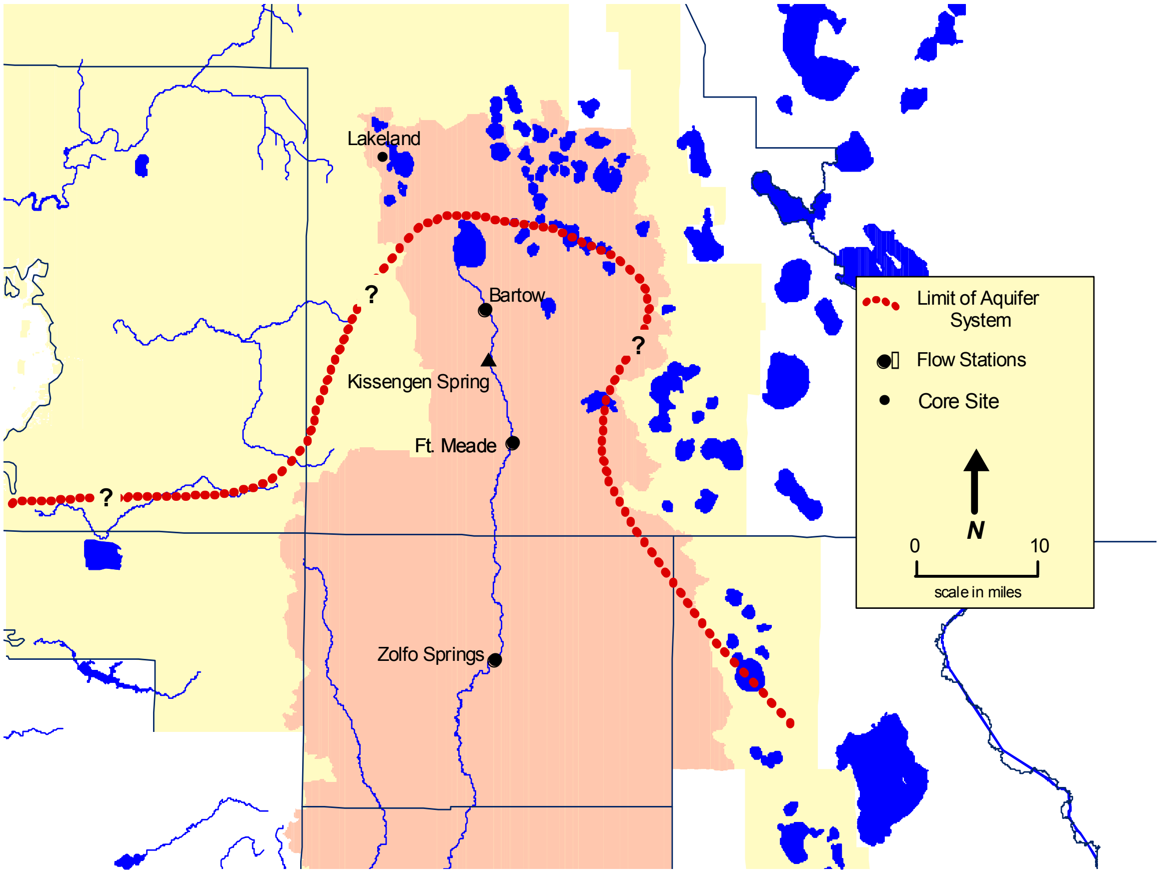

Figure 10. Regional extent of aquifers within the IAS

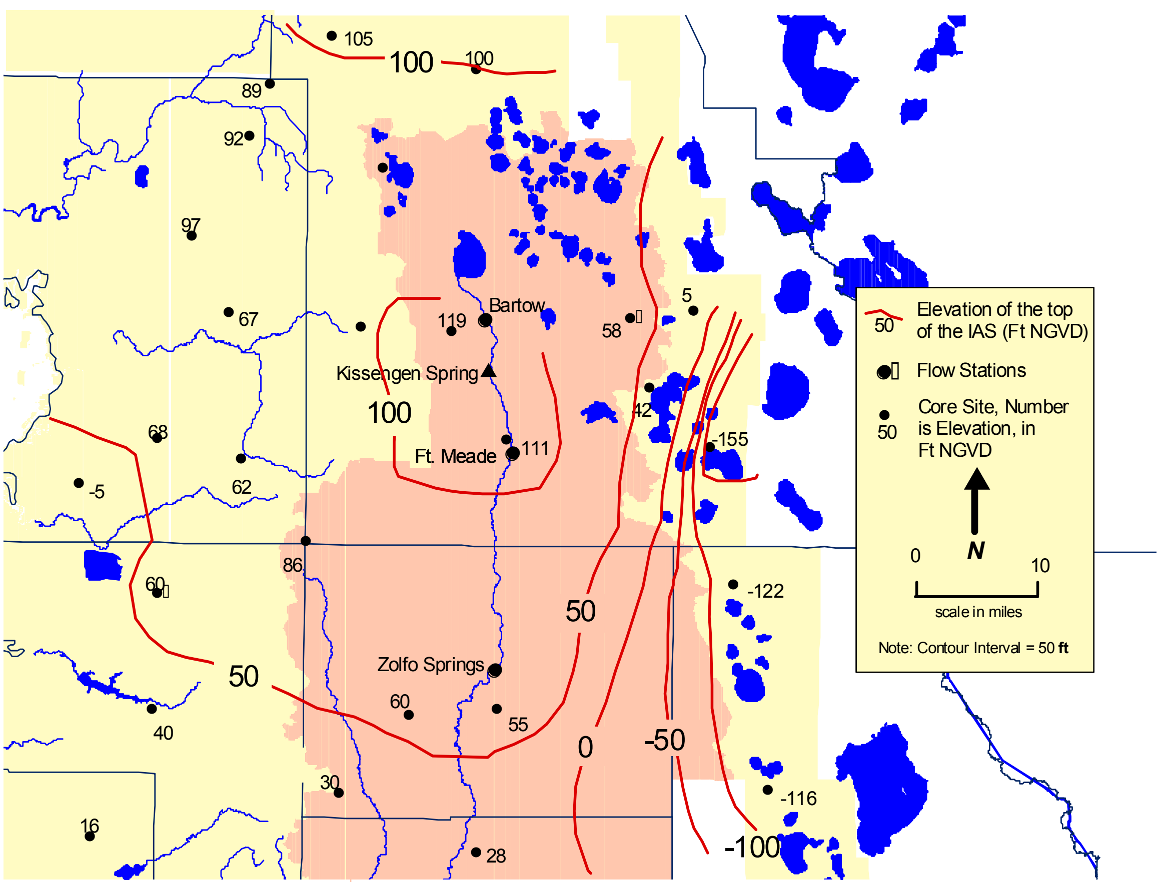

Figure 11. Elevation of the top of the IAS

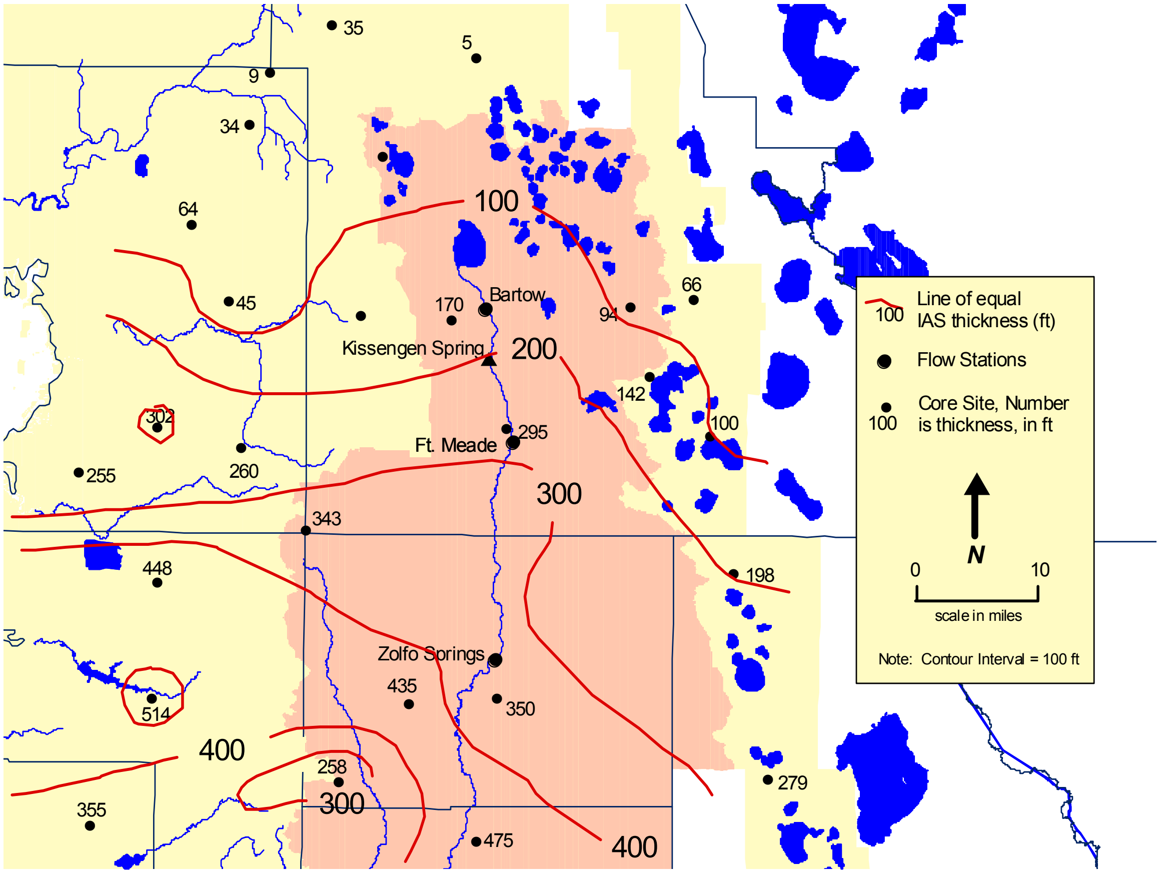

Figure 12. Thickness of the IAS.

Barr (1996) identified at least three separate aquifers in Sarasota County and labeled them in descending order PZ1, PZ2, and PZ3. The PZ1 zone, comprised of sand, shell, and thin dolostone layers, lies immediately below the surficial aquifer and above the Venice clay and is only found locally in central and southwestern Sarasota County. This unit is generally not found in the upper Peace River basin.

The PZ2 zone generally occurs within the Peace River Formation of the Hawthorn Group and is comprised of thin limestone and dolomite beds. The upper portion may be located stratigraphically within the phosphate-rich Bone Valley member of the Peace River Formation. The elevation of the top of the PZ2 zone is shown in Figure 13. The PZ2 zone appears to be the predominant aquifer within the intermediate system in central and southwest Polk County. It is probably the most regionally extensive unit in that water producing intervals can be defined in most of the upper Peace River basin. The lateral continuity of the zone is somewhat problematic because the producing zones are thin, poorly productive, and imbedded within a clay matrix. Since the permeability is quite low, the PZ2 zone may function hydrologically as a localized aquifer. Thickness of the PZ2 zone is illustrated in Figure 14.

The PZ3 zone is mostly composed of limestone that is represented by the Tampa or Nocatee Members of the Hawthorn Group. It is generally the most productive aquifer within the IAS. Beginning in southern Polk County, the base of the Tampa or Nocatee Member becomes mixed with clayey sand or sandy clay which forms the semi-confining bed between the PZ3 zone and the Upper Floridan aquifer. The zone thickens and dips toward the southwest from this point (Figures 15 and 16). North of this location, it appears that the Tampa or Nocatee Member is largely carbonate throughout its entire sequence and is in direct hydraulic connection with the Upper Floridan aquifer.

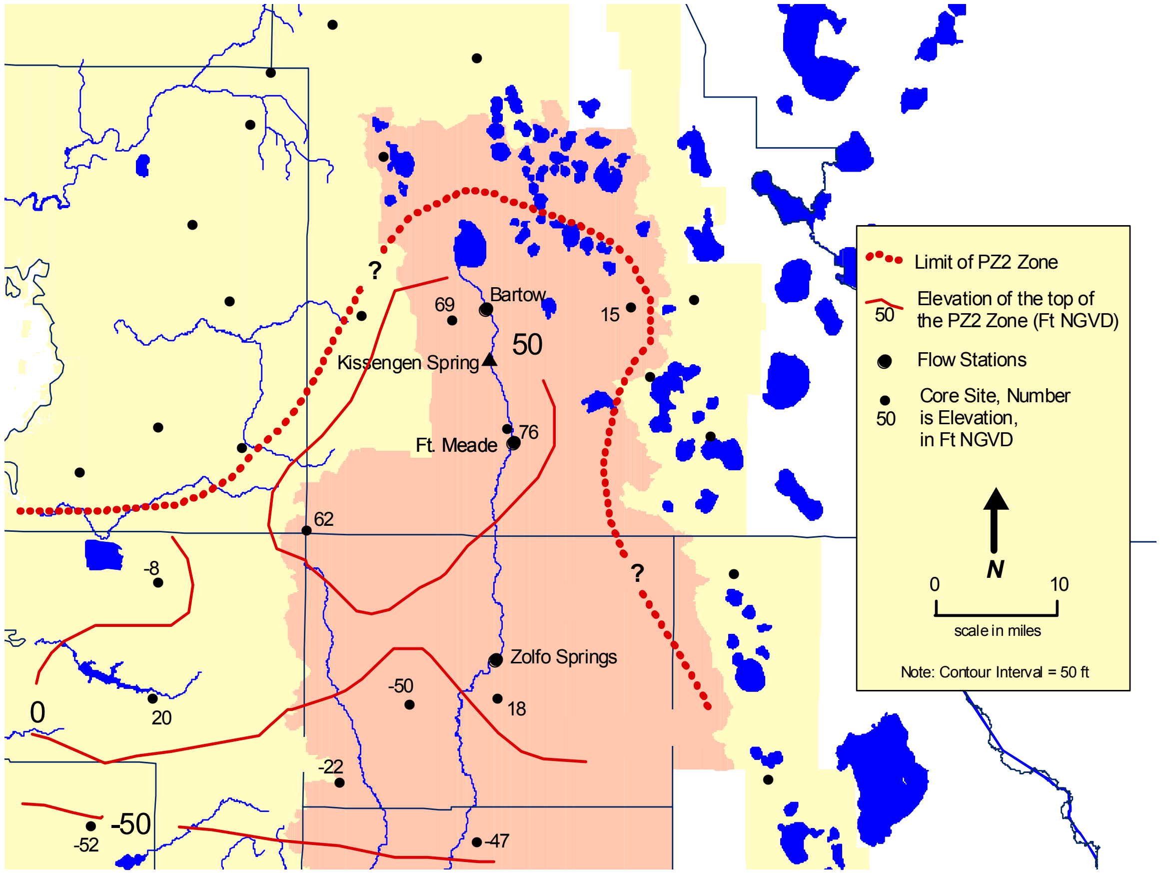

Figure 13. Elevation of the top of the IAS PZ2 zone.

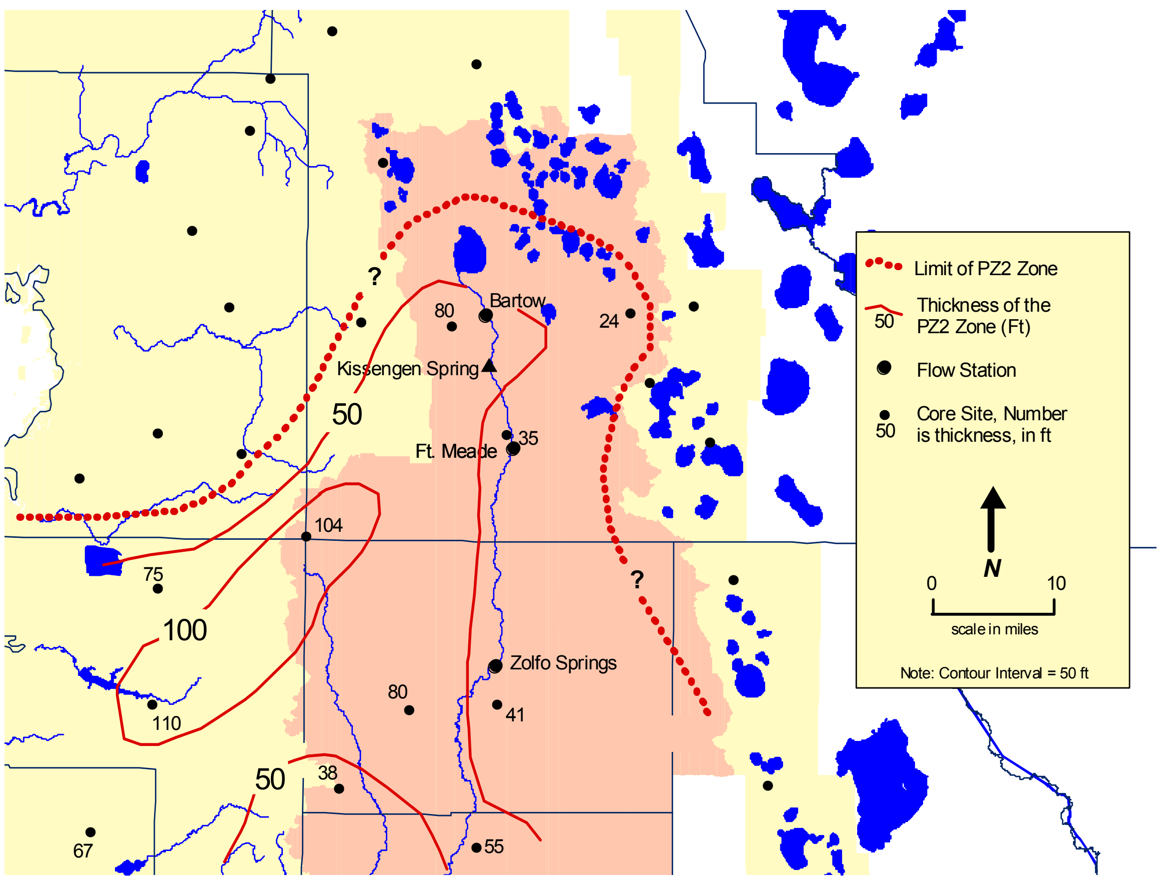

Figure 14. Thickness of the IAZ PZ2 zone.

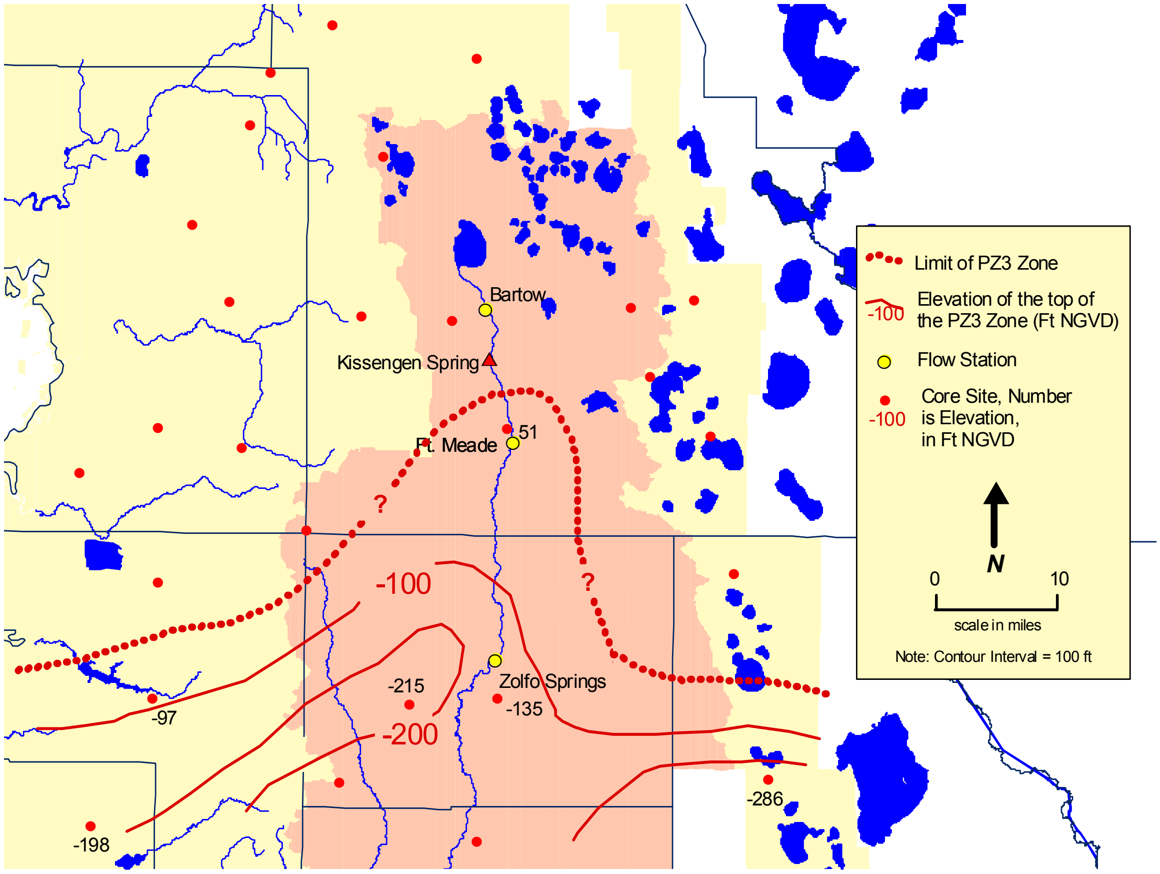

Figure 15. Elevation of the top of the IAS PZ3 zone.

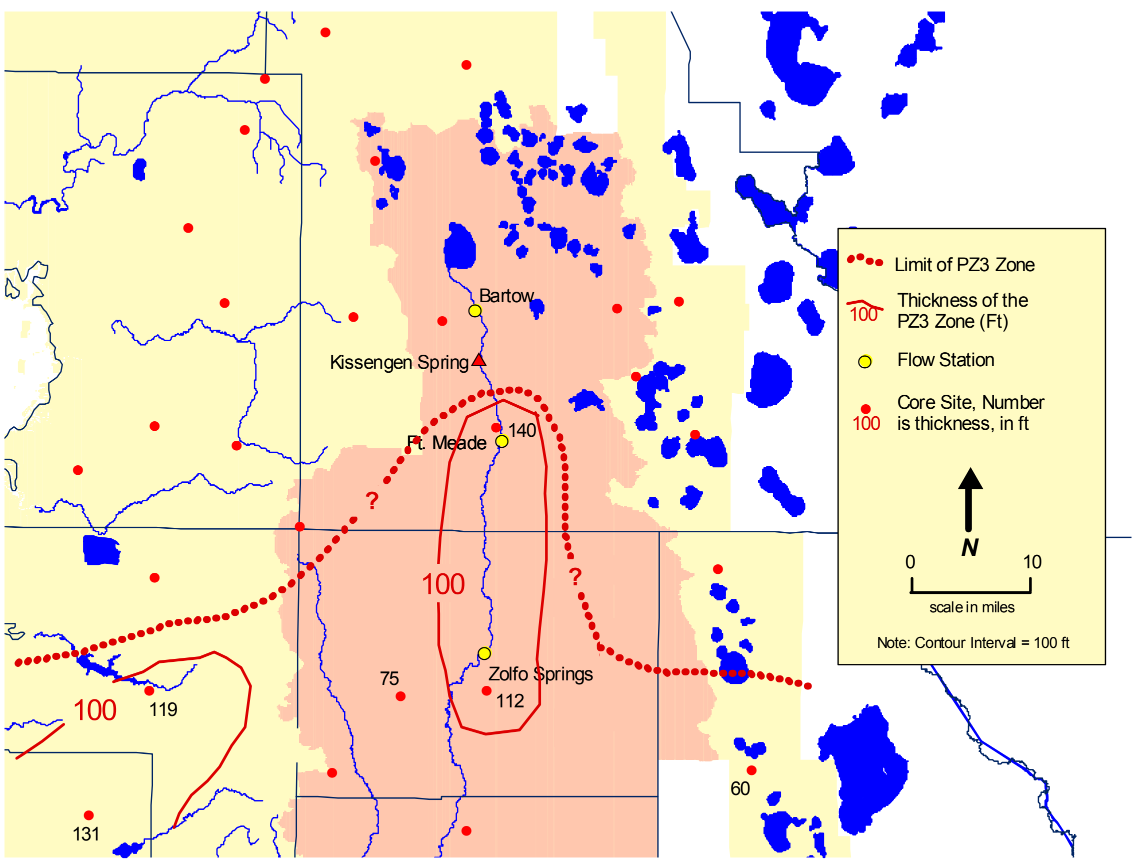

Figure 16. Thickness of the IAS PZ3 zone.

Data on the hydraulic properties of the IAS in the upper Peace River basin is generally limited and varies considerably because of the highly variable nature of the lithology. For the most part, the ability of the aquifer(s) to yield water in the IAS is low, with hydraulic conductivity values 10 to 100 times less than the underlying Upper Floridan aquifer. Transmissivity of the permeable units is generally less than 13,000 ft^2/day and varies over short distances indicating lithologic heterogeneity (Yobbi, 1996).

Hydraulic properties of the PZ2 and PZ3 water-producing zones of the IAS are generally not available in the upper Peace River basin due to limited test drilling and data collection. Based on discrete-zone aquifer tests in Hardee, Manatee, and Sarasota counties, horizontal hydraulic conductivity in the PZ2 zone varied from 0.01 to 36 ft/d. At both ROMP 25 in southwest Hardee County and ROMP TR7-2 in southwest Manatee County, hydraulic conductivity values were indicative of a semi-confining unit at less than 1 ft/d. At Osprey in northern Sarasota County, the hydraulic conductivity was 36 ft/d and transmissivity reached 1,800 ft^2/d from a 50-foot interval of the PZ2 zone. The PZ3 zone, the most permeable of all IAS zones, yielded hydraulic conductivity values from 0.3 to 19 ft/d with an average from four tests of 9 ft/d.

In general, the confining units in the IAS have very low hydraulic conductivity values and retard the movement of water between the overlying surficial and underlying Upper Floridan aquifer. Though the confining units do allow water to leak from one aquifer to another depending upon hydraulic gradients and permeability of the confining material. Patton (1981) mapped the location of local karst features along the upper stem of the river between Bartow and Ft. Meade which provide some degree of hydraulic connection with the lower aquifers. Regionally away from the river, however, the hydraulic connection between the surface and the IAS appears to be low. Hydraulic characteristics of the confining units based on field tests are extremely limited and are available only from regional flow model simulations. Along the upper Peace River from Bartow to the Polk-Hardee County line, leakance coefficients range from 1.0×10^{-5} to 9.9×10^{-5} ft/day/ft. Southward along the river to central Hardee County, the leakance coefficient is an order of magnitude lower (Metz, 1995).

2.5 Upper Floridan aquifer

The Upper Floridan aquifer is a carbonate sequence comprised of the Suwannee Limestone, Ocala Limestone, and portions of the Avon Park Formation. It generally consists of two permeable zones and one semi-confining unit. The term “permeable zone” has been adopted from previous literature (Hickey, 1982) and describes an identifiable horizon of enhanced water producing capabilities. The semi-confining unit is a lower permeability layer that lies between the permeable zones. The semi-confining unit is slightly more permeable than the confining units that overlie and underlie the Upper Floridan aquifer, namely the confining units of the IAS and the MCU. The entire sequence thickens and dips toward the south-southwest (Figures 17 and 18).

The top of the Upper Floridan aquifer generally coincides with the top of the Suwannee Limestone, which is the upper permeable zone (Basso, 2002). It is composed of a fossiliferous, biogenic calcarenite that contains moldic porosity. Below this zone, little apparent contribution of flow occurs due to the low permeability, fine-grained, chalky limestone of the Ocala Formation. The top of the Suwannee Limestone is sometimes marked by lost drilling circulation and is typically a zone of enhanced permeability. Review of lithologic logs from ROMP sites (nos. 59, 45, and 30) also indicate the deepest clay layer (lower intermediate confining bed) occurs just above the contact with the Suwannee Limestone.

The permeability of the Suwannee Limestone appears to be primarily intergranular with some minor contribution due to moldic porosity. In the northern part of the upper Peace River basin, solution cavities and conduits become more prominent due to the thinning of the intermediate confining unit. In this region, active karst processes enhance the permeability of the UPZ. Over most of the upper

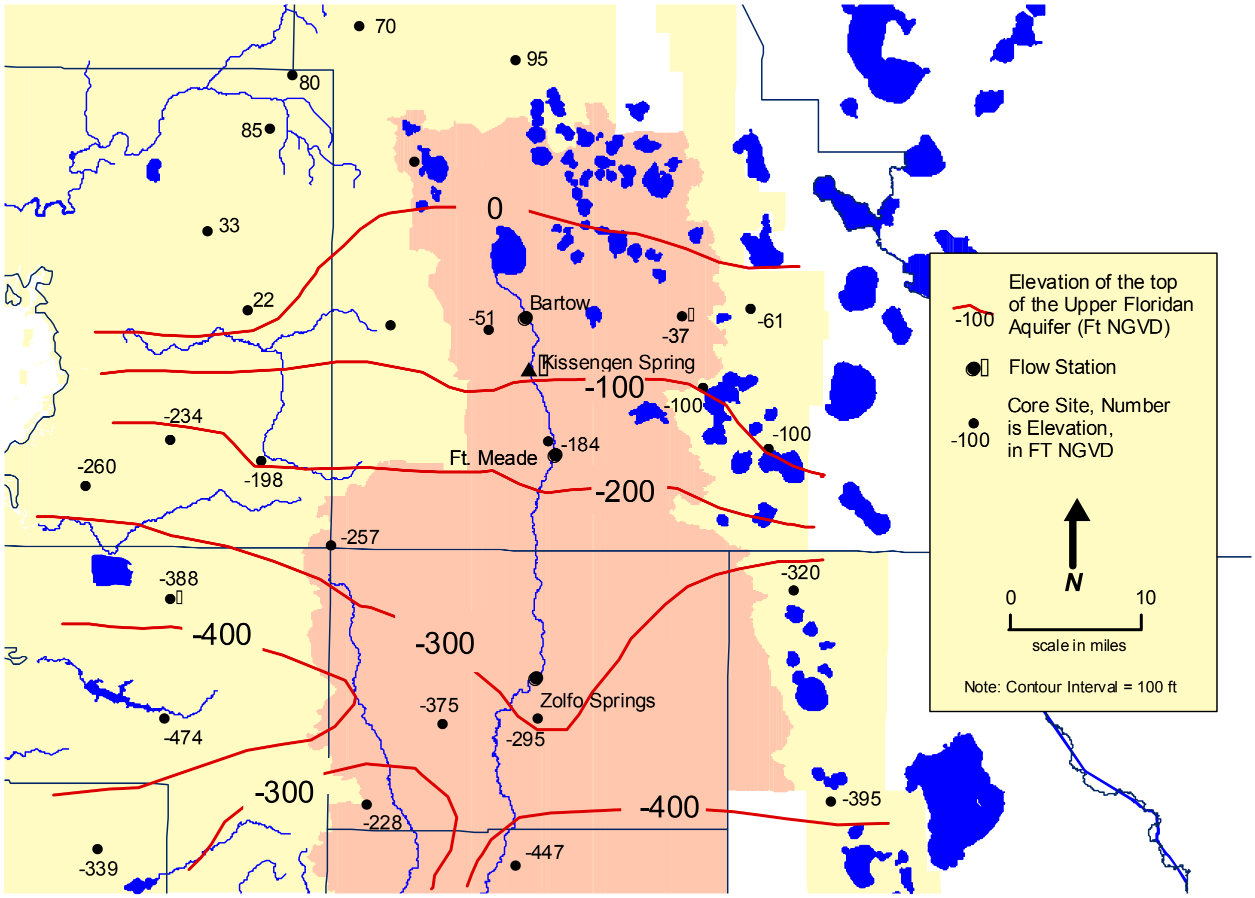

Figure 17. Elevation of the top of the Upper Floridan aquifer.

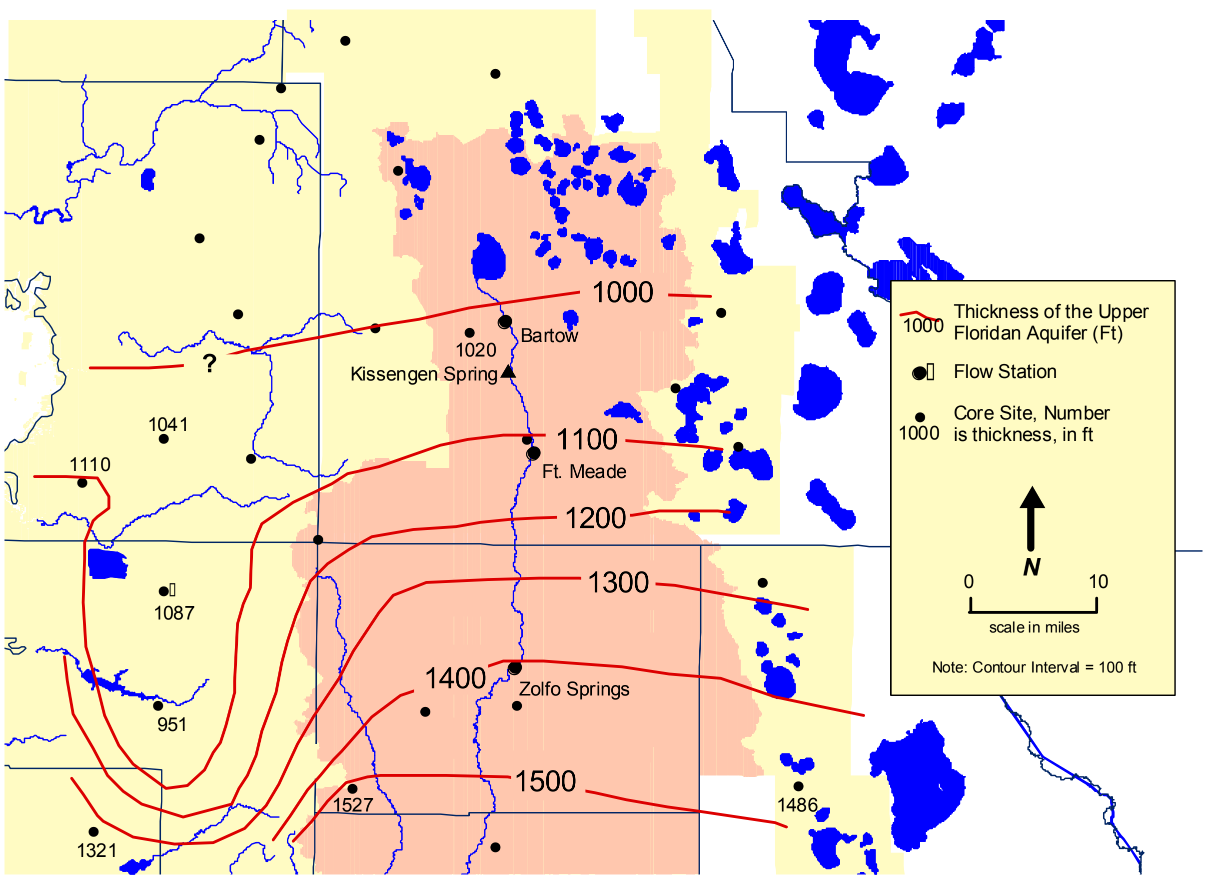

Figure 18. Thickness of the Upper Floridan aquifer.

Peace River basin, however, the primary permeability in the UPZ appears to be unrelated to karst activity. Single, discrete producing zones typically associated with secondary porosity features such as fractures or enhanced solution conduits are mostly absent from the UPZ. There is some evidence that the formational contacts between the Tampa Member/Suwannee Limestone and the Suwannee Limestone/Ocala Limestone provide enhanced flow contributions. Further investigation is needed, however, to more accurately define the contribution from these zones.

The UPZ has often been termed “moderately-permeable” when discussing the water yielding capabilities of the Upper Floridan aquifer. Horizontal hydraulic conductivities are often fairly uniform owing to the fact that most of the permeability is apparently derived from primary porosity. In the upper Peace Basin, few aquifer performance tests have been conducted solely on the UPZ. At ROMP 44, located just west of Crooked Lake in south-central Polk County, an aquifer test on the UPZ yielded a hydraulic conductivity of 8 ft/d. Further west, in Hillsborough, Manatee, and Sarasota Counties, hydraulic conductivity averaged 61 ft/d based on data from 11 aquifer tests (Basso, 2002).

Underlying the Suwannee Limestone is a semi-confining unit (SCU) that typically corresponds stratigraphically with the top of the Ocala Limestone. It is mostly composed of a soft, chalky, fine-grained, foraminiferal calcilutite and calcarenitic limestone. Near the lower portion, the Ocala Formation may contain sucrosic, dolomitic limestone. The semi-confining characteristics occur from the fine-grained calcarenitic limestone that comprises the majority of the formation. The base of the SCU is defined as the contact with the highly permeable, fractured dolomites of the Avon Park Formation. The entire SCU may include part of the Ocala Limestone, all of the Ocala Limestone, or the Ocala and upper portion of the Avon Park Formation.

Hydraulic properties of the Ocala Limestone are limited in the study area. Based on 56 cores collected from the Ocala Limestone in Pinellas, Hillsborough, Manatee, Hardee, Polk, and Sarasota Counties, mean vertical hydraulic conductivity of the SCU was 0.2 ft/d. Mean horizontal hydraulic conductivity, based on the results of 16 packer tests in the same region, was 0.5 ft/d.

The highly transmissive zone that occurs in the sucrosic, fractured dolomites of the Avon Park Formation is the lower permeable zone (LPZ) of the Upper Floridan aquifer. This zone, typically identified on the caliper log as fracturing and showing high resistivity values associated with dolostone or dolomitic limestone, is regionally extensive throughout the study area. The top of the LPZ is usually marked by high resistivity values on the 16N and 64N logs, large temperature deflections, fractured sections on the caliper log and the first persistent dolostone mineralogy found from core samples. The permeability of the LPZ is derived from secondary porosity formed through fracturing of recrystallized dolomite. Therefore, where there is consistent dolostone lithology, there is the likelihood of fracturing and high permeability associated with the LPZ, even without obvious signatures from caliper logs or deflections on static temperature logs.

The LPZ is conceptualized as occurring throughout the dolostone section of the Avon Park Formation primarily on the basis of mineralogy. While it is typical that there are multiple, discrete flow zones within the dolostone section as evidenced by the temperature logs, there are also relatively tight sections of 100 ft or more that sometimes separate the individual flow zones. Because of the discontinuous and sinuous nature of the fracturing, however, the entire dolostone section on a regional basis should be classified as the LPZ (J. Hickey, personal communication). Further support for this conceptualization is based on Duerr (1995) who classified the entire dolostone sections as a high permeability zone at the Manatee County and Atlantic Utilities injection well sites based on lithology, televison surveys and pumping temperature/flow meter logs.

The LPZ is the most productive horizon in the Upper Floridan aquifer. Yields from large diameter wells completed into this zone can reach 2,000 to 3,000 gallons per minute (gpm). Transmissivity of the LPZ often exceeds 100,000 ft^2/d. Hydraulic conductivity of the LPZ is more variable than the UPZ due to the existence of fractures and enhanced permeability features. Horizontal hydraulic conductivity ranged from 178 to 1,340 ft/d based on data from eight aquifer tests in the upper Peace River basin (SWFWMD, 1994). The mean value of hydraulic conductivity was 355 ft/d.

2.6 Middle Confining Unit

The top of the middle confining unit (MCU) is defined as the first occurrence of gypsiferous dolomite and anhydrite lithology. It is generally composed of interbedded dolostone and evaporites. This unit is considered the bottom boundary of the Upper Floridan aquifer. The top of the MCU dips toward the south in the project area (Figure 19). Deep test borings that penetrate to the top of the MCU are rare in the upper Peace River Basin. Miller (1986) indicates that the MCU terminates in the vicinity of the eastern boundary of the SWFWMD. Further east, that portion of the Avon Park Formation that is considered the MCU in the upper Peace River basin is a water-bearing unit of the Floridan aquifer system.

The thick, massive sequence of interbedded dolomite and gypsiferous limestone is extremely low in permeability. Horizontal hydraulic conductivity ranged from 0.002 to 0.04 ft/d based on five packer tests conducted in the Hillsborough, Manatee, and Sarasota county area.

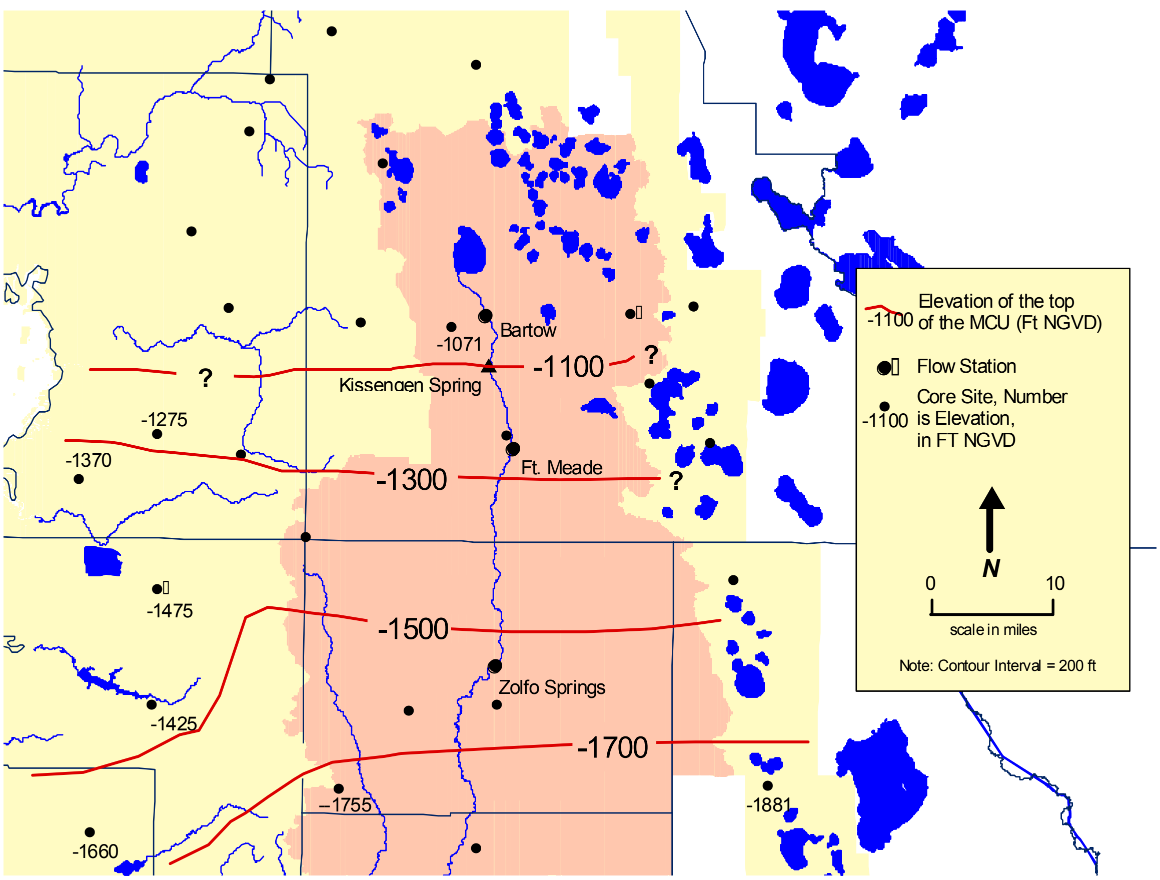

Figure 19. Elevation of the top of the MCU.

2.7 Ground-Water Flow

Ground-water flow patterns are determined by hydraulic gradients and the differences in head potential between the aquifers. The United States Geological Survey (USGS) publishes bi-annual maps in May and September of each year of the potentiometric surface of the intermediate aquifer system and the Upper Floridan aquifer. The potentiometric surfaces of the Upper Floridan aquifer for May and September of 2000 are shown in Figures 20 and 21. Lateral ground-water flow within the Upper Floridan aquifer moves west-southwest from center of the Green Swamp Potentiometric High toward the Gulf Coast.

Ground-water flow within the IAS is poorly understood in the upper Peace River basin. Little is known about the regional continuity of flow zones within the IAS. Since the USGS potentiometric surface of the intermediate aquifer system is a composite of both the PZ2 and PZ3 zones, and the regional extent of these flow zones is uncertain, the composite map has been excluded from this report. Until more information is gained through test drilling in the area, the IAS producing zones are conceptualized as local flow systems.

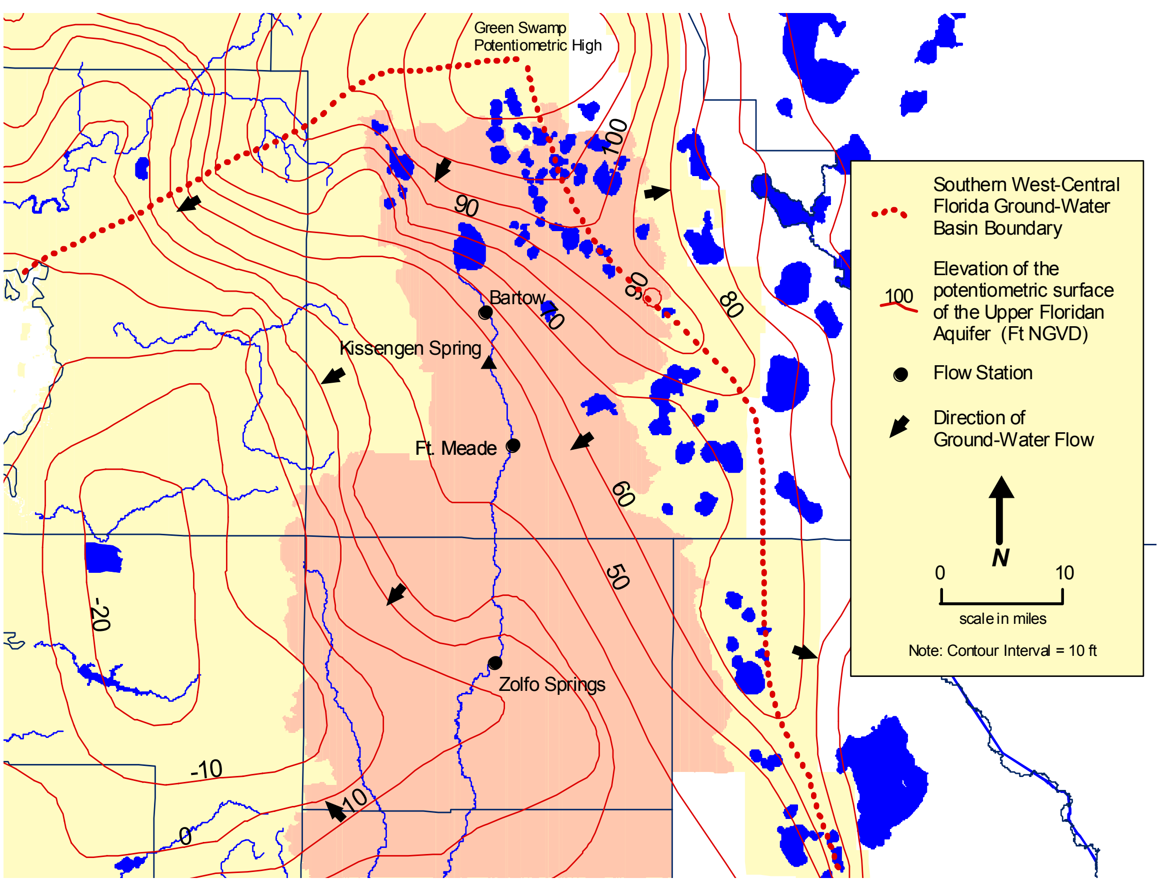

Figure 20. Potentiometric surface of the Upper Floridan aquifer, May 2002 (modified from Dueer, 2001).

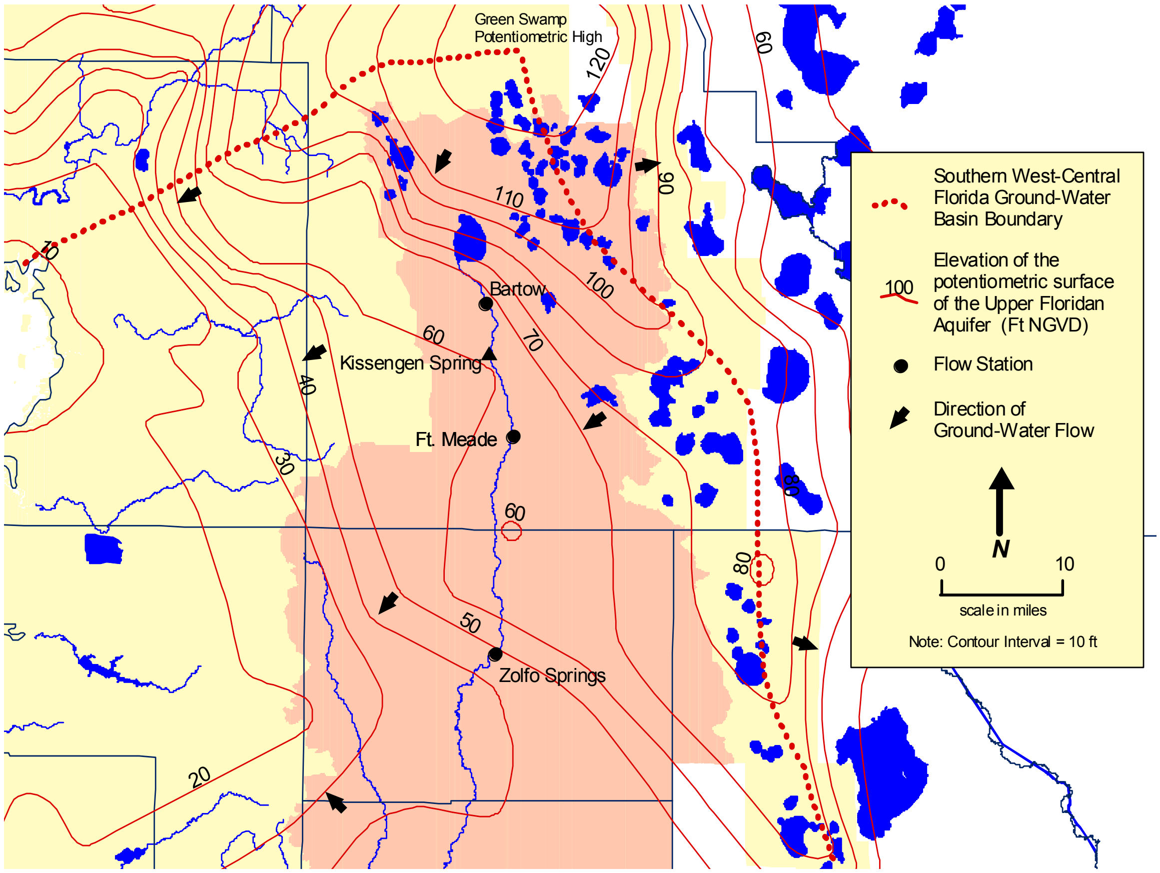

Figure 21. Potentiometric surface of the Upper Floridan aquifer, September 2000 (modified from Duerr, 2001).

2.8 Recharge/Discharge to the Upper Floridan Aquifer

The Upper Floridan aquifer is a regional flow system. Rainfall that infiltrates the surficial aquifer within the Southern West-Central Florida Ground-Water Basin (SWCFGWB) recharges the underlying confined aquifers where a downward head potential exists. Prior to significant ground-water withdrawals in the region, the Upper Floridan aquifer discharged into the Peace River along its entire length. Since the early-1960s, the vertical gradient has reversed from the headwaters to about the Polk-Hardee County line resulting in the potential for gravity drainage to the underlying confined aquifers.

1989 average annual recharge rates to the Upper Floridan aquifer are shown in Figure 22. The recharge rates are derived from the Eastern Tampa Bay regional ground-water flow model (Barcelo and Basso, 1993). Recharge to the Upper Floridan aquifer is highest immediately east and north of the Peace River along the Lake Wales Ridge. Recharge to the Upper Floridan aquifer decreases from northeast to southwest across the upper Peace River basin as confinement increases between the surficial aquifer and Upper Floridan aquifer.

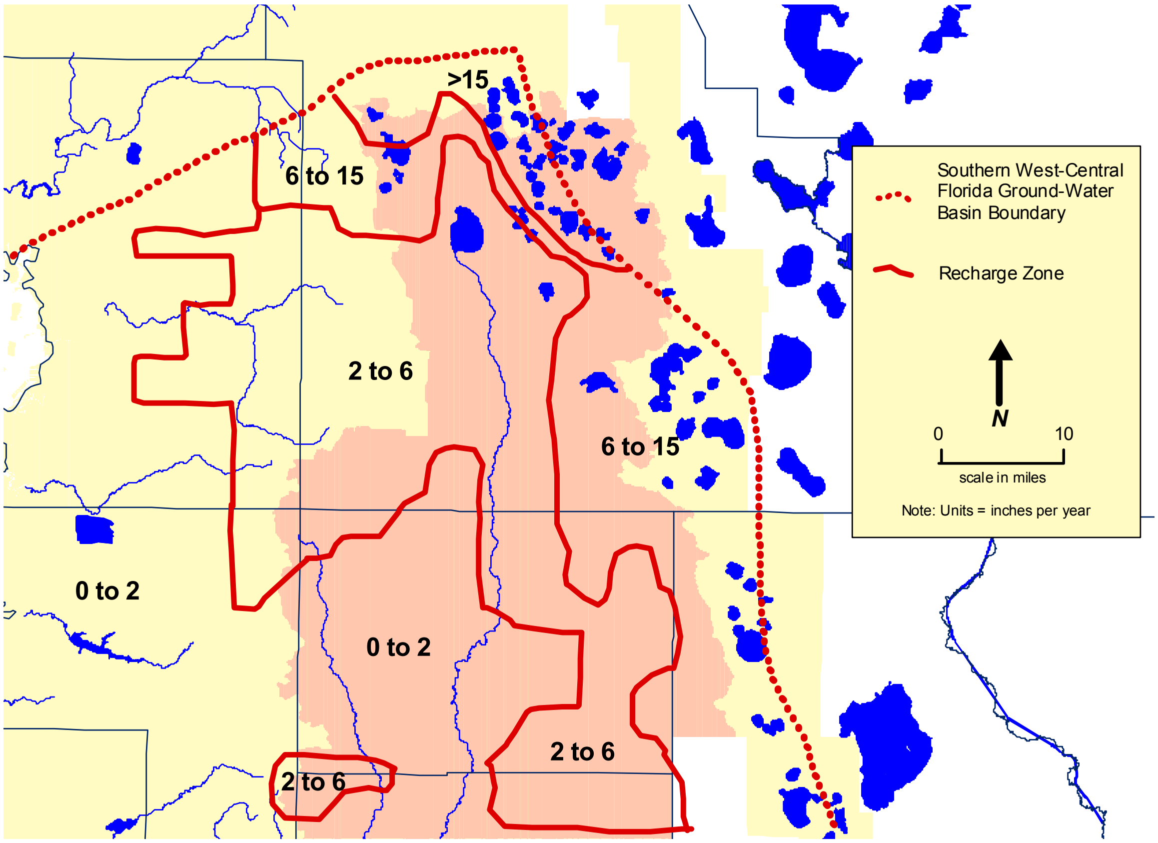

Figure 22. 1989 average annual recharge to the Upper Florida aquifer (Barcelo and Basso, 1993).

2.9 Degree of Hydraulic Connection

Head differences between aquifers and similar response in water levels can infer the relative degree of the hydraulic connection between the units. The District has installed cluster wells which monitor discrete vertical horizons in each aquifer system at several locations in the study area (Figure 23). Water levels at four representative sites, ROMP nos. 59, 45, 40, and 30, are shown in Figures 24-27. Based upon review of the hydrographs, it appears that the IAS PZ3 zone and Upper Floridan aquifers exhibit good hydraulic connection. In contrast, large head differences between the surficial aquifer and the Upper Floridan aquifer seem to indicate relatively low hydraulic connection and tight confinement separating the systems. The hydraulic separation between the upper zone and lower zone of the IAS appears to be variable, alternating between low and moderate connection.

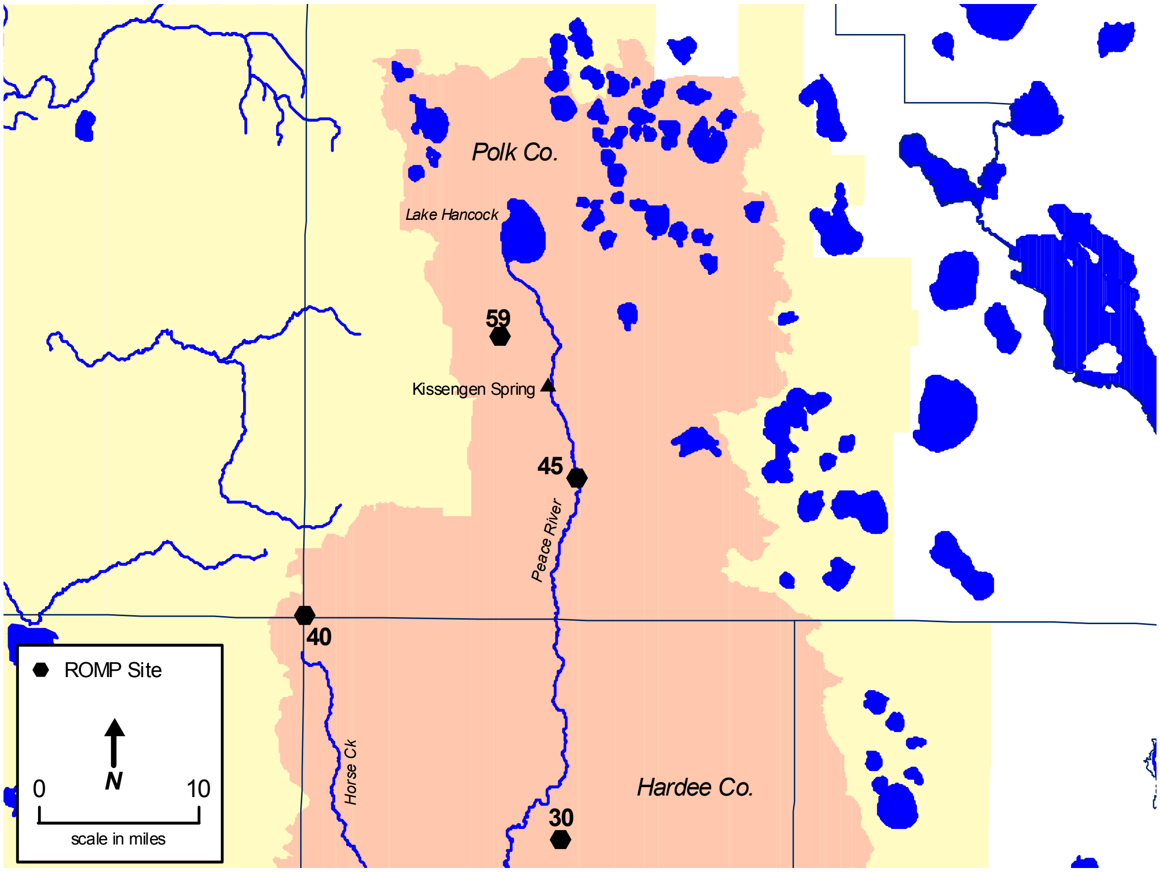

Figure 23. Location of selected ROMP sites.

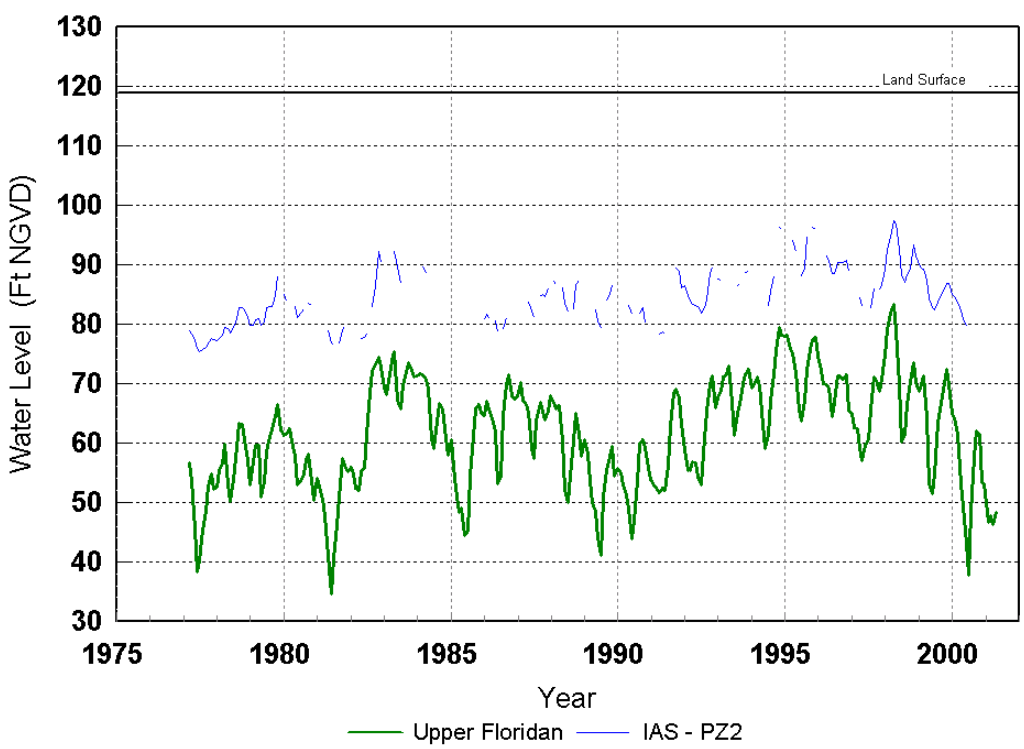

Figure 24. Water levels in the IAS and Upper Floridan aquifer at ROMP 59.

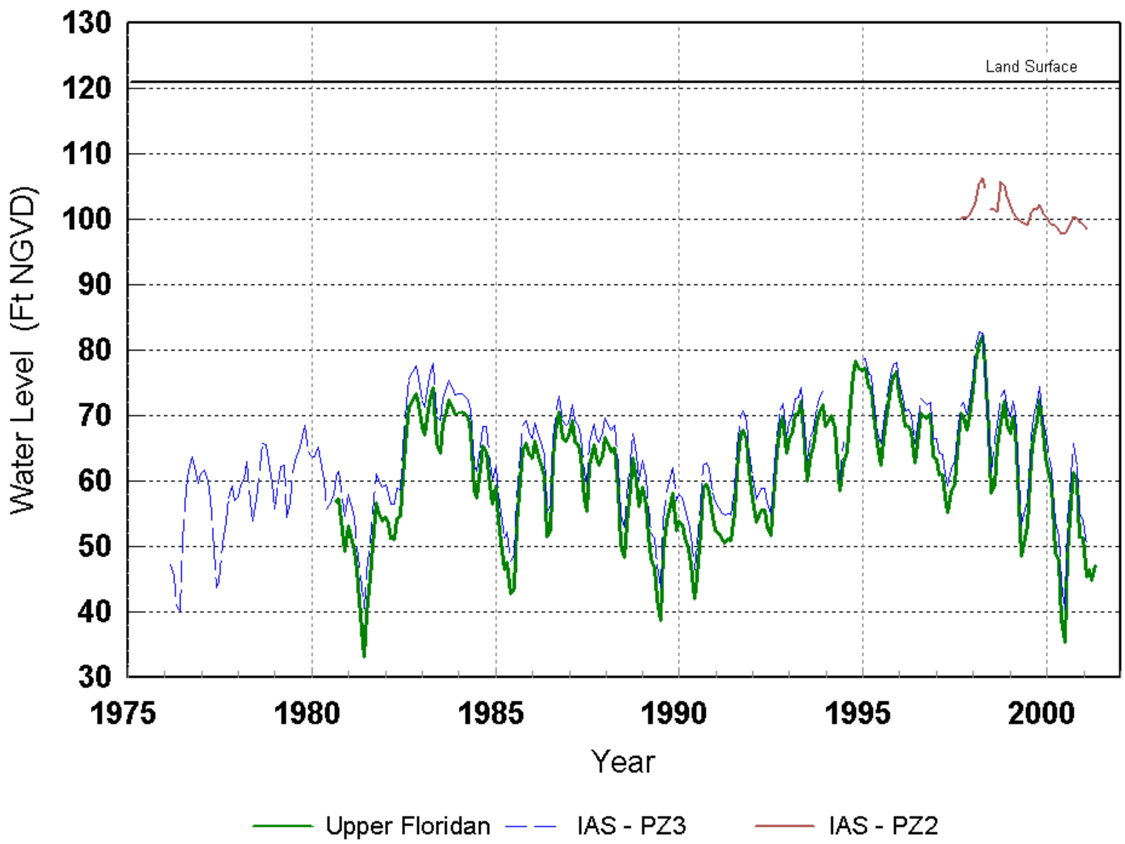

Figure 25. Water levels in the IAS and Upper Floridan aquifer at ROMP 45.

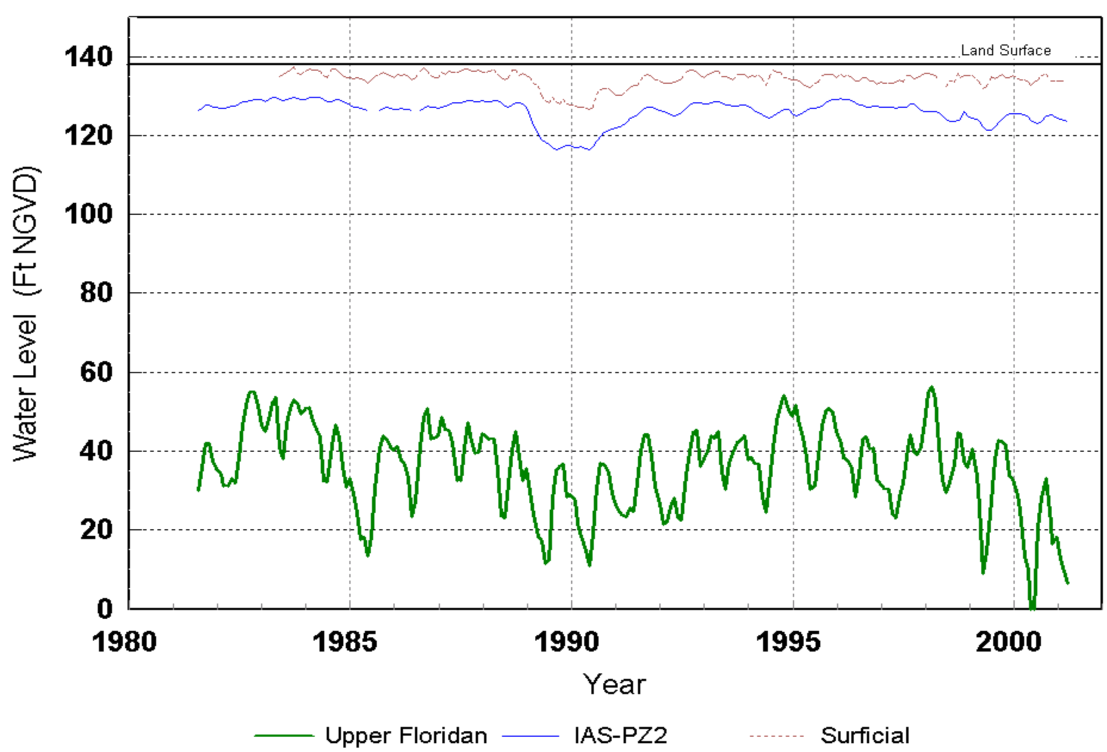

Figure 26. Water levels in the surficial aquifer, IAS, and Upper Floridan aquifer at ROMP 40.

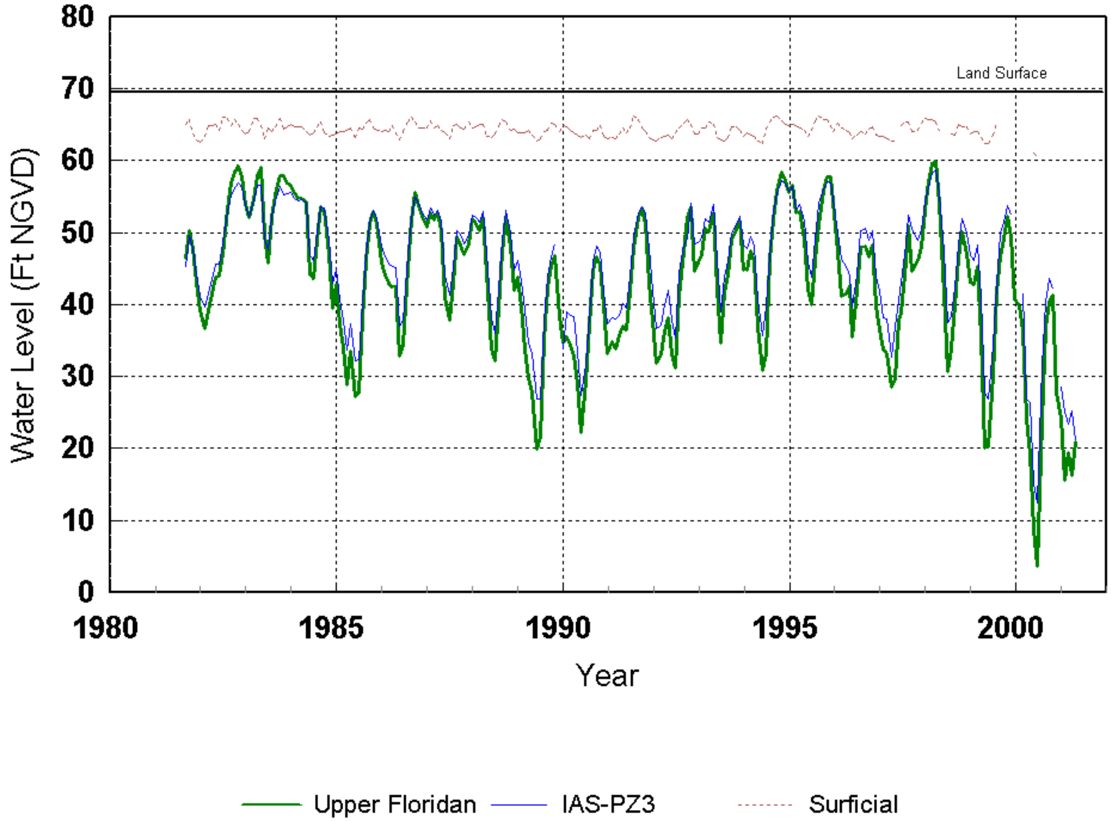

Figure 27. Water levels in the surficial aquifer, IAS, and upper Floridan aquifer at ROMP30

2.10 Peace River/Ground-Water System Connection

The surficial aquifer discharges into and provides baseflow to the Peace River when the water table elevation is above the stage. Ross and others (2001) estimated baseflow and runoff at the Bartow, Ft. Meade, and Zolfo Springs gaged sites for the 10-year period from 1989-1998 (Table 3). From the headwaters of the river to Ft. Meade, baseflow from the surficial aquifer contributed about 9 percent of total streamflow. From Ft. Meade to Zolfo Springs, baseflow from the surficial and confined aquifers contributed approximately 16 percent of total flow to the river.

Table 3. Mean annual runoff and baseflow estimates for the Peace River (1989-1998).

Stream Gage	Total Area (sq. miles)	Runoff (inches/yr)	Baseflow (inches/yr)
Bartow	404.7	6.2	0.6
Ft. Meade	479.6	6.3	0.6
Zolfo Springs	839.1	7.9	1.5

During predevelopment conditions (prior to significant ground-water withdrawals), the potentiometric surface of the Upper Floridan aquifer was much higher than the stage of the Peace River throughout its entire length (Figure 28). This condition allowed the potential for water to discharge upward into the intermediate aquifer system and eventually into the river. The amount or magnitude of upward leakage, however, is controlled by the thickness and permeability of sediments that separate the base of the river from the underlying aquifers and the presence of local karst features.

On a regional scale, there is little evidence of a good hydraulic connection between the surficial aquifer and the Upper Floridan aquifer in the area from Lake Hancock to Zolfo Springs based on the following observations:

1. There is a relatively thick sequence of low permeability sediments that separates the surficial aquifer from the Upper Floridan aquifer. Thickness of the IAS (with associated confining units) ranges from about 170 ft near Bartow to 350 ft near Zolfo Springs.

2. The Upper Floridan aquifer potentiometric surface fluctuates as much as 40 feet seasonally (Figures 24-27) but also shows regional long-term declines of 30 to 40 feet from Bartow to Zolfo Springs (Figure 29). Potentiometric surface declines in the Upper Floridan aquifer, from the headwaters to Zolfo Springs, show little attenuation due to vertical leakage from the surficial aquifer.

3. The long-term average hydraulic head difference between the surficial aquifer and Upper Floridan aquifer is greater than 50 feet from Lake Hancock to north-central Hardee County (Figure 30).

4. Leakance coefficients of the intermediate confining units range from 1×10^{-6} ft/day/ft to 9×10^{-5} ft/day/ft based on regional models by Yobbi (1996) and Metz (1995). These values indicate a tightly confined Upper Floridan aquifer.

5. Based on recharge (leakage) from the surficial aquifer to the Upper Floridan aquifer of 1 to 6 inches/year from the SWFWMD Eastern Tampa Bay model and a hydraulic head difference of 50 feet, calculated leakance coefficients would vary from 5×10^{-6} ft/day/ft to 1.5×10^{-5} ft/day/ft.

The hydraulic connection between the PZ2 and PZ3 units of the IAS and river bed is more problematic since little data exists on water levels and hydraulic properties in the immediate vicinity of the river. The PZ3 unit appears to be in good hydraulic connection with the Upper Floridan aquifer based upon review of hydrographs. Hydraulic connection between the surficial aquifer and the PZ2 zone, however, is poorly understood. Hydraulic head differences between PZ2 and PZ3 appear to be variable which indicates a low-to-moderate connection between the upper and low zones of the IAS.

Lewelling and others (1998) found that local karst features in the channel bed and adjacent flood plain from Bartow to Ft. Meade enhanced the connection between the Peace River and underlying confined aquifers (Figure 31). During low streamflow conditions typically experienced during the spring dry season, karst features located in the channel have the largest influence on river volumes. The five-mile section of the river from the Bartow sewage treatment plant to the USGS Homeland stream gaging site is where the highest streamflow loss occurs during low flow conditions (Bill Lewelling, personal communication). South of Homeland, streamflow losses due to in-channel karst features are minimal. An example of river loss near the Bartow treatment plant is shown in Figures 32 and 33.

Based on limited information, the majority of leakage from the Peace River to the underlying confined aquifers probably occurs through local karst conduits or sinkholes as opposed to diffuse leakage through the river bed. Additional drilling and hydraulic testing immediately adjacent to the river, however, would substantially improve our understanding of the physical mechanism of streamflow losses to the underlying confined aquifers.

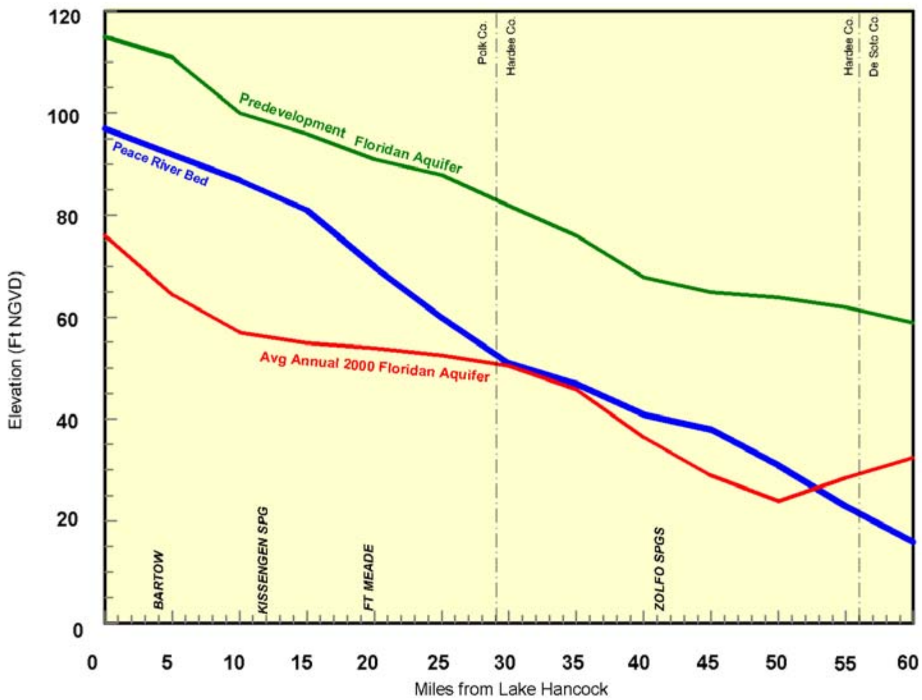

Figure 28. Hydrologic cross-section showing the relation between Peace River bed and the 2000 average annual potentiometric surface of the Upper Florida aquifer (modified from Lewelling and others, 1998).

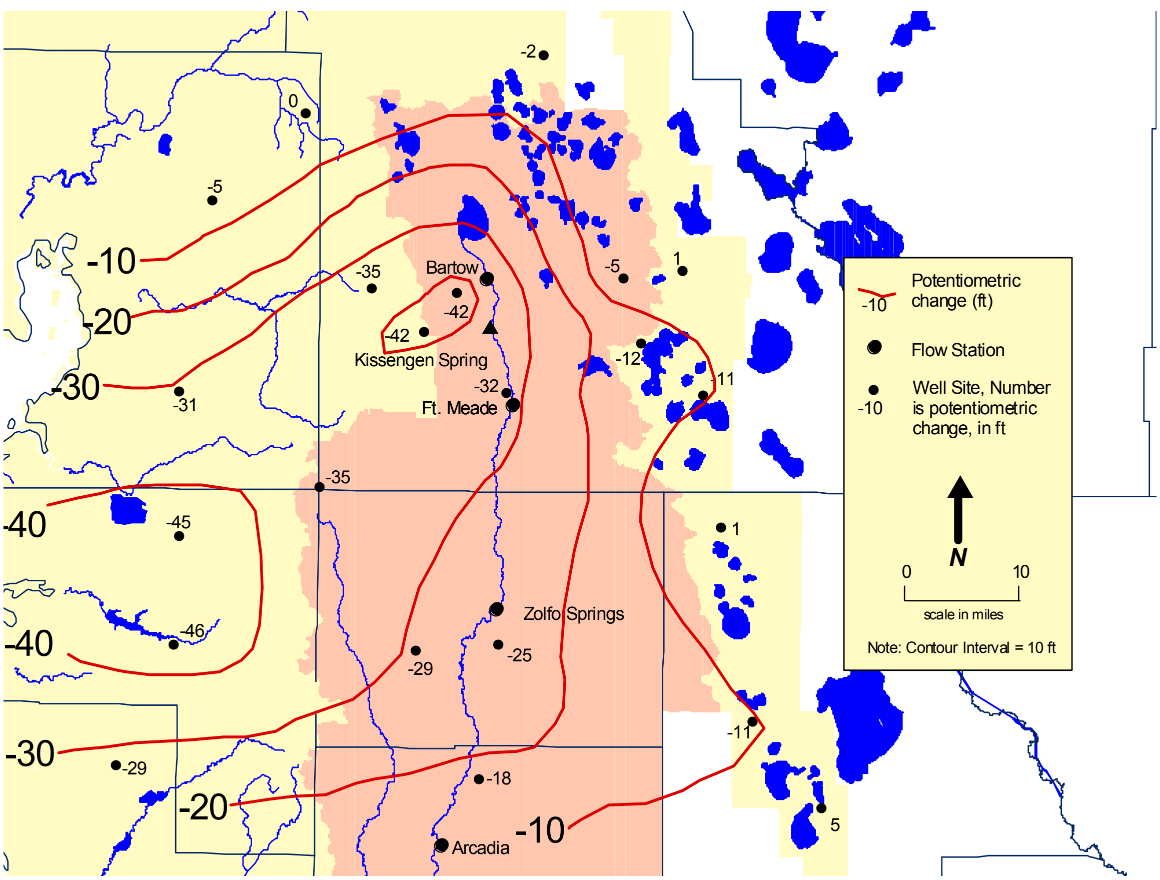

Figure 29. Change in the potentiometric surface of the Upper Floridan aquifer from predevelopment to average 1996-2000 conditions.

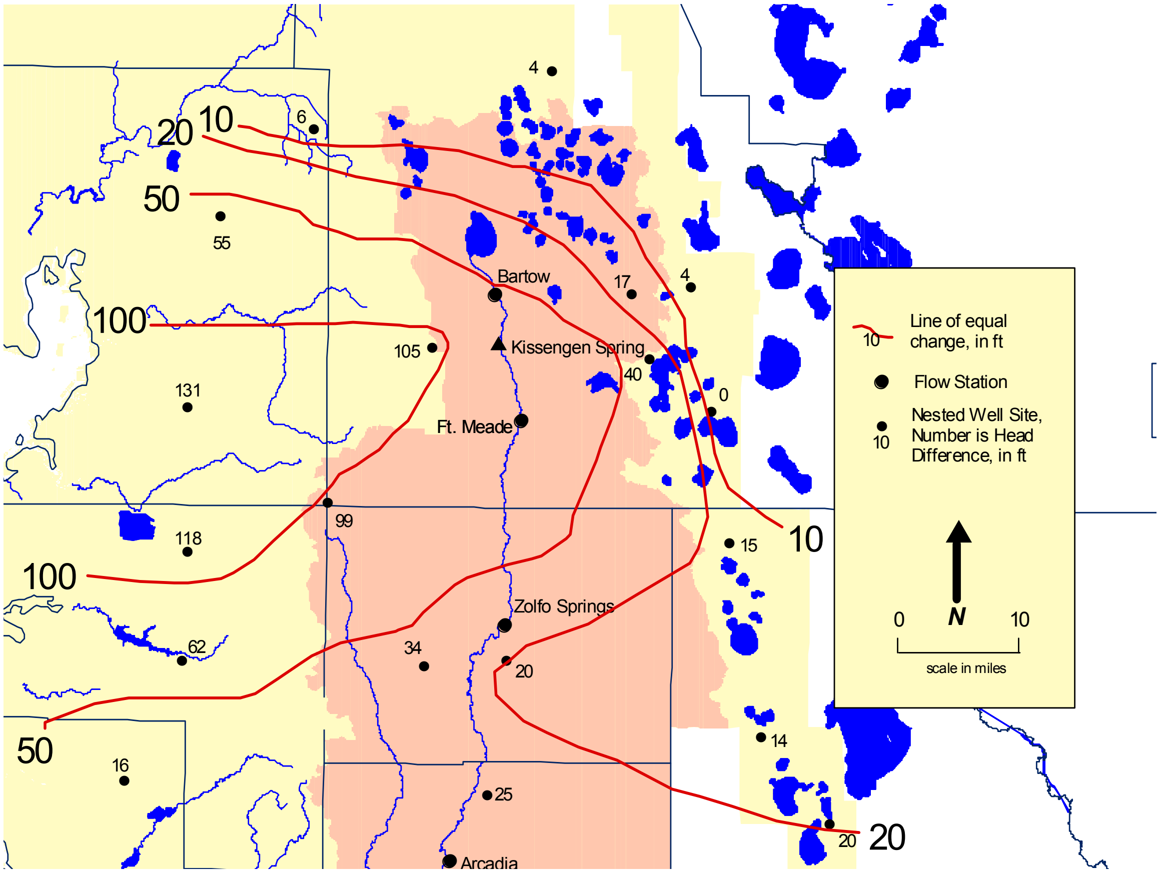

Figure 30. Long-term average hydraulic head difference between the surficial aquifer and Upper Floridan aquifer (minimum 5 year period-of-record).

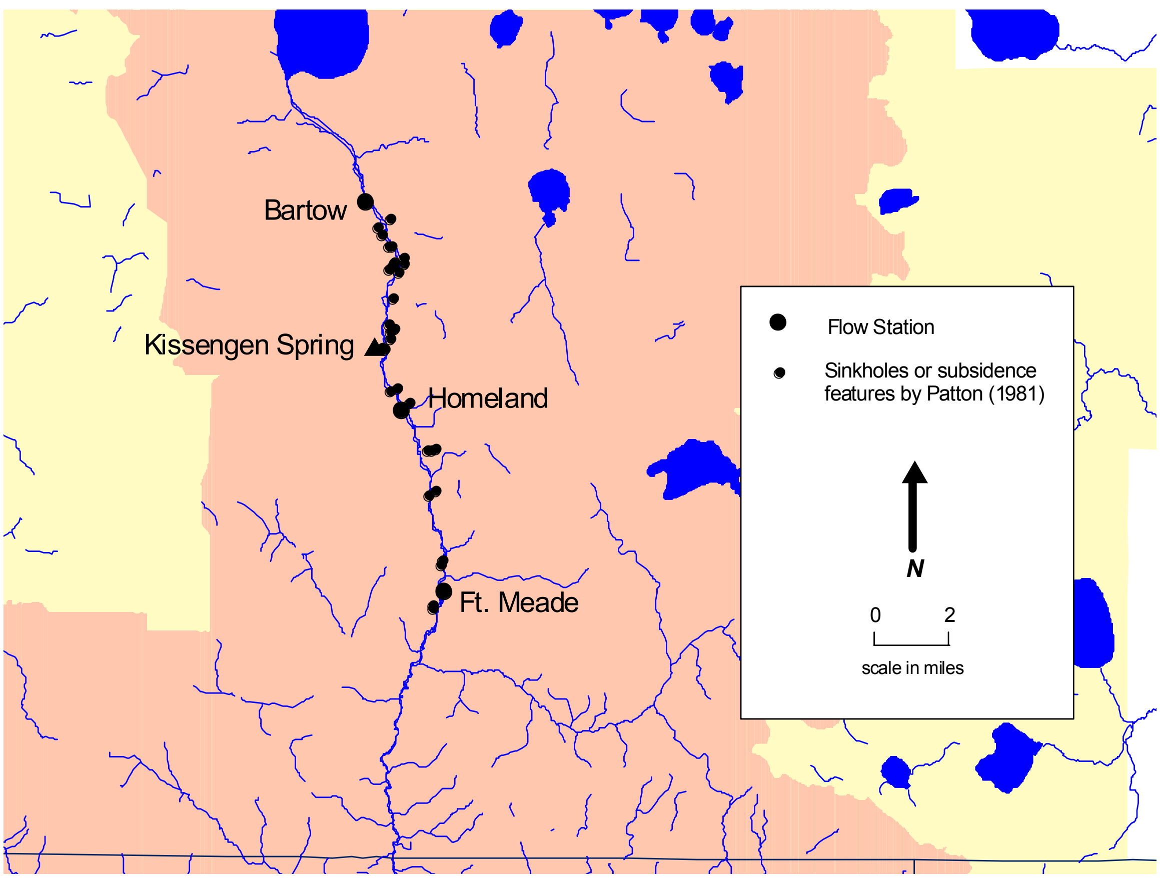

Figure 31. Location of karst features along the upper Peace River (modified from Lewelling and others, 1998)

Figure 32. Peace River flowing into solution conduit near the Bartow sewage treatment plant, May 9, 2002.

Figure 33. Solution feature in the Peace River bed draining all flow (0.3 cfs) near the Bartow sewage treatment plant, May 9, 2002.

3.1 Kissengen Spring Discharge

The USGS made a total of 177 discharge measurements at Kissengen Spring, the only major spring in the upper Peace River basin, from 1898 to 1960 (see Figure 29 for location). During the early-to-mid 1930s, flow from the spring averaged 19 mgd (29 cfs). From 1937 to 1950, springflow gradually declined until continuous discharge ceased in 1950 (Figure 30). Spring discharge briefly returned (less than 10 cfs) in 1955, 1959, and 1960, but the spring has not flowed since April 1960.

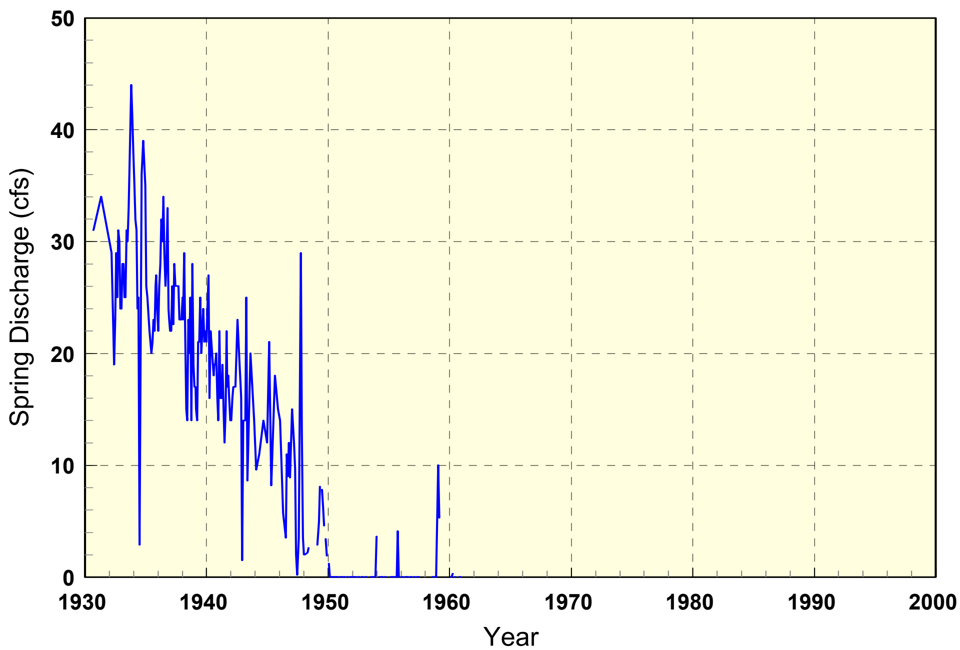

Figure 34. Springflow hydrograph for Kissengen Spring (1930-2000).

3.2 Ground-Water Levels

Long-term water level data (1930-2000) for the surficial aquifer and IAS is limited in the upper Peace River basin. Data exists for both aquifer systems from the late-1970s to present at the Romp 59, 45, and 40 well sites (see Figure 23 for location). Based upon this limited data, there appears to be no significant long-term change in water levels over the last 20 years.

Johnston and others (1980) published a predevelopment potentiometric surface map of the Upper Floridan aquifer that represents conditions prior to major ground-water development, generally around the early-1930s (Figure 35). In the Upper Floridan aquifer, two monitor wells, the Claude Hardin well, located near Lakeland, and the ROMP 60 well, located west of Bartow, have water-level information that dates back to the late-1940s and mid-1950s, respectively. The location of monitor wells completed into the Upper Floridan aquifer within or near the study area is shown in Figure 36.

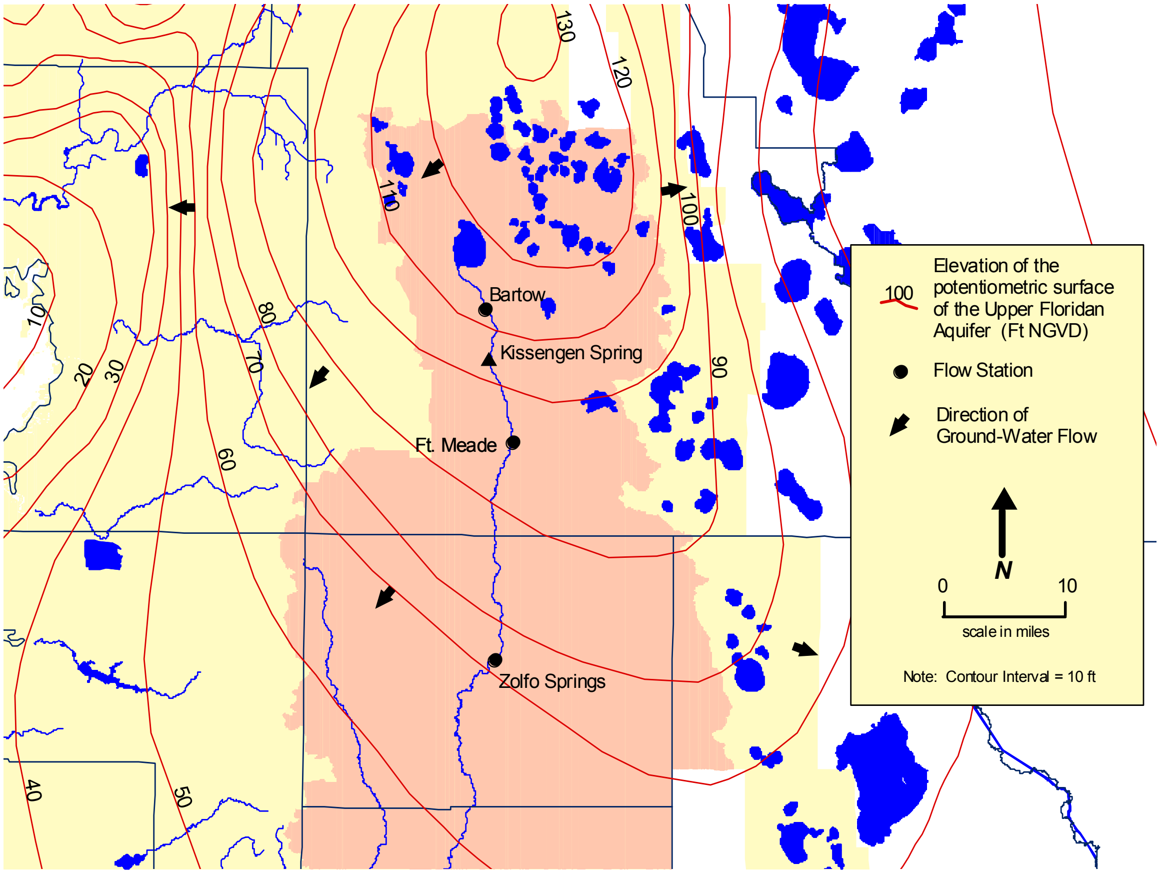

Figure 35. Potentiometric surface of the Upper Floridan aquifer during Predevelopment conditions (modified from Johnston and others, 1980).

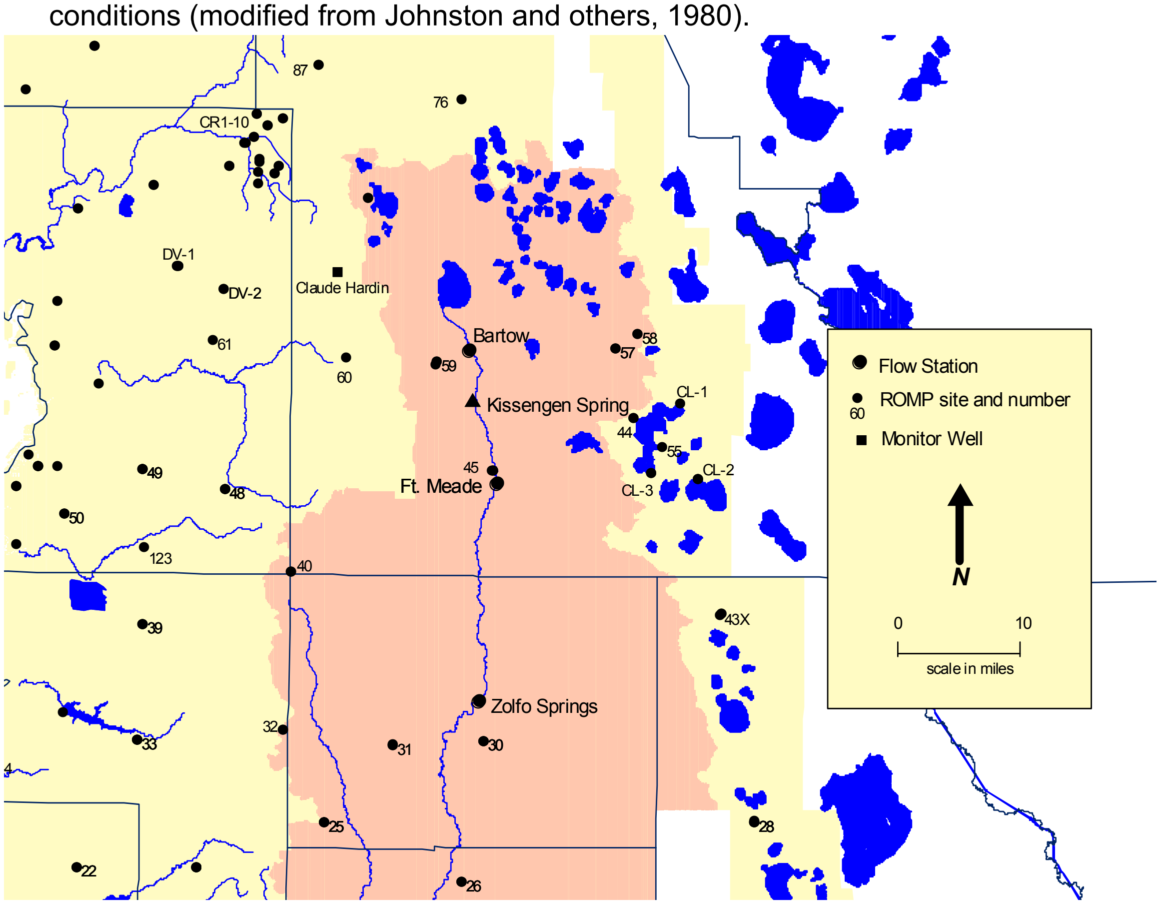

Figure 36. location of ROMP and other monitor wells completed into the Upper Floridan aquifer.

Declines in the potentiometric surface of the Upper Floridan aquifer range from 30 to 40 feet since predevelopment from Lake Hancock to about the Polk-Hardee County line (see Figure 30). Few existing Upper Floridan aquifer monitor wells, however, have water level data that pre-dates the early 1970s. Lewelling and others (1998) regressed the Claude Hardin well levels against water levels at the ROMP 60 well site from 1955-70. The correlation was quite good with an r-squared value of 0.96. By using this regression equation, water levels at ROMP 60 could be estimated back to 1948. Lewelling and others (1998) also regressed ROMP 60 water levels with ROMP 59 water levels. Again, the correlation was excellent with an r-squared value of 0.99. For this study, a similar approach was also applied to the Upper Floridan well at ROMP 45. By developing this statistical correlation among all four wells, water levels could be estimated back to the late-1940s at the Romp 60, 59, and 45 sites (Figures 37-39).

Review of the hydrographs for the Upper Floridan aquifer wells at ROMP 60, 59, and 45 indicate that a sharp decline in the ground-water level occurs after 1960. Water levels continue to decline, reaching their lowest point in the mid-1970s. Thereafter, ground-water levels gradually increase about 20 feet over the next 25 years. Figure 40 shows the annual average water levels at ROMP Nos. 60, 59, and 45 from 1948 through 2000. Ground-water levels from 1948 to the initial period-of-record for each well were based on correlations with the Hardin and ROMP 60 wells.

Ground-water levels were estimated at the ROMP 60, 59, and 45 sites during predevelopment conditions based on interpolation from the surface generated by Johnston and others (1980). Using this approach, the predevelopment water levels in the Upper Floridan aquifer range from 11 to 23 feet higher than the average from 1948 to 1960 (period prior to steep decline) at these three well sites (see Figures 37-39).

4.0 IMPACT OF GROUND-WATER LEVEL DECLINE

4.1 Springflow Cessation and Decline of Upper Floridan Aquifer Potentiometric Surface

Kissengen Spring, located along the Peace River between Bartow and Ft. Meade ceased continuous flow in 1950. Peek (1951) described the decline in the potentiometric surface of the intermediate and Upper Floridan aquifers as the primary factor related to the cessation of flow. Based upon the predevelopment potentiometric surface of the Upper Floridan aquifer, the potential for upward discharge from the Upper Floridan aquifer to the surface existed over the entire length of the river (see Figure 28). This higher pressure in the aquifer allowed the spring to flow at the surface. Stewart (1966) also reported the occurrence of flowing wells at Saddle Creek near the headwaters of the Peace River in 1948.

To assess the effect of Upper Floridan aquifer levels to discharge at Kissengen Spring, a time series plot was created of springflow versus ground-water level (Figure 41). Upper Floridan aquifer water levels at the spring were developed from the predevelopment and semi-annual USGS May and September potentiometric surface maps. Semi-annual maps begin in the mid-1970s. The May and September elevations were averaged to calculate an average annual aquifer level.

To estimate data from the late-1940s to 1975, water levels interpolated from the USGS maps were regressed against ROMP 60 water levels for the period 1975-2000. Using this relation, average annual water levels were estimated from 1948 through 1974 at the spring. Based on the estimated and observed data, the sharp decline in Upper Floridan aquifer water levels observed after 1960 has essentially eliminated any potential for discharge at Kissengen Spring.

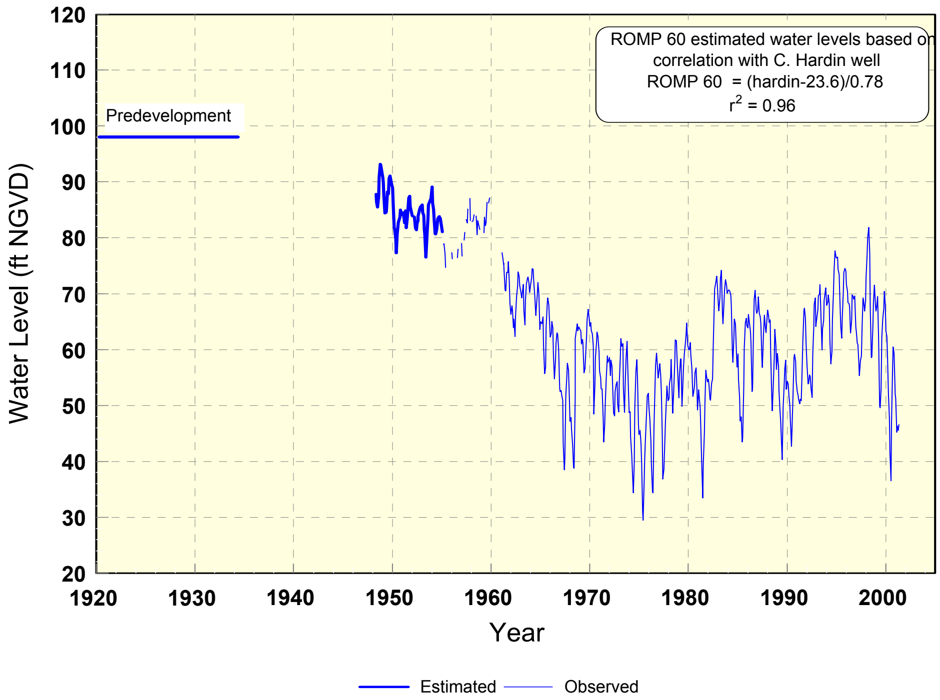

Figure 37. Estimated and observed water level of the Upper Floridan aquifer at ROMP 60.

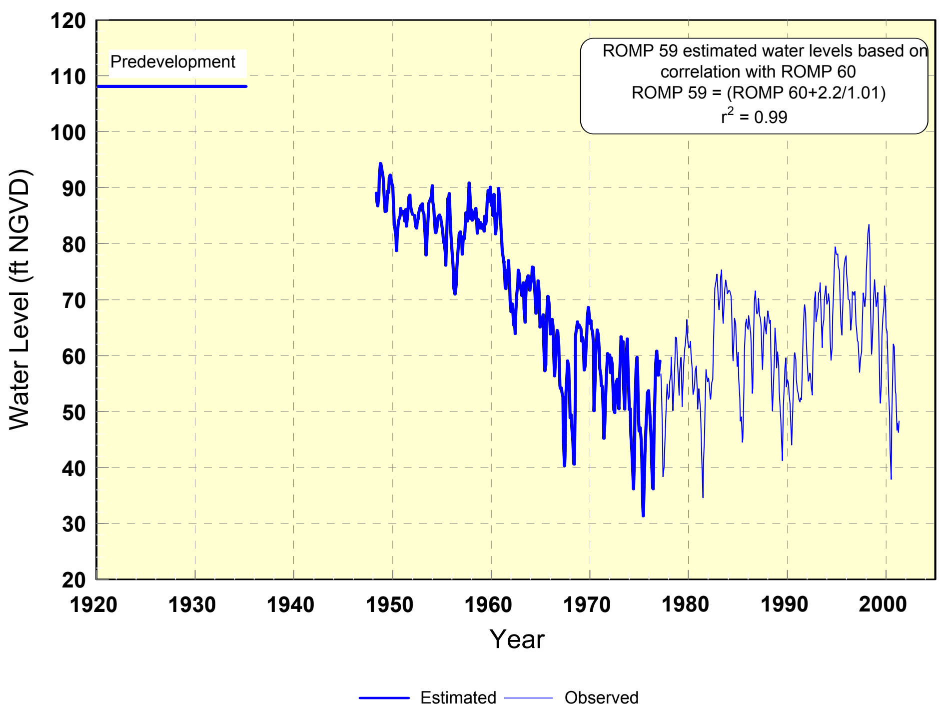

Figure 38. Estimated and observed water level of the Upper Floridan aquifer at ROMP 59.

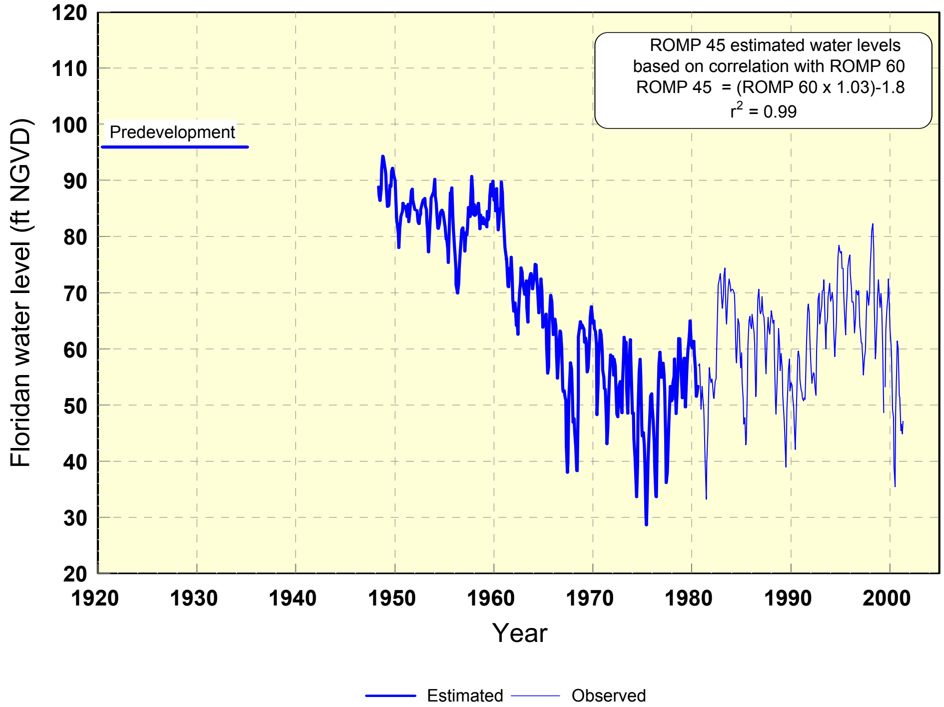

Figure 39. Estimated and observed water level of the Upper Floridan aquifer at ROMP 45.

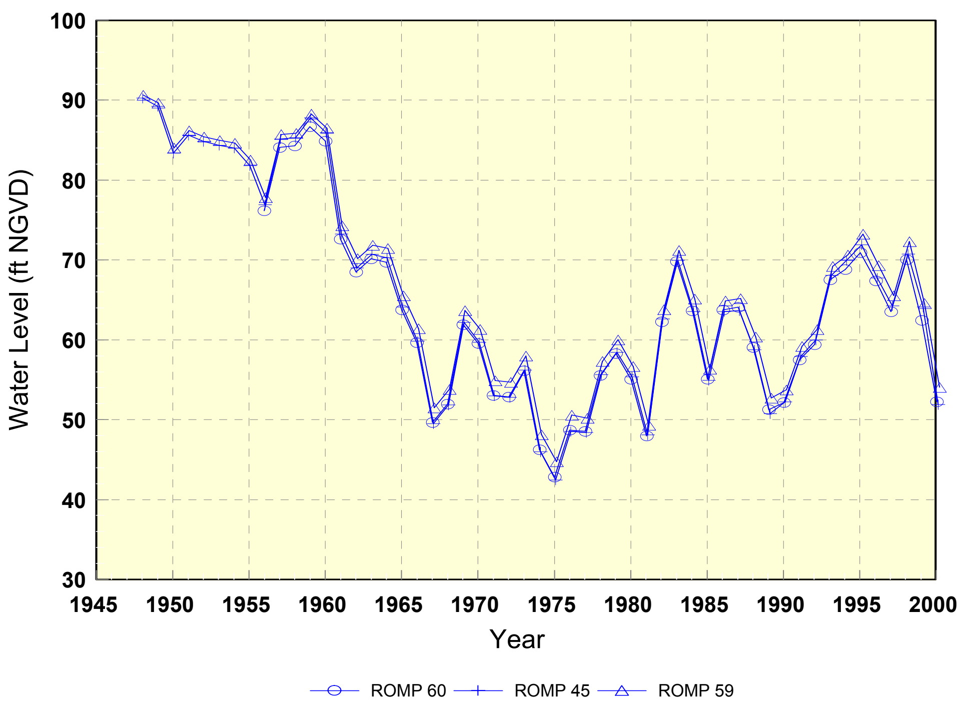

Figure 40. Estimated and observed average annual water levels in Upper Floridan aquifer wells at the ROMP 60, 59, and 45 sites (1948-2000).

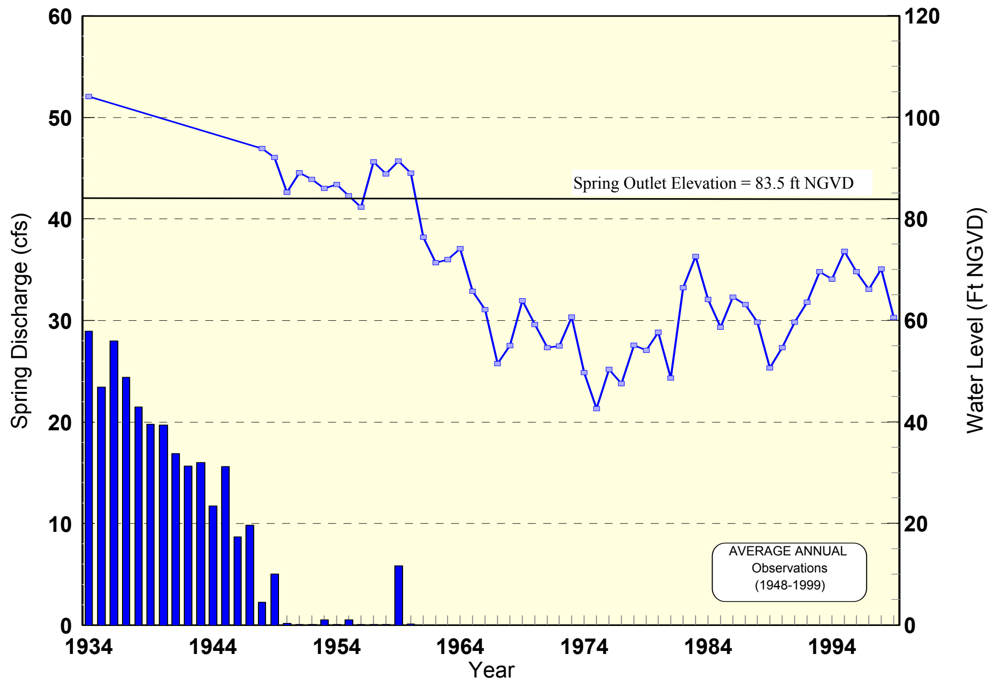

Figure 41. Comparison of Kissengen Spring discharge and Upper Floridan aquifer water levels (1934-1999).

4.2 Factor(s) related to the Decline of Upper Floridan Aquifer Potentiometric Surface

Ground-water withdrawals are the primary cause of long-term potentiometric decline in the upper Peace River basin. Peek (1951) estimated that ground-water withdrawals for phosphate mining in southwest Polk County were about 22 mgd in the early-1930s. By the mid-1940s withdrawals had increased to 68 mgd and by 1950 were approximately 90 mgd (Figure 42). Stewart (1966) estimated that mining withdrawals made up approximately 80 percent of total ground-water use in Polk County in 1959. Based on extrapolation of Stewart's data, Polk County ground-water withdrawals were probably about 110 mgd by 1950. This usage may be slightly overestimated since the percentage of non-mining water use was lower in 1950 (estimated number of irrigated acres of citrus in Polk County doubled from 1950 to 1959). By 1966, total ground-water withdrawn in Polk County had increased to over 340 mgd and peaked at 410 mgd in the mid-1970s. In the mid-to-late 1990s, ground-water withdrawals in Polk County were about 275 mgd, reflecting water-conserving practices instituted over the last 25 years by agricultural and phosphate mining users.

The role of climate tends to have an indirect influence on changes in the potentiometric surface of the Upper Floridan aquifer. During wetter periods, water levels largely increase because agriculture withdraws less ground-water for irrigation. Public supply utilities also use less ground-water when homeowners irrigate on a less frequent basis. During drier periods, the opposite occurs. This situation is valid for much of the upper Peace River basin from Lake Hancock south to Zolfo Springs. The Upper Floridan aquifer is generally a tightly-confined system - where withdrawals are largely derived from storage (i.e. lowering of water levels) rather than vertical leakage from the surface. Widespread lowering of the potentiometric surface is caused from multiple withdrawals. The cone-of-influence from a well can propagate a long distance from the point-of-withdrawal. The combined effect can cause regional lowering of the potentiometric surface.

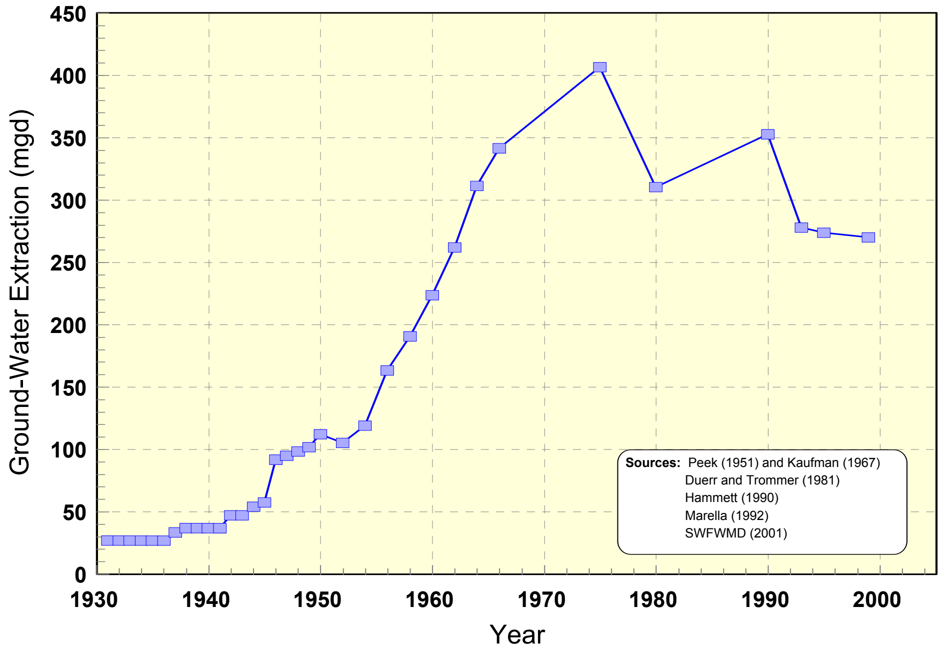

Figure 42. Ground-water withdrawals in Polk County (1931-1999).

4.3 Effect of Potentiometric Surface Decline on Peace River Flow

Prior to 1937, Kissengen Spring provided between 13 to 19 mgd of baseflow to the upper Peace River. The source of flow from Kissengen Spring was from a shallow part of the Upper Floridan aquifer, based on an oil test well drilled 300 feet northeast of the spring. During drilling operations, flow to the spring was intercepted at 220 feet below land surface (Peek, 1951).

There is little evidence that surficial aquifer water levels have been lowered due to the regional lowering of the Upper Floridan aquifer potentiometric surface south of Lake Hancock. There are thick, multiple-clay confining units that separate the surficial aquifer from the PZ3 zone of the IAS and the Upper Floridan aquifer. Hydraulic head differences between the surficial aquifer and Upper Floridan aquifer average more than 50 feet. In addition, long-term decline of 30 to 40 feet in Upper Floridan aquifer water levels coupled with generally tight leakance coefficients used in calibrated flow models of the area support this conceptualization.

However, along the river corridor between Bartow and Ft. Meade, several sinks and subsidence features have been documented (Patton, 1981). Lewelling and others (1998) reported a flow loss of 17.6 cfs (11.4 mgd) along a 3.2-mile section of the upper Peace River during high-baseflow conditions in May 1996. During high-flow conditions in August 1995, when discharge at Bartow exceeded 970 cfs, Lewelling and others (1998) indicated a loss of 118 cfs (76 mgd) or 10 percent of total river flow along a 7.2-mile reach from the Clear Springs mine bridge to the Mobil mine bridge near Ft. Meade. Results of the high flow loss are based on an estimated measurement error of five to eight percent. The authors recognize this fact when they state "The magnitude of most seepages calculated during the high-flow seepage run along the 13-mile reach between Bartow and Ft. Meade may be within the range of discharge measurement error."

Analysis of hydrologic data indicates that Kissengen Spring discharge and streamflow has been reduced by the long-term decline of the Upper Floridan aquifer potentiometric surface. The upper section of the Peace River loses water to the underlying confined aquifers. However, baseflow can still occur from the surficial aquifer and perhaps the PZ2 unit of the IAS below Ft. Meade.

Estimates of baseflow reduction and flow losses are difficult to calculate because of the karst topography along the river. The USGS estimated that as much as 11 mgd flows into sinkholes and openings along the river between Bartow and Ft. Meade during the dry season. This condition has probably existed since the early-1960s when potentiometric levels in the Upper Floridan aquifer declined abruptly. However, the loss of flow to the confined aquifers only became apparent after the mid-1980s because river augmentation by mining releases and sewage treatment plants supplemented dry season river flow prior to this point (Marty Kelly, personal communication).

Figures 43-45 compare Peace River stage to Upper Floridan aquifer water levels at the Bartow, Kissengen Spring, and Ft. Meade sites. Annual Upper Floridan aquifer water levels were estimated at each site based on averaging the USGS May and September potentiometric surface maps from 1975 to present. To estimate data from the late-1940s to 1975, water levels from the USGS maps were regressed against ROMP 60 water levels for the period 1975-2000. Using this relation, average annual water levels were estimated from 1948 through 1974 at each site.

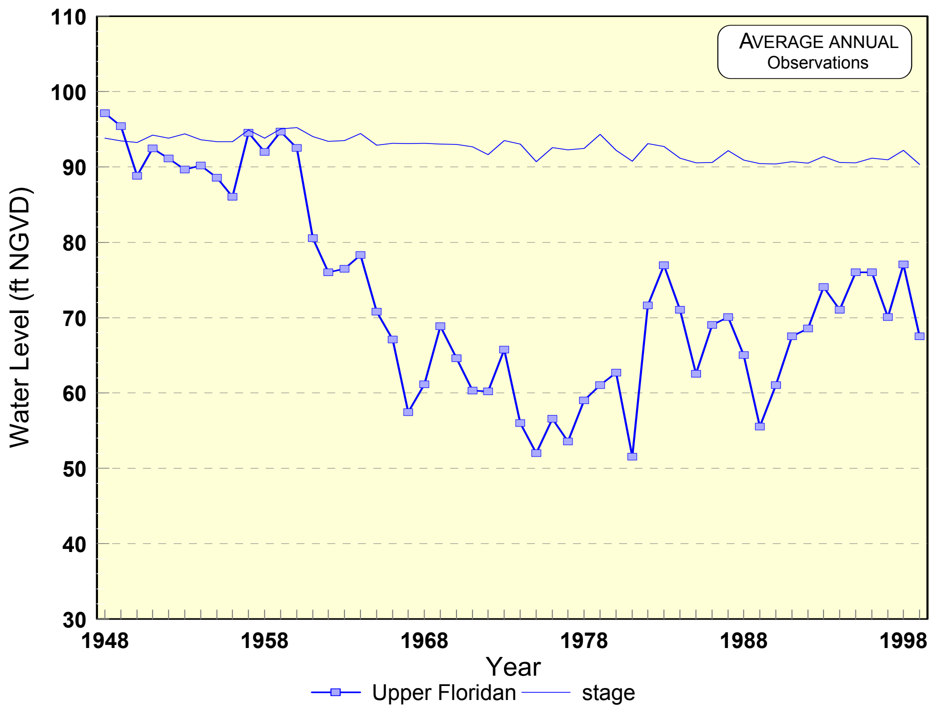

Figure 43. Comparison of average annual Peace River stage to Upper Floridan aquifer water level at Bartow.

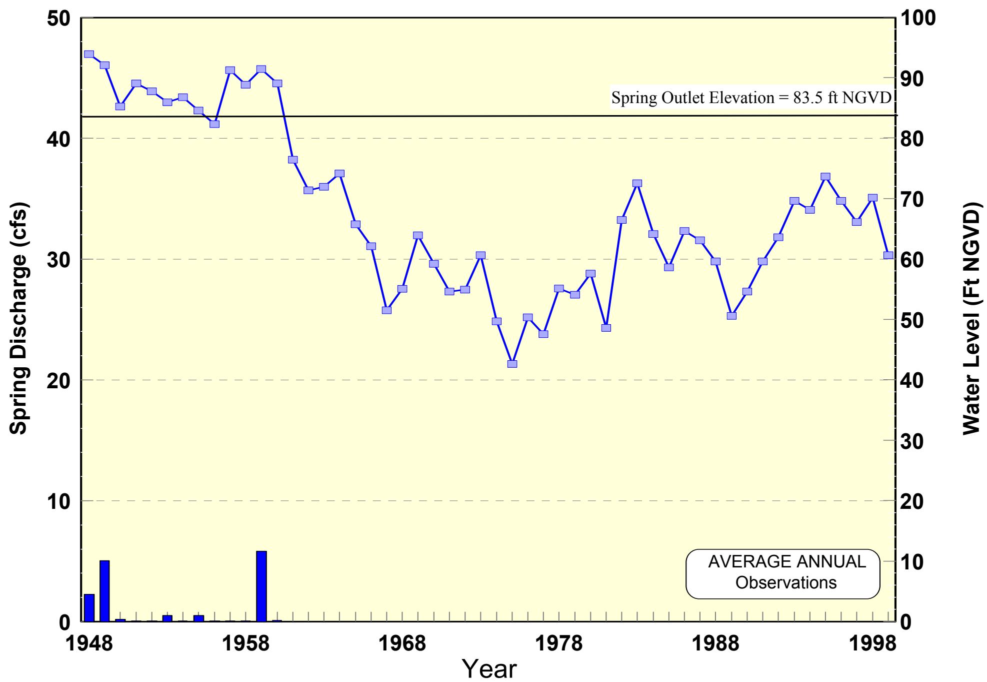

Figure 44. Comparison of average annual Upper Floridan aquifer water level to discharge at Kissengen Spring.

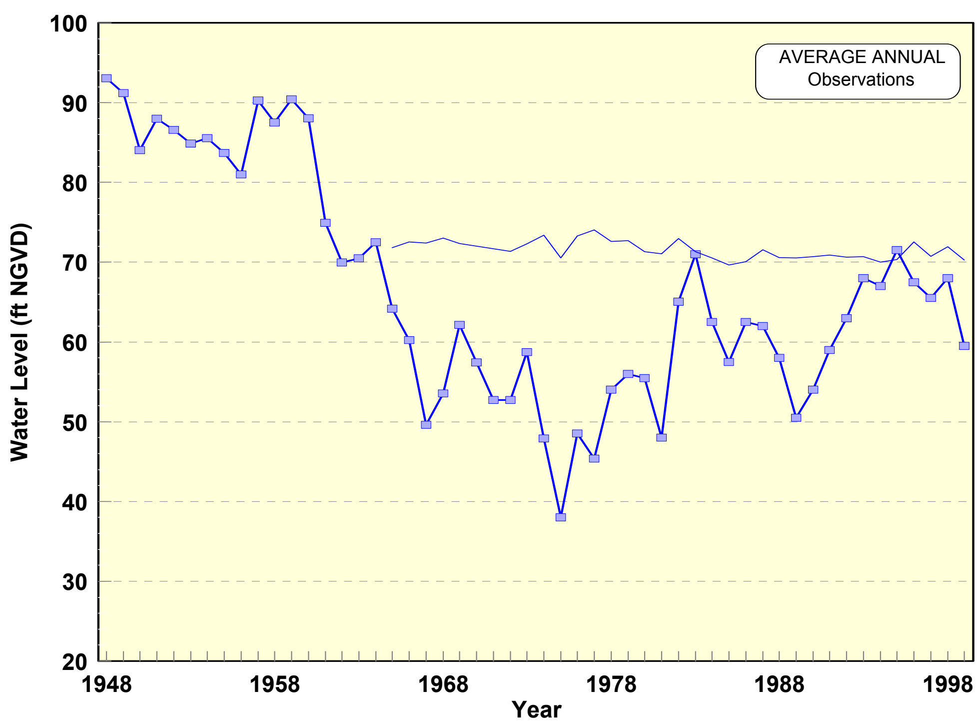

Figure 45. Comparison of average annual Peace River stage to Upper Floridan aquifer water level at F. Meade.

5.0 GROUND-WATER REDUCTION SCENARIOS

5.1 Reduction in Ground-Water Withdrawals - Effect on Spring and Peace River Flow

The SWFWMD is establishing minimum low streamflow volumes at the Bartow, Ft. Meade, and Zolfo Springs gaging stations by the end of the year 2002. The minimum low-flow criteria will apply during the spring dry season. Under current April-May dry season conditions, there is little potential for baseflow contribution from the Upper Floridan aquifer due to historic lowering of the potentiometric surface from the Polk-Hardee County line north to Lake Hancock (Figure 46). Figure 47 illustrates low streamflow conditions during April-May of 1999 at Ft Meade.

The amount of streamflow lost to the underlying confined aquifers is difficult to quantify due to limited data and the uncertainty of flow volume lost to in-channel karst conduits. However, graphical analysis and numerical flow model simulations were developed to estimate the reduction in ground-water withdrawals necessary to reverse the vertical gradient to an upward potential and reestablish flow at Kissengen Spring. The ground-water reduction scenarios were focused on the spring dry season since maintaining minimum low stream flow is most critical during this time and gravity drainage to the underlying confined aquifers periodically results in ephemeral conditions on the river from Bartow to Homeland.

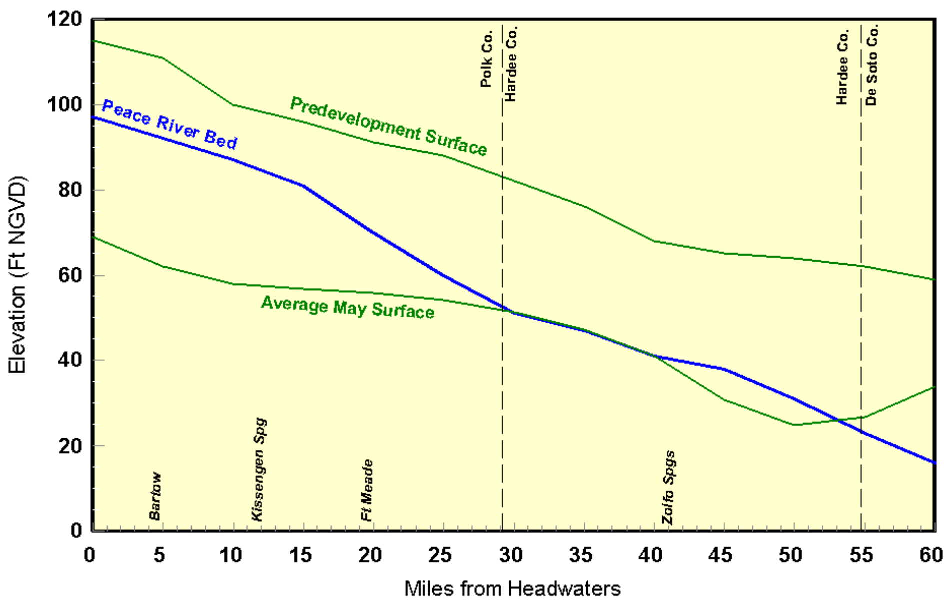

Figure 46. Predevelopment and long-term average May (1989-2000) potentiometric surfaces of the Upper Floridan aquifer.

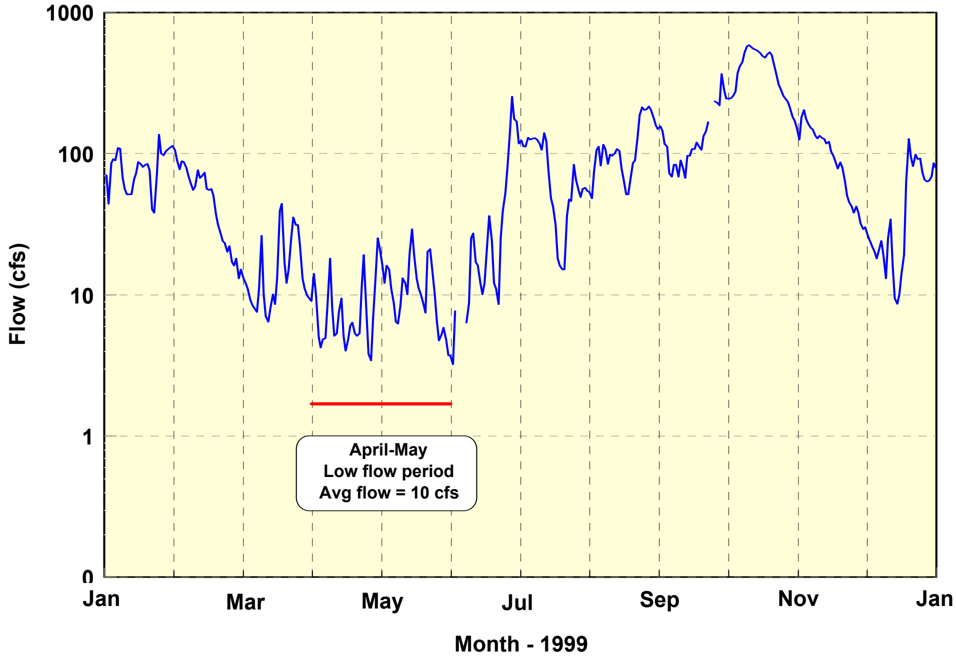

Figure 47. April-May low streamflow conditions for the Peace River at Ft. Meade station (1999).

5.2 Analytical Methods

Kissengen Spring discharge was plotted against Upper Floridan aquifer levels at the ROMP 60 monitor well from the early-1930s to present (Figure 48). Measured water levels are available at the ROMP 60 well since the mid-1950s. In order to estimate water levels at ROMP 60 back to the early-1930s, a statistical correlation using linear regression was applied between the Sarasota No. 9 and ROMP 60 wells. The Sarasota No. 9 well period-of-record begins in 1932. As a check of estimated data, the USGS predevelopment Upper Floridan aquifer level (Johnston and others, 1980) at the ROMP 60 site was compared to the earliest estimated water level in 1932. Both values were identical at 98 Ft NGVD. Ground-water withdrawals for Polk County were also added from 1932 to 1999.

Review of the graphical analysis indicates that about a 60 percent reduction in existing annual ground-water withdrawals (275 mgd in 1999 to 110 mgd in 1950) from the Upper Floridan aquifer would have to occur for Kissengen Spring to resume flow. The reduction in ground-water withdrawals would mostly be limited to Polk County but could include adjacent counties within the Southern West-Central Florida Ground-Water Basin (SWCFGWB) due to the regional nature of the Upper Floridan aquifer. Polk County withdrawals were cited because Kissengen Spring is centrally located there and the county has the best early record of ground-water use based on published reports from Peek (1951) and Kaufman (1967). Using the same graphical analysis, existing annual withdrawals in the county would have to be reduced by more than an 80 percent to return about one-half of historic flow (15 cfs) at Kissengen Spring.

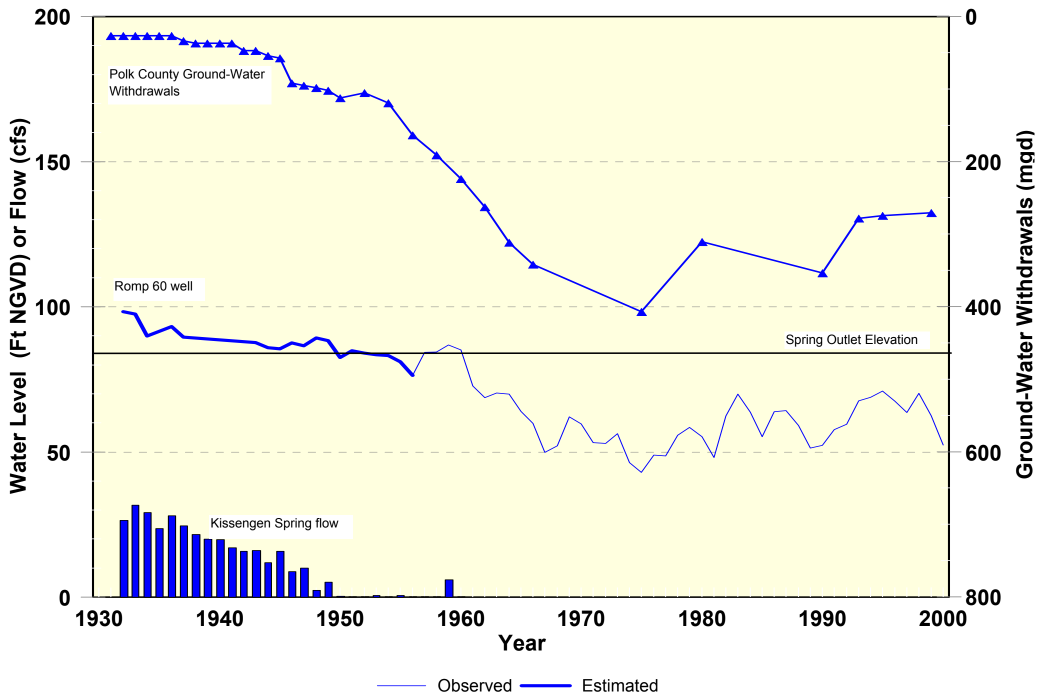

Figure 48. Polk County ground-water withdrawals, ROMP 60 water levels, and Kissengen Spring flow.

5.3 Numerical Model Scenarios

The Eastern Tampa Bay Regional Ground-Water Flow model (ETBGWFM) was used to conduct a number of different scenarios. Existing withdrawals from the Upper Floridan aquifer were reduced during the spring dry season since maintaining minimum low-flow volumes would be most critical during this period. The model scenarios consisted of two basic withdrawal reduction approaches, one where all users in the SWCFGWB were decreased a fixed percent and the other process where all pumpage was removed in a selected area centered about Kissengen Spring. Results of each scenario are represented in two ways: 1) by the length of river bed (in miles) where there would be a potential for upward discharge from the Upper Floridan aquifer when compared to current conditions, and 2) if flow would occur at Kissengen Spring.

The ETBGWFM covers the entire SWCFGWB and consists of 60 columns and 56 rows of uniform two mile by two mile grid spacing (Figure 49). The uppermost layer represents the unconfined surficial aquifer, the second layer the permeable unit(s) within the IAS, and the third layer the Upper Floridan aquifer from the Suwannee Limestone down to the Avon Park Formation. The bottom no-flow boundary is represented by the evaporites of the Middle Confining Unit of the Floridan aquifer system. Layer 1 (surficial aquifer) is characterized by a specified head water table condition. The numerical model was calibrated to average 1989 steady-state and 1989 water year transient conditions. A complete description of the ground-water flow model is contained in Barcelo and Basso (1993).

Using the 1989 transient simulation, Upper Floridan aquifer withdrawals in the SWCFGWB were reduced by 20, 40, and 80 percent during the months of April and May to note the increase in water levels at the end of May. Total ground-water withdrawn averaged approximately one billion gallons per day (bgd) for the two months. After each scenario run, simulated head in layer 3 was subtracted from original simulated head to determine the change in water levels associated with each reduction.

The change in head was added to the 12-year average May potentiometric surface of the Upper Floridan aquifer (1989-2000) to estimate the elevation associated with each withdrawal scenario. Figures 50-52 illustrate the change in water levels associated with each run. To determine the length of river bed where the potential for upward flow could occur due to reduced withdrawals, a hydrologic section from Lake Hancock to the Hardee-DeSoto line was constructed (Figures 53 and 54).

The long-term average May potentiometric surface of the Upper Floridan aquifer is currently at or above the bed of the Peace River from about Zolfo Springs to the Polk-Hardee County line. When dry season withdrawals are reduced by 20 percent, upward flow potential from the Upper Floridan aquifer occurs along 5 additional miles of river. When withdrawals are reduced 40 percent, upward flow potential from the Upper Floridan aquifer would occur along 10 miles of river bed from the Polk-Hardee County line northward. The most heavily impacted section, from the headwaters to Ft. Meade, however, would not receive any benefit (potential for upward flow from the Floridan aquifer) until ground-water withdrawals were decreased by more than 40 percent or 400 mgd during the spring dry season. At a ground-water withdrawal reduction of 80 percent, Kissengen Spring would potentially flow again (Table 4).

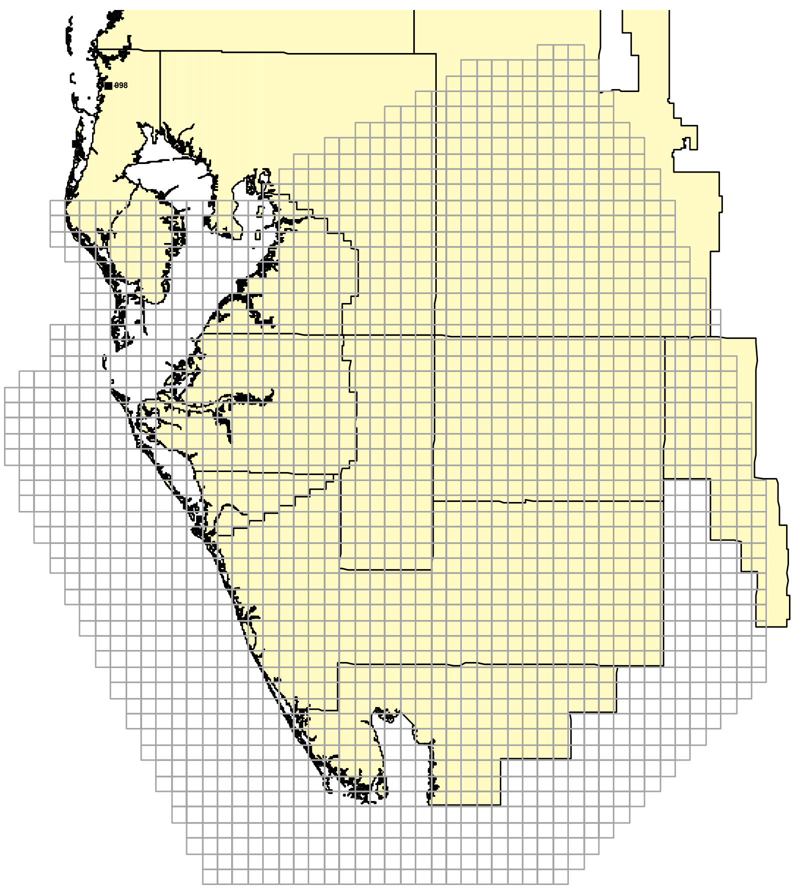

Figure 49. Location of the Eastern Tampa Bay ground-water flow model grid.

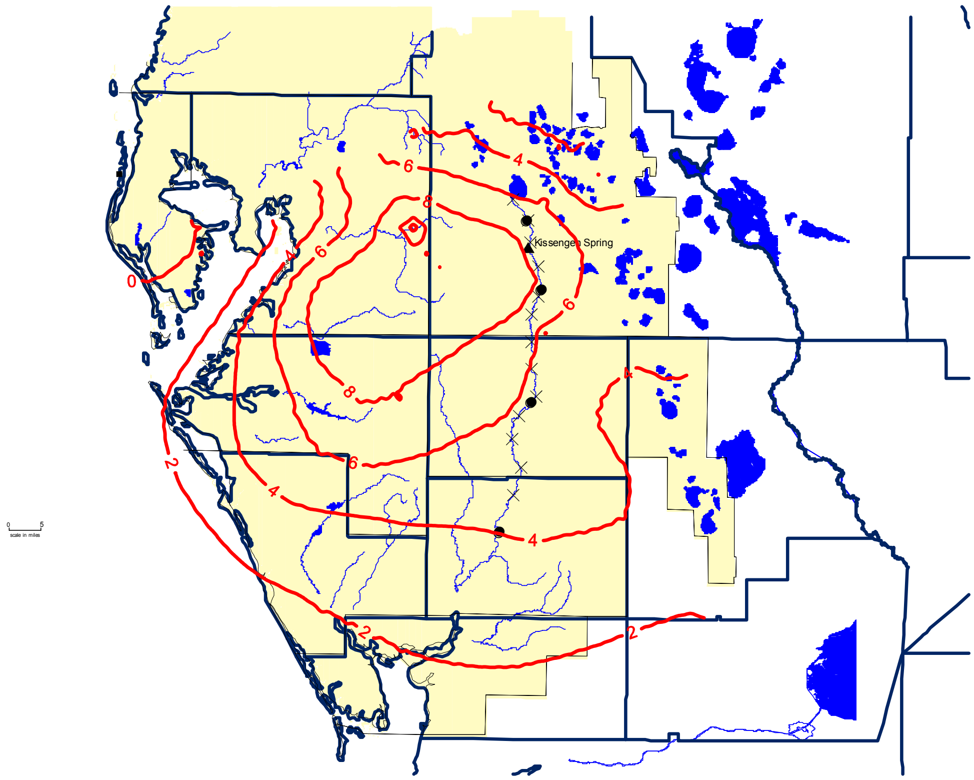

Figure 50. Simulated increase in Upper Floridan aquifer potentiometric surface when April-May ground-water withdrawals are reduced 20 percent across SWCFGWB.

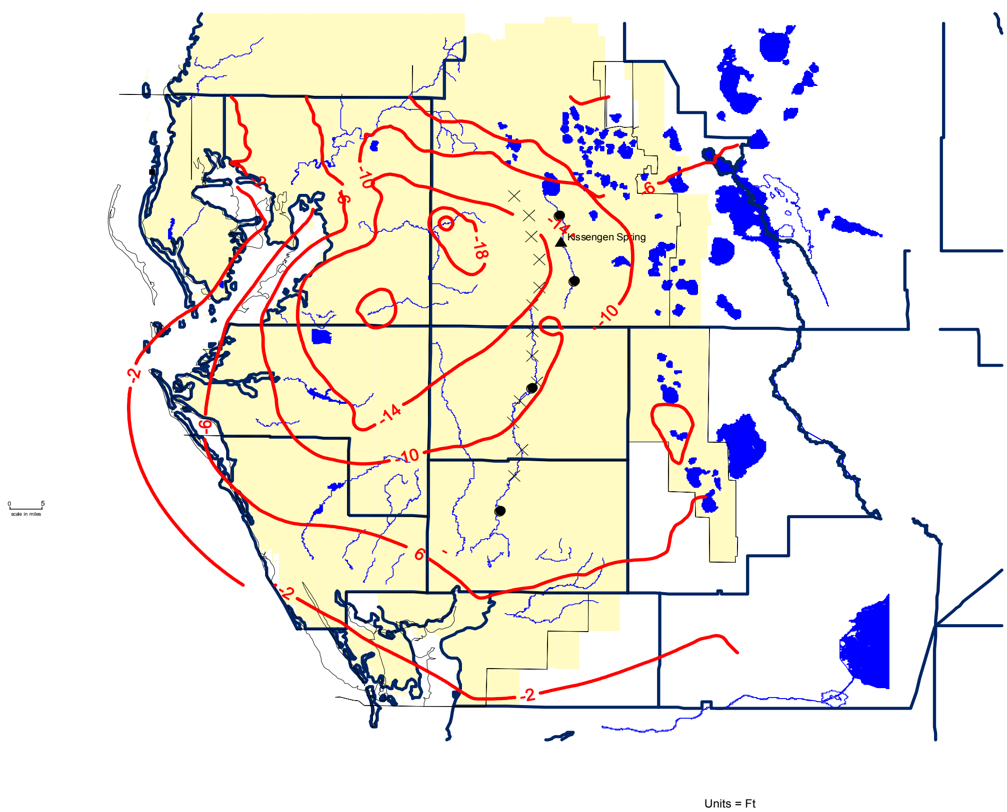

Figure 51. Simulated increase in Upper Floridan aquifer potentiometric surface when April-May ground-water withdrawals are reduced 40 percent across SWCFGWB.

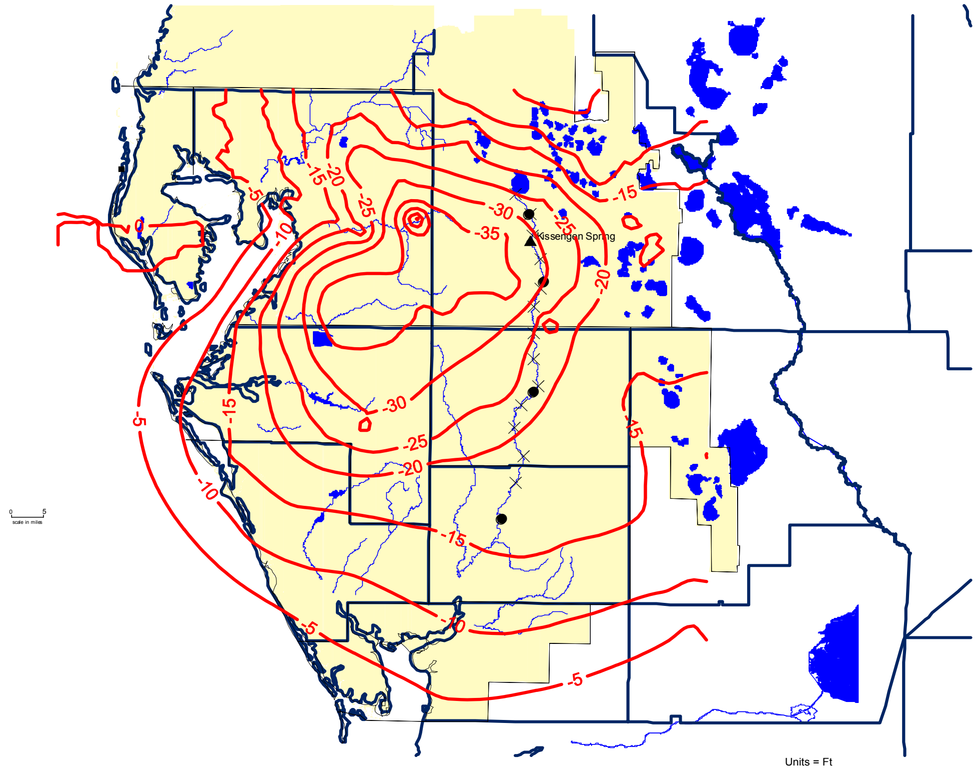

Figure 52. Simulated increase in Upper Floridan aquifer potentiometric surface when April-May ground-water withdrawals are reduced 80 percent across SWCFGWB.

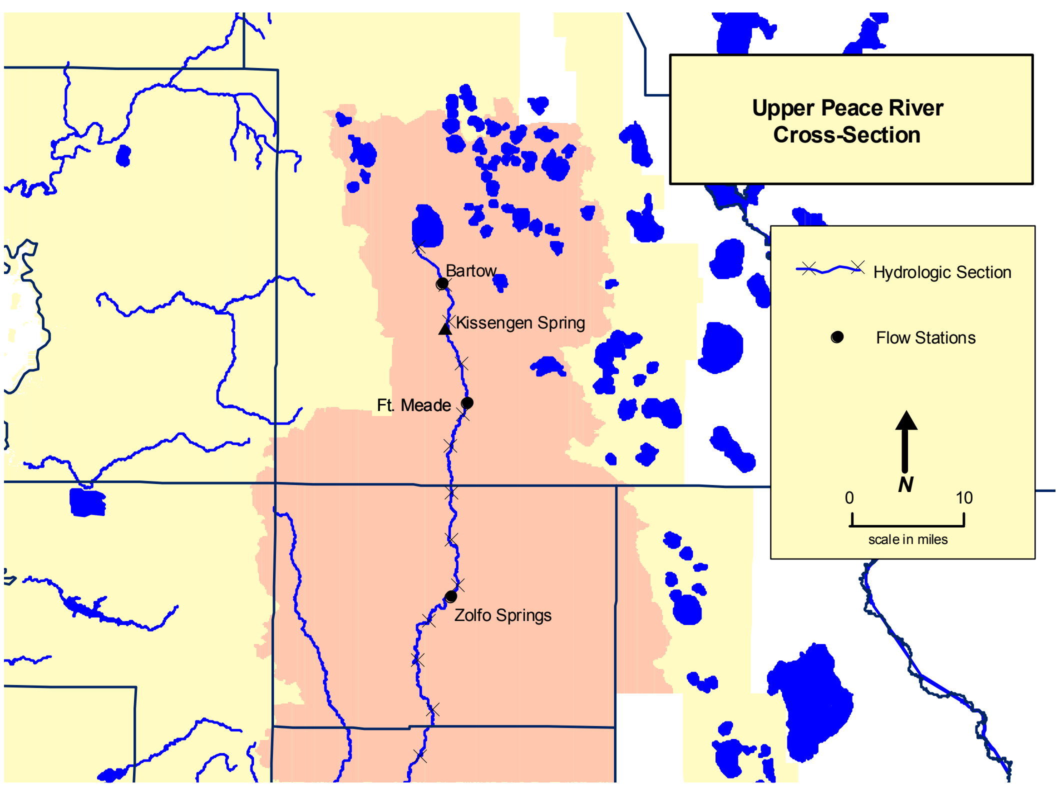

Figure 53. Location of upper Peace River hydrologic section.

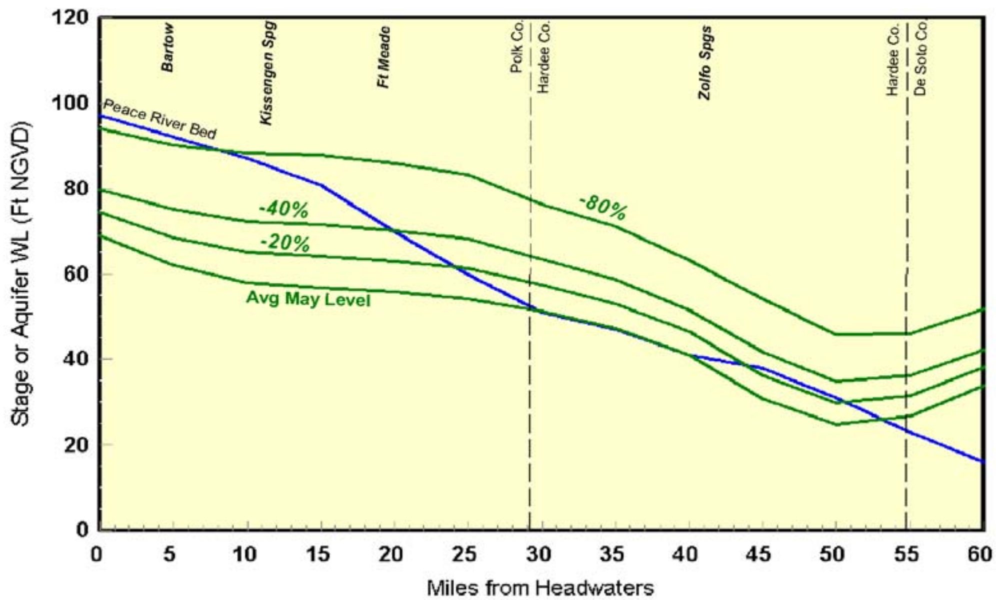

Figure 54. Predicted increase in the elevation of the Upper Floridan aquifer potentiometric surface during May due to reductions in pumpage of 20, 40, and 80 percent.

Table 4. Hydrologic change associated with reducing April-May ground-water withdrawals across the SWCFGWB.

Ground-Water Withdrawal Reduction		Upward Flow Potential from the Upper Floridan Aquifer		Potential for Kissengen Spring flow
Percent	Mgd	Headwaters to Ft. Meade (miles)	Polk-Hardee Line Northward (miles)	
20	200	0	5	No
40	400	0	10	No
80	800	10	20	Yes

The second modeling approach was to eliminate or reduce ground-water withdrawals in an area surrounding Kissengen Spring. Under this scenario, ground-water withdrawals were reduced by 50 percent (105 mgd) and 100 percent (210 mgd) during April-May within a 676 square-mile area (Figure 55). The area (26 mi x 26 mi) was initially determined through an iterative process by gradually expanding the "area of no withdrawals" around Kissengen Spring until flow could be simulated at the spring. The predicted increase in Upper Floridan aquifer levels is shown in Figure 56. The results indicate that for a 50-percent reduction in pumping, there would be an upward potential for the Upper Floridan aquifer to discharge along 8.5 miles of river bed north of the Polk-Hardee County line (Figure 57). In the most heavily impacted area, no baseflow contribution would occur from the Upper Floridan aquifer and Kissengen Spring. If all withdrawals were eliminated within the 676 square-mile area, 19 miles of river bed north of the Polk-Hardee County line would have an upward potential for discharge from the Upper Floridan aquifer and flow would likely occur at Kissengen Spring (Table 5).

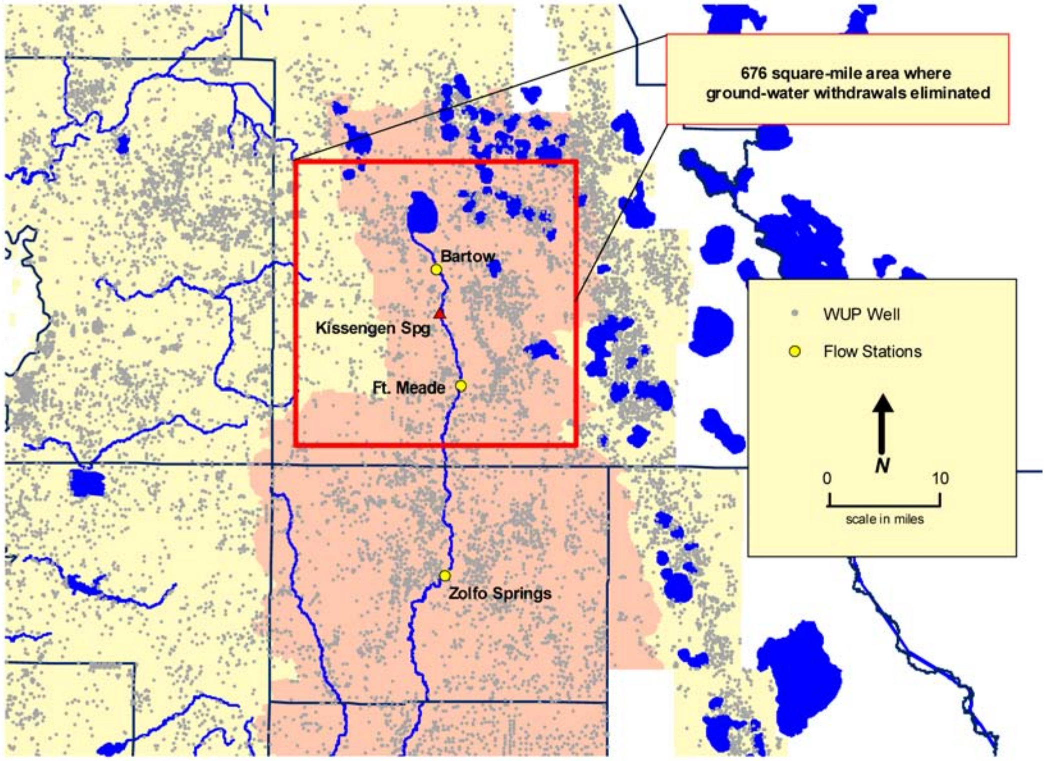

Figure 55. Location of 26 x 26 mile area where ground-water withdrawals eliminated.

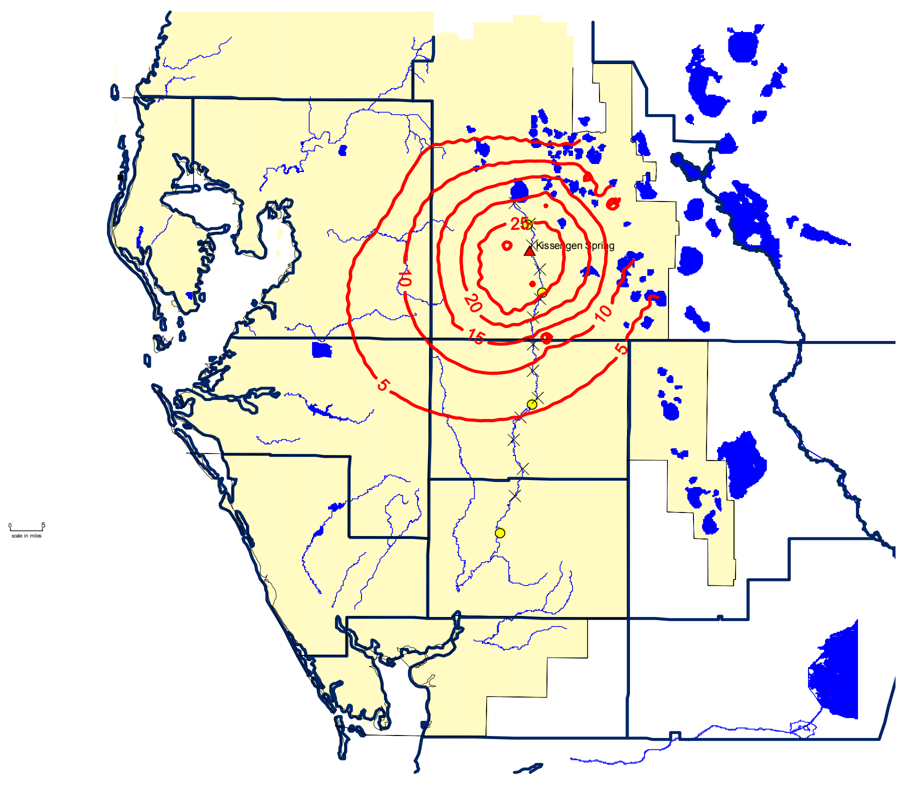

Figure 56. Simulated increase in Upper Floridan aquifer potentiometric surface when April-May ground-water withdrawals are reduced 100 percent within the 676 square-mile area.

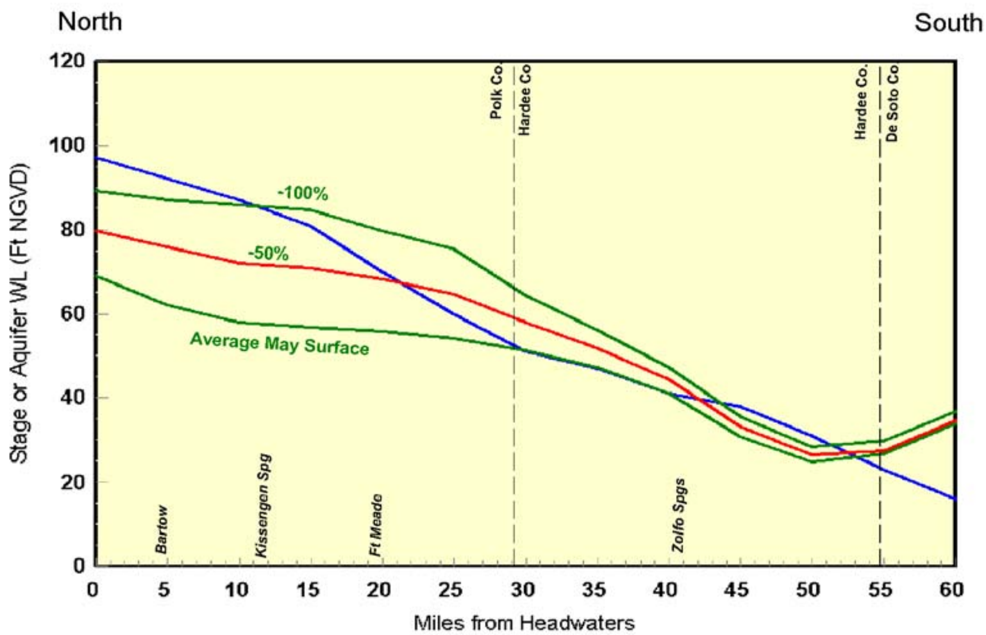

Figure 57. Predicted increase in the elevation of the Upper Floridan aquifer potentiometric surface during May due to reduction in pumpage of 50 and 100 percent in a 676 square-mile area.

Table 5. Hydrologic change associated with reducing April-May ground-water withdrawals within a 676 square-mile area around Kissengen Spring.

Ground-Water Withdrawal Reduction		Upward Flow Potential from the Floridan Aquifer		Potential for Kissengen Spring flow
Percent	Mgd	Headwaters to Ft. Meade (miles)	Polk-Hardee Line Northward (miles)	
50	105	0	8.5	No
100	210	9	19	Yes

6.0 SUMMARY AND RECOMMENDATIONS

The hydrogeology of the upper Peace River basin is defined by a multi-aquifer system that consists of an unconfined surficial aquifer, a confined IAS, and a confined Upper Floridan aquifer. The base of the Upper Floridan aquifer is represented by a gysiferous dolomitic zone of very low permeability. Regionally across the area from Lake Hancock south, the surficial aquifer is hydraulically separated from the Upper Floridan aquifer by multiple clay confining units within the IAS which limits significant leakage from the overlying water table to the Upper Floridan aquifer. Limited data suggests that the surficial/IAS PZ2 zones are in good hydraulic connection as well as the IAS PZ3 zone and Upper Floridan aquifer. A persistent thick clay layer separates the upper portion of the IAS from the lower producing zone. Karst features found locally along the upper stem of the Peace River, from Bartow to Ft. Meade, provide good hydraulic connection between the river and the underlying confined aquifers.

Historic declines of 30 to 40 feet in the elevation of the potentiometric surface of the Upper Floridan aquifer have occurred since predevelopment due to ground-water withdrawals. Kissengen Spring discharge averaged about 20 to 30 cfs during the 1930s and eventually ceased continuous flow in 1950 due to gradual lowering of the Upper Floridan aquifer potentiometric surface. From the headwaters of the Peace River to the Polk-Hardee County line, the Upper Floridan aquifer water level is below the channel bed during the spring dry season. Graphical analysis and numerical model simulations indicate that existing ground-water withdrawals would need to be reduced by 60 to 80 percent (or 100 percent within a 676 square-mile area) to return flow to Kissengen Spring and contribute Upper Floridan aquifer baseflow to half of the heavily-impacted section of the river from Bartow to Ft. Meade. It is unknown at this time the magnitude of baseflow contribution from the ground-water system that would occur if reductions in existing withdrawals could be achieved.

Additional data collection and analysis is needed to more fully assess flow reductions in the upper Peace River due to the decline of the Upper Floridan aquifer potentiometric surface. Characterizing and mapping in-stream karst features is urgently required to determine seepage losses to the underlying confined aquifers. Defining the hydraulic characteristics of the PZ2 and PZ3 zones of the IAS and its connection to the river and underlying Upper Floridan aquifer would substantially improve the conceptual understanding of the system. In particular, the baseflow contribution from the IAS is poorly known.

Additional test borings and nested monitor wells are needed to understand the dynamics of the river/ground-water interaction and how it varies seasonally. In his report on Kissengen Spring, Jackson (2000) states, “Existing hydrogeologic information and data is not sufficient for understanding the dynamics of the Kissengen Spring site....(additional data collection) could enhance our understanding of the upper Peace River system from a regional perspective.”

In addition to more data collection, the development of a long-term, calibrated integrated surface water/ground-water model would greatly increase our understanding of the dynamics of rainfall, land-use alterations, and surface/ground-water interaction. Since all of the hydrologic variables are included in this model (i.e. rainfall, runoff, streamflow, baseflow, and the ground-water aquifers), it would represent the most definitive tool yet to sort the magnitude of each cause-and-effect factor.

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Appendix A

Site Name	LS Elev. Ft NGVD	SAS Thickess (ft)	UICU Thickess (ft)	PZ2 Thickess (ft)	MICU Thickess (ft)	PZ3 Thickess (ft)	LICU Thickess (ft)	ICU Thickess (ft)	IAS Thickess (ft)	UFA Thickess (ft)	Top of IAS PZ2 Ft NGVD	Top of IAS PZ3 Ft NGVD	Top of UFA Ft NGVD	Top of MCU Ft NGVD
CR 1	94	5						9					80	
CR 8	96	4						34					85	
ROMP 87	110	5						35					70	
ROMP 76	135	35						5					95	
ROMP DV-1	113	16						64					33	
ROMP 61	72	5						45					22	
ROMP 59	119	0	50	80			40		170	1020	69		-51	-1071
ROMP 57	128	70	43	24			27		94		15		-36	
ROMP 57X	197	192						66					-61	
ROMP 44	133	91						142					-100	
ROMP CL-2	82	237						100					-100	
ROMP 45	121	10	35	15	10	140	95		295		76	51	-184	
ROMP 49	145	77						302		1041			-234	-1275
ROMP 48	102	40						260					-198	
ROMP 50	50	55						255		1110			-260	-1370
ROMP 39	125	65	68	75			305		448	1087	-8		-388	-1475
ROMP 40	138	52	24	104			215		343		62		-257	
ROMP 43X	148	270						198					-320	
ROMP 30	70	15	37	41	112	112	48		350		18	-135	-295	
ROMP 31	80	20	110	80	85	75	85		435		-50	-215	-375	
ROMP 33	75	35	20	110	7	119	258		514	951	20	-97	-474	-1425
ROMP 22	35	19	68	67	79	131	10		355	1321	-52	-198	-339	-1660
ROMP 25	85	55	52	38			168		258	1527	-22		-228	-1755
ROMP 26	78	50	75	55			345		475		-47		-447	
ROMP 28	84	200	170			60	49		279	1486		-286	-395	-1881