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ESTIMATES OF UPPER FLORIDAN AQUIFER RECHARGE AUGMENTATION BASED ON HYDRAULIC AND WATER-QUALITY DATA (1986-2002) FROM THE WATER CONSERV II RIB SYSTEMS, ORANGE COUNTY, FLORIDA

ESTIMATES OF UPPER FLORIDAN AQUIFER RECHARGE AUGMENTATION BASED ON HYDRAULIC AND WATER-QUALITY DATA (1986-2002) FROM THE WATER CONSERV II RIB SYSTEMS, ORANGE COUNTY, FLORIDA

by

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with

Recharge Estimates Based on Water Quality

by

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BASIC FINDINGS

- By the end of 2002, 6.73×10^{10} gallons of reclaimed water had been discharged to the Water Conserv II rapid infiltration basins (RIBs). Of this volume, 96% was discharged to RIB sites 5, 6, and 7 (in operation since late 1986).

- Relatively sparse ground water level data and few water quality data were available from Water Conserv II RIB sites to document background conditions prior to their construction and operation (beginning in late 1986). Lake-level data were adequate. A comprehensive suite of data has been collected during the operational phase of the RIB sites.

- After a short time, water recharged into the surficial aquifer through the Water Conserv II RIB sites causes the recharge of an almost equivalent volume of surficial-aquifer water to the Upper Floridan aquifer in the immediate RIB site areas.

- RIB recharge has caused extensive “mounding” of the water table in the surficial aquifer, but only in areas that are in relatively close proximity to the RIB recharge areas. The mounding is not cumulative but equilibrates rapidly to the prevailing RIB recharge rates.

- RIB recharge waters do not flow laterally in the surficial aquifer for any great distance and the hydraulic effects of the lateral flow that does occur in the surficial aquifer probably will never extend more than about 3,000 feet from any of the RIB site areas if recharge rates do not substantially increase.

- The effects of RIB recharge on stages in lakes adjacent to the Water Conserv II area are probably small and are not discernable in graphical representations of lake stages and stage fluctuations. Recent high lake levels in lakes adjacent to Water Conserv II are not the result of additional lateral inflow caused by recharge through Water Conserv II RIB sites.

- Water quality in the surficial aquifer immediately beneath and surrounding RIB sites 5 and 7 is nearly the same as that of the RIB recharge water. At greater depth, in less permeable layers of the surficial aquifer and confining layer, the resident aquifer water is probably a mixture of RIB recharge waters and water originating as precipitation recharge, so that such a mixture would characterize water presently reaching the Upper Floridan. Over time, the proportion of RIB recharge water in this mix will tend to increase.

- In the Upper Floridan, gradually lengthening and somewhat diluted plumes of RIB recharge water will extend to the north and northeast from the RIB sites.

- Estimated volumes of recharge to the Upper Floridan and estimated leakance coefficients derived in this study are consistent with values previously used in numerical models of the USGS and SJRWMD.

- The present monitoring of surficial-aquifer and Upper Floridan aquifer water levels and water quality is designed to meet regulatory requirements. Scientific analysis of the effects of recharge and movement of the recharge water would benefit from additional measurements of water levels and quality. Additional water quality measurements would include analyses for conservative parameters such as chloride. Additional measurements of nitrate nitrogen and trihalomethane would also be helpful.

EXECUTIVE SUMMARY

Because the need for water may soon exceed the sustainable supply available from the principal source in central Florida, the Upper Floridan aquifer, processes such as artificial recharge that have the potential to augment the quantity available from the aquifer are of great significance. This fact has generated interest in the Water Conserv II area of Orange County, where, since 1986, reclaimed water has been used to recharge the shallow subsurface by discharge to rapid infiltration basins (RIBs). The present study uses various data collected from a network of observation wells and piezometers during the operation of the RIB basins, and additional data previously acquired, as a basis for demonstrating that recharge to the Upper Floridan aquifer has likely been enhanced by the operation of the RIB sites and to estimate the degree of this enhancement.

Discharge of reclaimed water began in late 1986 at four RIB sites having numerical designations as sites 5, 6, 7, and 9. By the end of 2002, 1.436 x 10^{10} gallons had been discharged to site 5, 2.035 x 10^{10} gallons had been discharge to site 6, and 3.004 x 10^{10} gallons had been discharged to site 7. Only 0.029 x 10^{10} gallons had been discharged by the end of 2002 at site 9, because site 9 was not used except for short periods. Discharge began at RIB site 8 in July 1999, and by the end of 2002, 0.113 x 10^{10} gallons had been discharged. Discharge began at sites 3 and 4 in January 2002, and the respective volumes discharged by the end of the year were 0.074 x 10^{10} and 0.037 x 10^{10} gallons. Discharge rates were highest during the high-rainfall years from 1995 to early 1998 and substantially lower than these rates during the drought period of mid-1998 to mid-2002.

Discharge is to a surficial layer of sands of low-to-moderate permeability that decreases with depth. A leaky confining layer comprised of clastics of low permeability that includes the Hawthorn Group underlies this layer. The confining layer is underlain by the Upper Floridan aquifer of high permeability. Under natural conditions, the hydraulic gradient in the Water Conserv II area is downward from the surficial aquifer to the Upper Floridan aquifer, and water from the surficial aquifer leaks through the confining layer to the Upper Floridan aquifer at a rate that depends on the confining-zone leakance and the head difference between the aquifers.

In areas centered about locations of discharges to RIB basins, the water table altitude has risen as a result of the discharges, causing the rate of downward

leakage to the Upper Floridan aquifer to increase. In the vicinity of RIB sites, the water leaking to the Upper Floridan can include a part of the reclaimed water, so that dissolved chemical substances present in the reclaimed water might be detected in downgradient Upper Floridan monitor wells.

Within the mounded water table surrounding a RIB site, the additional volume of water present as a result of the RIB discharges will be removed by downward leakage to the Upper Floridan aquifer, lateral movement away from the main points of reclaimed water discharge within the surficial aquifer, migration toward and discharge to surface-water bodies, and additional evapotranspiration where the mounded water table is close to land surface. Beyond the effective lateral boundary of the water table mound, appreciable lateral flow of additional water does not occur, and all of the additional water within its boundary is removed by downward leakage or evapotranspiration, if there are no discharges to surface water bodies. The mounding is not cumulative at near-constant discharge rates and reaches an equilibrium condition in which further discharge volumes are in balance with volumes removed by the other processes. When discharge rates decrease, as in 1998–2001, altitudes of the water table mounds decrease.

Seventeen chemical and biological parameters are measured in the stream of reclaimed water from the treatment plants. Of the parameters of greatest interest, nitrate nitrogen has been measured since 1986 (concentrations were combined with nitrite nitrogen between 1991 and 1998). Specific conductance was added to the list of sampled parameters in 1994, chloride and sodium were added in 1997, and total dissolved solids (TDS) was added in 2001. Sampling is daily, weekly, or sporadically, depending on the parameter, and sample values for each parameter typically show a high degree of variance.

Monthly stage measurements have been made at numerous lakes within or surrounding the Water Conserv II area since 1987. The stage data files for many of the lakes have been augmented with previous data from other sources extending as far back in time as 1959. The lake stages generally show a correlation with the recent accumulation of rainfall in the region, being high in 1995-98 and substantially lower in the subsequent drought period. Possible stage increases caused by RIB site discharges are not readily evident from the stage-data record, although if significant, they might have been masked by fluctuations caused by rainfall and by the effects of regional wellfield withdrawals.

Staff gages have been installed in shallow, closed depressional areas within or near the Water Conserv II RIB sites to measure the stages of pooled water that occurs as a result of rainfall accumulation or the reclaimed water discharges to the RIB basins. The latter influence is clearly shown in the record of stage in depressions within and closest to the RIB sites. The record closely resembles that of water levels measured in shallow wells.

In the four RIB sites in operation since 1986, 62 surficial aquifer monitor wells have provided water level data, of which 42 were in areally extensive site 6. Five piezometers were installed in site 5 and 170 piezometers were installed in site 6. Six wells in the Upper Floridan aquifer provided head data. Water-level measurements available from the period before discharge to the RIB site began are few. Several measurements were made in surficial wells at sites 5, 7, and 9 in the months before discharge began. A consulting firm prepared synoptic water level contours of the four sites in 1983–84.

The record of surficial water levels shows that substantial increases in the water table altitude occurred during the period of RIB discharges. However, well water level increases do not continue after reaching a higher equilibrium, and water table altitudes decrease during periods of lower discharges. Water table buildup variations within RIB sites 5 and 7 and the limited water level data in the surrounding areas was used to approximate the areal extent of the water table mounds. Estimated average head buildups within the mounds were used to estimate the average additional recharge to the Upper Floridan aquifer.

No flowing surface water bodies were present within the mounds, but parts of several lakes were present at the approximate boundaries of the mounds. It was assumed that the volume of additional groundwater flow to the lakes resulting from RIB discharges was small. It was also assumed that the amount of additional evapotranspiration resulting from the RIB-cell discharges was also small.

Assuming average head buildups of 13 ft (site 5) and 6 ft (site 7) and using estimates of confining-zone leakance from previous model studies, estimates of discharge to the Upper Floridan in the 1986-2002 period were somewhat less (site 5) and somewhat more (site 7) than the known volume of discharge. If it were assumed that 5% of the water table mound is removed by evapotranspiration and seepage to lakes, and the remaining 95% percolates to the Upper Floridan aquifer, the known amount of discharge to site 5 is accounted for by assuming a confining zone leakance of 5.5×10^{-4} d^{-1}, and the corresponding average leakage rate would be 31.4 in/yr higher than under natural conditions. Based on the same assumptions, the known amount of discharge to site 7 is accounted for by assuming a confining zone leakance of 12.85×10^{-4} d^{-1}, and the corresponding average rate of additional leakage would be 33.5 in/yr. If estimated slight head buildups in the upper Floridan aquifer are taken into account, the leakance estimate for RIB site 5 would increase by 23% and the leakance estimate at RIB site 7 would increase by 200%.

RIB site 6 was considered too large and hydraulically variable, with insufficient data to define the spatial variability, to perform the type of analysis described above. Water table altitudes at RIB site 9 remained at natural levels, except during three short time periods, so that the analysis previously described was not applicable at site 9.

Head variations are nearly identical at all Upper Floridan aquifer wells, and are largely the result of regionally distributed influences, such as pressure loading from changes in the water table caused by rainfall. The hydraulic influence of RIB recharge appears to cause an approximate 3-ft mound in the Upper Floridan aquifer at RIB site 5, and a 4 ft-mound in the Upper Floridan aquifer at RIB site 7.

Over the period of RIB discharges since 1986, 18 chemical and biological parameters have been monitored in all surficial and Upper Floridan monitor wells. Of these parameters, eight (specific conductance, chloride, total dissolved solids, nitrate nitrogen, total phosphorus, biochemical oxygen demand, pH, and total trihalomethanes) received the greatest attention in this study.

The occurrence of anomalously high concentrations of dissolved substances characteristic of reclaimed water in water samples from the eight monitor wells in the Upper Floridan aquifer used for water quality sampling are considered evidence that a part of the reclaimed water has percolated through the confining layer to the Upper Floridan aquifer. The three parameters used in this study as evidence of downward percolation were nitrate nitrogen, chloride, and total trihalomethanes.

Using nitrate nitrogen as a tracer has to be qualified in that, while natural concentrations are nearly zero in pristine areas lacking anthropogenic influences, background concentrations can be as high as 6 mg/L in parts of the aquifer underlying areas where nitrate fertilizers have been used for substantial periods of time. There are no measurements of nitrate nitrogen in the Upper Floridan aquifer within the RIB sites prior to the application of reclaimed water. On the other hand, the natural concentration of chloride is generally less than 10 mg/l in the Upper Floridan aquifer. Trihalomethanes do not naturally occur in the Upper Floridan aquifer. The correlation between high concentrations or increasing trends in concentrations of nitrate nitrogen, chloride, and total trihalomethanes in samples from six of the Upper Floridan wells was interpreted as indicating that part of the reclaimed water discharged to the RIB sites had percolated to the Upper Floridan aquifer.

The total nitrogen to chloride ratio in samples from the Upper Floridan monitor well at site 5 is higher than the ratios measured in the reclaimed water and in samples from the surficial monitor wells, suggesting an additional source of nitrogen at this site. The ratios observed at one of the upper Floridan wells at each of sites 7 and 9 are similar that of the reclaimed water, supporting the conclusion that reclaimed water has percolated to the upper Floridan at those sites.

Estimates of the fraction of reclaimed water recharging the Upper Floridan aquifer based on water quality in RIB sites 5 and 7 are smaller than those estimated using leakance values for the intermediate confining unit. However, because of the uncertainty in the actual leakance values for the intermediate confining unit in RIB sites 5 and 7 and because of an unknown open hole interval for the Upper Floridan aquifer monitor wells in RIB sites 5 and 7, the above differences are remarkably similar.

Based on the findings of this study, certain recommendations would enhance scientific analyses of the RIB recharge and an understanding of the movement of the recharged water in the subsurface. These are (1) frequent sampling should be made in Upper Floridan monitor wells for trihalomethanes or some conservative tracer unique to the reclaimed water; (2) water quality sampling and water level measurements should begin at least several months before reclaimed water discharges begin at a new RIB site; (3) piezometers at off-site locations would be helpful in defining the extent of the hydraulic influence of the RIB site discharges; (4) more Upper Floridan monitor wells should be made available for water quality sampling, particularly in the vicinity of RIB site 6; and (5) Upper Floridan monitor wells sampled for water quality should have small (1–5 ft) open hole intervals.

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INTRODUCTION

Recent studies have indicated that water supply needs will exceed the sustainable supply available from the principal source in central Florida, the Upper Floridan aquifer, perhaps within the present decade. This outlook demonstrates the significance of processes such as artificial recharge that have the potential to augment the quantity available as supply from the aquifer.

In the Water Conserv II area of Orange County, reclaimed water is used to recharge the shallow subsurface by discharges to rapid infiltration basins (RIBs) and by its use for agricultural irrigation. Since October 1986, reclaimed water has been discharged to the seven basins (identified as sites 3, 4, 5, 6, 7, 8, and 9) shown in Figure 1, which reproduces a map prepared by PB Water, who advise on operation of the RIB sites under contract by the City of Orlando and Orange County Utilities Department through Woodward and Curran, Inc. Detail maps show sites 3, 4, and 5 (Figure 2), site 6 (Figure 3), and sites 7, 8, and 9 (Figure 4). It is possible that this recharge of the shallow subsurface with reclaimed water has increased the quantity of recharge to the Upper Floridan aquifer.

Water-level data, pressure-head data, and water quality data have been collected from a network of observation wells and piezometers during the operation of the RIB basins since late 1986. The present study uses this database and additional data previously acquired during the design and testing phase (1983–1984), as a basis for demonstrating that recharge to the Upper Floridan aquifer has likely been enhanced by the operation of the RIB sites and to estimate the degree of this enhancement. Previous studies did not include an analysis of the extensive operational-period data set, much of it collected since the completion of the earlier studies. Such an analysis is needed to determine whether the data support the theoretical conclusions reached in earlier studies concerning additional recharge to the Upper Floridan aquifer.

BACKGROUND

In order to cease making discharges of wastewater to surface water bodies, Orange County and the City of Orlando joined in a venture to create Water Conserv II, a system that distributes reclaimed water for agricultural irrigation, particularly in citrus groves, and for recharge to the shallow

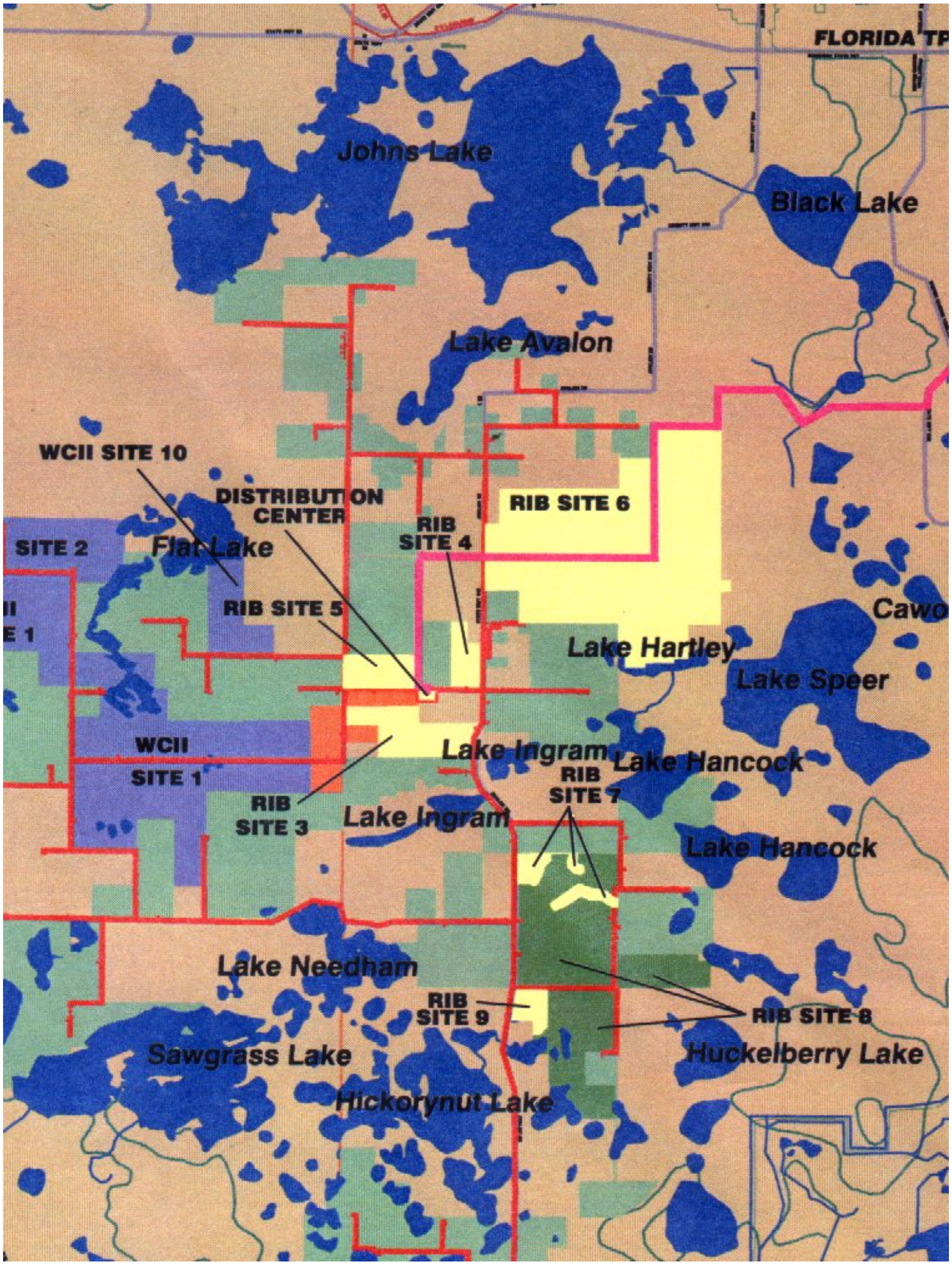

Figure 1. Map of Water Conserv II area (from PB Water)

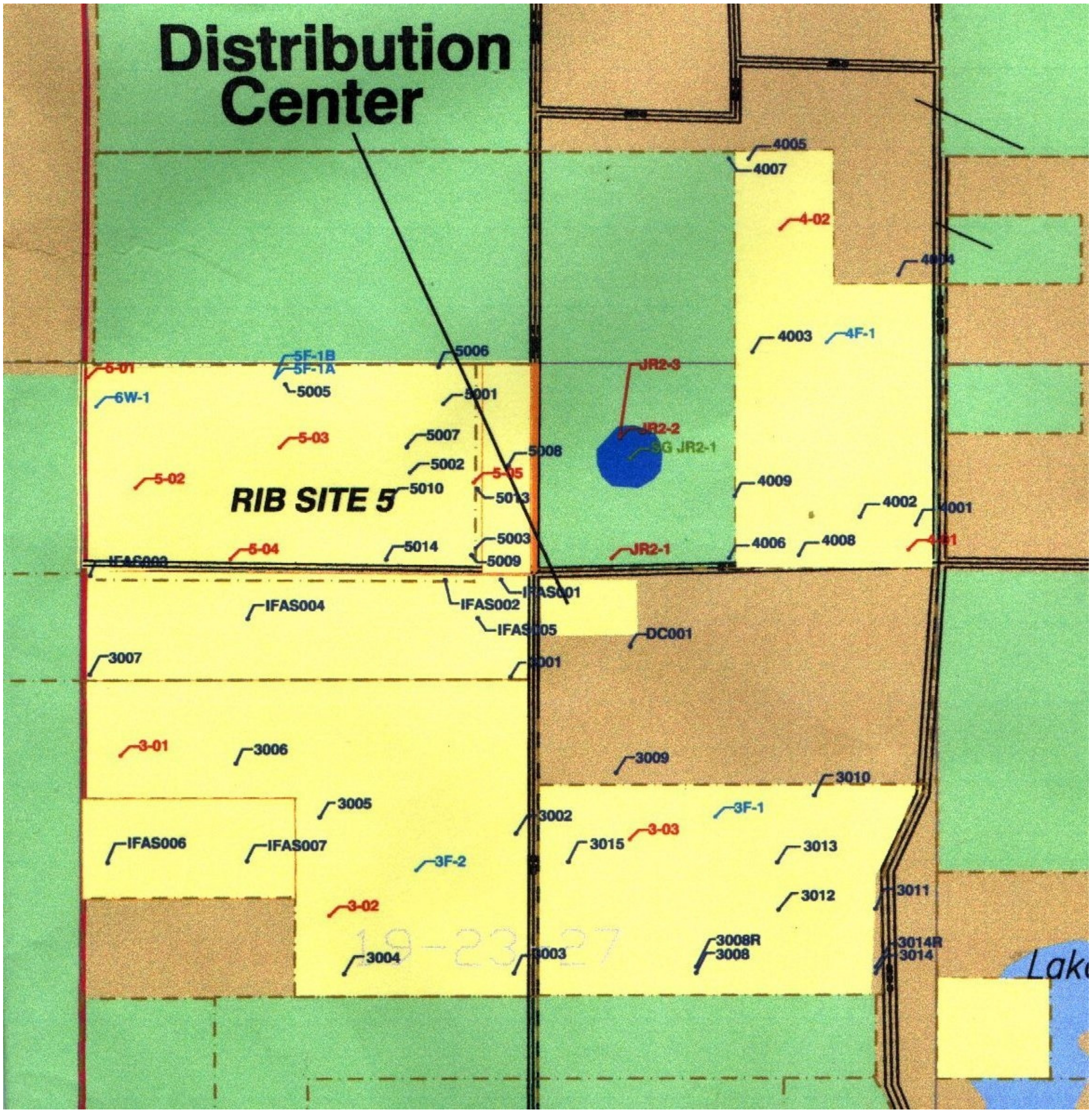

Figure 2. Map showing details of RIB sites 3, 4, and 5 (from PB Water)

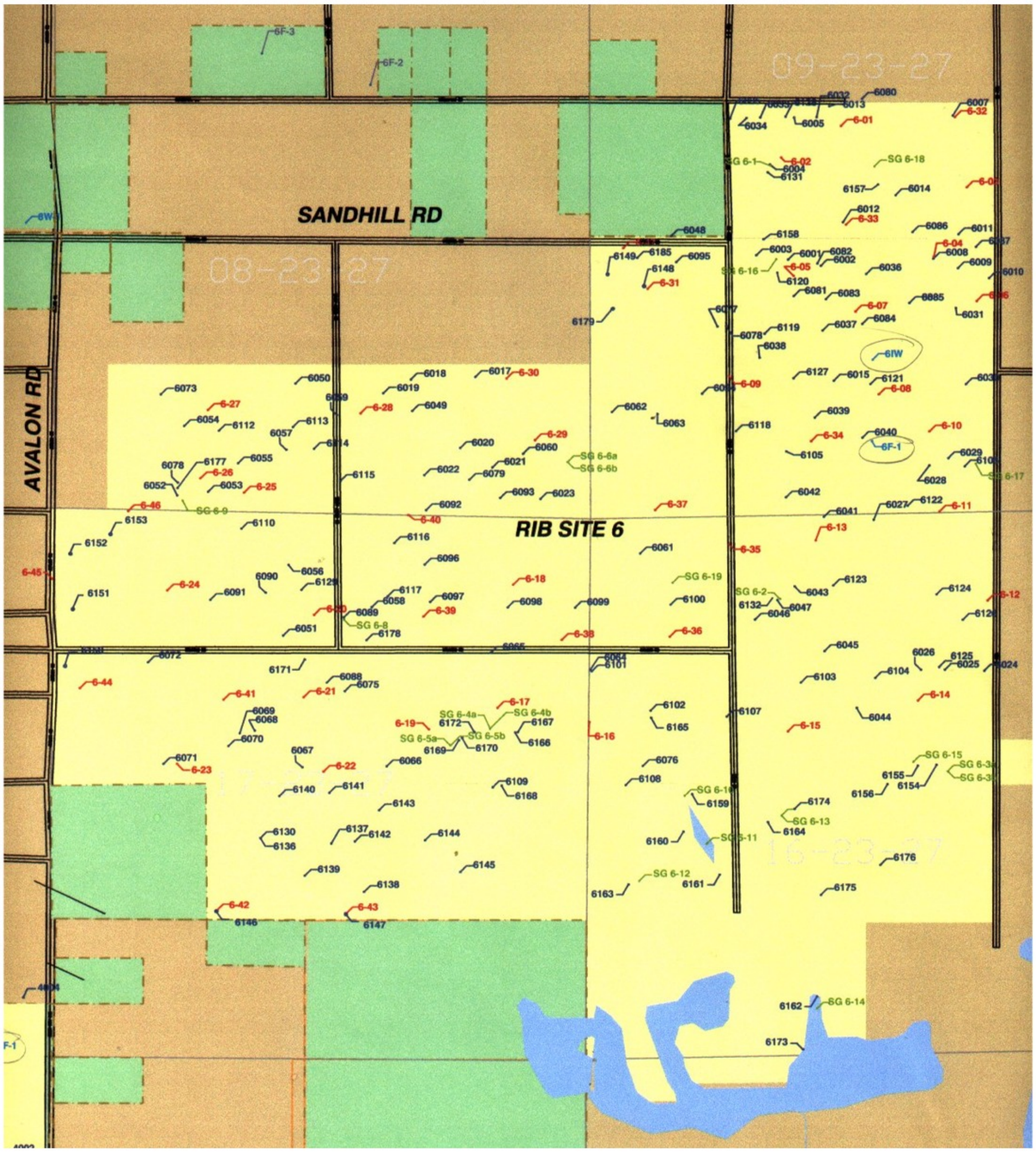

Figure 3. Map showing details of RIB site 6 (from PB Water)

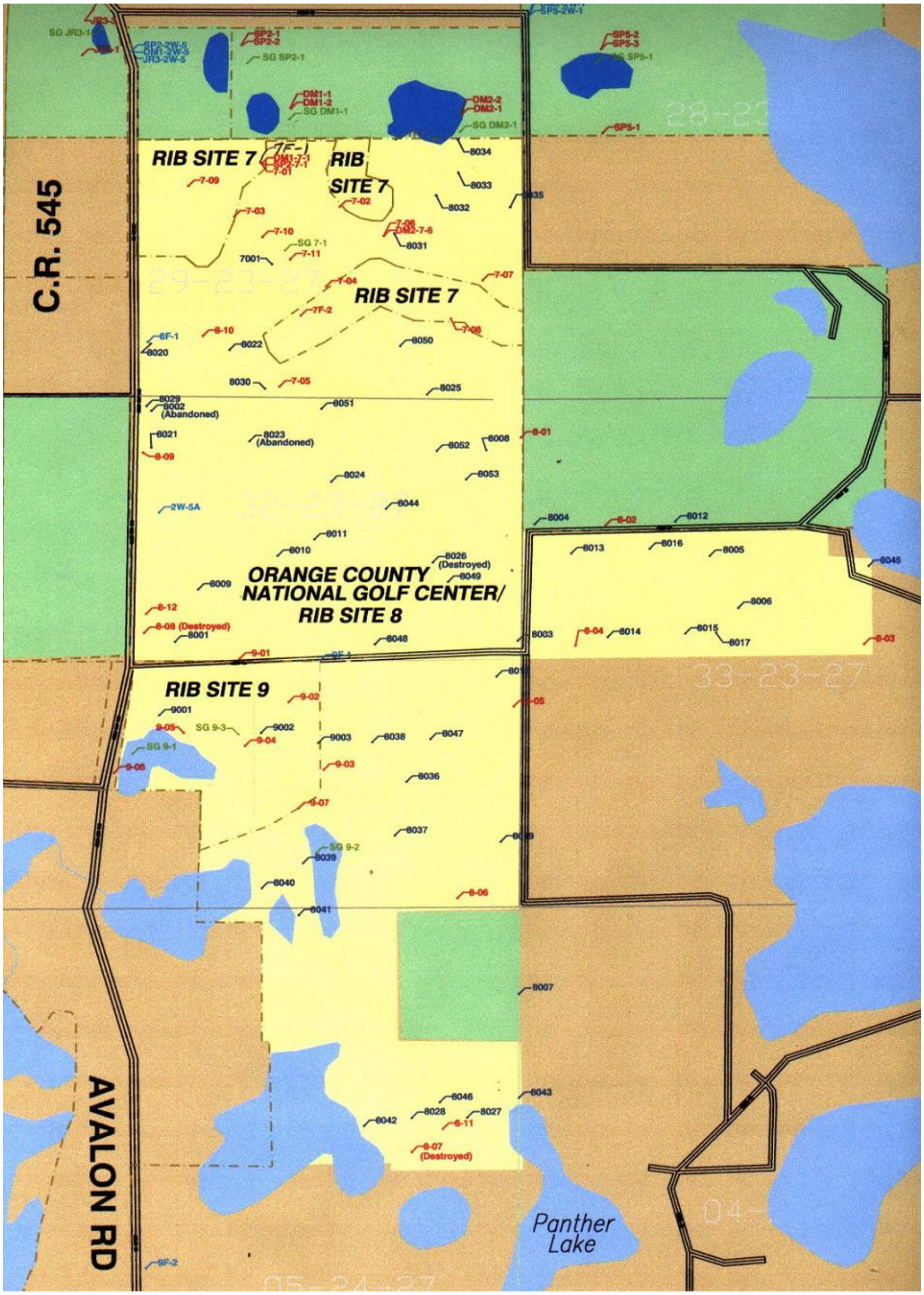

Figure 4. Map showing details of RIB sites 7, 8, and 9 (from PB Water)

subsurface in rapid infiltration basins (RIBs). A distribution system was designed and tests of discharge to RIBs were conducted in two test basins (Camp, Dresser, and McKee Inc. 1983).

Four 5-year contracts have been awarded to private companies to operate and manage the distribution system. The first two were awarded to Metcalf and Eddy, and the third and fourth were awarded to Woodward and Curran. For more than 11 years, PB Water has provided hydrologic services to the primary contractor. It is PB Water that maintains and updates the operational database used for the present study.

PREVIOUS STUDIES

A detailed assessment of conditions at the proposed sites for the Water Conserv II RIBs, together with an analysis of results of operational tests at two pilot RIB sites and the description of a numerical flow model, were presented by Camp, Dresser, and McKee, Inc. (CDM) (1983). Data from the CDM study were used by the U. S. Geological Survey (USGS) (O'Reilly 1998) to construct a numerical hydraulic model of a region that included the RIB sites of Water Conserv II and the Reedy Creek Improvement District (RCID). Data from the studies by CDM (1983) and O'Reilly (1998) were used by the St. Johns River Water Management District (SJRWMD) in the construction of a regional model of flow in the surficial and Floridan aquifer systems in east-central Florida (McGurk and Presley 2002).

PURPOSE AND SCOPE

This report presents in graphical form a substantial part of the data that has been collected from the Water Conserv II RIB sites since 1983, and selected data (lake stages) previously available from the surrounding area. The report also presents the conclusions of analyses concerning the problem of vertical recharge to the Upper Floridan aquifer and whether and by how much it may have increased in the vicinity of the RIB sites.

Water level and chemical data from various environments (wastewater flows, surficial aquifer, Upper Floridan aquifer) are exhibited together with timelines to facilitate interpretation. Water level (hydraulic head), chemical, and volumetric flow data are used for interpretations related to the quantity of recharge to the Upper Floridan aquifer.

HYDROLOGIC CONDITIONS IN THE WATER CONSERV II REGION

Reclaimed water discharge to the RIB basins enters a surficial aquifer composed of fine sands, which are clean and well drained near the surface. The permeability of the sandy materials of the aquifer was measured in the laboratory on numerous samples acquired by pit excavations and test borings (CDM 1983). The horizontal hydraulic conductivities of samples near the surface were averaged to yield values of 69 feet per day (ft/d) at site 5, 47 ft/d in the northeastern part of site 6, 72 ft/d in the remainder of site 6, 61 ft/d at site 7, and 82 ft/d at site 9. Measured vertical hydraulic conductivities generally ranged from half to slightly greater than the horizontal values. Field determinations of permeability tended to have somewhat lower values. The content of silt increases with depth, lowering the hydraulic conductivity. O'Reilly (1998) used a hydraulic conductivity value of 30 ft/d for the surficial aquifer in the Water Conserv II RIB area in calibrating a numerical model. McGurk and Presley (2002) used a value of 20 ft/d in a regional model of the surficial and Floridan aquifer systems in east-central Florida.

Measured porosities were 36–41% at site 5, 38–-51% at site 7, and 40–49% at site 9. A "fillable" (effective) porosity of 10% was used in analysis of mounding effects (CDM 1983).

Under natural conditions not affected by anthropogenic influences, contours on the surface of water table aquifers of relatively low permeability are subdued reflections of the variable topography, and the direction of water movement is locally variable. CDM (1983) prepared water table contour maps based on synoptic water level data sets, and found water table altitudes to range from 132 to 135 ft above sea level in site 5, from 85 to 149 ft above sea level in site 6, from 84 to 110 ft above sea level in site 7, and from 92 to 99 ft above sea level in site 9. The report stated that the water table could vary seasonally by 2 to 5 feet under natural conditions at each data point location. An example of such water table behavior is found in the well referred to by the USGS as the Lake Oliver Shallow Well near Vineland. In this well, southwest of the RCID RIB site, the water table varied over a range of 4.26 ft during the years 1997–98 (Figure 5), and has varied over a range of 6.17 ft since the beginning of record in 1959.

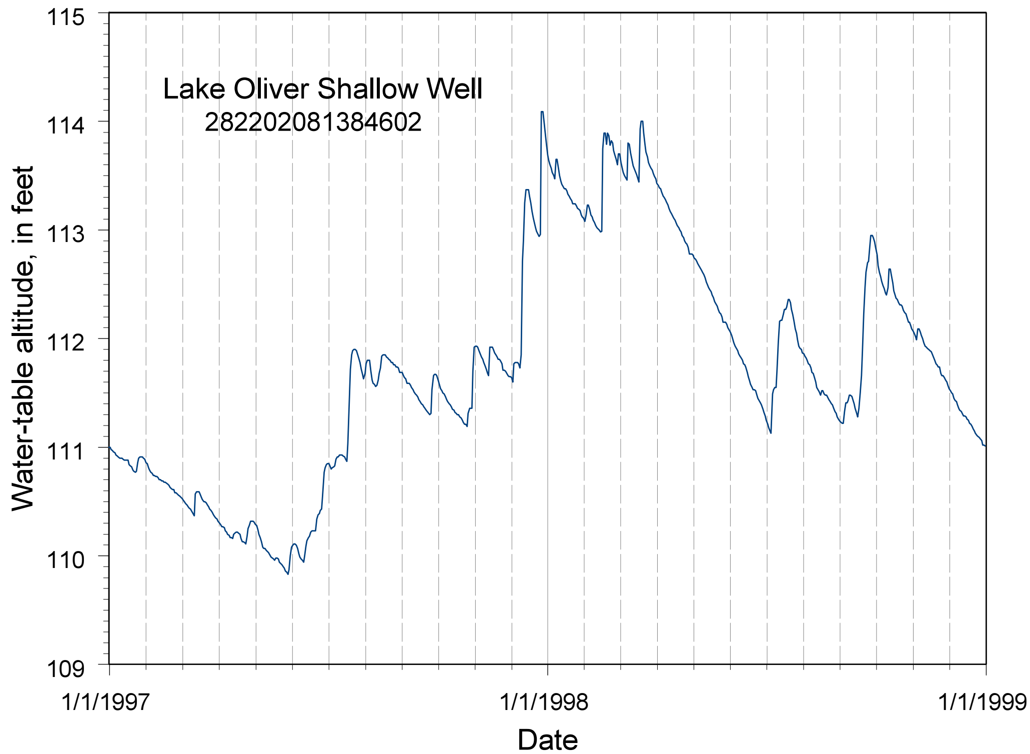

Figure 5. The water level recorded in a USGS shallow observation well in 1997–98

The terrain of the Water Conserv II area is hilly and areas of lower land-surface elevation and lower water table altitude correspond to closed depressions that contain ponded water during periods of extended heavy rainfall. RIBs were constructed in areas of higher elevation selected so that predicted water table mounds from RIBs loading could be contained within the unsaturated zone and at sufficient distance from depressions so that the development of seepage faces on the edges of the water table mounds would be minimized.

An aquifer test cited by CDM (1983) at site 5 yielded estimates of the transmissivity of the Upper Floridan aquifer of 49,500 to 56,700 ft^2/d and a leakance coefficient of 9.2×10^{-4} d^{-1}. A second aquifer test in the northeastern corner of site 6 yielded transmissivity estimates of 70,850 to 128,350 ft^2/d and a leakance coefficient between 4.5×10^{-5} d^{-1} and 1.6×10^{-4} d^{-1}. In a numerical model of the Floridan aquifer system in east-central Florida, Tibbals (1990) represented the transmissivity of the Upper Floridan aquifer as decreasing from 200,000 to 35,000 ft^2/d in a south-southeasterly direction in the region containing the RIB sites. The numerical model of O'Reilly (1998) used a similar distribution, with calibrated transmissivity decreasing from 250,000 to 50,000 ft^2/d in a south to south-southeasterly direction. The "mega-model" of Sepulveda (2002) also uses a distribution of values decreasing in a southerly direction from more than 100,000 to less than 50,000 ft^2/d.

The leakance coefficient referred to previously is mainly a measure of the resistance to downward flow through the intermediate confining unit that lies between the surficial aquifer and the Upper Floridan aquifer. This confining unit is composed mainly of the clayey Hawthorn Formation and overlying silty sands in the lower part of the surficial aquifer. Model-derived leakance coefficients were $1 \times 10^{-4}\ d^{-1}$ to $3 \times 10^{-4}\ d^{-1}$ (Tibbals 1990), and less than $3 \times 10^{-4}\ d^{-1}$ to greater than $11 \times 10^{-4}\ d^{-1}$ (Sepulveda 2002). Both estimates were applied in large regional models. McGurk and Presley (2002) reported leakance values for an area including Water Conserv II of from 1×10^{-4} to greater than $10 \times 10^{-4}\ d^{-1}$.

O'Reilly (1998) used a complex system of leakance coefficients in the Water Conserv II area within a small regional model. The leakance coefficient ranged from less than $0.5 \times 10^{-4}\ d^{-1}$ to greater than $5 \times 10^{-4}\ d^{-1}$ over site 6, was between $1 \times 10^{-4}\ d^{-1}$ and $5 \times 10^{-4}\ d^{-1}$ at site 5, greater than $50 \times 10^{-4}\ d^{-1}$ at site 7, and between $5 \times 10^{-4}\ d^{-1}$ and $10 \times 10^{-4}\ d^{-1}$ at site 9. CDM (1983) assigned the vertical hydraulic conductivity of the confining layer to be 0.0048 ft/d in their model of RIB site 5. In their site 5 subregional model, they estimate a confining layer thickness of 80 ft, which would imply a leakance value of $0.6 \times 10^{-4}\ d^{-1}$. Elsewhere, they assume a thickness of the Hawthorn of between 15 and 45 ft in site 5. The resulting leakance coefficient would lie between 1.1×10^{-4} and $3.2 \times 10^{-4}\ d^{-1}$.

CDM (1983) measured the potentiometric surface of the Upper Floridan aquifer at site 5 in a well on the northeast corner of the site (83.6 ft) and in a well on the southwest corner of the site (82.3 ft). Upper Floridan water levels (78–79 ft) were measured in several wells in the northeastern corner of site 6. The head in the Upper Floridan was estimated to range 75–78 ft in the remainder of site 6 based on a then-recent USGS publication. This same source was used to estimate Upper Floridan heads of 85 ft above sea level at site 7 and 90 ft above sea level at site 9.

A comparison of the pre-RIB water table altitudes and Upper Floridan heads shows that the water table is higher. There is a difference of about 50 ft at site 5 and <10 ft at site 9. Noting that the RIBs are located in areas of higher land-surface elevation (and higher water table elevation) at each site, the difference in heads is about 0–25 ft at site 7. Site 6 is too large and spatially variable to succinctly characterize, but the water table is higher than Upper Floridan heads.

Because the water table is higher than the head in the Upper Floridan aquifer, water will tend to percolate downward through the confining layer to the Upper Floridan aquifer. The rate of percolation between the surficial and Upper Floridan aquifers will depend on the confining-zone leakance and on the head difference between the aquifers. The average head difference during the operation of the RIBs has increased at monitoring wells (65–85 ft at site 5, 30–45 ft at site 6, and 5–30 ft at site 7).

The Upper Floridan aquifer heads have temporal variations that are quite similar (without any time lag) to natural variations in water levels in the surficial aquifer that are caused by area-wide variations in rainfall recharge and evapotranspiration. However, this does not imply a rapid equalization of heads by water exchange following rainfall or drought events (in some cases, the head difference remains several tens of feet), but probably is caused by pressure loading from the surface when the water table elevation changes. The loading is rapidly transmitted through the intervening rock matrix to the water in the lower aquifer.

The concept of pressure loading is familiar in the study of the effects of ocean tides and atmospheric-pressure fluctuations (Jacob 1940), but has received little or no attention in the study of the effects of water table fluctuations. A ratio of the pressure change in the Upper Floridan aquifer to that at the water table is referred to as "loading efficiency." The changes in pressure in the surficial aquifer and in the Upper Floridan aquifer may lead to a change in the rate of downward percolation, further influencing the head relations.

Examples of pressure loading are shown in Figures 6 and 7, which compare the heads of a surficial and an Upper Floridan well at sites 5 and 9, respectively. Two scales are used in Figure 6 to display the heads of the surficial well 5-01 and Upper Floridan well 5F-1, 1,200 ft away from 5-01, because the heads are separated by 65–70 ft. The greater variation at 5-01 is partly the result of water table mounding from the RIBs loading, although the effect at this well is less than at other surficial wells at site 5. Because the water table mound in the surficial aquifer is localized, it is not effective in pressure loading the Upper Floridan aquifer.

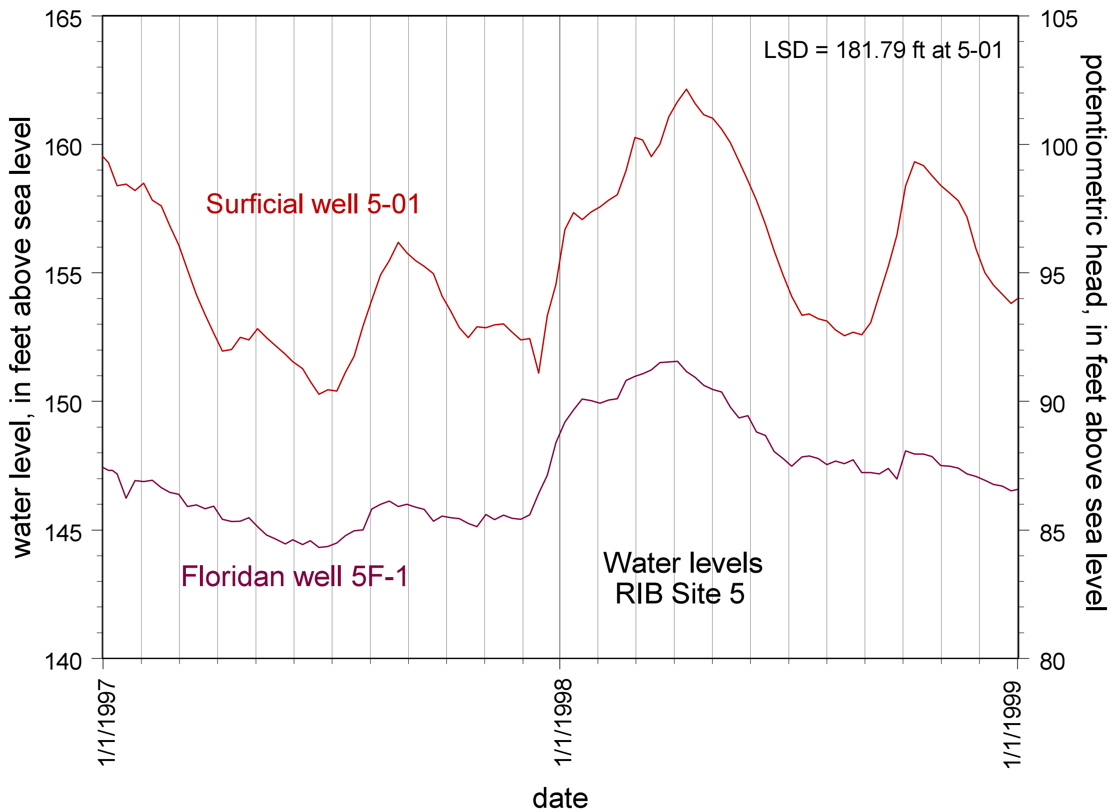

Figure 6. Water level of surficial well 5-01 and head of Upper Floridan well 5F-1 at RIB site 5

At site 9 (Figure 7), a more natural situation free of most anthropogenic influences is shown, because RIB loading only took place between February and May 1997 at three RIBs and in September and October 1997 at one RIB. The head difference between surficial well 9-01 and Upper Floridan well 9F-1 remains about 10 ft except during the first period of RIB recharge. The greater variation at the location of Upper Floridan well 9F-1 cannot be explained without further study. The water table effects from RIB loading in early 1997

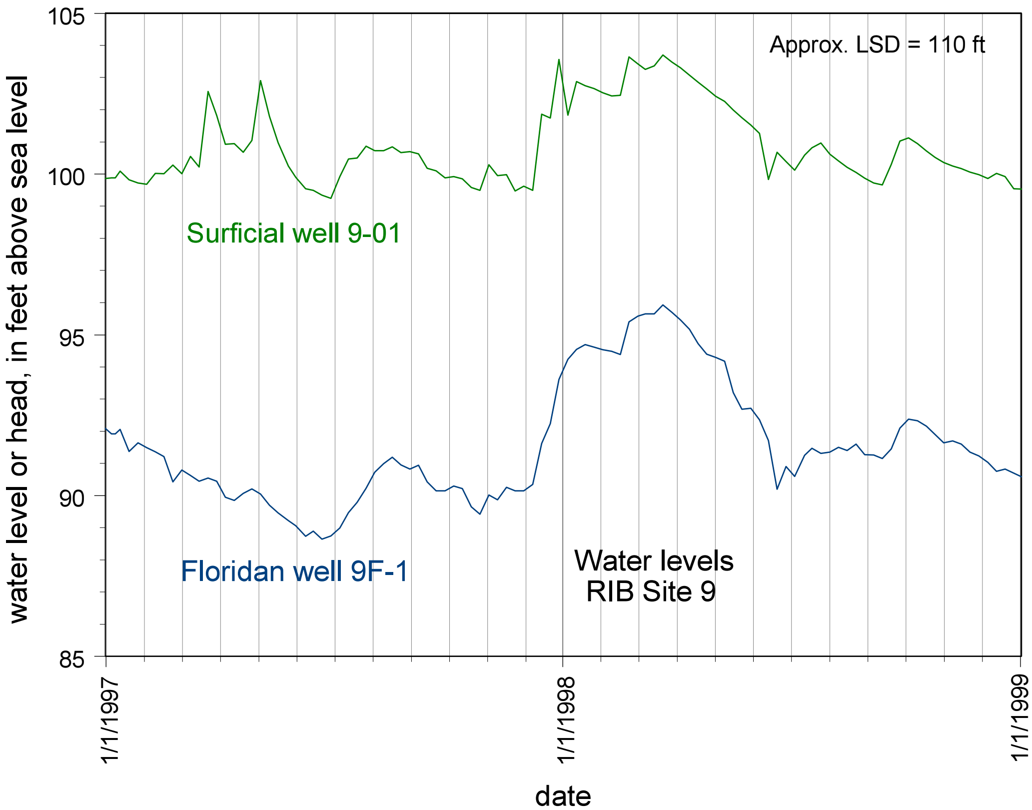

Figure 7. Water level of surficial well 9-01 and head of Floridan well 9F-1 at RIB site 9

are not transmitted to 9F-1, 900 ft away from 9-01, probably because the mounding is localized. The pressure loading effect is most effective when the loading is areally distributed, as from the effect of rainfall.

One way of determining whether the percolation of reclaimed water into the Upper Floridan aquifer has occurred is by detecting concentrations of constituents that are higher than those naturally occurring in the native water and which are present in high concentrations in the reclaimed water. For purposes of this analysis, certain assumptions are made concerning concentrations of constituents or levels of specific conductance that would be considered typical in natural water in the Upper Floridan aquifer in the Water Conserv II area. Where this water is unaffected by man, it is potable and could be used for public supply.

Adamski and Knowles (2001) performed a statistical analysis of chemical constituents found in Upper Floridan water samples obtained from aquifer springs and wells in Lake County (LC) and in the Ocala National Forest (ONF). In 81 samples from Lake County, the median value of specific conductance was 289 μS/cm (microsiemens per centimeter). In 57 samples from the ONF, the median value was 360 μS/cm. On the basis of these findings, it is assumed that the natural level of specific conductance probably rarely exceeds 400 μS/cm. Adamski and Knowles (2001) found median concentrations of total dissolved solids (TDS) of 176 milligrams per liter (mg/L) (LC, 81 samples) and 204 mg/L (ONF, 57 samples). They found median concentrations of chloride of 10 mg/L (LC, 86 samples) and 18 mg/L (ONF, 74 samples). Tibbals (1990) placed the Water Conserv II area within a region where the chloride concentration in the upper 100 ft of the Upper Floridan aquifer was less than 25 mg/L. Based on this evidence, naturally occurring concentrations of chloride and total dissolved solids probably rarely exceed 25 and 300 mg/L, respectively. A scan of water quality data from the Upper Floridan aquifer in the Water Conserv II region in the USGS database appears to confirm these limits. Chloride values are commonly less than 10 mg/L in pristine areas.

Adamski and Knowles (2001) report median concentrations for nitrate of 0.04 mg/L (LC, 47 samples) and 0.05 mg/L (ONF, 26 samples) and median concentrations of phosphate of 0.05 mg/L (LC, 38 samples) and 0.03 mg/L (ONF, 19 samples) in samples from the Upper Floridan aquifer. Observing that Upper Floridan nitrate concentrations as high as 7.5 mg/L were measured in Lake County, but no concentrations higher than 0.20 mg/L were measured in the ONF, they noted that “nitrate concentrations in the Upper Floridan aquifer appear to be related to land use in Lake County” and that “low concentrations of nutrients in the Upper Floridan aquifer in the Ocala National Forest probably are the result of the pristine forested land use of the area.”

Sprinkle (1989) measured nitrate concentrations in 328 filtered samples and 332 unfiltered samples from the Floridan aquifer system, and found that 75% of the values were less than 0.09 mg/L (filtered samples) and less than 0.02 mg/L (unfiltered samples). However, concentrations as high as 7.6 mg/L were measured. After analyzing 83 filtered samples and 261 unfiltered samples, Sprinkle also observed 75% of samples contained less than 0.1 mg/L of P (P = phosphorus, the values converted from measurements of phosphate). In reference to the higher concentrations of nitrate sometimes measured, Hem (1985) noted “the full impact of leached fertilizer nitrogen on ground water is slow to develop in many areas because transport of solutes through the unsaturated zone between the land surface and the water table is slow" (Hem 1985). Also "phosphate is a component of sewage", but that "phosphates are not very mobile in soils or sediments." Additionally, "the chemistry of the element favors its precipitation, and dissolved phosphorus added through disposal of waste or leaching of fertilized fields may not remain available for long periods."

In summary, it seems that concentrations of nitrate and phosphate in the Upper Floridan aquifer are usually close to zero and do not normally exceed 0.10 mg/L in natural pristine areas in the absence of a source. However, where nitrate fertilizers are used in the overlying surficial aquifer, concentrations can range to nearly 10 mg/L.

Finally, Adamski and Knowles (2001) report median values for pH of the Upper Floridan aquifer of 7.7 (LC, 81 samples) and 7.6 (ONF, 57 samples). For the surficial aquifer, they report median values of 6.4 (LC, 15 samples) and 5.8 (ONF, 26 samples). The alkalinity of the Upper Floridan samples is probably related to the solution of carbonate rocks, and the acidity of the surficial samples is probably from the acidity of rainfall recharge.

IMPACTS OF RIB RECHARGE

The discharge of reclaimed water to the elongated RIB basins creates mounds in the water table that will expand and become higher with time as discharge continues. The higher water table caused by the discharge of reclaimed water will also cause an increase in downward percolation to the Upper Floridan aquifer in the vicinity of the water table mound. Some water that would recharge the water table within the mound will be removed by evapotranspiration. It remains to be determined on a site-specific basis whether the rate of evapotranspiration will increase relative to that occurring prior to the creation of the water table mound.

It is possible that, sufficient time elapses, and if the rate of discharge to a RIB remains relatively constant, a new equilibrium will be established among these processes: (1) the occurrence of lateral flow in the surficial aquifer from the water table mound; (2) the increased downward percolation to the Upper Floridan aquifer in the vicinity of the mound; and (3) the rate of evapotranspiration. If the rate of RIB discharge changes, a new equilibrium will be established after sufficient additional time has passed.

If surface-water bodies are present within the mounded water table area, additional water will discharge to those water bodies, increasing the stage or flow rate. At the limit of the water table mound, outward flow within the mound will cease and all water removed from the mound within this perimeter will have been removed by processes of evapotranspiration, downward percolation to the Upper Floridan aquifer, or by discharge to surface-water bodies.

Because the surficial aquifer has relatively low permeability, the discharged reclaimed water will spread laterally relatively slowly, so that wells in the surficial aquifer near the point of discharge will tend to show constituent concentrations similar to those in the treatment plant effluent. Farther away in the surficial aquifer, background native-water concentrations will persist for long periods of time. In some locations, the background concentrations will be affected by agricultural activities (primarily the fertilization and irrigation of orange groves) that predate the RIB systems. In other locations, background concentrations represent pristine natural conditions lacking anthropogenic influences.

The increased rate of percolation of water to the Upper Floridan aquifer under the water table mound generated by discharge to a RIB site does not necessarily imply that part of the discharged reclaimed water will be contained in the water percolating to the aquifer. However, with the passage of time and continuing discharges to the RIB cells, the likelihood increases that part of the mix of waters percolating to the Upper Floridan aquifer will be reclaimed water.

Because the Upper Floridan aquifer is highly transmissive, the head (decreasing to the north and northeast) is largely independent of topography and local variations in recharge, and is mainly determined by regional-scale conditions. Movement of water in the aquifer is relatively rapid in the direction of the decreasing gradient, so that if reclaimed water enters the aquifer, concentrations of characteristic wastewater constituents will tend to be diluted and the constituents may not be detected at all unless the monitoring well is in the direction of regional flow from a RIB site.

DATA ANALYSIS AND EVALUATION

RECLAIMED WATER APPLICATION

The rates of application of reclaimed water at the RIB sites have been compiled by the private companies contracted to operate the systems, most recently by a subcontractor, PB Water. Application rates have been compiled for individual RIB cells. The data units are volumes per week in gallons, and data compiled to February 18, 2003, were used in the following summaries. Data values are rounded to the nearest thousand, or in some cases, hundreds of gallons. The number of RIB cells per site, and the date weekly compilation of flow data began at each site, are given in Table 1.

Table 1. Number of cells per RIB site and the date reclaimed water application began

RIB Site	Number of Cells	Beginning Date	Comments
3	6	January 29, 2002	
4	4	January 29, 2002	
5	3 4 3	October 10, 1986 November 12, 1996 January 29, 2002	New cell added New distribution
6	36 40	December 23, 1986 January 29, 2002	New cells added
7	6	October 10, 1986	
8	11 12	July 13, 1999 January 29, 2002	New cell added
9	4	October 10, 1986	

At site 5, it seems that the system of cells and distribution of flows was re-engineered in January 2002 without the loss of any previously used RIB cells. At site 6, some cells or parts of cells were closed to facilitate construction of a highway, the Western Beltway.

For purposes of this study, it was desired to convert the flow data into monthly and annual tabulations per RIB site. Weekly values at each RIB were converted to daily values based on an assumption that the flow rate was constant over each weekly period. Sums for each RIB were then computed, and concurrent sums for all RIBs at a site were computed for a total RIB site value. Monthly totals in gallons for all RIB sites since the beginning of operation are shown in Table 2. Annual totals in gallons for all RIB sites through 2002 are shown in Table 3.

Total volumes in gallons x 10^{10} discharged to each RIB site by the end of 2002 are listed in Table 4.

The annual discharge volumes are plotted in Figures 8–11 for the four RIB sites that have been in use since 1986–87. At most of these sites, discharge volumes peaked in years 1994–97, which were years of above-average rainfall. An increase over the previous two drought years is noted for the year 2002, in which substantial rainfall occurred. It is also noted that discharges of any appreciable volume ceased at RIB Site 9 after the initial year (1987), except for the high-rainfall year 1997 and for 2001. The reader should note that the vertical scales of Figures 10 and 11 differ from that common to Figures 8 and 9.

RECLAIMED WATER QUALITY

Measurements of chemical and biological constituents in the reclaimed water used for irrigation and disposal to the RIB basins have been obtained daily since December 2, 1986, the date of the first samples in the database maintained by PB Water The data file is formatted to contain values for 17 chemical and biological parameters. However, some parameters have only been measured during part of the period of record and others have been sampled at less than a daily frequency. The file used for this study contains values through August 31, 2002, and ‘pres’ refers to sampling that continued to nearly that date. Table 5 lists the parameters (table heading in parentheses), units of measurement, usual frequency of sampling, and the period of record for that parameter used in this study.

Total nitrogen (TN) is not measured directly but is computed as the sum of total Kjeldahl nitrogen, nitrate nitrogen, and nitrite nitrogen. Several parameters of special interest were plotted for inclusion in this report (Figures 12–19). These are specific conductance, total dissolved solids, chloride, nitrate nitrogen, phosphate, pH, biochemical oxygen demand (BOD), and fecal coliform. It is believed that the phosphate values have been converted to equivalent weights of phosphorus.

A statistical analysis was made for each illustrated constituent, and the range of values, mean value, median value, and standard deviation are included in each figure. The concentration values of each chemical or biological

Table 2. Monthly discharge volumes in gallons to individual RIB sites

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 1986	0	0	9761764	0	6384636	0	4345193
November, 1986	0	0	18252148	0	17877664	0	8700932
December, 1986	0	0	11483173	25752350	27663371	0	13999561
January, 1987	0	0	26879114	58331450	63135329	0	21312614
February, 1987	0	0	28152700	70914557	99420000	0	24054200
March, 1987	0	0	58254143	37379300	142856429	0	5309457
April, 1987	0	0	19511071	4881043	70800429	0	4039443
May, 1987	0	0	40219871	10678300	91738286	0	7516900
June, 1987	0	0	39482143	1916757	147368571	0	8763200
July, 1987	0	0	86293914	347643	157089286	0	219100
August, 1987	0	0	64598245	537600	71722750	0	28200
September, 1987	0	0	77821912	155929	134178107	0	0
October, 1987	0	0	58410700	5488529	92399000	0	580600
November, 1987	0	0	54641486	20482071	190790429	0	39600
December, 1987	0	0	76474314	7957071	217059714	0	1800
January, 1988	0	0	24256200	0	117096714	0	13700
February, 1988	0	0	66908343	34725843	187664286	0	1982171
March, 1988	0	0	67405114	47608414	119784143	0	2911529
April, 1988	0	0	2438786	55009629	68017957	0	200943
May, 1988	0	0	12457943	90492314	71968486	0	326257
June, 1988	0	0	46638700	97086857	52472271	0	318471
July, 1988	0	0	49663914	113378586	96114043	0	328229
August, 1988	0	0	6838529	166603457	245183771	0	421943
September, 1988	0	0	38911729	121859729	219986657	0	416443
October, 1988	0	0	6753657	135113386	124586343	0	431914
November, 1988	0	0	29138929	136236686	165233214	0	279200
December, 1988	0	0	93568300	65431414	136095757	0	97000
January, 1989	0	0	70223071	92941286	127907971	0	95800
February, 1989	0	0	27816414	67660043	81859686	0	72800
March, 1989	0	0	32624729	143975571	124576957	0	91114
April, 1989	0	0	49485543	132543343	130154414	0	177586
May, 1989	0	0	7098600	129339571	76094900	0	135400
June, 1989	0	0	26254586	112304529	123287286	0	61600
July, 1989	0	0	40214014	116547843	159572243	0	106000
August, 1989	0	0	46179729	168422614	146592057	0	25286
September, 1989	0	0	73542800	160322729	209088186	0	101000

Table 2—*Continued*

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 1989	0	0	77946857	143560957	94710514	0	153414
November, 1989	0	0	52218014	131105286	109524800	0	98000
December, 1989	0	0	64555167	77940814	216743076	0	93600
January, 1990	0	0	71591162	156212971	120718281	0	102214
February, 1990	0	0	68706714	150801114	137048357	0	34286
March, 1990	0	0	45900614	159206729	111698586	0	63900
April, 1990	0	0	91825243	165107286	109936143	0	115700
May, 1990	0	0	18527643	132034043	42259043	0	212186
June, 1990	0	0	66700929	182409929	138121157	0	98114
July, 1990	0	0	51459929	198261886	176684843	0	193800
August, 1990	0	0	82206443	132389914	182187800	0	301800
September, 1990	0	0	47983900	77952257	129281200	0	328643
October, 1990	0	0	63191743	106458571	142324243	0	20457
November, 1990	0	0	44729114	48936871	86530586	0	316300
December, 1990	0	0	31747300	59669929	121080329	0	39900
January, 1991	0	0	59605700	146327757	114120243	0	165214
February, 1991	0	0	32362643	106908171	98186314	0	150657
March, 1991	0	0	70927886	118774486	108424843	0	95429
April, 1991	0	0	14985414	113172043	214624814	0	81086
May, 1991	0	0	74384071	131323086	169833800	0	78857
June, 1991	0	0	76165371	134622786	217543843	0	84943
July, 1991	0	0	125025743	50501971	335162343	0	10214
August, 1991	0	0	111264014	0	240184729	0	0
September, 1991	0	0	61847557	0	137832971	0	0
October, 1991	0	0	107629000	0	202203743	0	0
November, 1991	0	0	67092129	0	105856100	0	0
December, 1991	0	0	60853357	0	71329814	0	0
January, 1992	0	0	35937814	0	150908814	0	0
February, 1992	0	0	106759343	0	176599214	0	0
March, 1992	0	0	77386386	0	102611414	0	0
April, 1992	0	0	111183857	0	214968857	0	0
May, 1992	0	0	18235971	0	71571743	0	0
June, 1992	0	0	103760243	0	269467971	0	0
July, 1992	0	0	63816800	0	175236514	0	0
August, 1992	0	0	117604900	0	274270514	0	0
September, 1992	0	0	99261500	91003386	76769857	0	0

Table 2—*Continued*

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 1992	0	0	19945714	186213714	176597486	0	0
November, 1992	0	0	70957886	165968100	162728657	0	0
December, 1992	0	0	71729900	135307786	90005757	0	0
January, 1993	0	0	88384014	147542600	200425186	0	0
February, 1993	0	0	72871571	96925386	239085971	0	0
March, 1993	0	0	119391771	114745457	242394729	0	0
April, 1993	0	0	46969486	110701629	136228286	0	0
May, 1993	0	0	59017057	120122843	109202871	0	0
June, 1993	0	0	59915986	137157771	176591414	0	0
July, 1993	0	0	101792043	126770129	263563257	0	0
August, 1993	0	0	22215814	163827186	65869557	0	0
September, 1993	0	0	53914257	141331229	95973100	0	0
October, 1993	0	0	37509971	150483271	67685243	0	0
November, 1993	0	0	38549986	151837200	57520157	0	0
December, 1993	0	0	16266271	159452586	42906057	0	0
January, 1994	0	0	29496771	167011129	53890914	0	0
February, 1994	0	0	40068700	148048200	132563700	0	0
March, 1994	0	0	40486057	148302757	150657186	0	0
April, 1994	0	0	5639943	146705229	30171486	0	0
May, 1994	0	0	26331071	158305814	51428171	0	0
June, 1994	0	0	78774214	120393143	244555386	0	0
July, 1994	0	0	133176714	60978600	328602214	0	0
August, 1994	0	0	107961186	77475257	261989657	0	0
September, 1994	0	0	141505243	142504600	287046286	0	2825700
October, 1994	0	0	109811571	123076700	268247614	0	7100
November, 1994	0	0	131570586	196175400	230275771	0	167400
December, 1994	0	0	123094543	222761043	267826814	0	0
January, 1995	0	0	124679000	167665614	256770029	0	0
February, 1995	0	0	102332371	92404729	207490071	0	0
March, 1995	0	0	101506814	97055729	215270586	0	0
April, 1995	0	0	62776271	103433229	177624471	0	0
May, 1995	0	0	54563800	172046671	110989114	0	0
June, 1995	0	0	96344986	177375914	154671500	0	0
July, 1995	0	0	153372929	164235171	250593943	0	0
August, 1995	0	0	158975786	148620529	326422771	0	0
September, 1995	0	0	166211914	144120600	257637114	0	0

Table 2—*Continued*

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 1995	0	0	142377571	155954143	293264143	0	0
November, 1995	0	0	82213857	56187029	242575000	0	0
December, 1995	0	0	83966143	108445600	173626857	0	0
January, 1996	0	0	126925429	167826200	270958000	0	0
February, 1996	0	0	77791000	97670400	175293286	0	0
March, 1996	0	0	126888143	150445614	292107286	0	0
April, 1996	0	0	88545714	132625671	164114143	0	0
May, 1996	0	0	62775286	82584200	150032714	0	0
June, 1996	0	0	109956286	165905814	313608286	0	0
July, 1996	0	0	124390000	150668671	234989857	0	0
August, 1996	0	0	127303857	181102700	268004857	0	0
September, 1996	0	0	122570714	166711529	267612286	0	0
October, 1996	0	0	295513714	162285643	277756429	0	0
November, 1996	0	0	309783143	94451100	159167429	0	0
December, 1996	0	0	116648000	147053586	228073714	0	0
January, 1997	0	0	139088143	141966886	218913286	0	0
February, 1997	0	0	77859571	135600657	177171714	0	9176871
March, 1997	0	0	43864429	115905329	141395429	0	28744829
April, 1997	0	0	99841143	152534186	171007143	0	24417043
May, 1997	0	0	66718143	99321257	75100286	0	11795857
June, 1997	0	0	72037714	202050557	137108571	0	0
July, 1997	0	0	143416571	163265800	302629000	0	0
August, 1997	0	0	126807857	149148657	287937286	0	0
September, 1997	0	0	55306429	82341386	115352286	0	4518714
October, 1997	0	0	78340714	127578414	104089429	0	10877286
November, 1997	0	0	73615143	101104886	202819000	0	0
December, 1997	0	0	131402857	176320286	316410000	0	0
January, 1998	0	0	159645714	133895614	310544857	0	0
February, 1998	0	0	144166857	181879214	271220286	0	0
March, 1998	0	0	163169429	202685014	272368000	0	0
April, 1998	0	0	91678000	80282300	145145143	0	0
May, 1998	0	0	76161714	48508843	91908429	0	0
June, 1998	0	0	13129429	1507186	24479429	0	0
July, 1998	0	0	76674143	99772429	207556000	0	0
August, 1998	0	0	103028143	113093671	232536857	0	0
September, 1998	0	0	230152429	173105971	150924714	0	0

Table 2—*Continued*

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 1998	0	0	86505571	101188414	140410429	0	0
November, 1998	0	0	72506000	81586214	126224857	0	0
December, 1998	0	0	81283714	108759143	113351286	0	0
January, 1999	0	0	103838429	133461300	164532143	0	0
February, 1999	0	0	83685000	100791543	128131714	0	0
March, 1999	0	0	65073714	75123843	53557286	0	0
April, 1999	0	0	25312714	16874571	79646714	0	0
May, 1999	0	0	56208429	44730500	167979857	0	0
June, 1999	0	0	69620000	159025371	248311286	0	0
July, 1999	0	0	76042000	130895386	162226571	9163857	0
August, 1999	0	0	58792000	125138629	127181286	1431143	0
September, 1999	0	0	81357714	107686414	194015571	0	0
October, 1999	0	0	125607143	134190257	278507857	0	0
November, 1999	0	0	89158429	147286271	175504571	0	0
December, 1999	0	0	69123429	140253000	158478571	0	0
January, 2000	0	0	71196286	170648271	186578286	0	0
February, 2000	0	0	75708000	126934843	118631000	0	0
March, 2000	0	0	41735714	50176900	22368143	0	0
April, 2000	0	0	43872714	52382471	96789571	0	0
May, 2000	0	0	9632714	15563214	28766000	0	0
June, 2000	0	0	29406857	47247571	96986143	0	0
July, 2000	0	0	72989000	123540700	213572143	0	0
August, 2000	0	0	64987857	127019329	188588571	0	0
September, 2000	0	0	74479429	152407786	152789857	0	0
October, 2000	0	0	28874429	81166343	62615571	0	0
November, 2000	0	0	38194429	77078200	68544714	123000	0
December, 2000	0	0	78283000	113845957	145791429	611143	0
January, 2001	0	0	69894429	119637614	156071429	15220571	6355571
February, 2001	0	0	50315000	119926543	108163286	25297857	8760600
March, 2001	0	0	49346286	151936771	159167857	55886000	10879400
April, 2001	0	0	28018143	68666857	80544286	60904429	7808229
May, 2001	0	0	34639714	54420600	10814000	57103000	12882986
June, 2001	0	0	115040286	113688729	33242714	109389429	25842300
July, 2001	0	0	112565286	157772871	150042714	112108143	10249129
August, 2001	0	0	62429000	190533100	126169857	94415000	1567486
September, 2001	0	0	79668857	44868571	178447571	39464143	0

Table 2—*Continued*

Month and Year	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
October, 2001	0	0	44712857	56688386	63811857	24741000	0
November, 2001	0	0	32482000	100725357	77300143	34909857	0
December, 2001	0	0	23595000	76299886	82571143	38551429	0
January, 2002	117857	54000	25257714	95323471	120044000	45089857	0
February, 2002	1753571	3719000	26606857	106091886	114442714	31927571	0
March, 2002	27460714	8240000	27968286	96044443	71999714	37091429	0
April, 2002	25368571	4773000	17728000	73387586	26317714	23706857	0
May, 2002	19011143	7897714	17778429	41594800	21913571	13004714	0
June, 2002	59635286	23256000	90579857	177383114	186032571	50177429	0
July, 2002	73707857	44911286	102620429	243935400	191090857	57888143	0
August, 2002	98561714	54913857	123862143	170520229	212898000	40976429	0
September, 2002	114856286	58920143	115380286	74853271	152832857	28472571	0
October, 2002	96145857	46822857	85950143	71675600	100498857	41431000	0
November, 2002	106075714	56447143	97387571	50249614	106645571	40460857	0
December, 2002	116186429	55177857	132125714	112705100	188491857	38747571	0
January, 2003	131939714	32993143	108438143	131390629	122857857	17757286	0

Table 3. Annual discharge volumes in gallons to individual RIB sites

Year	Site 3	Site 4	Site_5	Site 6	Site 7	Site 8	Site 9
1986	0	0	39497086	25752350	51925671	0	27045686
1987	0	0	630739614	219070250	1478558329	0	71865114
1988	0	0	444980143	1063546314	1604203643	0	7727800
1989	0	0	568159524	1476664586	1600112090	0	1211600
1990	0	0	684570733	1569441500	1497870567	0	1827300
1991	0	0	862142886	801630300	2015303557	0	666400
1992	0	0	896580314	578492986	1941736800	0	0
1993	0	0	716798229	1620897286	1697445829	0	0
1994	0	0	967916600	1711737871	2307255200	0	3000200
1995	0	0	1329321443	1587544957	2666935600	0	0
1996	0	0	1689091286	1699331129	2801718286	0	0
1997	0	0	1108298714	1647138300	2249933429	0	89530600
1998	0	0	1298101143	1326264014	2086670286	0	0
1999	0	0	903819000	1315457086	1938073429	10595000	0
2000	0	0	629360429	1138011586	1382021429	734143	0
2001	0	0	702706857	1255165286	1226346857	667990857	84345700
2002	738881000	365132857	863245429	1313764514	1493208286	448974429	0
Totals	738881000	365132857	14335329430	20349910315	30039319288	1128294429	287220400

Table 4. Total volumes in 10^{10} gallons applied to each RIB site as of December 31, 2002

Site 3	0.074
Site 4	0.037
Site 5	1.436
Site 6	2.035
Site 7	3.004
Site 8	0.113
Site 9	0.029

Table 5. Parameters measured in the discharge stream from the Wastewater Treatment Plant

Parameter	Unit of Measurement	Frequency of Sampling	Period of Record
CL2			12/2/86–pres
5-day biochemical oxygen demand (CBOD5)	mg/L	Daily to sporadically	12/2/86–pres
Total suspended solids (TSS)	Milligrams per liter (mg/L)	Daily to sporadically	12/2/86–pres
pH	pH units	Daily	12/2/86–pres
Nitrate nitrogen plus nitrite nitrogen (NOx)	mg/L	Daily	11/1/91–9/30/98
Nitrate nitrogen (NO3)	mg/L	Daily	12/2/86–10/31/91 10/1/98–pres
Fecal coliform (FC)	CFU/100ml	Sporadically	12/2/86–12/19/99
Nitrite nitrogen (NO2)	mg/L	Daily to sporadically	12/2/86–3/31/88 10/1/91 - pres
Ammonia (NH3)	mg/L	Daily	12/2/86–3/31/88 10/1/91 - pres
Total Kjeldahl nitrogen (TKN)	mg/L	Daily	12/2/86–3/31/88 11/1/93 - pres
Total nitrogen (TN)	mg/L	Daily	12/2/86–3/31/88
Phosphate (PO4)	mg/L	Daily Weekly	12/2/86–3/31/88 10/1/97 - pres
Orthophosphate (OPO4)	mg/L	Daily	12/2/86–3/31/88
Specific conductance (ECW)	microsiemens per centimeter	Daily	1/1/94 - pres
Chloride	mg/L	Weekly	10/1/97 - pres
Sodium	mg/L	Weekly	10/1/97 - pres
Total dissolved solids (TDS)	mg/L	Weekly	12/12/01 - pres

Note: in Table 5 “pres” refers to August 31, 2002

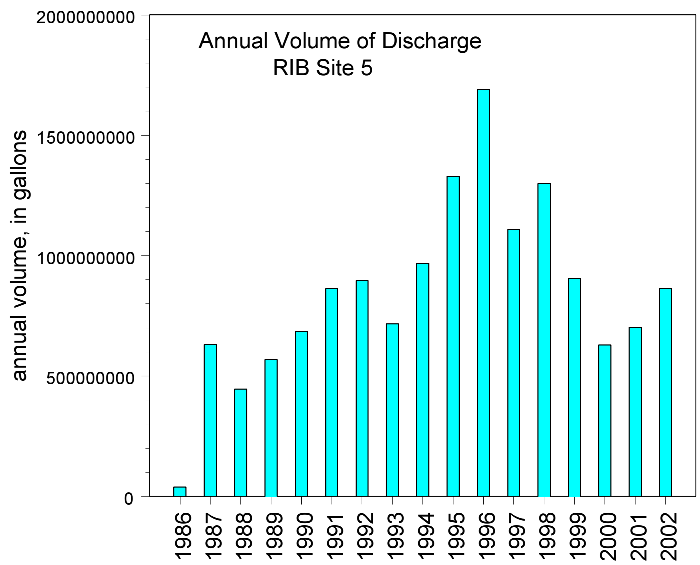

Figure 8. Annual volumes of discharge at RIB Site 5

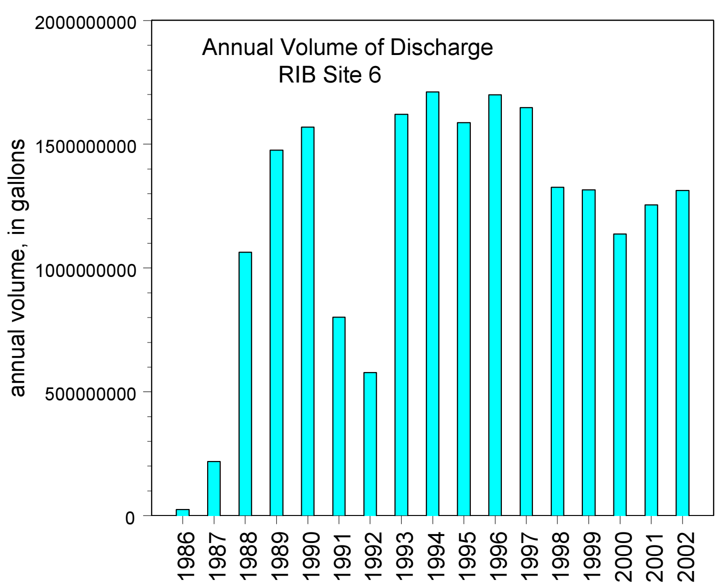

Figure 9. Annual volumes of discharge at RIB Site 6

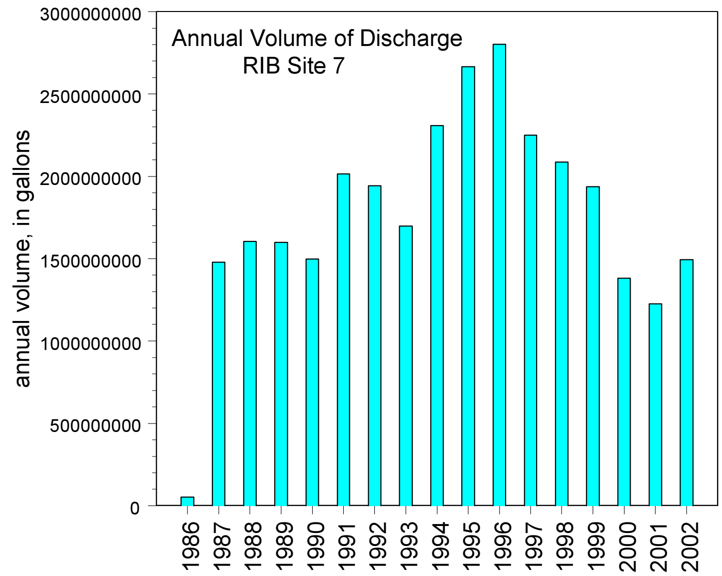

Figure 10. Annual volumes of discharge at RIB Site 7

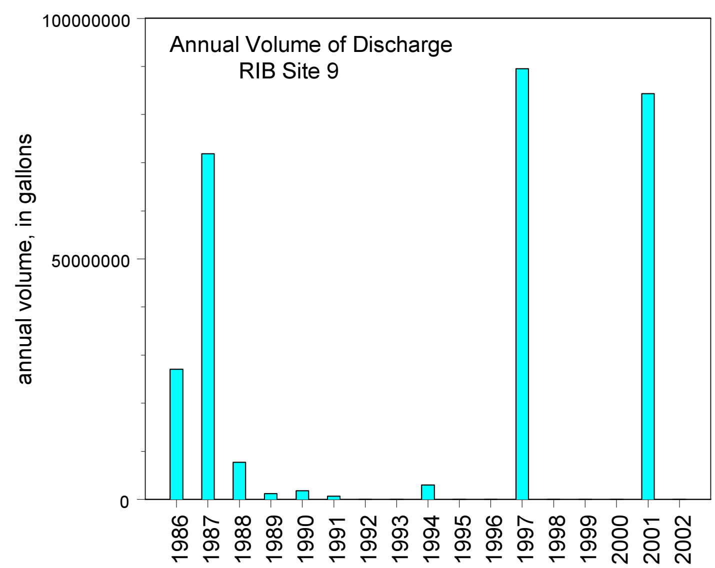

Figure 11. Annual volumes of discharge at RIB Site 9

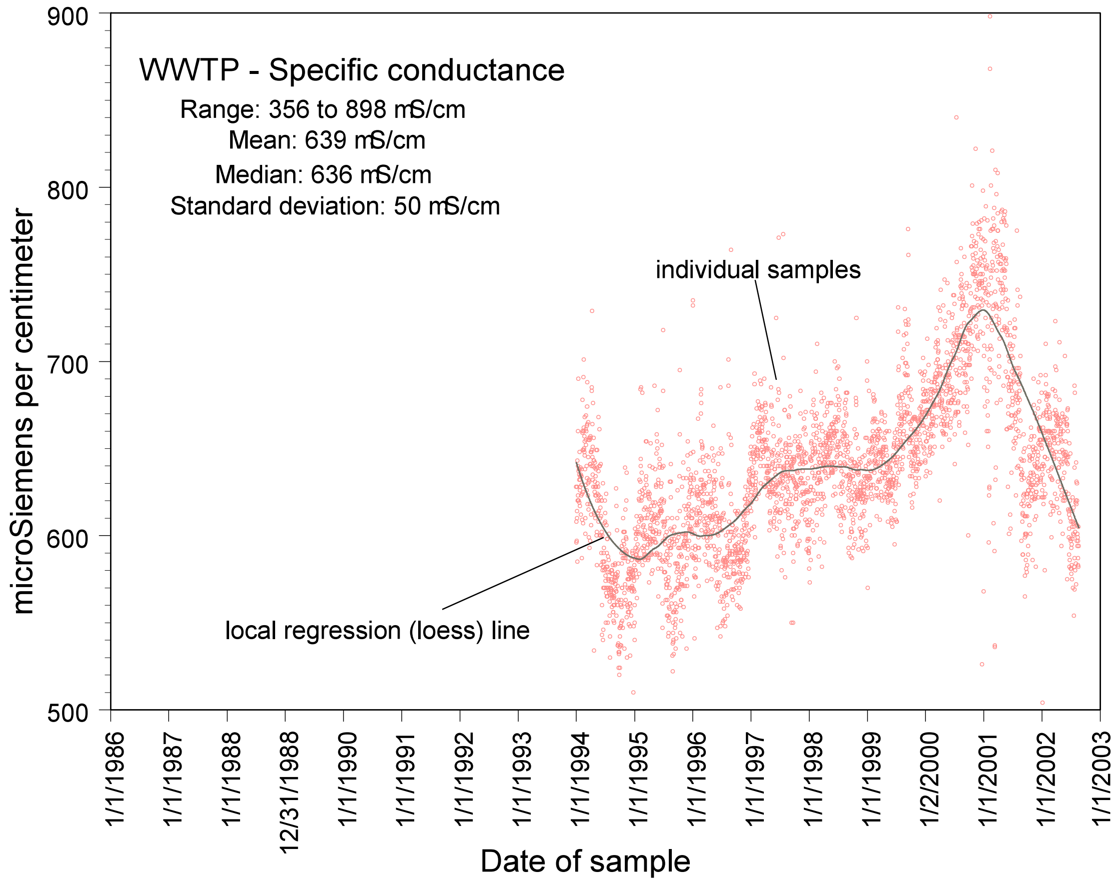

Figure 12. Measurements of specific conductance in the reclaimed water used for recharge in the RIB basins

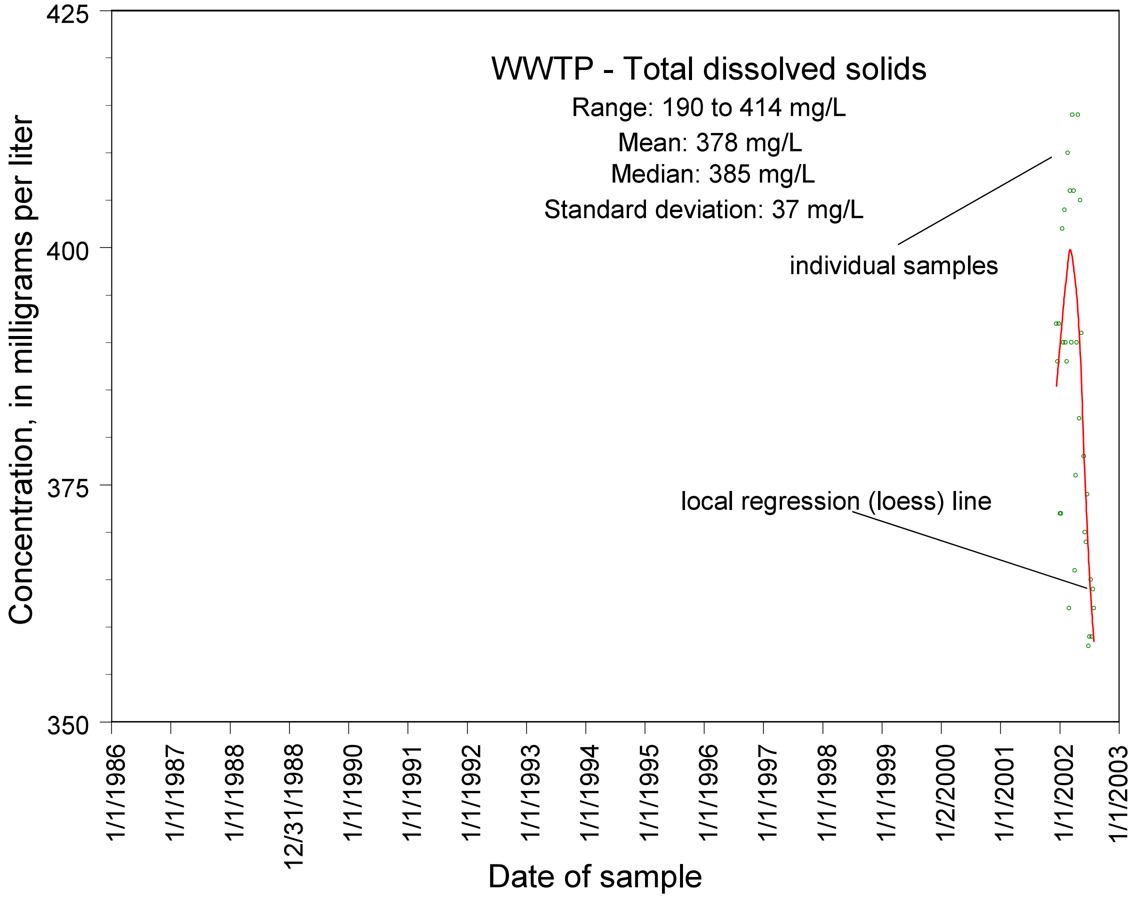

Figure 13. Measurements of total dissolved solids in the reclaimed water used for recharge in the RIB basins

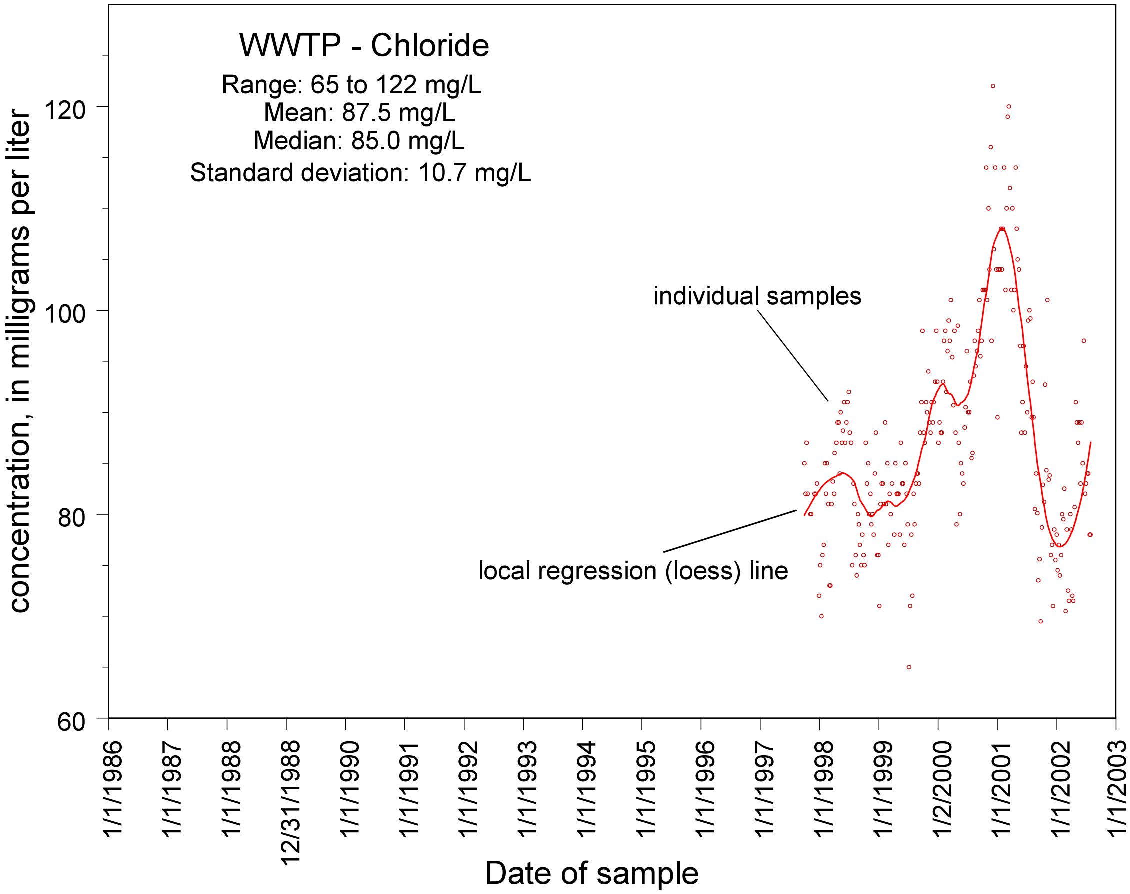

Figure 14. Measurements of chloride in the reclaimed water used for recharge in the RIB basins

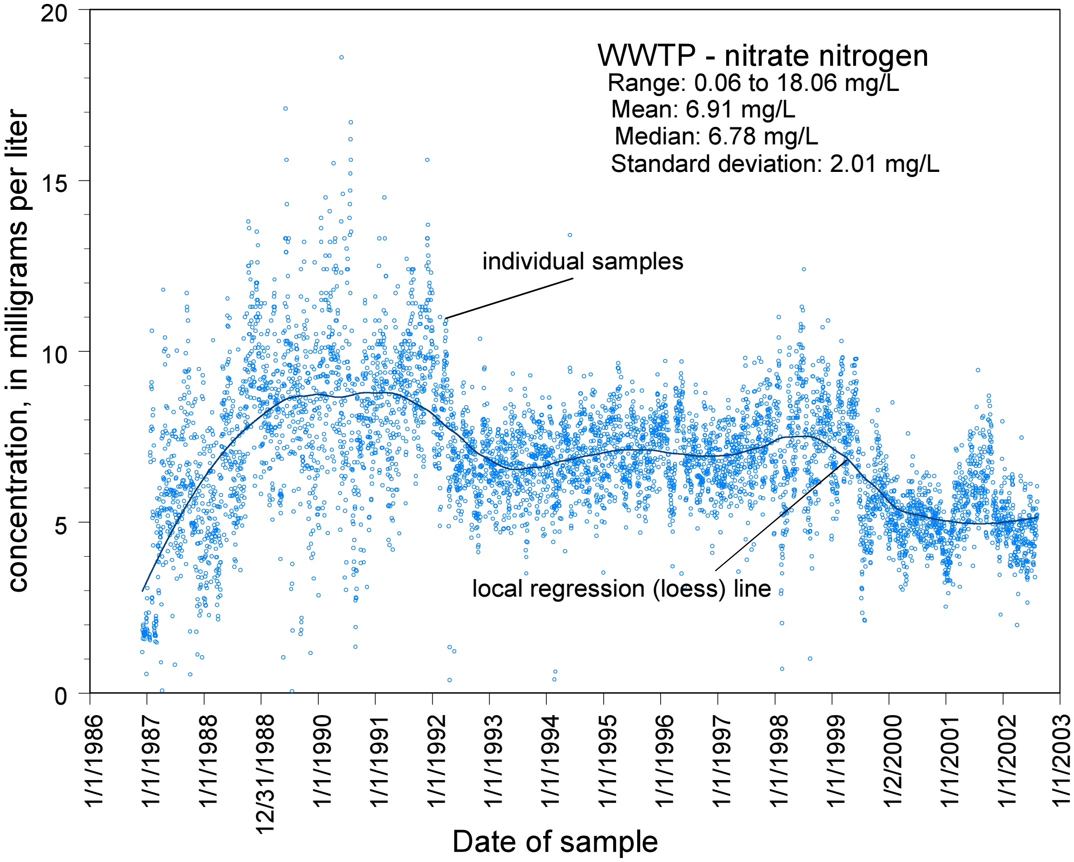

Figure 15. Measurements of nitrate nitrogen in the reclaimed water used for recharge in the RIB basins

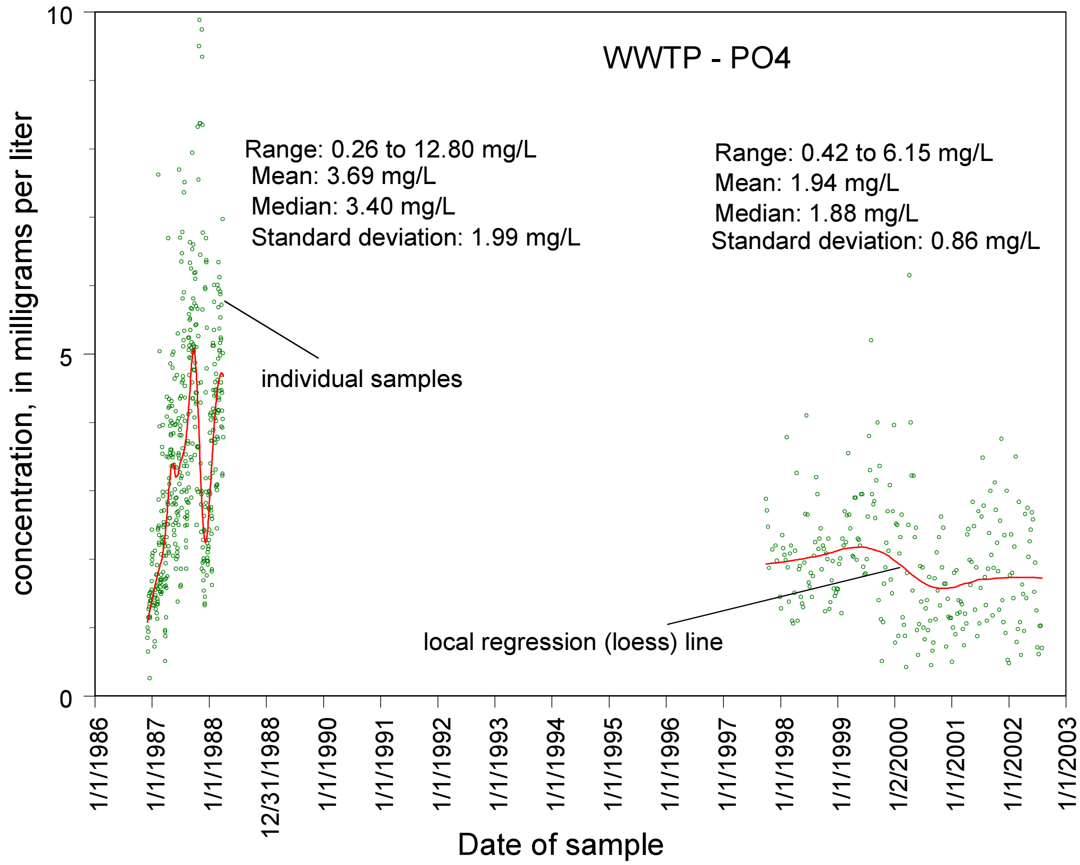

Figure 16. Measurements of phosphate in the reclaimed water used for recharge in the RIB basins

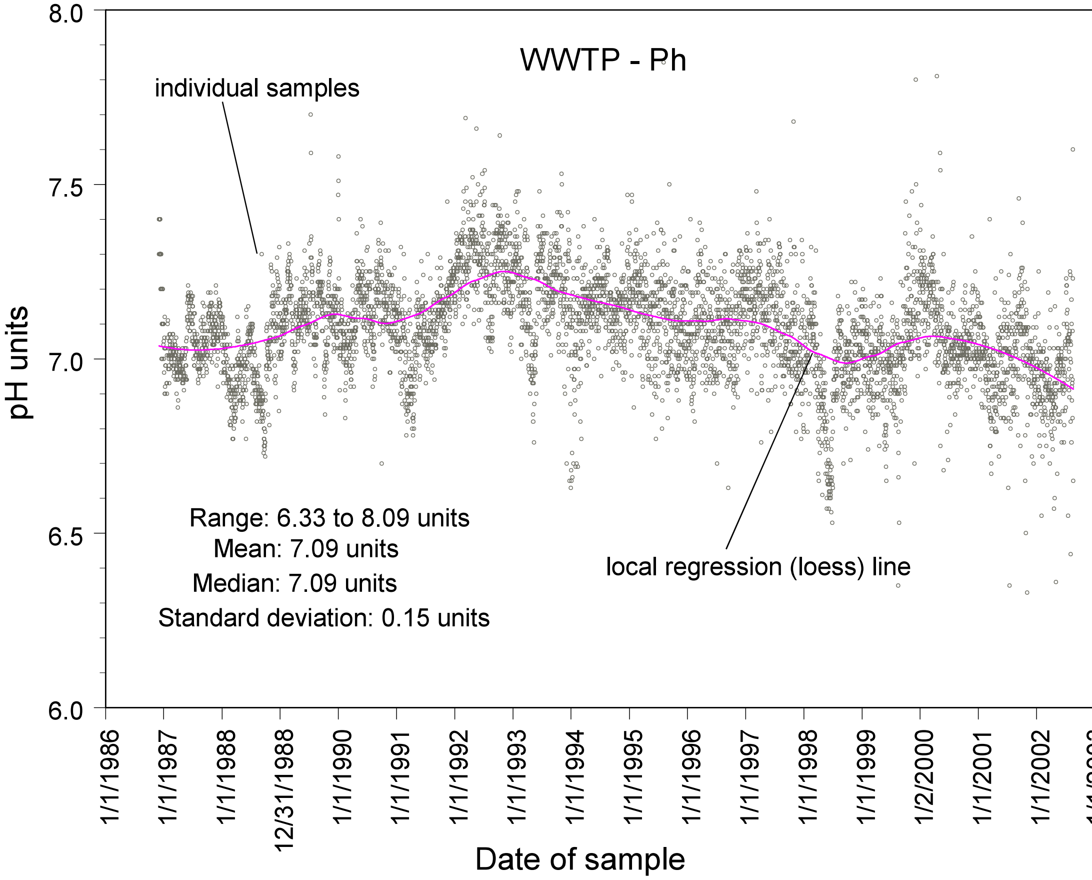

Figure 17. Measurements of pH in the reclaimed water used for recharge in the RIB basins

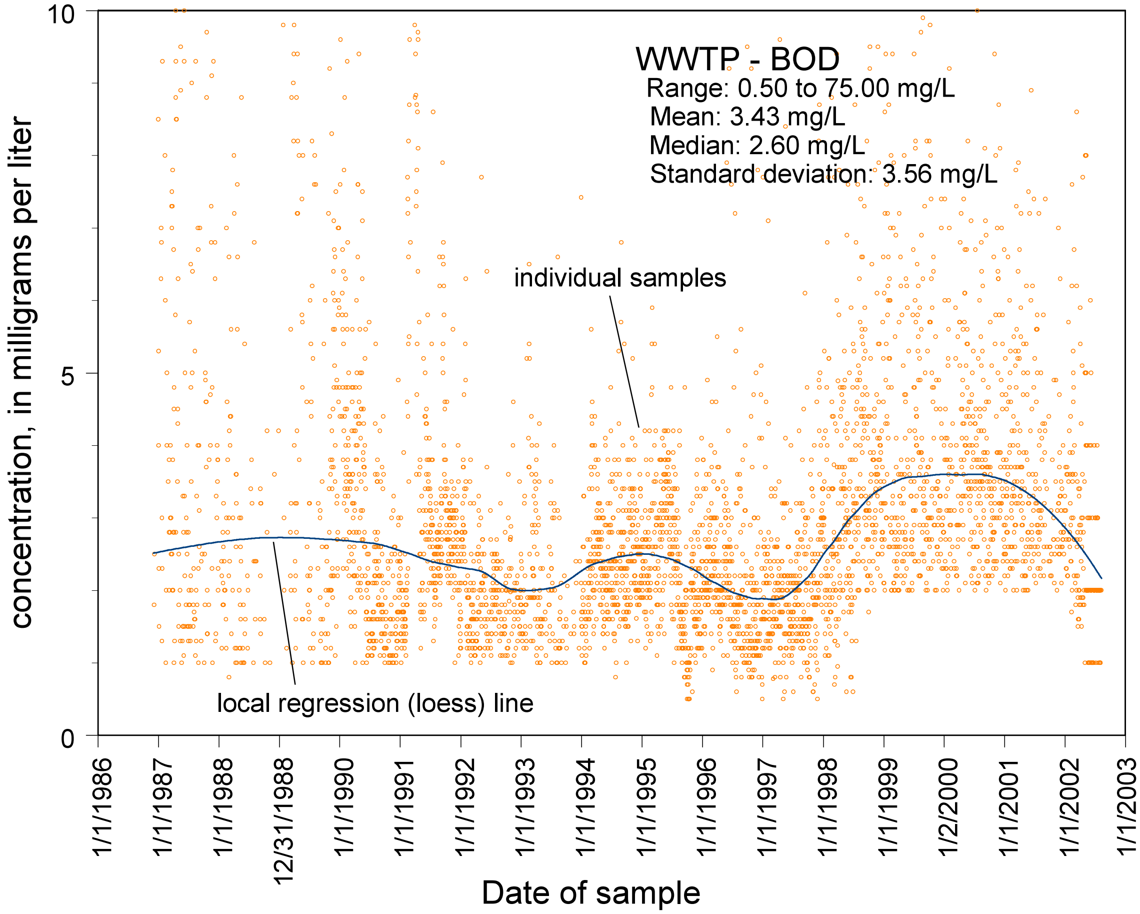

Figure 18. Measurements of 5-day biochemical oxygen demand (BOD_5) in the reclaimed water used for recharge in the RIB basins

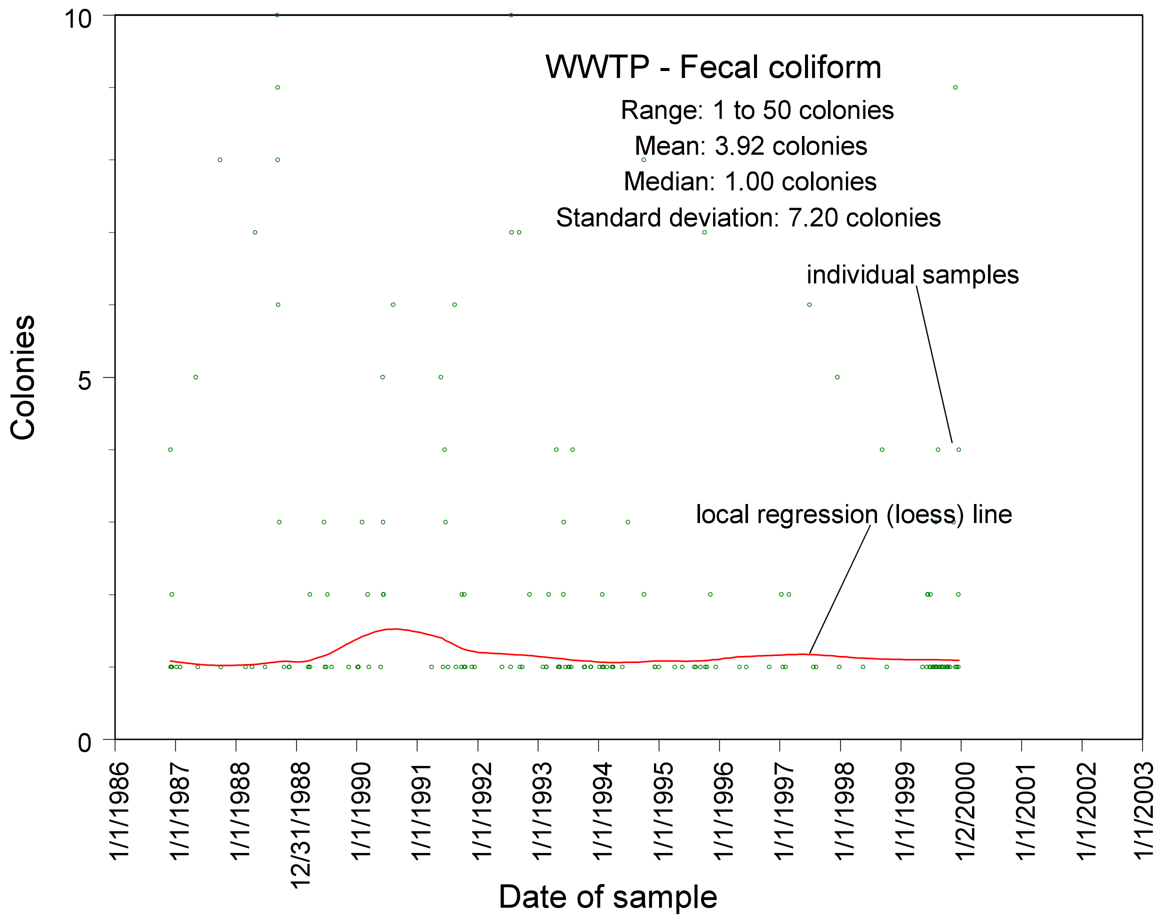

Figure 19. Measurements of fecal coliform in the reclaimed water used for recharge in the RIB basins

constituent have a high degree of variance. Therefore, in order to more clearly depict time trends in the data, a local least squares regression (loess) line was computed and plotted over the data. The loess procedure is a non-parametric noise-reduction smoothing algorithm. The distribution of errors was assumed to be symmetric, a span of 0.3 was used, and the fit was of second degree and unweighted.

The mean values of specific conductance and concentrations of total dissolved solids, chloride, nitrate nitrogen, and phosphate found in the reclaimed water are higher than would be found in natural, background water samples from the surficial or Upper Floridan aquifers, with the exception that nitrate nitrogen concentrations as high could be found where aquifer water has been altered by fertilization and irrigation for agriculture. The mean pH is only slightly greater than neutral.

RAINFALL

The daily rainfall data record maintained by PB Water begins on March 12, 1987, at eight stations, one in RIB site 5, four in RIB site 6, two in RIB site 7, and one in RIB site 9. The data file used for this study contains data to August 18, 2002. On January 10, 2002, six new daily rainfall stations were activated, three in RIB site 3, two in RIB site 4, and an additional station in RIB site 6.

Data for the eight long-term stations are compiled as monthly totals in Table 6, which also has a column containing the eight-station average. Annual totals from 1988 through 2001 are presented in Table 7.

The eight-station averages for years 1988-2001 are shown in Figure 20. Figure 21 depicts the cumulative memory factor (Merritt 2001) at rainfall station 5-1 (at RIB site 5). The “memory factor” is a sum of antecedent rainfall amounts multiplied by weights that reduce their significance in the sum in proportion to the time elapsed since the rainfall occurred. Here the rainfall values are monthly, and a 60-month memory factor is computed using weights of $1-(i-1)/60$, where i is the number of elapsed months from the present month in the calculation. The values are normalized about their average. The memory factor does not have a precise hydrologic significance and a different weighting system and time span might be used for other applications, but it is useful in illustrating the cumulative effect of rainfall and for developing correlations with other hydrologic data.

Memory factor values are not computed before May 1992, at the end of the first 60-month data period from station 5-1. The plot shows the significance of high rainfall amounts in late 1994, late 1995 and early 1996, and during the El Nino winter of 1997-98. Also shown is the effect of the drought that began in late 1999 and lasted until the summer of 2002.

LAKE-STAGE MEASUREMENTS

The Water Conserv II area includes many large and small lakes. Because the stages of these lakes might be impacted by the discharge of reclaimed water to the RIB basins, with concomitant economic impacts, stages of these lakes have been monitored. The database now maintained by PB Water contains

Table 6. Monthly rainfall totals in inches from eight stations in four RIB sites and the eight-station average

Month	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
5/1987	4.92	2.82	2.32	2.66	3.1	4.08	4.79	4.79	3.685
6/1987	3.91	2.51	2.45	2.79	3.73	2.25	1.8	1.83	2.65875
7/1987	3.21	5.07	4.4	4.64	4.16	3.75	4.04	3.76	4.12875
8/1987	4.2	4.94	5.84	6.15	4.72	5.77	5.9	5.46	5.3725
9/1987	3.8	4.76	4.8	4.04	3.92	5.76	6.17	7.22	5.05875
10/1987	2.88	2.42	2.42	2.7	2.35	2.66	2.66	2.45	2.5675
11/1987	9.99	9.89	9.88	10.18	10.37	9.96	10.28	10.49	10.13
12/1987	0.34	0.24	0.19	0.26	0.52	0.63	0.61	0.37	0.395
1/1988	4.96	4.65	4.16	4.62	4.7	3.87	3.85	3.62	4.30375
2/1988	1.46	1.26	1.13	1.32	1.22	1.23	1.34	1.51	1.30875
3/1988	7.6	7.09	7.21	7.36	7.43	6.42	7.84	8.23	7.3975
4/1988	0.65	0.46	0.46	0.47	0.43	0.6	0.6	0.57	0.53
5/1988	2.17	2.33	2.35	2.4	2.33	2.47	2.57	2.57	2.39875
6/1988	6.97	7.36	6.71	7.33	7.39	5.9	4.71	5.86	6.52875
7/1988	5.6	4.88	4.81	4.45	4.78	6.43	5.7	5.58	5.27875
8/1988	4.83	4.23	4.37	4.76	4.64	4.79	5.01	5.5	4.76625
9/1988	5.47	6.01	6.17	6.35	5.61	6.6	6.29	6.73	6.15375
10/1988	1.91	3.11	2.45	2.66	2.52	1.89	1.56	1.65	2.21875
11/1988	6.73	6.41	6.51	6.7	6.7	6.38	6.61	6.74	6.5975
12/1988	1.79	1.79	2.01	1.83	1.89	1.55	1.46	1.4	1.715
1/1989	3.23	2.89	2.79	2.92	2.73	3.19	2.98	3.09	2.9775
2/1989	0.06	0.07	0.09	0.09	0.05	0.13	0.15	0.1	0.0925
3/1989	1.27	1.02	0.99	0.96	0.81	0.99	1	1.13	1.02125
4/1989	3.93	2.54	2.28	2.98	3.37	3.46	3.51	2.89	3.12
5/1989	2.18	1.97	1.68	1.65	2.31	2.39	2.32	2.12	2.0775
6/1989	5.92	4.08	3.47	4.19	5.47	4.92	4.78	3.93	4.595
7/1989	8.51	8.29	8.77	8.13	8.62	10.04	9.79	6.97	8.64
8/1989	2.36	3.93	4.58	3.83	3.82	2.8	3.06	2.63	3.37625
9/1989	7.79	5.73	6.22	7.34	8.09	8.45	8.2	7.27	7.38625
10/1989	0.35	0.33	0.41	0.37	0.25	0.44	0.31	0.35	0.35125
11/1989	1.56	1.3	1.28	1.36	1.43	1.66	1.67	2.44	1.5875
12/1989	5.13	5.32	5.13	4.84	4.7	4.45	4.54	4.7	4.85125
1/1990	0.53	0.44	0.44	0.43	0.51	0.34	0.34	0.29	0.415
2/1990	3.22	2.69	2.68	2.79	2.91	3.44	3.51	3.6	3.105
3/1990	1.16	1.26	1.36	1.16	0.95	1.42	1.15	1.34	1.225
4/1990	1.52	0.78	0.89	0.99	0.97	1.07	1.08	1.12	1.0525
5/1990	1.8	0.65	0.83	0.92	1.07	1.58	1.91	2.12	1.36

Table 6—*Continued*

Month	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
6/1990	10.06	5.63	5.73	6.35	7.13	7.28	6.77	6.4	6.91875
7/1990	7.33	5.59	5.39	6.09	6.6	7.86	7.71	8.6	6.89625
8/1990	6.3	8.18	9.74	7.81	7.63	6.39	7.5	7.16	7.58875
9/1990	4.8	4.09	4.44	4.62	5.04	5.02	6.1	6.42	5.06625
10/1990	2.62	3.36	2.73	2.63	2.77	2.23	2.48	2.05	2.60875
11/1990	1.13	0.91	1.22	0.97	0.97	0.76	0.6	1	0.945
12/1990	0.39	0.26	0.28	0.23	0.25	0.48	0.47	0.35	0.33875
1/1991	2.4	2.11	1.94	1.97	2.06	2.35	2.65	2.6	2.26
2/1991	0.41	0.39	0.37	0.34	0.42	0.41	0.42	0.55	0.41375
3/1991	5.09	6.49	6.29	5.94	6.52	5.43	5.45	5.35	5.82
4/1991	6.33	7.4	7.68	7.12	7.86	6.36	6.35	6.41	6.93875
5/1991	4.9	4.03	4.13	4.18	4.21	7.51	8.38	11.4	6.0925
6/1991	7.23	8.27	7.96	8.66	8.48	4.64	6.37	4.11	6.965
7/1991	13.96	12.04	11.31	12.09	12.89	15.51	14.87	13.42	13.26125
8/1991	2.79	3.64	4.02	3.63	3.62	2.3	1.99	2.36	3.04375
9/1991	1.75	1.55	1.82	1.55	1.6	2.26	2.3	1.81	1.83
10/1991	3.24	4.77	4.35	4.93	4.12	3.46	3.71	2.54	3.89
11/1991	0.18	0.2	0.2	0.2	0.24	0.24	0.19	0.21	0.2075
12/1991	0.15	0.13	0.12	0.09	0.11	0.1	0.1	0.2	0.125
1/1992	1.64	1.69	1.55	1.6	1.67	1.19	1.19	1.23	1.47
2/1992	4.11	3.79	3.67	4.05	3.74	3.98	3.96	4.1	3.925
3/1992	3.33	2.67	2.6	2.68	2.51	3.29	3.07	3.37	2.94
4/1992	3.65	3.45	3.52	3.63	4.02	3.52	3.29	3.31	3.54875
5/1992	1.03	0.67	1.16	1.37	0.9	1.2	1.24	1.36	1.11625
6/1992	9.08	9.09	8.51	8.74	9.36	8.5	8.82	7.95	8.75625
7/1992	3.67	2.38	2.59	2.81	2.75	3.02	2.65	1.67	2.6925
8/1992	9.43	7.99	6.46	6.36	8.06	6.02	5.04	6.31	6.95875
9/1992	4.08	4.93	4.32	4.9	5.54	5.25	6.12	5.78	5.115
10/1992	4.39	4.25	3.53	4.11	4.32	4.07	4.24	3.97	4.11
11/1992	4.23	3.41	3.48	3.26	3.98	3.7	4.05	4.43	3.8175
12/1992	0.49	0.37	0.42	0.44	0.51	0.58	0.64	0.74	0.52375
1/1993	4.99	5.59	4.91	4.86	5.01	5.5	6.01	5.77	5.33
2/1993	2.28	1.82	2.47	2.16	2.23	2.72	3.28	3.67	2.57875
3/1993	3.55	3.79	3.95	4.12	4.24	4.19	4.13	4.4	4.04625
4/1993	2.11	1.9	1.45	1.84	1.95	2.05	2.14	2.29	1.96625
5/1993	4.34	5.48	4.52	4.02	4.81	4.23	3.99	4.85	4.53
6/1993	3.49	2.16	1.72	1.77	2.67	1.57	1.26	2.57	2.15125
7/1993	5.99	2.96	3.38	4.24	4.12	4.94	5.78	5.88	4.66125

Table 6—*Continued*

Month	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
8/1993	3.89	4.93	4.72	4.45	5.43	4.5	5.19	4.83	4.7425
9/1993	3.89	4.07	3.93	3.55	4.69	4.35	3.79	4.85	4.14
10/1993	2.97	3.35	3.63	3.48	3.01	2.5	2.57	3.23	3.0925
11/1993	0.12	0.03	0.02	0.1	0.06	0.06	0.17	0.14	0.0875
12/1993	1.08	0.96	0.91	0.94	1	0.97	0.94	0.86	0.9575
1/1994	6.44	4.96	4.92	5.09	5.61	4.24	4.39	4.66	5.03875
2/1994	1.07	0.74	0.74	0.64	0.87	1	1.13	1.16	0.91875
3/1994	2.21	2.05	2.12	1.79	1.94	2.4	2.4	2.4	2.16375
4/1994	1.9	1.02	1.27	1.1	1.36	1.33	1.36	1.38	1.34
5/1994	1.04	1.89	2.03	1.51	1.35	1.16	1.26	1.39	1.45375
6/1994	18.56	16.34	18.94	18.58	19.21	14	13.67	11.78	16.385
7/1994	7.89	10.8	9.38	8.94	8.21	8.5	9.11	9.61	9.055
8/1994	7.41	7.2	7.3	7.42	7.56	6.47	7.98	7.77	7.38875
9/1994	12.59	10.02	11.63	11.54	11.41	13.72	13.9	12.87	12.21
10/1994	2.65	2.68	2.61	2.83	2.2	2.2	2.33	2.08	2.4475
11/1994	4.35	4.82	5.05	5.01	4.89	4.49	4.97	4.31	4.73625
12/1994	4.38	3.29	3.37	3.36	3.78	3.13	2.86	1.17	3.1675
1/1995	1.51	1.87	1.8	1.79	1.89	1.78	1.73	1.62	1.74875
2/1995	0.71	0.78	0.74	0.85	0.77	0.74	0.88	0.62	0.76125
3/1995	2.88	2.32	1.96	2.08	2.57	2.19	2.03	1.81	2.23
4/1995	3.2	3.15	2.69	2.9	3.1	2.96	3.1	3.16	3.0325
5/1995	2.87	3.48	3.51	3.61	3.64	1.7	1.78	1.93	2.815
6/1995	10.04	8.43	8.47	10.42	9.36	8.67	9.03	8.18	9.075
7/1995	6.26	10.65	11.82	10.76	11.32	8.72	10.05	7.44	9.6275
8/1995	12.65	10.56	10.98	11.75	12.6	12.18	12.66	12.83	12.02625
9/1995	4.93	1.71	2.37	2.36	2.38	5.11	4.89	4.42	3.52125
10/1995	4.87	5.72	5.91	6.22	5.89	6.44	6.44	7.39	6.11
11/1995	0.36	0.52	0.5	0.38	0.38	0.29	0.4	0.29	0.39
12/1995	0.55	0.61	0.59	0.54	0.2	0.24	0.26	0.24	0.40375
1/1996	6.56	6.66	6.38	6.45	6.02	5.56	5.14	5.2	5.99625
2/1996	1.61	1.52	1.35	0.8	1.58	1.59	1.71	1.5	1.4575
3/1996	9.57	8.62	7.47	8.72	8.82	9.96	9.27	10.16	9.07375
4/1996	1.01	0.98	0.85	0.98	0.9	1.46	1.35	1.11	1.08
5/1996	5.17	4.72	4.47	4.76	5.5	5.76	5.11	4.7	5.02375
6/1996	4.04	3.42	4.55	4.39	3.99	6.09	5.45	5.72	4.70625
7/1996	2.88	3.49	3.44	3.68	3.61	2.26	2.24	2.11	2.96375
8/1996	5.31	8.85	7.57	7.8	9.71	7.47	6.6	6.67	7.4975
9/1996	1.77	3.34	2.97	2.5	2.58	3.11	3.46	2.5	2.77875

Table 6—*Continued*

Month	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
10/1996	2.55	3.33	3.69	3.28	2.97	3.6	3.83	3.38	3.32875
11/1996	0.39	0.41	0.26	0.58	0.48	0.52	0.64	0.83	0.51375
12/1996	2.23	2.24	3.08	2.64	2.43	2.42	2.63	2.19	2.4825
1/1997	1.06	1.14	1.11	1.38	1.16	1.02	0.93	1.1	1.1125
2/1997	0.45	0.47	0.59	0.82	0.49	0.48	0.39	0.46	0.51875
3/1997	2.36	2.66	2.45	2.58	2.46	2.93	3.02	2.99	2.68125
4/1997	3.76	4.09	4.44	4.76	4.32	3.96	4.38	3.48	4.14875
5/1997	1.18	1.26	1.33	1.5	1.83	1.82	1.34	1.15	1.42625
6/1997	3.77	3.12	2.81	3.52	4.06	4.68	4.33	5.18	3.93375
7/1997	14.13	10.33	9.75	11.25	12.78	13.07	10.82	12.77	11.8625
8/1997	5.84	7.31	7.03	5.96	6.19	8.47	7.74	8.18	7.09
9/1997	4.06	2.47	2.46	2.84	3.18	3.22	2.59	2.89	2.96375
10/1997	1.71	1.8	1.66	1.61	1.67	1.89	2.02	2	1.795
11/1997	4.38	3.9	3.73	3.88	4.53	4.37	4.38	4.75	4.24
12/1997	17.06	17	16.97	17.26	18.12	19.22	18.14	16.89	17.5825
1/1998	1.96	2.13	1.63	1.85	2.39	2.13	1.91	1.91	1.98875
2/1998	8.49	8.26	7.66	8.06	8.36	8.54	7.96	8.02	8.16875
3/1998	5.56	5.27	5.18	4.76	6.06	5.67	5.35	5.71	5.445
4/1998	0.08	0.14	0.17	0.18	0.19	0.15	0.14	0.14	0.14875
5/1998	0.49	0.63	0.57	0.64	0.67	0.98	0.87	1.07	0.74
6/1998	1.17	0.05	0.16	0.17	0.23	0.37	0.18	0.31	0.33
7/1998	6.88	7.63	8.72	7.65	7.39	8.66	9.35	9.45	8.21625
8/1998	4.45	6.42	6.2	6.88	7.17	4.46	3.74	3.02	5.2925
9/1998	8.26	6.66	8.03	8.06	8.3	10.45	9.66	9.87	8.66125
10/1998	0.09	3.41	3.44	3.42	2.83	1.85	2.85	0.96	2.35625
11/1998	1.54	1.17	1.25	1.43	1.5	1.25	1.05	1.05	1.28
12/1998	0.62	0.58	0.83	0.82	0.87	0.58	0.45	0.46	0.65125
1/1999	2.71	2.62	2.73	2.69	3.02	2.54	2.41	2.83	2.69375
2/1999	0.19	0.53	0.54	0.53	0.42	0.24	0.15	0.12	0.34
3/1999	1.42	1.46	1.33	1.35	1.35	1.35	1.22	1.51	1.37375
4/1999	1.78	2.11	2.42	2.02	2.32	2.21	1.95	1.98	2.09875
5/1999	4.13	2.38	2.58	2.31	2.68	4.34	2	4.8	3.1525
6/1999	9.44	7.91	8.83	8.28	8.44	11.19	9.52	12.22	9.47875
7/1999	3.29	6.33	5.98	5.6	5.47	1.1	1.56	5.88	4.40125
8/1999	1.05	1.48	1.74	1.55	1.84	2.3	3.06	2.52	1.9425
9/1999	4.44	5.65	5.85	5.76	6.14	4.72	4.99	4.46	5.25125
10/1999	3.85	5.9	6.38	5.47	5.4	5.11	5.03	6.85	5.49875
11/1999	1.83	1.95	2.02	1.95	2	2.26	2.5	2.16	2.08375

Table 6—*Continued*

Month	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
12/1999	2.19	1.9	1.99	1.52	1.86	2.2	2.05	1.99	1.9625
1/2000	0.99	0.76	0.81	0.81	1	0.81	0.26	0.95	0.79875
2/2000	0.62	0.62	0.62	0.49	0.8	0.59	0.59	0.53	0.6075
3/2000	0.09	0.22	0.15	0.13	0.05	0.23	0.34	0.35	0.195
4/2000	0.67	0.69	0.85	0.74	0.66	1.14	1.27	1.89	0.98875
5/2000	1.15	0.2	0.3	0.55	0.45	0.82	1.12	1.1	0.71125
6/2000	3.72	2.59	2.99	3.3	3.53	4.22	3.85	4.55	3.59375
7/2000	4.31	6.78	6.92	7.69	9.07	8.18	8.75	8.43	7.51625
8/2000	5.05	4.12	4.51	4.99	5.43	5.34	5.16	3.73	4.79125
9/2000	3.68	3.67	3.8	3.4	3.37	3.67	3.37	3.77	3.59125
10/2000	0.19	0.22	0.2	0.22	0.23	0.23	0.2	0.14	0.20375
11/2000	0.84	0.89	0.91	0.92	1.05	1.19	1.17	1.2	1.02125
12/2000	0.61	1.05	1.03	0.97	0.91	0.92	0.86	0.89	0.905
1/2001	0.78	0.71	0.71	0.75	0.85	0.62	0.63	0.41	0.6825
2/2001	2.07	2.12	1.98	1.99	2.52	1.97	1.8	1.51	1.995
3/2001	5.78	5.62	5.58	5.8	6.1	5.74	6.52	6.17	5.91375
4/2001	0.33	1.13	0.66	0.59	0.67	0.3	0.31	0.21	0.525
5/2001	2.33	1.73	1.62	1.6	1.98	2.18	1.82	2.18	1.93
6/2001	3.84	3.23	3.8	3.81	3.47	5.73	5.24	6	4.39
7/2001	9.73	6.55	7.61	8.05	7.78	12.11	11.57	6.98	8.7975
8/2001	12.11	8.11	8.72	8.45	9.01	10	8.43	6.39	8.9025
9/2001	10.75	15.13	14.77	14.47	15.14	8.59	9.59	6.7	11.8925
10/2001	0.42	0.65	0.63	0.65	0.5	0.62	0.54	0.52	0.56625
11/2001	1.23	1.37	1.43	1.37	1.52	0.95	0.82	0.73	1.1775
12/2001	0.22	0.12	0.1	0.13	0.16	0.16	0.21	0.21	0.16375
1/2002	2.42	2.31	2.39	2.58	2.46	2.19	2.34	2.1	2.34875
2/2002	2.61	2.65	2.61	2.69	2.54	2.56	2.93	2.87	2.6825
3/2002	0.77	0.72	0.6	0.71	0.66	0.99	0.9	0.98	0.79125
4/2002	0.78	0.26	0.19	0.43	0.28	0.86	0.69	0.79	0.535
5/2002	0.7	0.78	0.45	0.53	0.47	1.07	0.89	1.26	0.76875
6/2002	18.48	14.42	15.34	16.45	15.67	17	13.29	13.64	15.53625
7/2002	10.02	8.38	8.28	8.93	7.69	12.23	10.22	10.67	9.5525

Table 7 Annual rainfall totals in inches from eight stations in four RIB sites and the eight-station average

Year	stat 5-1	stat 6-1	stat 6-2	stat 6-3	stat 6-4	stat 7-1	stat 7-2	stat 9-1	Average
1988	50.14	49.58	48.34	50.25	49.64	48.13	47.54	49.96	49.2
1989	42.29	37.47	37.69	38.66	41.65	42.92	42.31	37.62	40.08
1990	40.86	33.84	35.73	34.99	36.8	37.87	39.62	40.45	37.52
1991	48.43	51.02	50.19	50.7	52.13	50.57	52.78	50.96	50.85
1992	49.13	44.69	41.81	43.95	47.36	44.32	44.31	44.22	44.97
1993	38.7	37.04	35.61	35.53	39.22	37.58	39.25	43.34	38.28
1994	70.49	65.81	69.36	67.81	68.39	62.64	65.36	60.58	66.31
1995	50.83	49.8	51.34	53.66	54.1	51.02	53.25	49.93	51.74
1996	43.09	47.58	46.08	46.58	48.59	49.8	47.43	46.07	46.9
1997	59.76	55.55	54.33	57.36	60.79	65.13	60.08	61.84	59.35
1998	39.59	42.35	43.84	43.92	45.96	45.09	43.51	41.97	43.28
1999	36.32	40.22	42.39	39.03	40.94	39.56	36.44	47.32	40.28
2000	21.92	21.81	23.09	24.21	26.55	27.34	26.94	27.53	24.92
2001	49.59	46.47	47.61	47.66	49.7	48.97	47.48	38.01	46.94

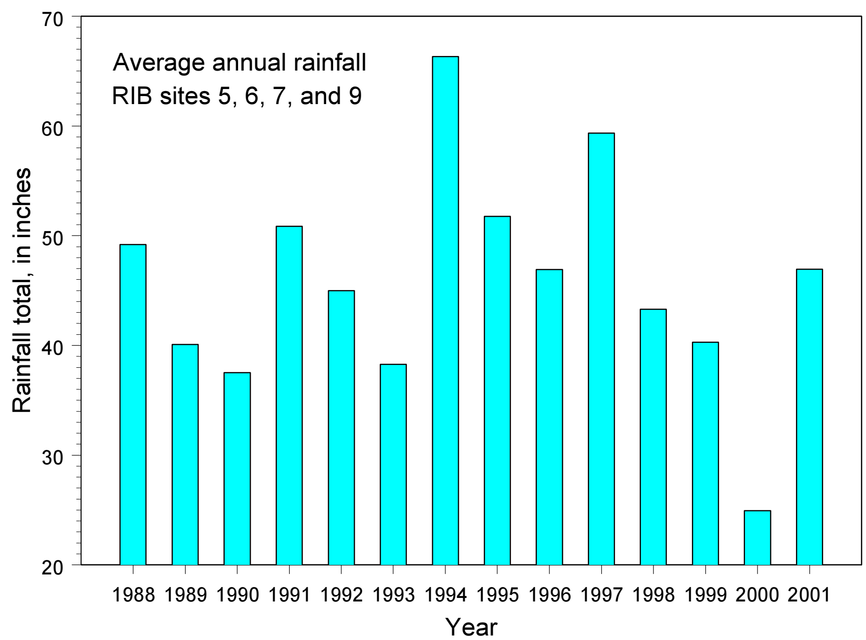

Figure 20. Average annual rainfall totals from eight rainfall stations in RIB sites 5, 6, 7, and 9

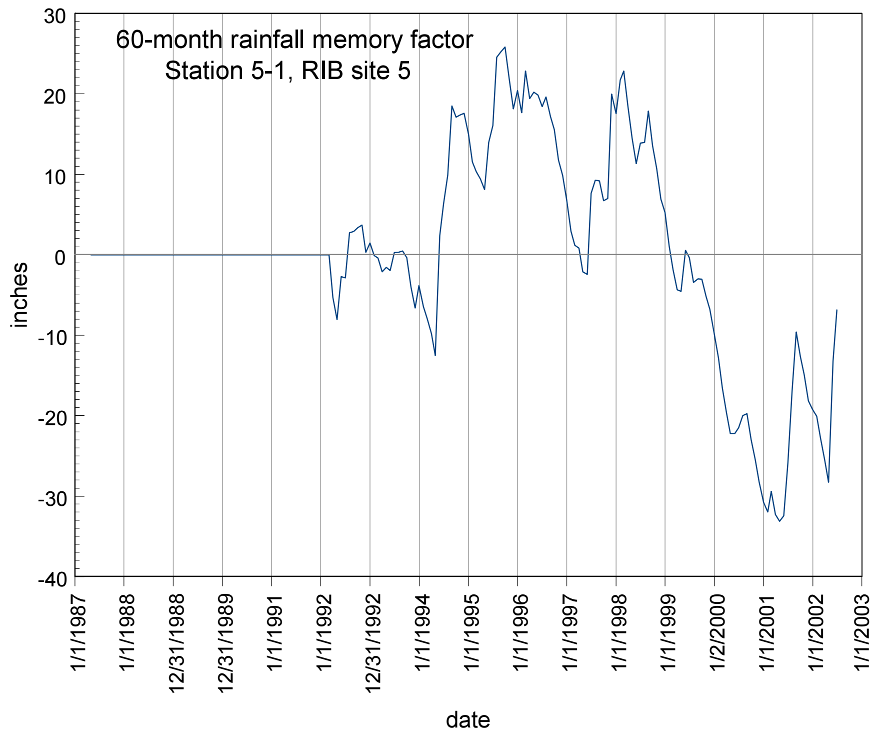

Figure 21. Computed rainfall memory factor based on monthly rainfall totals at station 5-1 in RIB site 5

monthly lake stages from April or May 1987. Earlier stage measurements from these lakes, from as early as 1959, have been acquired from public agencies and added to the database. The combination of pre-RIB and later stage data facilitates comparison of lakes stages from before and after the RIB basin discharges.

The stage history of twelve such lakes located near the RIB sites (Figure 1) are illustrated in Figures 22–33. Two lakes for which records have been maintained, Caewood West and Crescent Lake, were considered to be far enough from all RIB sites that they were excluded. It was assumed that, if impacts to lakes were to occur, that the stages of Johns Lake, Black Lake, Lake Avalon (all to the north of RIB site 6), Lake Speer (to the southeast of site 6), and Lake Hartley (on the southern boundary of site 6), would be primarily influenced by site 6. The stage of Lake Ingram, surrounded by RIB sites, might be impacted by any of them. Those sites might impact the stage of Lake Hancock, south of site 6 and east of sites 7 and 8. Those sites might impact the stage of Huckleberry Lake, east of sites 8 and 9. Those sites might impact the

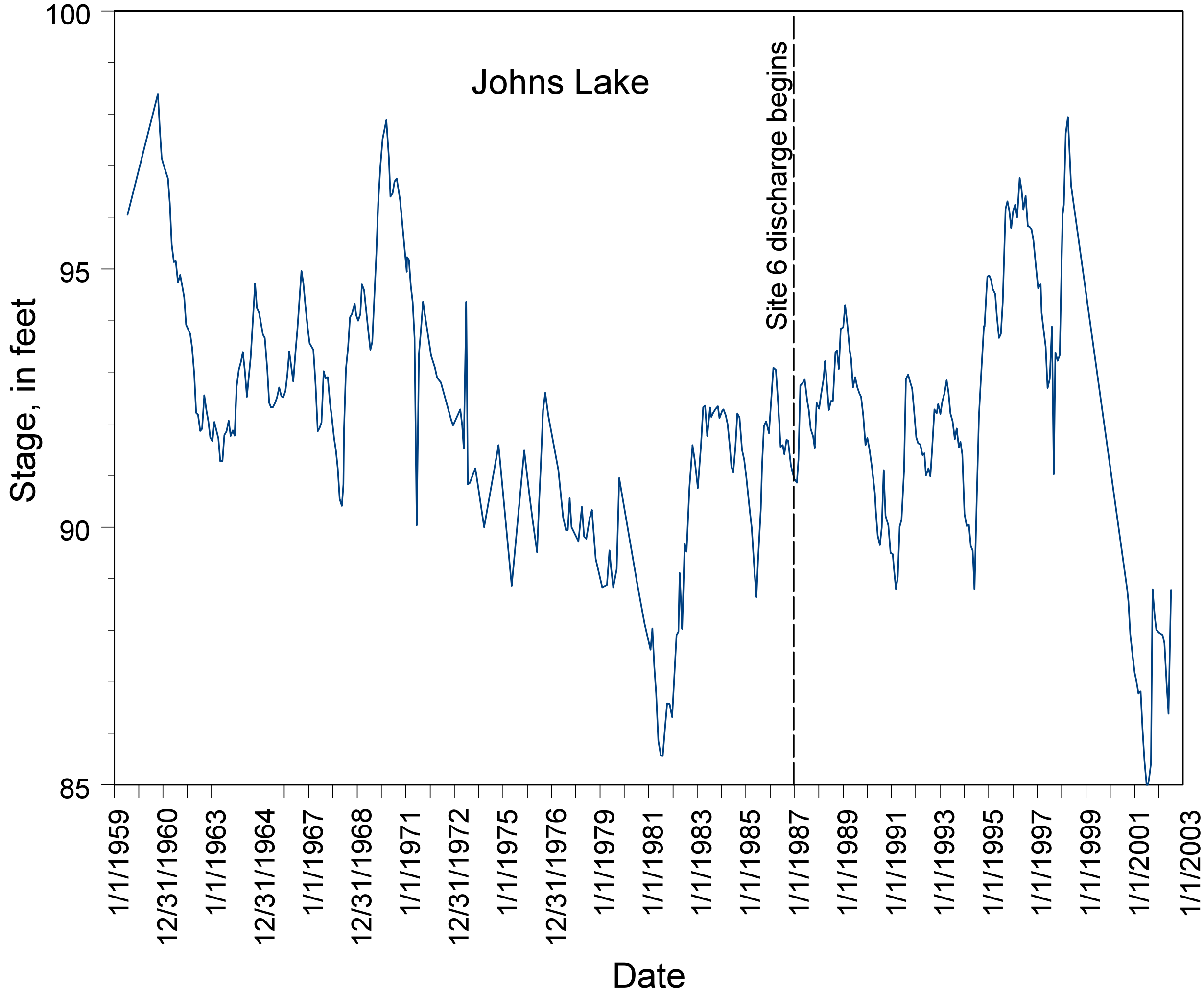

Figure 22. The stage of Johns Lake, 1959-2002

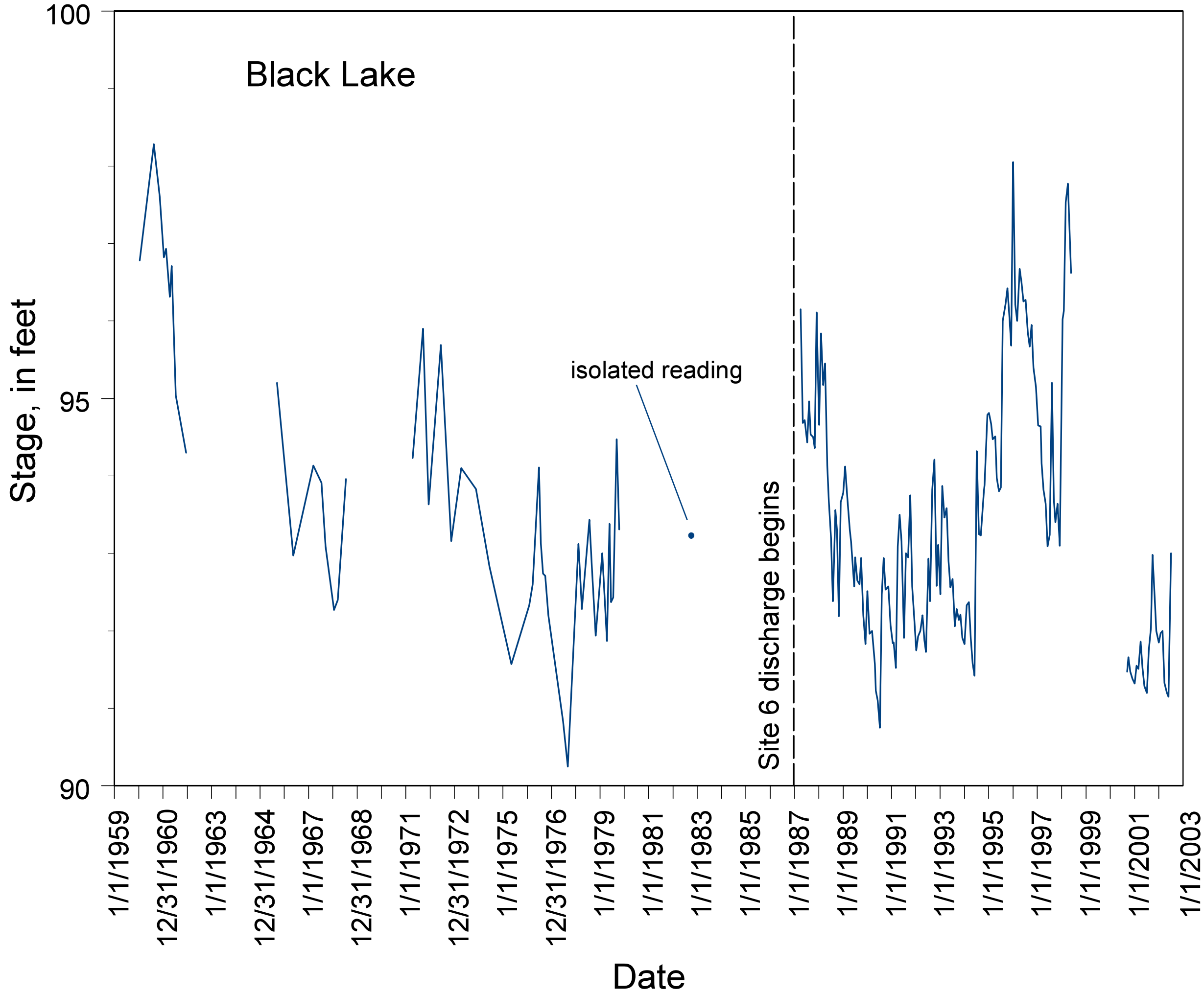

Figure 23. The stage of Black Lake, 1960–2002

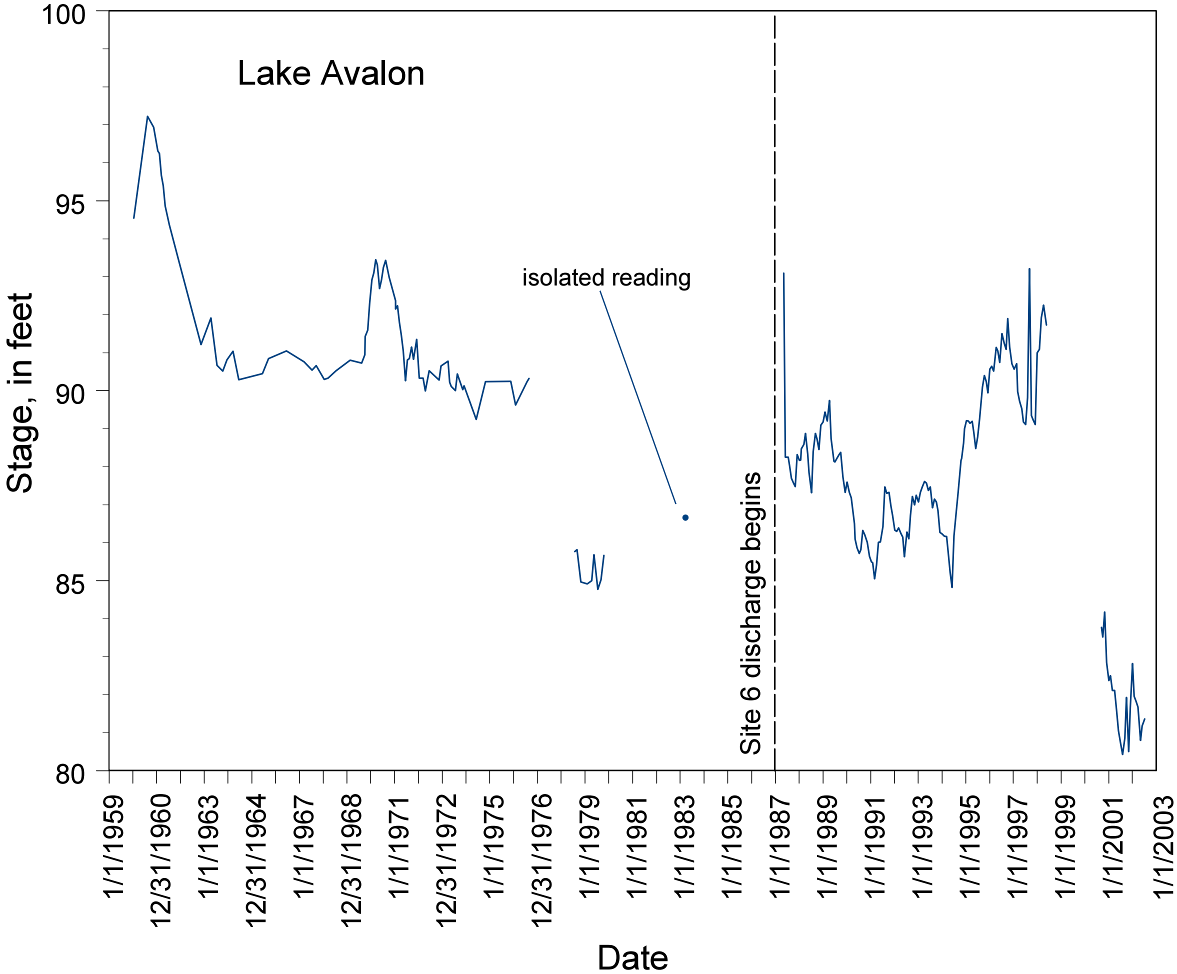

Figure 24. The stage of Lake Avalon, 1960–2002

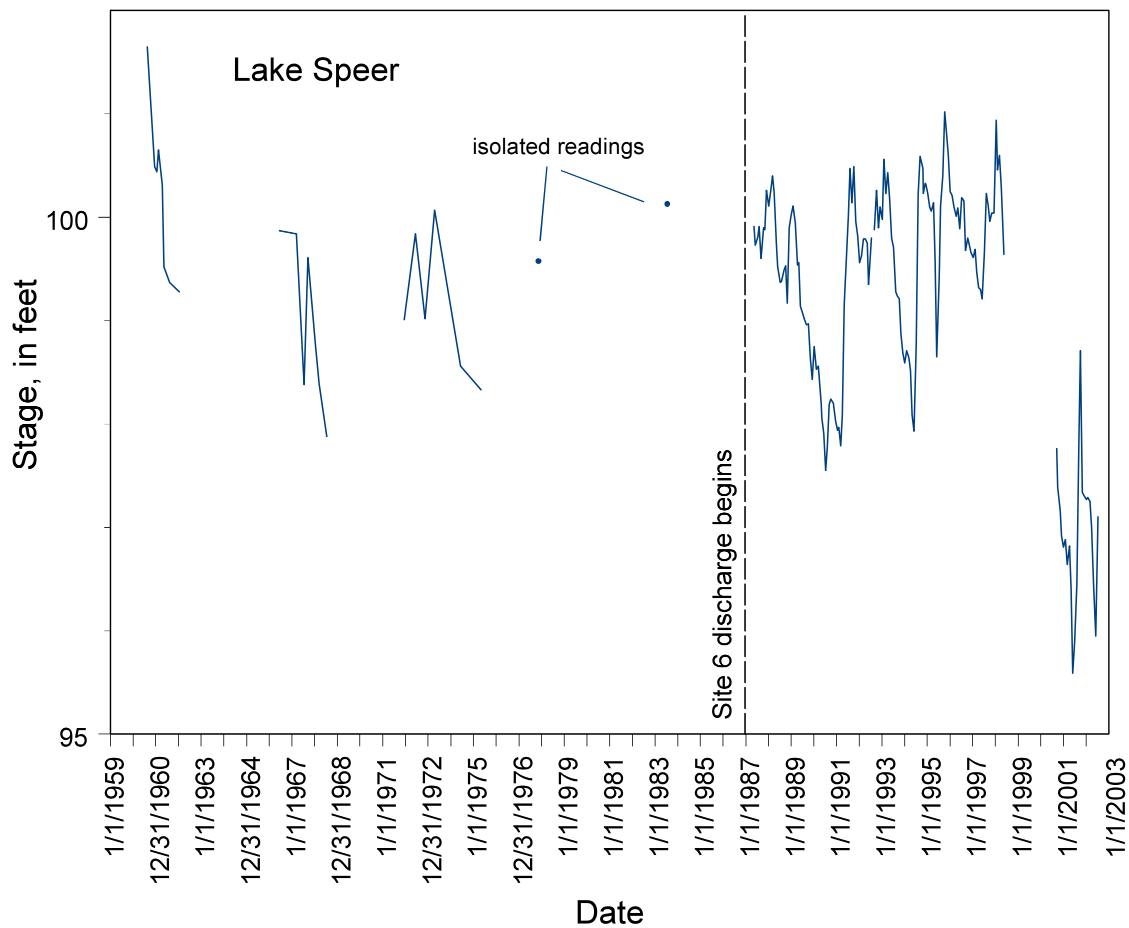

Figure 25. The stage of Lake Speer, 1960–2002

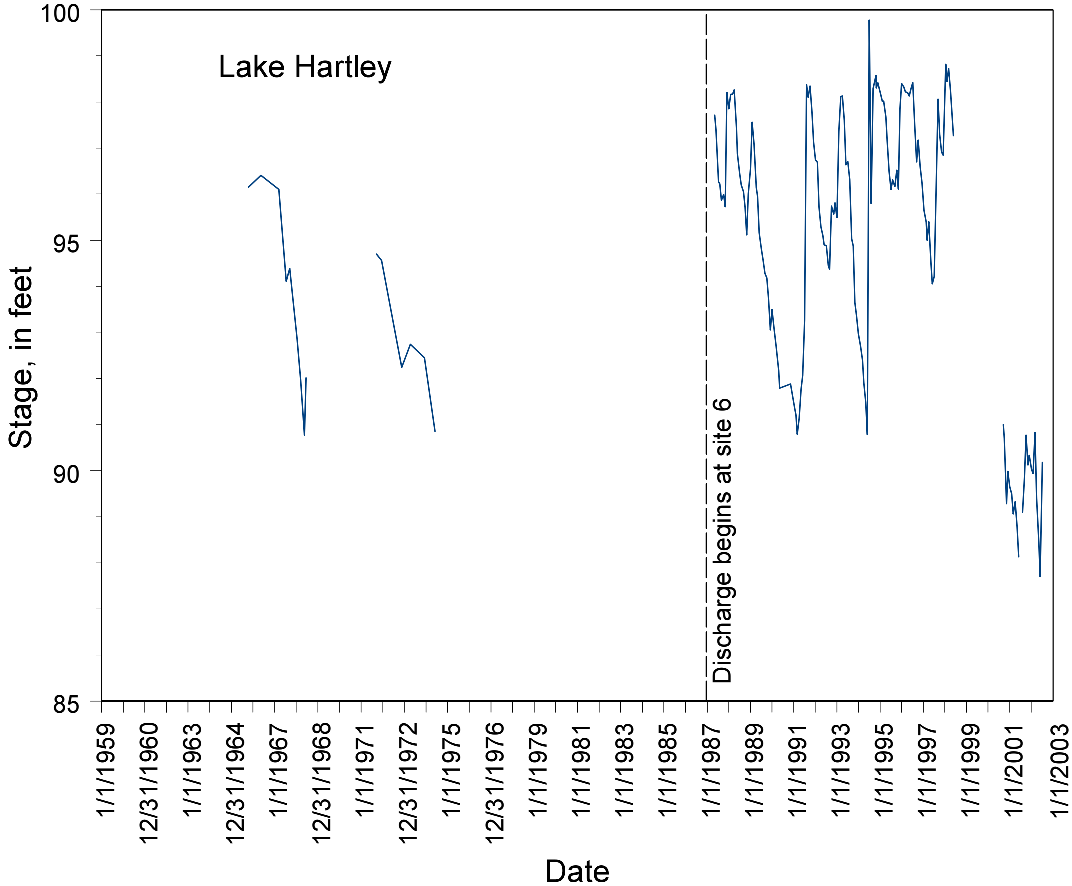

Figure 26. The stage of Lake Hartley, 1965–2002

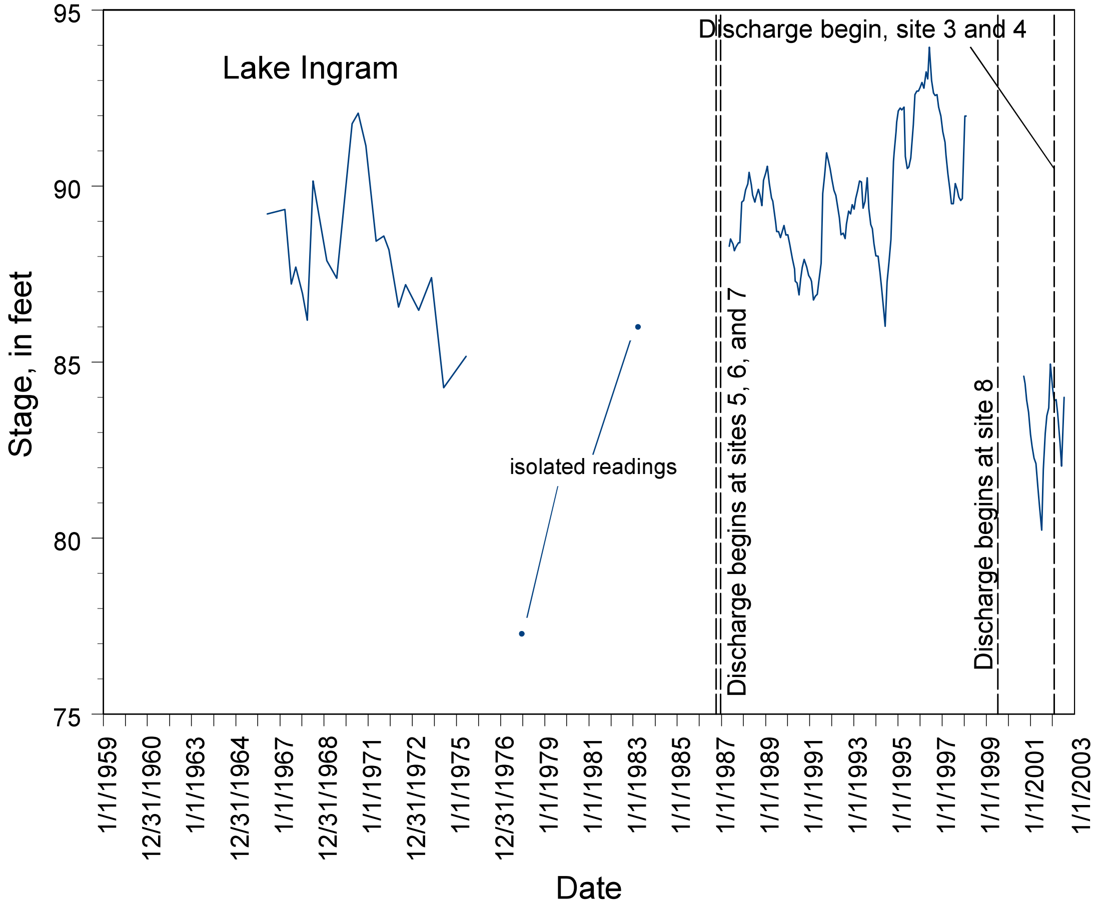

Figure 27. The stage of Lake Ingram, 1966–2002

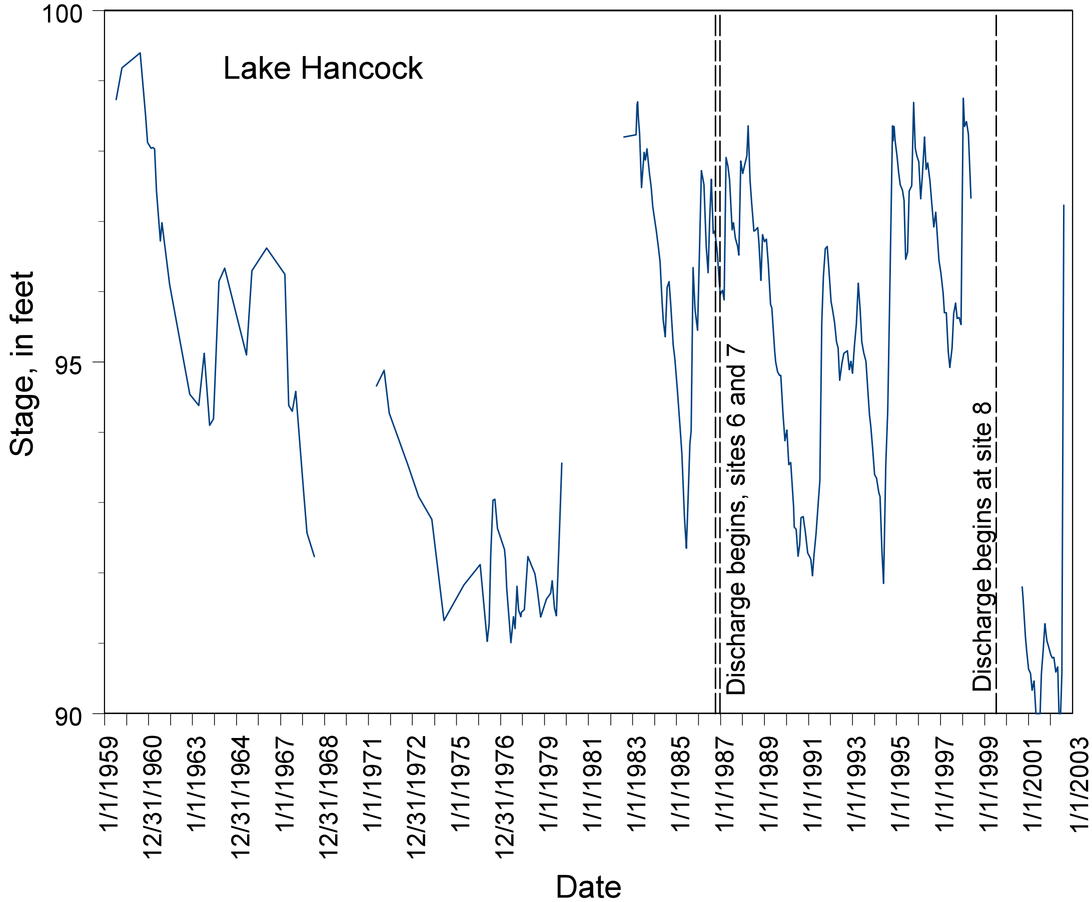

Figure 28. The stage of Lake Hancock, 1959–2002

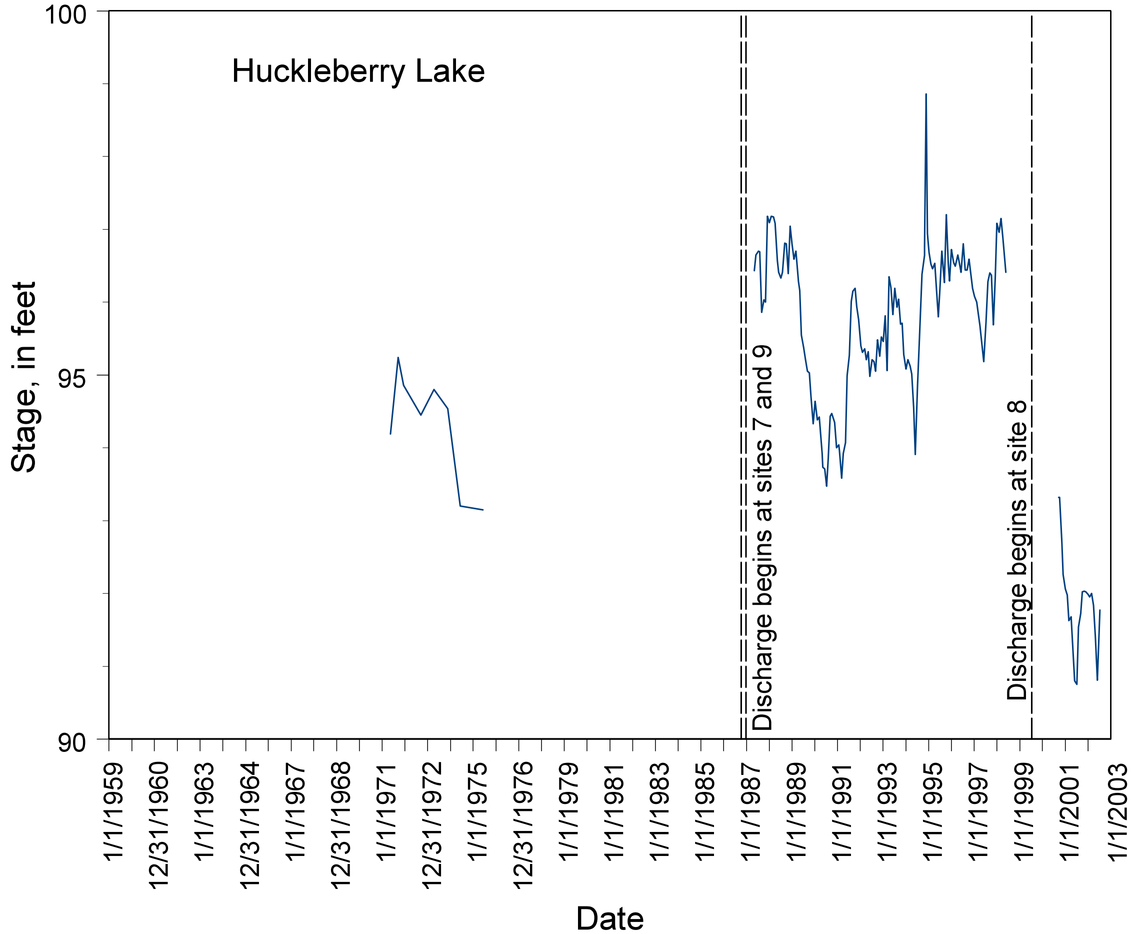

Figure 29. The stage of Huckleberry Lake, 1971–2002

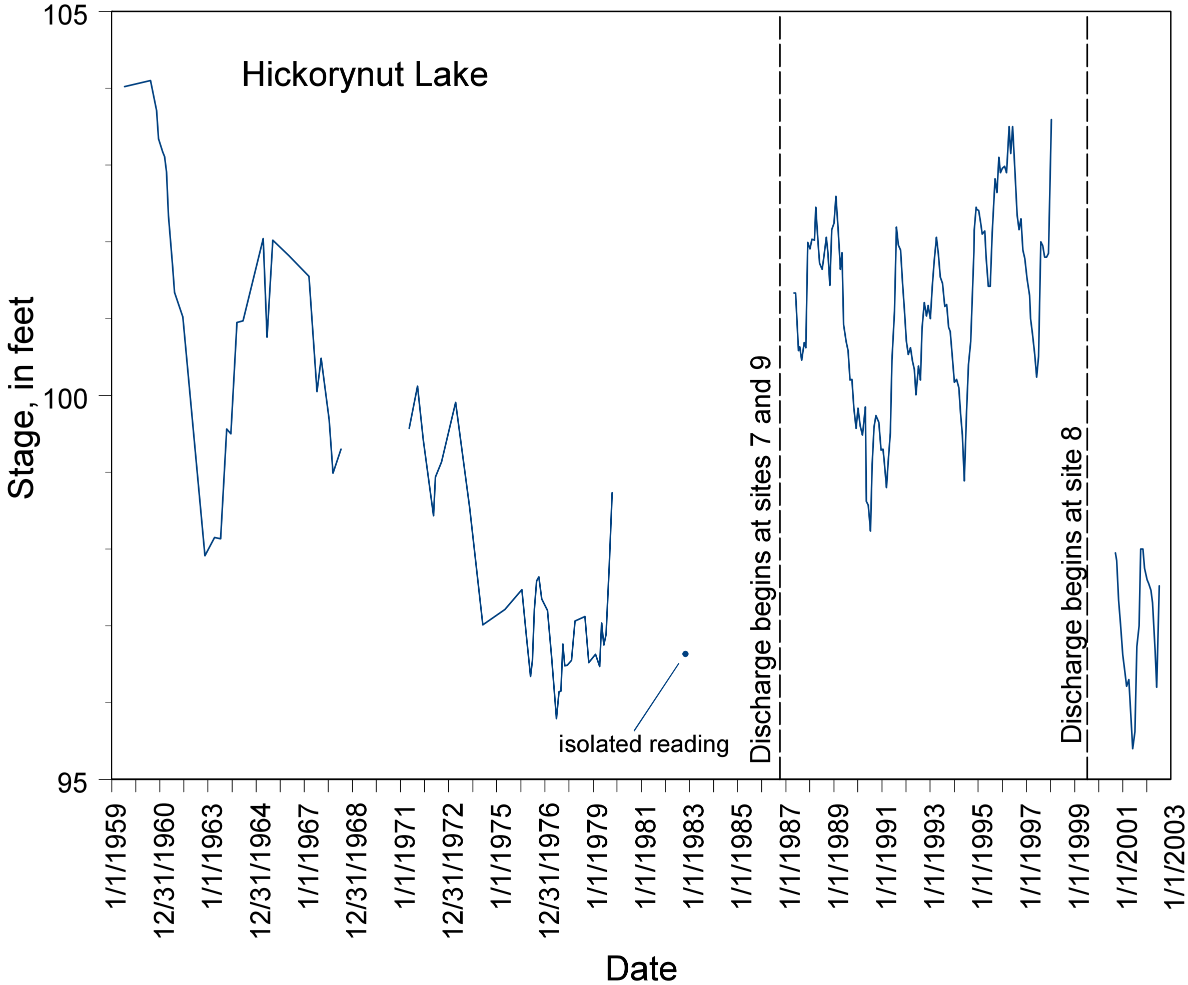

Figure 30. The stage of Hickorynut Lake, 1959–2002

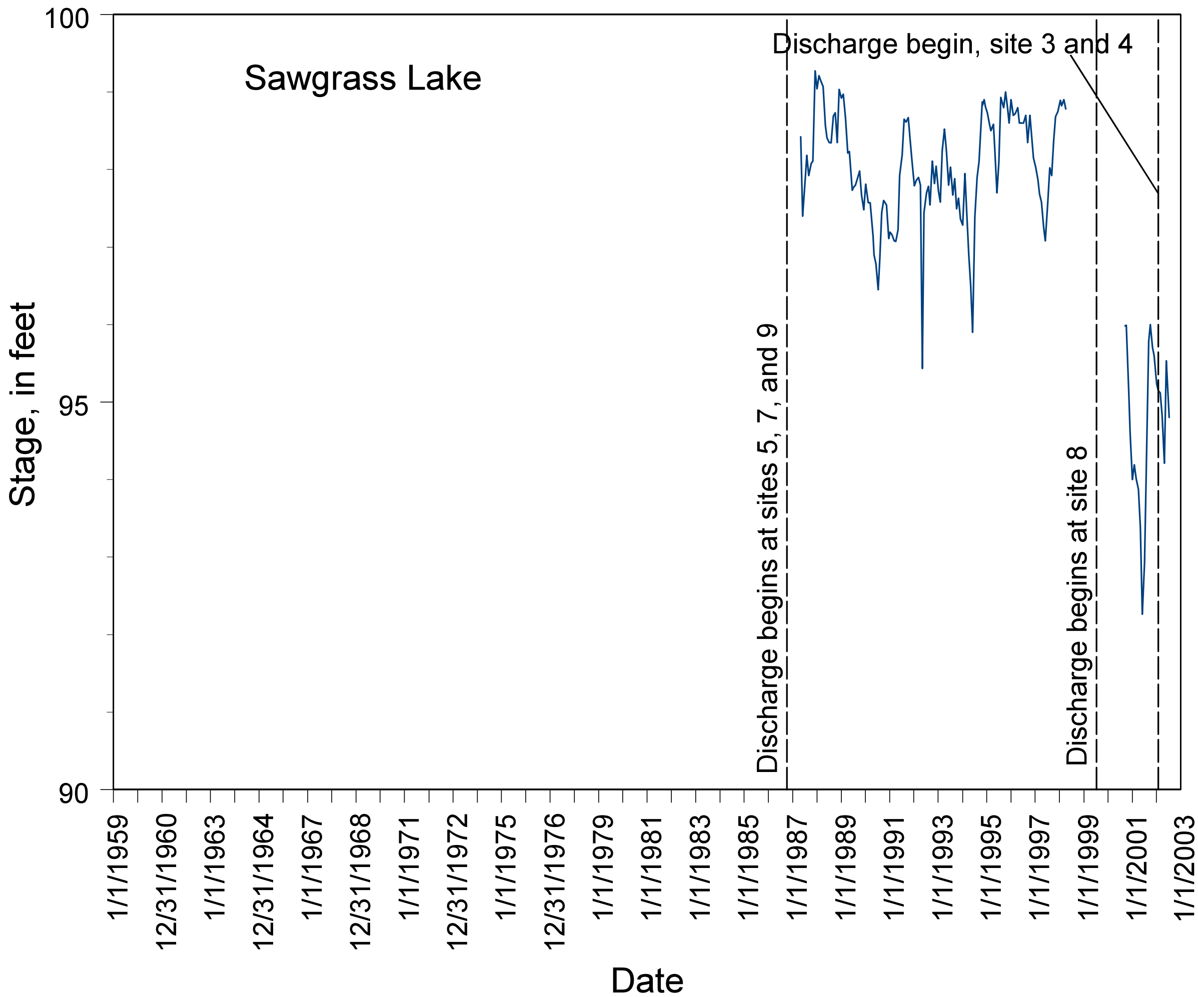

Figure 31. The stage of Sawgrass Lake, 1987–2002

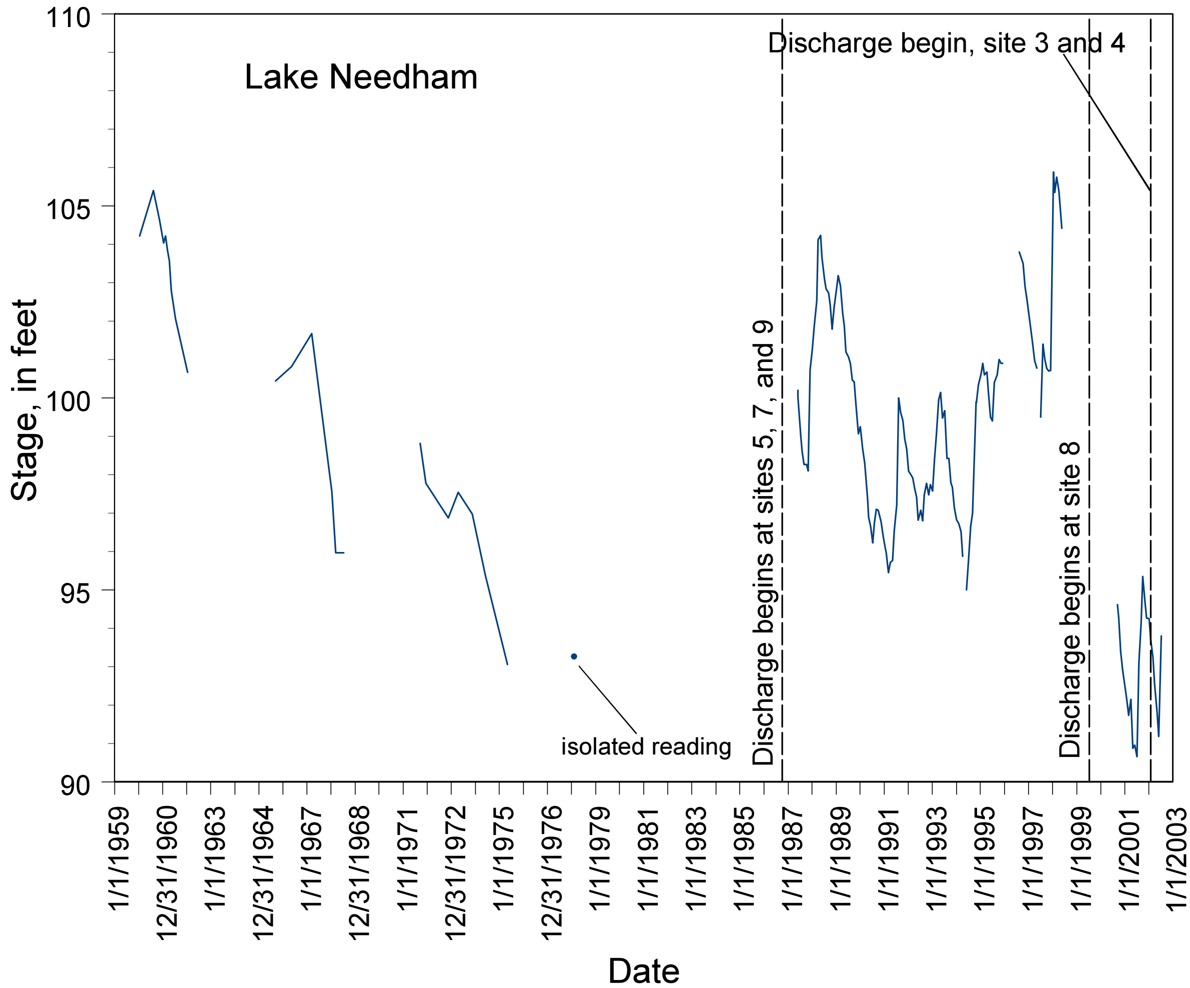

Figure 32. The stage of Lake Needham, 1960–2002

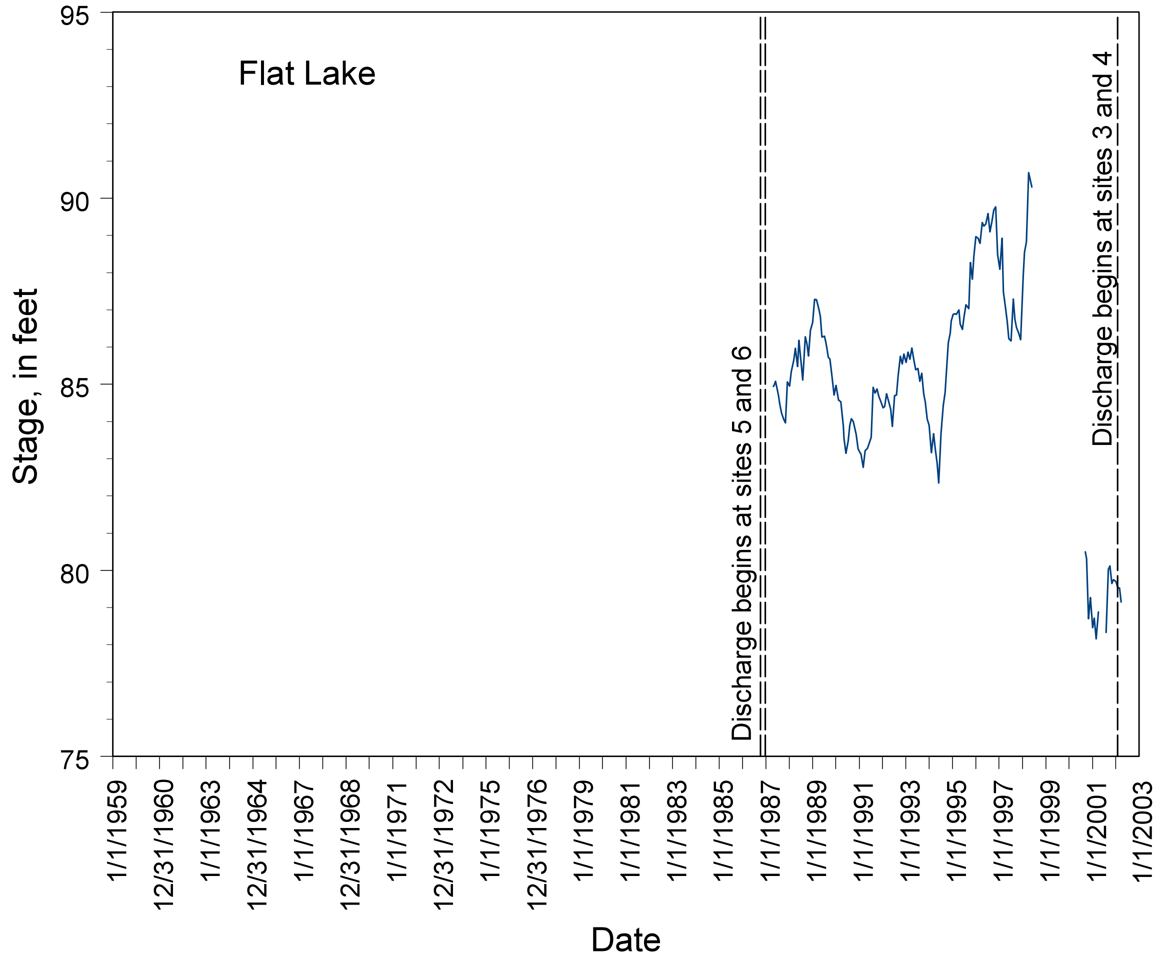

Figure 33. The stage of Flat Lake, 1987–2002

stages of Hickorynut Lake, Sawgrass Lake, and Lake Needham, to the east of sites 7, 8, and 9. Those sites might impact the stage of Flat Lake, northwest of sites 3, 4, and 5 and west of site 6.

The lake stage illustrations do not show readily evident influences from RIB discharges. Where records from 1960 are available, it is seen that lake stages at that time were generally higher than any that have occurred since the beginning of RIB discharges in late 1986 and until the end of the data record available for this study (July 2002). After the beginning of discharges to the RIB sites, stages were highest in 1987-88 and in the high-rainfall years 1995–1998. During the drought years (2000 to mid-2002) stages at all of the lakes have been near record lows. From these observations, it appears that the predominant influence on lake stages is the accumulation of rainfall (Figure 21).

However, it is possible that relatively small but areally extensive changes in the potentiometric surface of the Upper Floridan arising from regional pumping or from the RIB recharges could have caused changes in the stages in some lakes, depending on the degree of interconnection between the lake and the Upper Floridan aquifer. Evidence of such changes would be hard to discern in the lake hydrographs.

STAFF-GAGE MEASUREMENTS

Of interest in relation to RIB discharges are measurements of the stage of bodies of water that accumulate in shallow closed depressions near the RIB sites. These depressions may become inundated in response to the accumulation of rainfall in the area, or, possibly, to the mounding of the water table that occurs as a result of discharges to the RIB basins.

Stages were measured in a depression 600 ft east of the eastern boundary of RIB site 5 (Figure 2) during periods of inundation in the years 1994–1998 (Figure 34, staff gage JR2-1). Staff gages were also installed in five depressions north of RIB site 7 (Figure 4), at distances ranging from 300 to 2,400 ft from the RIB basins. Inundation during the years 1994-1999 occurred at four of the basins (Figures 34–36, DM1-1, JR3-1, SP2-1, and SP5-1), but the fifth (DM2-1) remained dry. Another staff gage, 7-1 (Figure 36), also measured inundation during this period.

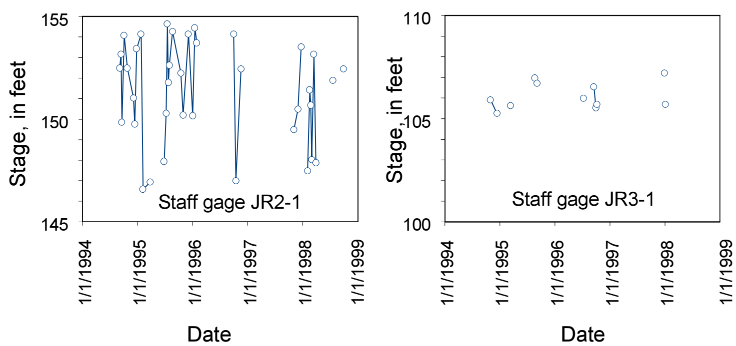

Figure 34. Staff-gage measurements at stations JR2-1 and JR3-1

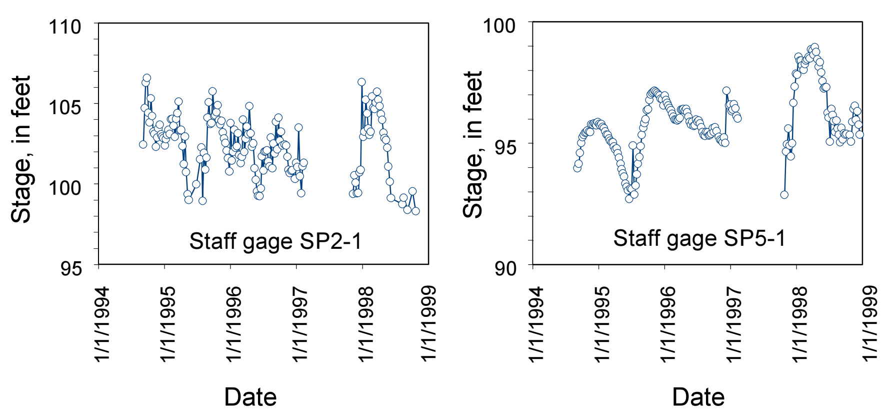

Figure 35. Staff-gage measurements at stations SP2-1 and SP5-1

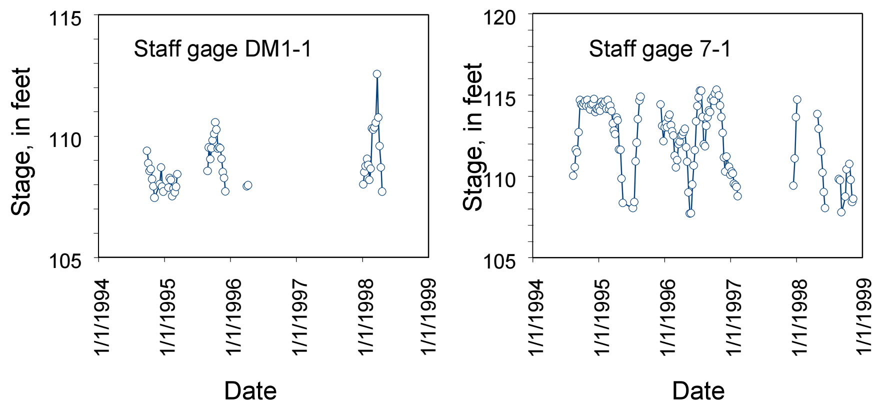

Figure 36. Staff-gage measurements at stations DM1-1 and 7-1

As previously noted, predischarge water table altitudes measured by CDM (1983) ranged from 132 to 135 ft in RIB site 5. The stages measured at staff gage JR2-1 from 1994 to 1999 are appreciably higher and show a range of variation greater than would normally occur in the surficial aquifer in this region. This stage behavior is attributed to the influence of discharges to RIB site 5. It is noted that the stage increases are not cumulative and stages tend to decline rapidly after increases.

The occurrences of inundation and high stages of ponded water at RIB site 7 during the 1994–1999 period shown in Figures 35–36 correlate well with the high water tables of that period that were caused by large accumulations of rainfall (Figure 21). But discharges at RIB site 7 are a principal influence on these stages. The predischarge water table altitude measured in the northern part of site 7 (CDM 1983) was about 90 ft. The stages shown are appreciably higher and show wide fluctuations that reach over 115 ft at staff gage 7-1. As at site 5, the stage increases are not cumulative. Many of the staff gages show that the altitude of the water surface in the depressional areas being measured became appreciably lower after the period of heavy rainfall ended in the first part of 1998.

Staff gages were also placed in depressional areas within or near RIB site 9 (Figure 4). Gages 9-1 and 9-3 were within the site, and gage 9-2 was located 400 to 500 ft from the southeast boundary of the site. Gages 9-1 and 9-2 have continuous records of stage within the depression from late 1986 till August 2001 (Figure 37). At gage 9-3, records of stage extend through the high-rainfall period of 1994–1998 and into the drought period of early 2000, when the altitude of the water surface was lowered by more than 5 ft.

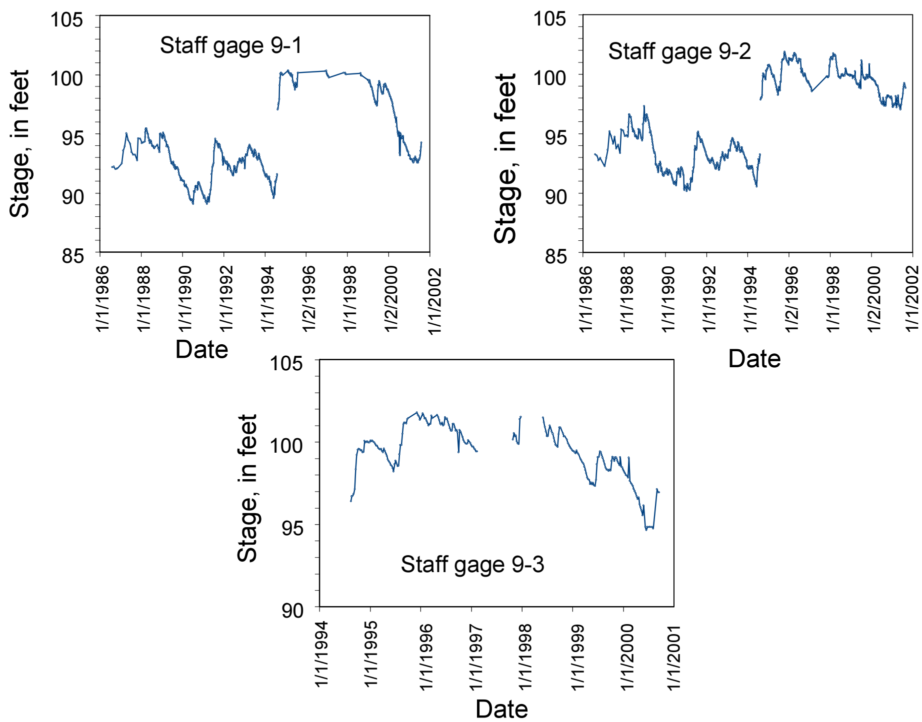

Figure 37. Stages measured at staff gages 9-1, 9-2, and 9-3

The plots for gages 9-1 and 9-2 show an abrupt rise in stage between August 8 and 15, 1994. Beginning on August 15, a datum was used to convert depth to water to elevation above sea level; before that date, two arbitrary datums were used. Because the documentation of the details of the change is inadequate, and because the change occurred during a period of heavy rainfall and rapid rise of the water table and surface-water stages, the correction that should be applied to the pre-August 15 data is not known, and the post-August 15 datum correction is applied to the entire time series. Because a rise of over 5 ft in stage during a one-week period is unlikely to occur even during a period of heavy rainfall, the pre-August 15 stages apparently are incorrect by a uniform, unknown factor.

Predischarge water table altitudes in RIB site 9 ranged from 90 to 100 ft (CDM, 1983). Because discharges to RIB site 9 only occurred during three short periods, the water table was largely undisturbed, and the staff gage measurements tend to reflect that water table.

Stages were recorded at 19 staff gages in RIB site 6 (Figures 38–42). In most cases, a datum correction is established in July1993 (previous data were referred to an arbitrary datum) and revised in August 1994. The final datum correction is applied to the entire series of depth to water measurements. Because little documentation of the process of establishing the datum is available, it is possible that the data shown in the figures before August 1994 might contain an unknown bias error. The apparent large stage increases shown in the summer of 1994 are higher than would be anticipated given the antecedent rainfall, though high rainfall beginning in this period should cause an appreciable stage increase.

The uncertainty over the datum correction hampers interpretation of these data. However, the large fluctuations that occur at some of the staff gages suggest a response to discharges at nearby RIB cells. In fact, the variation of staff gauge measurements is quite similar to that of water levels measured in surficial wells and piezometers. As at sites 5 and 7, large stage increases at the staff gauges are followed by equal decreases, and no cumulative influence on the water table is shown in this data. Stages decrease sharply in the drought period of 1998–2002.

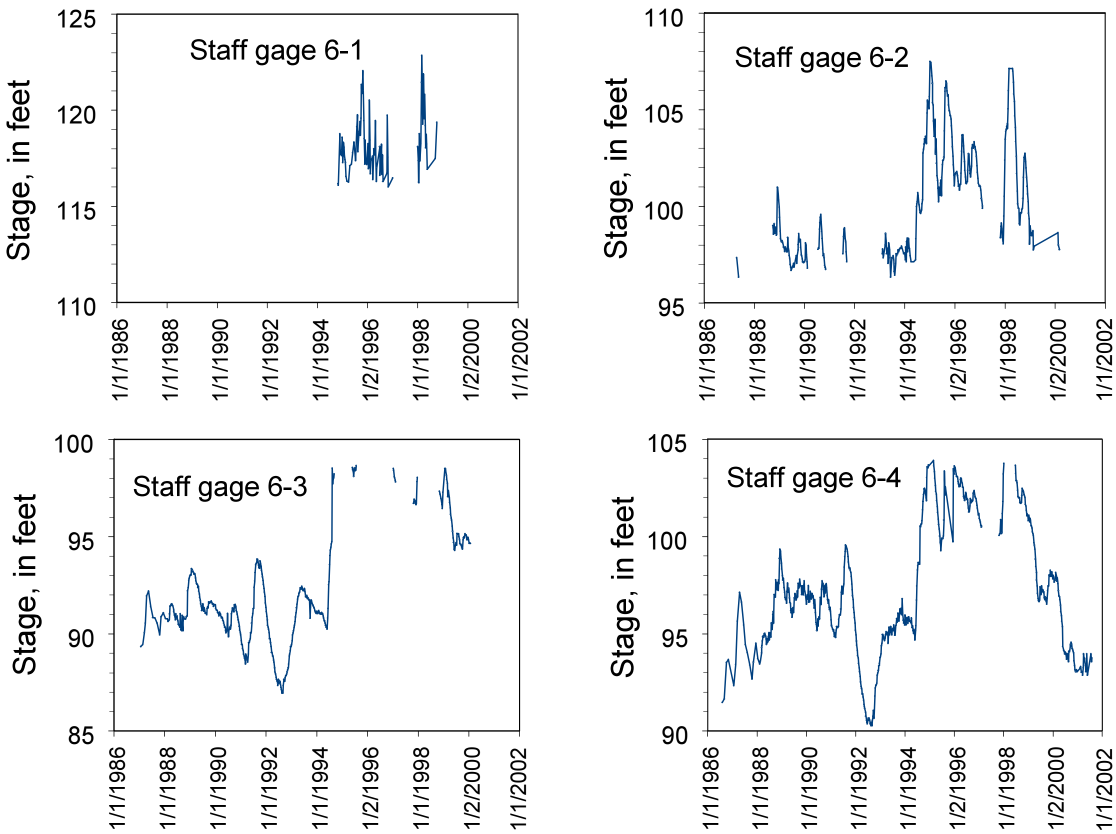

Figure 38. Stages recorded at staff gages 6-1, 6-2, 6-3, and 6-4

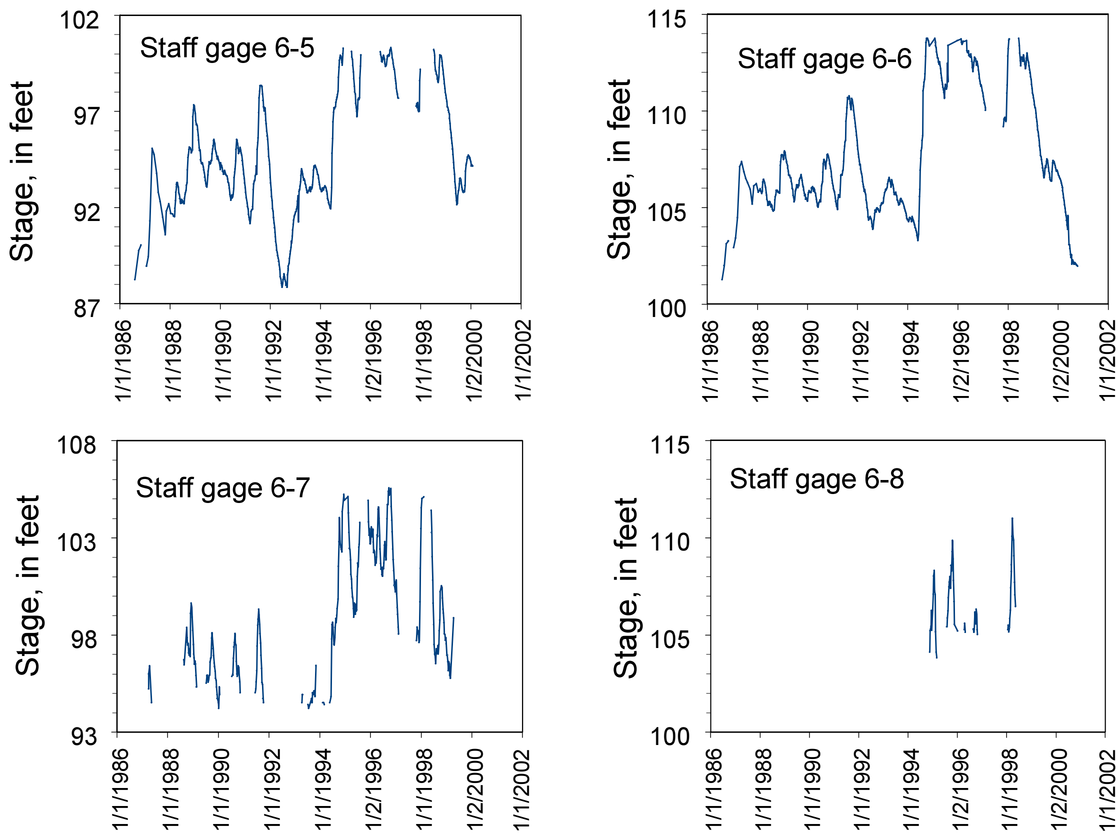

Figure 39. Stages recorded at staff gages 6-5, 6-6, 6-7, and 6-8

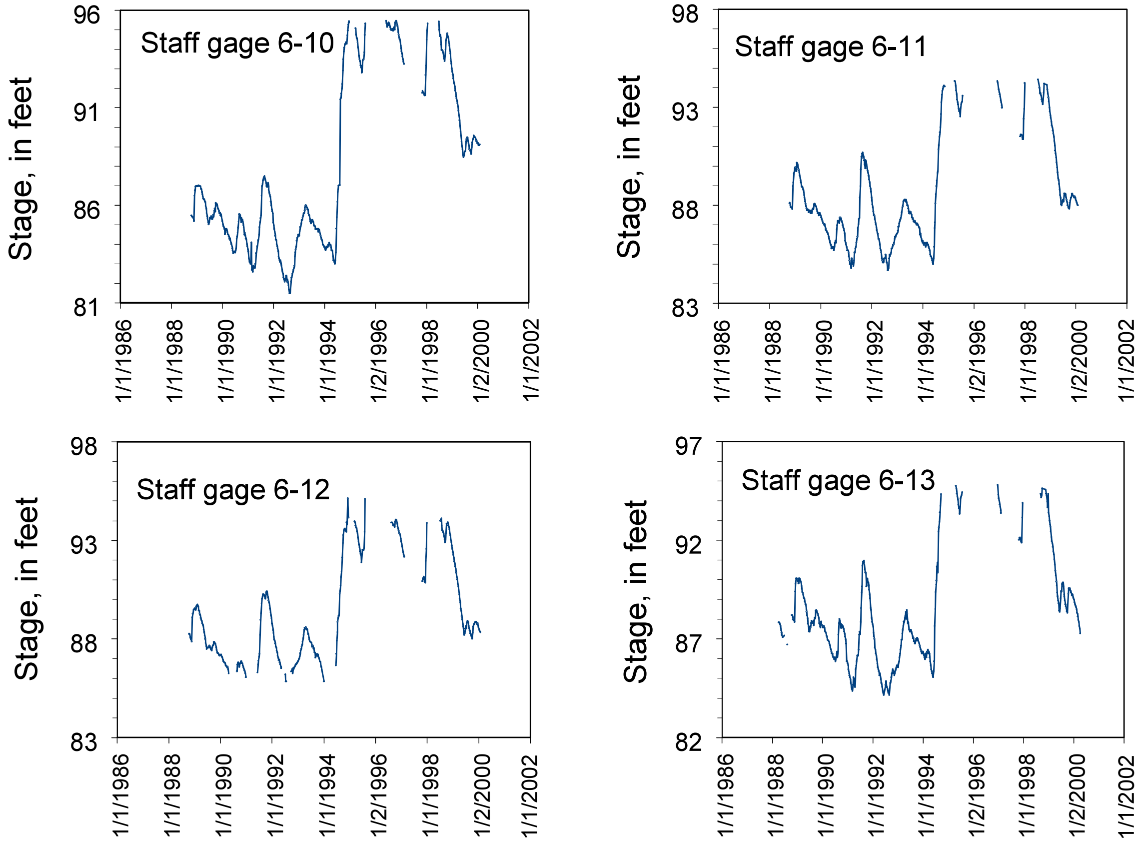

Figure 40. Stages at staff gages 6-10, 6-11, 6-12, and 6-13

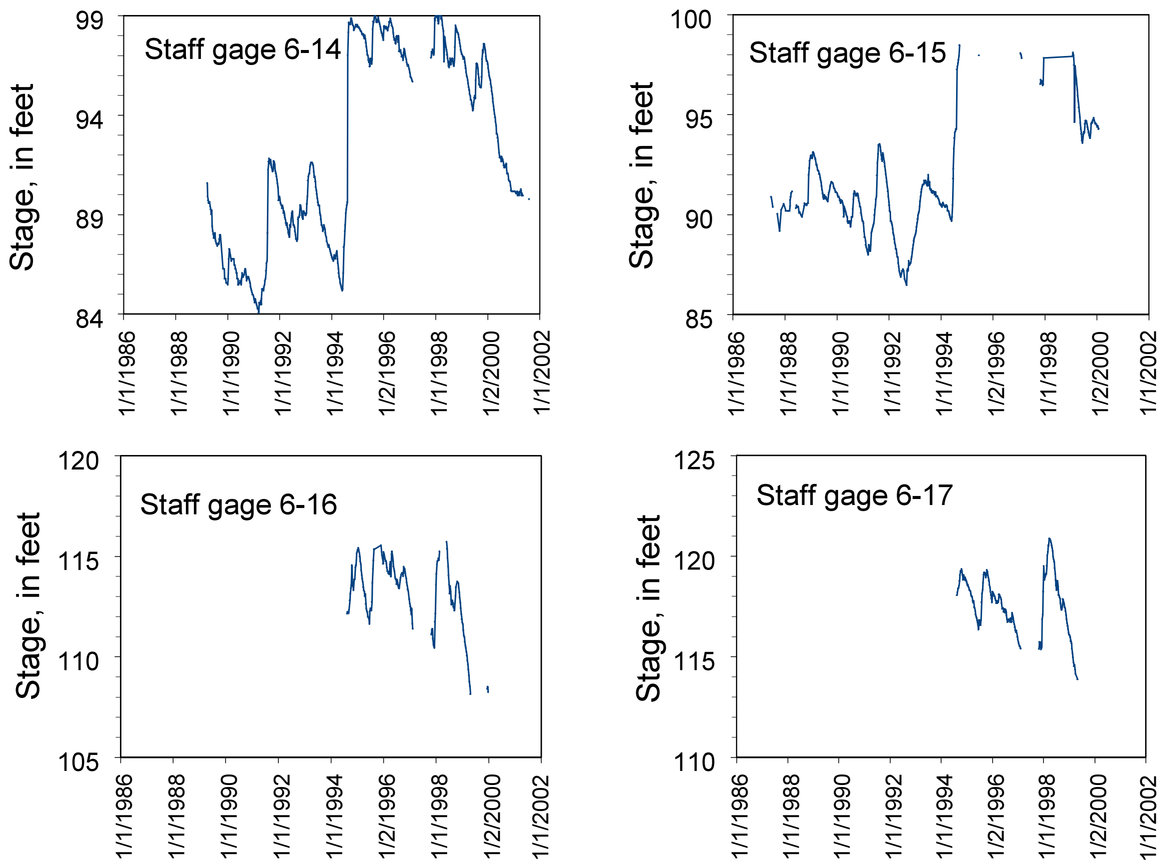

Figure 41. Stages measured at staff gages 6-14, 6-15, 6-16, and 6-17

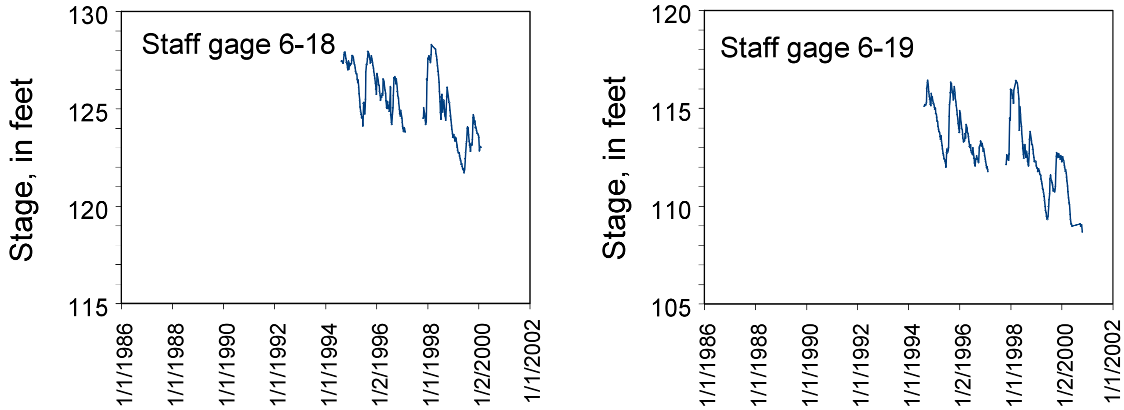

Figure 42. Stages measured at staff gages 6-18 and 6-19

WATER QUALITY DATA

The collection of water samples for chemical analysis from several wells in the surficial aquifer at sites 5, 6, 7, and 9 began before the beginning of discharge to the RIB basins in October 1986. Samples were obtained from three wells in site 5 in early July 1986, and from 25 wells in site 6, seven wells in site 7, and five wells in site 9, in late June and early July 1986. Samples were obtained from monitor wells in the Upper Floridan aquifer at sites 5, 6, 7, and 9 in April and May 1987. The most recent samples in the record made available for this study were obtained in May 2002. PB Water maintains a database of the measured concentrations of 18 water quality parameters (Table 8).

For purposes of this study, it was decided to illustrate and evaluate the concentrations of eight parameters at monitor wells in the surficial and Upper Floridan aquifers: specific conductance, chloride, total dissolved solids, nitrate nitrogen, total phosphorus, biochemical oxygen demand, pH, and total trihalomethanes. Graphs of these eight parameters are presented in the following figures for RIB sites 5, 7, and 9. Because of the volume of data from RIB site 6, it was concluded that a briefer data presentation would be desirable, and only chloride and nitrate nitrogen from surficial and Upper Floridan monitor wells at site 6 are presented in this report. The figures also show a local least squares regression (loess) line based on the daily values of the concentrations measured in the outflow from the wastewater treatment plant (WWTP). Also indicated are starting dates for the discharge of reclaimed water at each site.

Table 8. Parameters measured in monitor wells at RIBs

Parameter	Abbreviation	Unit of Measurement
Fecal coliform	FC	CFU/100ml
Biochemical oxygen demand	BOD	Milligrams per liter (mg/L)
Total Kjeldahl nitrogen	TKN	mg/L
Nitrate nitrogen plus nitrite nitrogen	NOx	mg/L
Nitrate nitrogen	NO3	mg/L
Nitrite nitrogen	NO2	mg/L
Ammonia	NH3	mg/L
Total phosphorus	TP	mg/L
Chloride	CL	mg/L
Total dissolved solids	TDS	mg/L
Total organic carbon	TOC	mg/L
Total trihalomethanes	TTHM	mg/L
Total carbon	TC	mg/L
Turbidity	TURB	NTU
Depth	Depth	Feet
Temperature	Temp	Degrees Celsius
Specific conductance	ECW	mhos/cm
pH	PH	pH units

Note: in Table 8, “Total trihalomethanes” (TTHM) is the sum of concentrations of chloroform, bromodichloromethane, dibromodichloromethane, and bromoform. “Depth” is the depth to water from the top of casing.

In this section, the data is evaluated, but interpretations related to recharge of the Upper Floridan aquifer are deferred until a later section. Concentration values for various constituents reported for pre-1991 samples show a high variance. PB Water (written commun., 2004) believes that this may be the result of poor quality control. Samples from Upper Floridan wells must be qualified in that little is known about the depth or open interval of most of these wells, most having been constructed for grove irrigation prior to the Water Conserv II project. If the open interval of the well does not correspond to the main zone of movement in the Upper Floridan aquifer of constituents migrating from the surficial aquifer, or if the open interval is too lengthy, the measured concentrations of recharge water constituents will be lower than those in the water recharging the Upper Floridan aquifer.

Specific Conductance

At RIB site 5, the earliest values of specific conductance at most surficial wells were approximately in the range of 50–100 μS / cm, well within the limit (400 μS / cm) considered to characterize natural background level in this area. The first value for well 5-04 looks anomalous, and could represent a decimal-place error. In the latter part of the record, specific conductance values generally resemble those of the reclaimed water. Values from well 5-04 are notably less than values from the other wells. Even though 5-04 is only 100 ft away from a RIB cell, it is at a higher elevation and would be hydraulically up gradient from the RIB cell under natural conditions. The specific conductance value at well 5-01 is near the reclaimed water value, even though 5-01 is 700 ft from the nearest RIB cell. Well 5-01 is in a depression and is hydraulically downgradient from the RIB cells. The specific conductance at the Upper Floridan well (5F-1) remains in the low part of the natural range, but shows a slow, consistent increasing trend beginning in 1998.

At RIB site 7, early specific conductance values from five of the eight surficial wells were less than 200 μS / cm, but values from all wells in the later part of the record are similar to those of the reclaimed water. Early specific conductance values from the first Upper Floridan well (7F-1) were in the higher part of the natural range, but rose above that range from 1995 till sampling was discontinued in 1999. Values from the replacement Upper Floridan well (7F-2), starting in January 2001, have all been similar to those characterizing the reclaimed water, which suggests the possibility that the Upper Floridan aquifer may have been invaded by drilling fluids from the surficial aquifer. However, sufficient development after drilling and the natural movement of aquifer water would counteract any such effect.

At RIB site 9, the only substantial discharges occurred in early 1987, early 1997, and early 2001. Early specific conductance values from six of seven monitor wells were less than or equal to 100 μS / cm. Specific conductance values from surficial wells remain below 100 μS / cm for much of the period of record, with increases to 300–400 μS / cm after the inflow periods. Generally, the values remain well below those characteristic of the reclaimed water. Well 9-03 shows an increase to over 500 μS / cm in early 2002. Specific conductance from the two Upper Floridan wells (9F-1 and 9F-2) remain in the upper part of the natural range until 2001, when values from 9F-1 quickly rise to nearly those of the reclaimed water. Sampling of well 9F-2 was discontinued after December 1999.

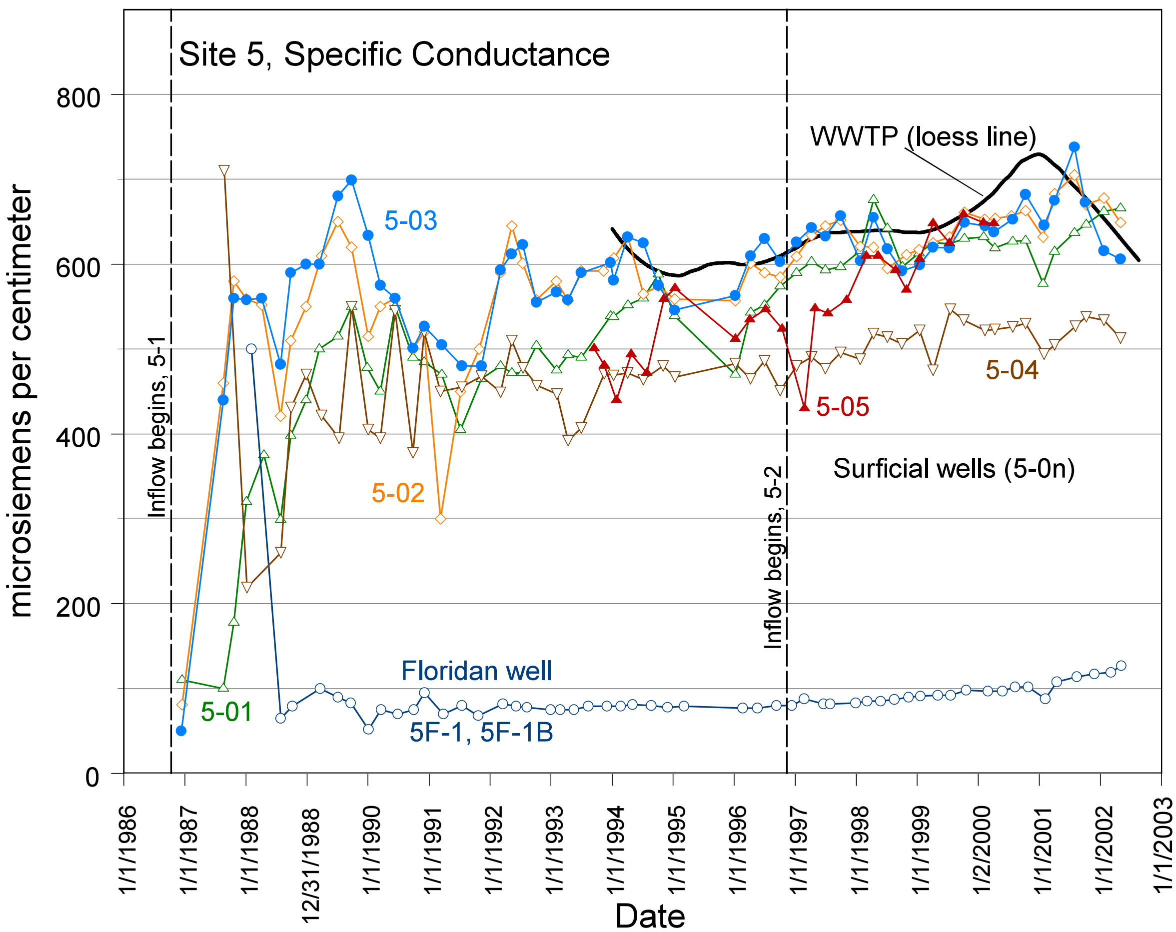

Figure 43. Specific conductance values measured at five surficial monitor wells and one Upper Floridan monitor well at RIB site 5 and at the wastewater treatment plant, 1986–2002

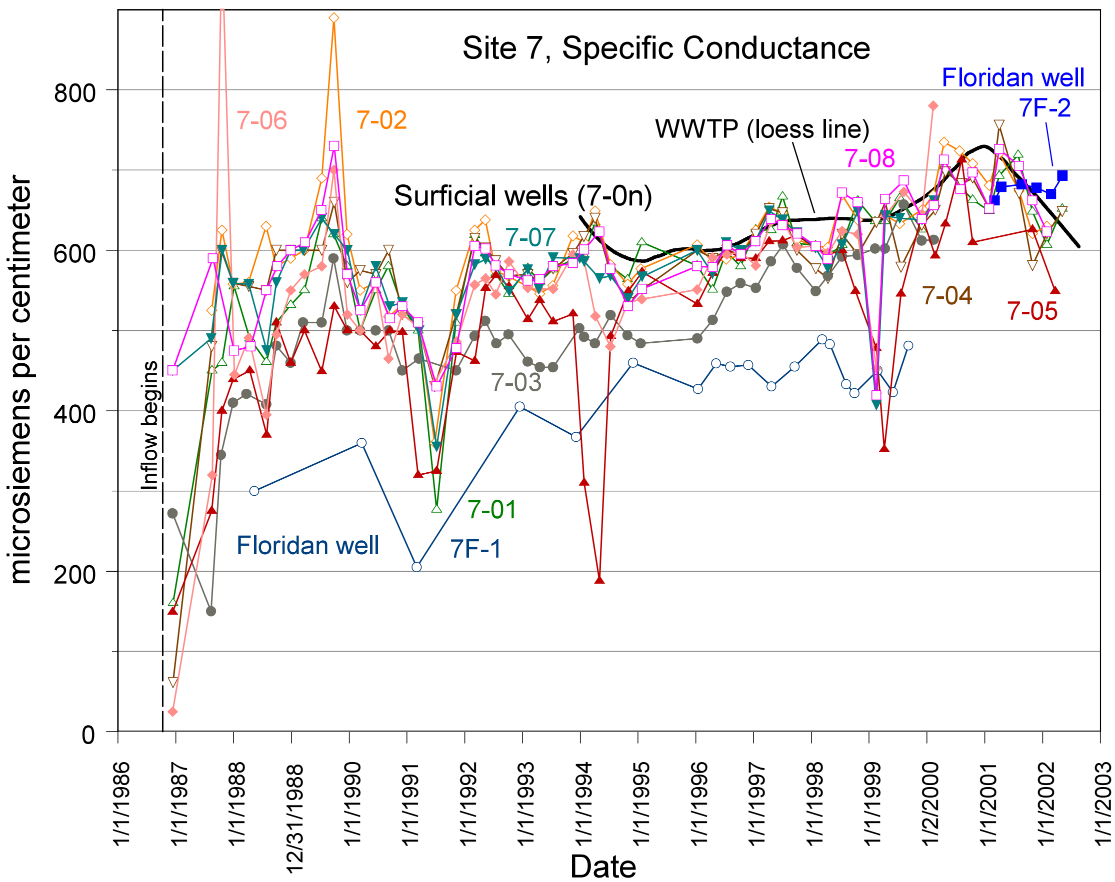

Figure 44. Specific conductance values measured at eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

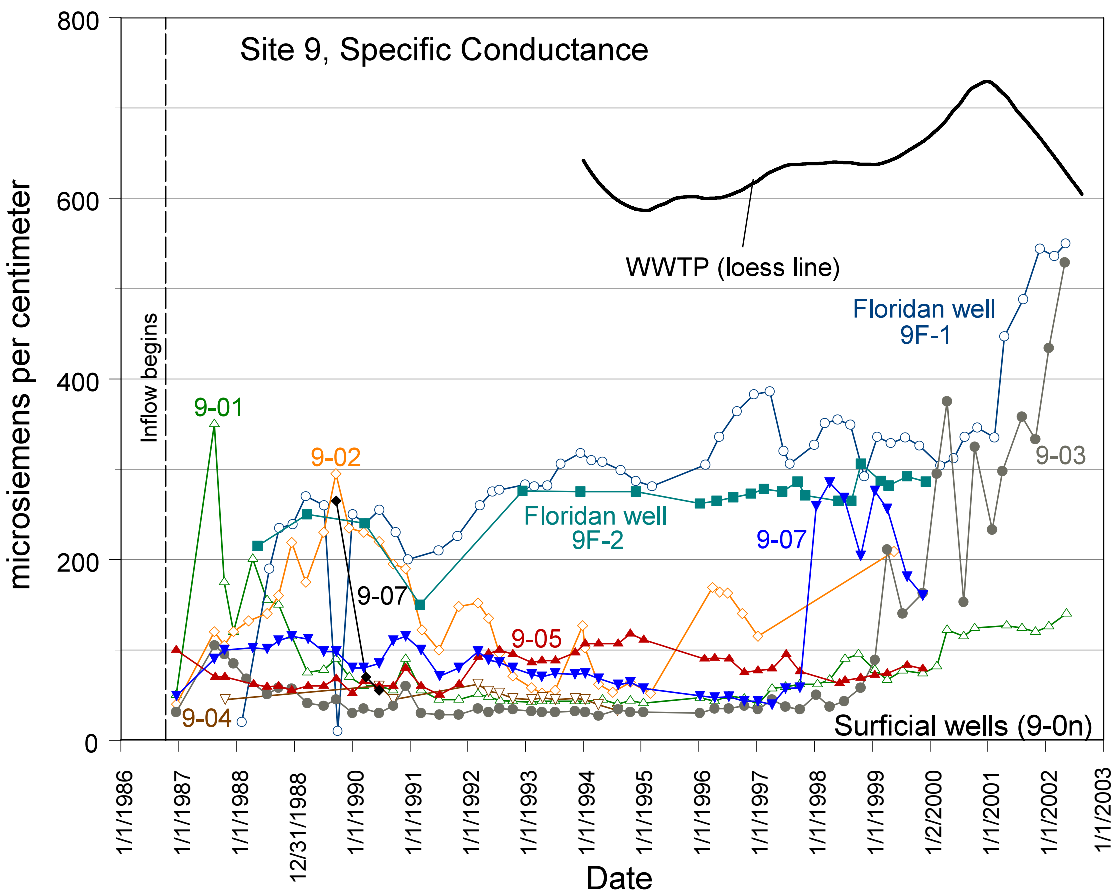

Figure 45. Specific conductance values measured at seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

Chloride

Chloride concentrations measured in the surficial and Upper Floridan wells since 1986 at RIB sites 5, 6, 7, and 9 are shown in Figures 46–51. It is noted that, at surficial wells at all four sites having data samples before or slightly after the beginning of injection at those sites, most of the measured chloride concentrations are less than 25 mg/L. Many of the measured concentrations are about 10 mg/L. Early concentrations at 7-07 and 7-08 were about 30 mg/L. At many of these same wells, some early concentrations fluctuated as high as 70 mg/L for unknown reasons.

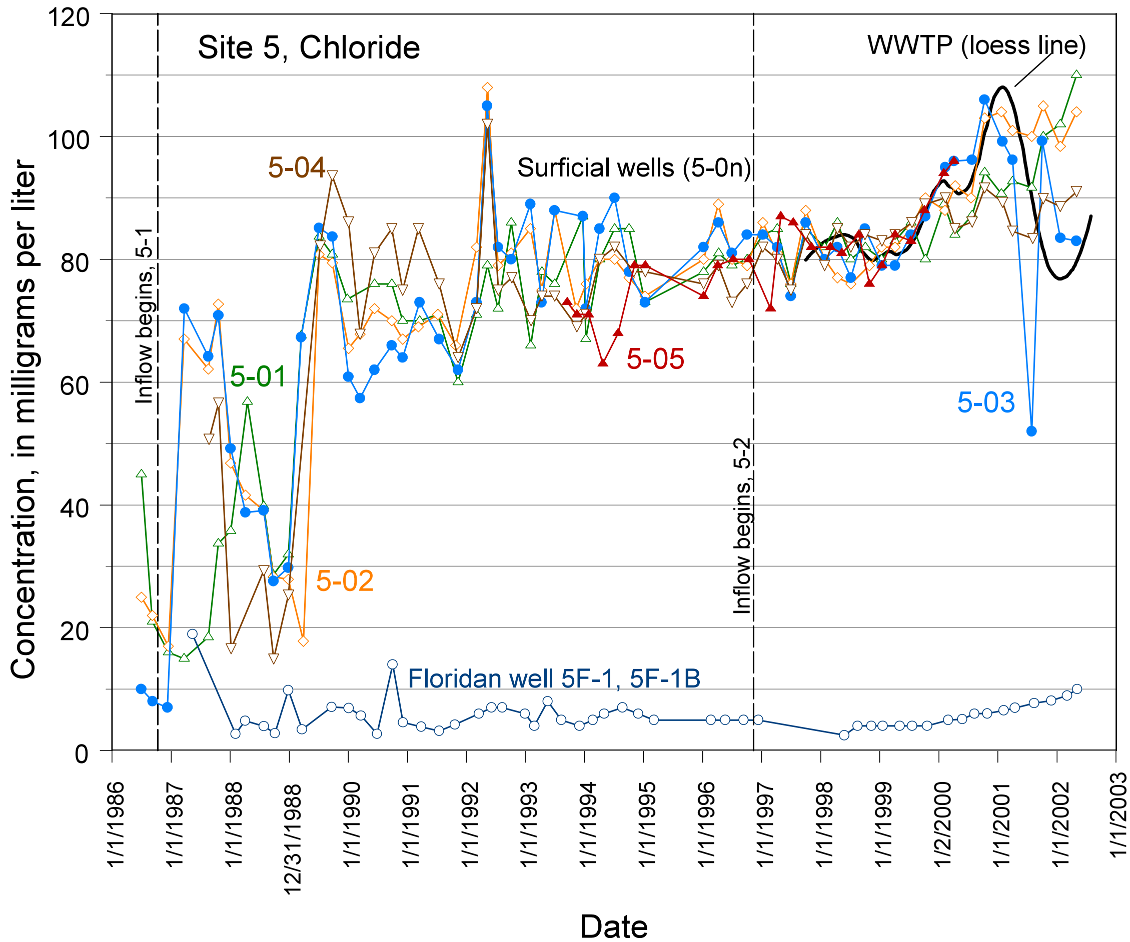

Figure 46. Chloride concentrations measured at five surficial monitor wells and one Upper Floridan monitor well at RIB site 5 and at the wastewater treatment plant, 1986–2002

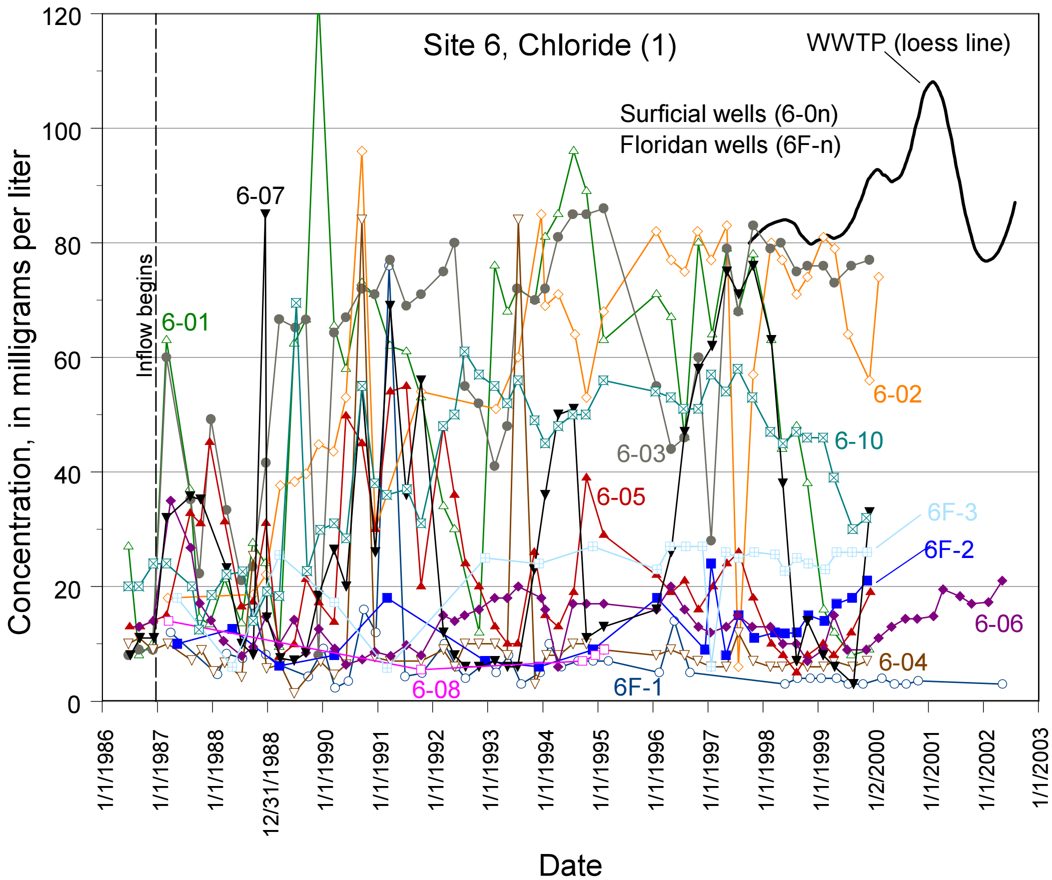

Figure 47. Chloride concentrations measured at nine surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

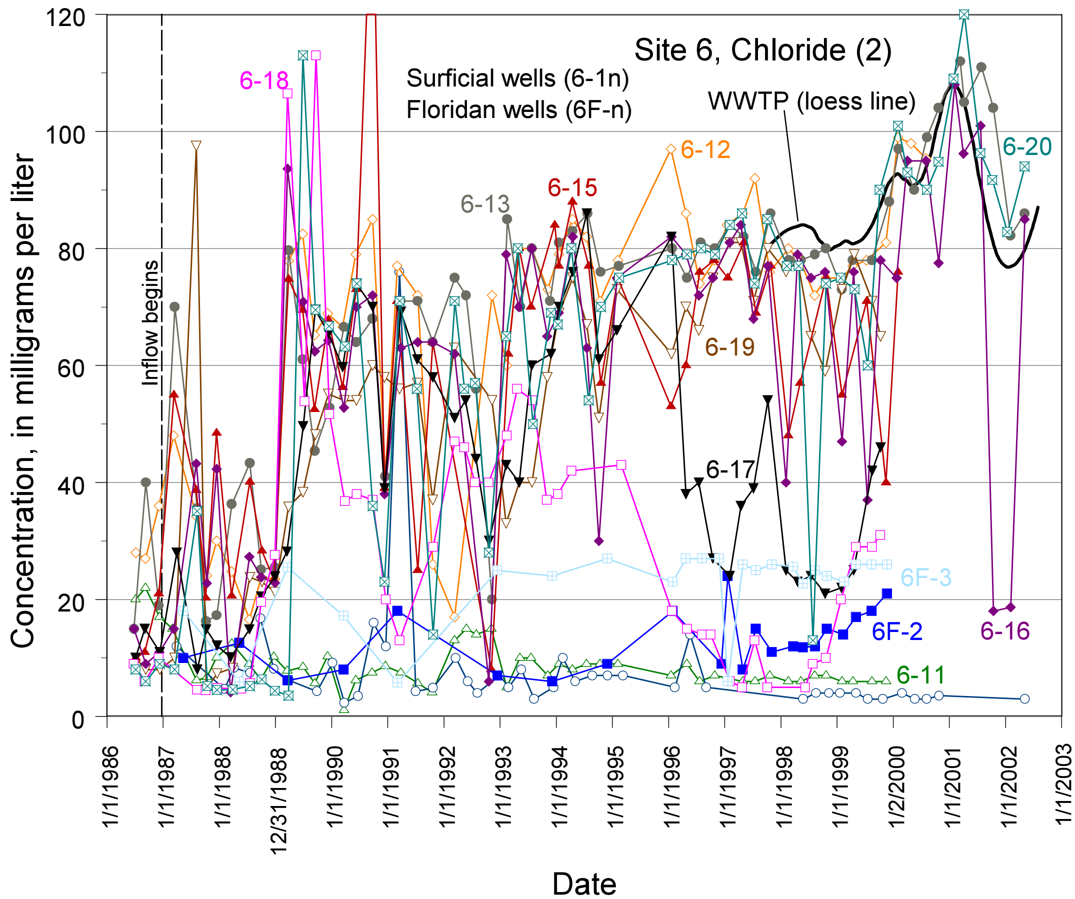

Figure 48. Chloride concentrations measured at nine surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

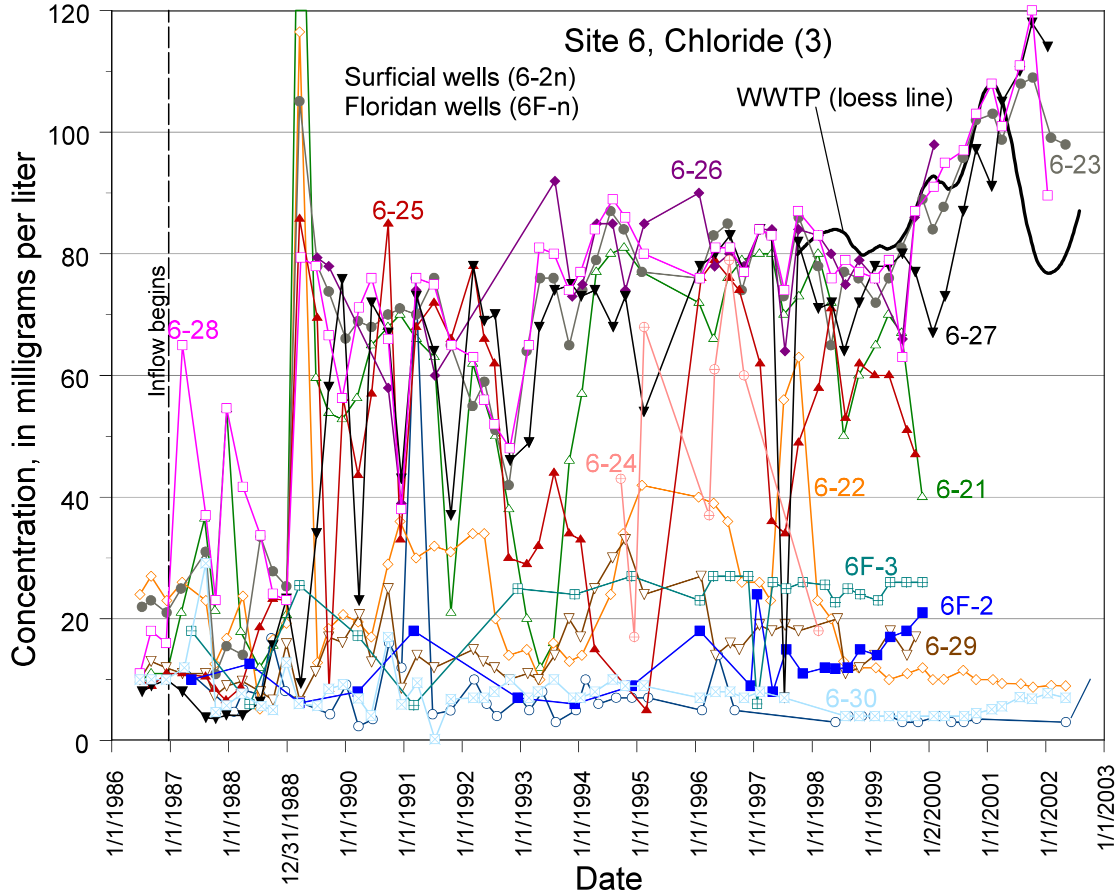

Figure 49. Chloride concentrations measured at ten surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

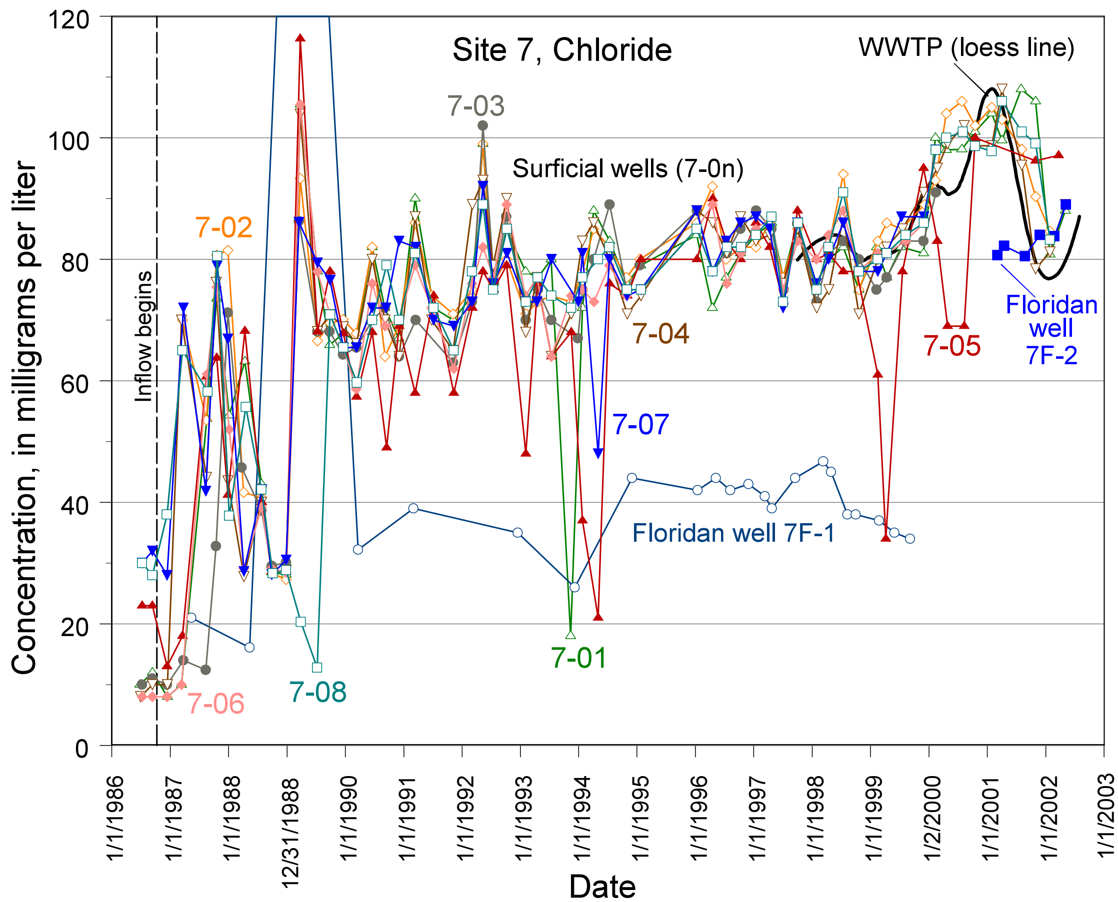

Figure 50. Chloride concentrations measured at eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

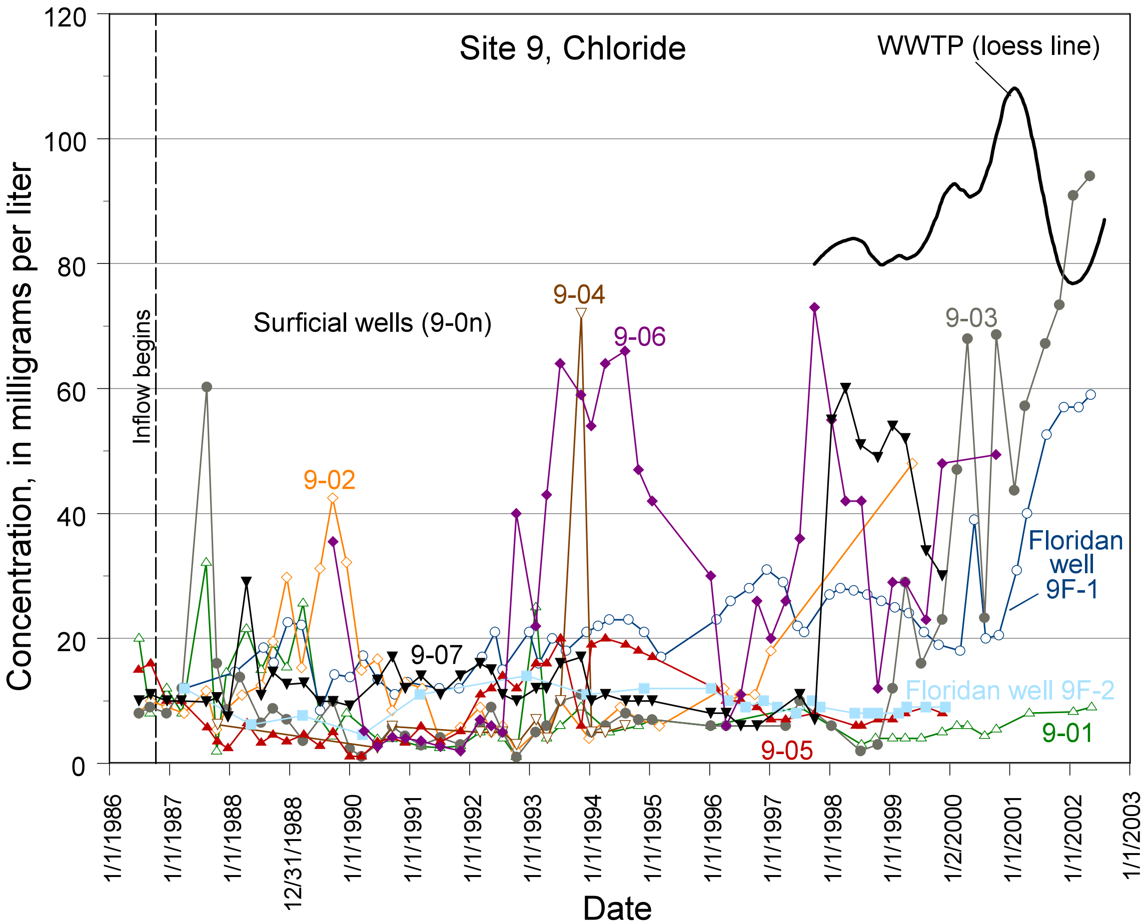

Figure 51. Chloride concentrations measured at seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

Early chloride samples at RIB sites 5 and 7 were within the natural range. Later, chloride concentrations measured at surficial wells at RIB sites 5 and 7 closely follow the local least square (loess) line through the widely fluctuating concentrations in the reclaimed water. At site 6, concentrations at surficial wells follow either the WWTP trend (6-03, 6-13, 6-20, and 6-23) or a natural background trend (6-04, 6-11, and 6-30), and concentrations from some wells (6-07 and 6-22) alternate between these two patterns. In the latter cases, the high chloride concentrations occur during the high rainfall years 1994-98 when the volumes of discharge of reclaimed water were highest, and the lower concentrations occurred during 1992–1994 and during the recent drought years (after mid-1998).

The time series of chloride concentrations from Upper Floridan wells at each site are plotted with concentrations from the surficial wells in Figures 46–51 to facilitate comparative analysis. An additional perspective on chloride concentration changes occurring at the Upper Floridan wells is provided by plotting the data from RIB sites 5, 6, 7, and 9 together (Figure 52).

Only three wells (7F-1, 7F-2, and 9F-1) have yielded water samples with chloride concentrations that are consistently above the limit (25 mg/L) of concentrations considered to be characteristic of the Upper Floridan aquifer under natural conditions unaffected by anthropogenic influences. Recent concentrations from well 9F-1 have shown a pattern of rapid increase. The single high concentration from 6F-1 could represent a decimal point error.

The high concentrations from 7F-2 are similar to the smoothed concentration values (loess line) from the WWTP, possibly with a time lag of two years. Because the well was drilled after the surficial aquifer was saturated with discharged reclaimed water, there might be a possibility that the Upper Floridan aquifer near the new well was invaded by reclaimed water during the drilling. This possibility would be substantially reduced if the well were developed sufficiently after the drilling was completed. According to the well completion report, it was “developed by submersible pump for four hours.” If invasion of water from the surficial aquifer were the case, downgradient advection of water in the Upper Floridan aquifer would cause a return to background conditions at the location of the well after a period of time.

Of the sample concentrations remaining within the natural background range, samples from 6F-3 have been consistently at the upper limit of that range. Samples from 6F-2 have usually been lower than those from 6F-3 but began to show an increasing trend (to 21 mg/L) during 1999. Sampling was

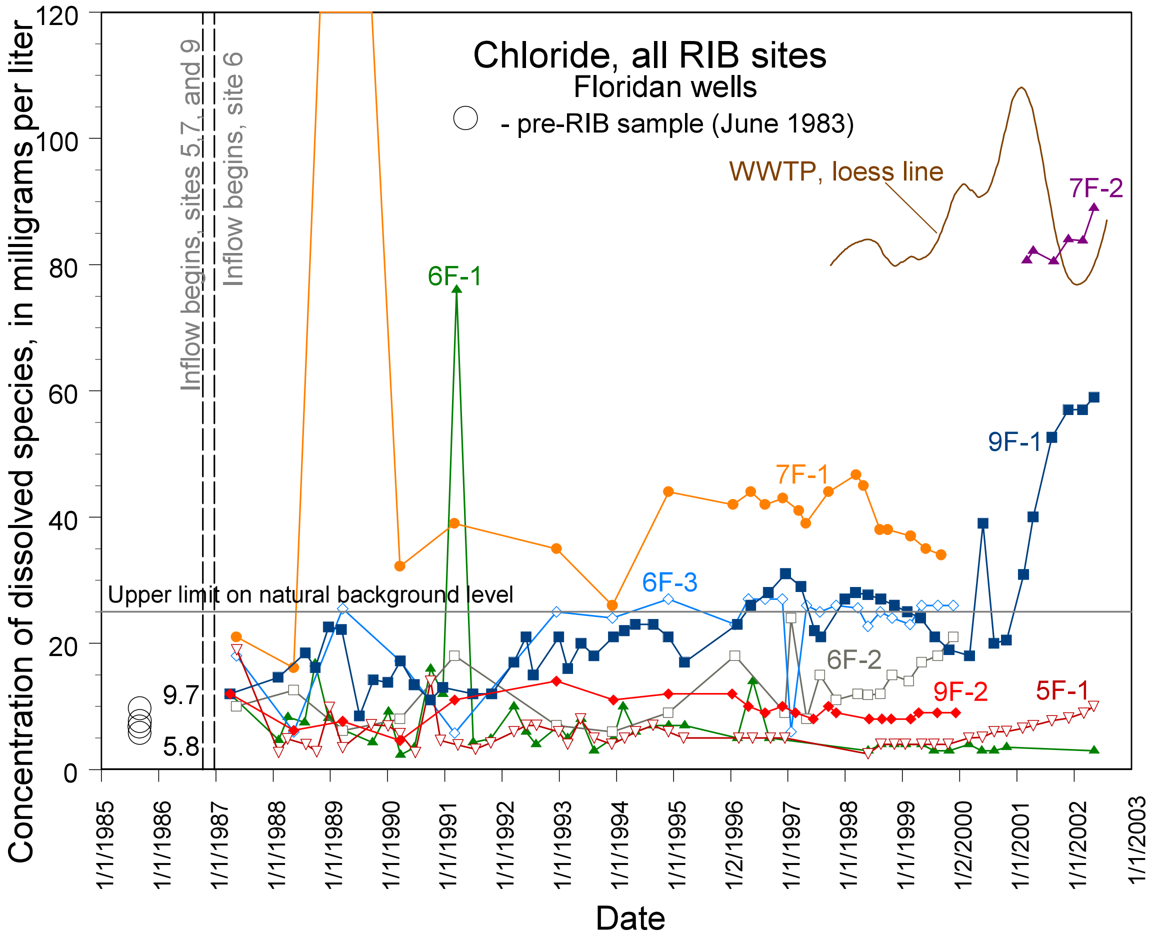

Figure 52. Chloride concentrations measured at Upper Floridan aquifer monitor wells at RIB sites 5, 6, 7, and 9

discontinued after November 1999. Chloride concentrations in samples from 6F-1 have remained low, as have concentrations from 9F-2. Chloride concentrations from 5F-1 have generally remained less than 10 mg/L, but have shown a steady increasing trend during 2000–2002.

Because the direction of flow in the Upper Floridan aquifer is generally northward or northeastward, many of the off-site Upper Floridan monitor wells (6F-2, 6F-3, and 7F-1) are generally in the direction of regional flow. An exception is 9F-2, located some distance up gradient. Many of the off-site wells (6F-2, 6F-3, and 7F-1) were irrigation wells and were regularly pumped for that purpose. In the late 1990s the Florida Department of Environmental Protection (FDEP) required that the off-site monitor wells be replaced by onsite wells. This required that well 7F-2 be drilled to replace 7F-1. Sampling at the off-site wells was discontinued in late 1999.

Total Dissolved Solids

Plots are provided showing the total dissolved solids (TDS) concentrations in water samples from surficial and Upper Floridan monitor wells for RIB sites 5, 7, and 9 (Figures 53–55). TDS concentrations are available from the WWTP discharge only from December 2001. It is not known whether TDS concentrations are computed from other measurements or are directly measured.

Data evaluations are similar to those made for specific conductance and chloride. The concentrations obtained from samples from surficial wells at RIB sites 5 and 7 are generally in mutual agreement with one another and with the smoothed local average (loess line) of WWTP data for the short period when the TDS concentrations from the WWTP are available. Again, concentrations from 5-04 samples are slightly less than from other surficial wells at site 5.

The Upper Floridan monitor well at site 5 has provided TDS concentrations in the low part of the natural background range. However, there appears to be a slight increasing trend starting in 1999. Concentrations from Upper Floridan monitor well 7F-1 are in the high part of the natural range till sampling was discontinued in September 1999. As for the chloride concentrations, TDS concentrations from Upper Floridan monitor well 7F-2, beginning in March 2001, are substantially higher than those previously measured at 7F-1.

At RIB site 9, TDS concentrations remain generally in the natural range, showing upward spikes following the short periods of discharge in 1987, 1997 and 2001. Concentrations from the two Upper Floridan monitor wells generally remain within the natural range, but are also generally higher than concentrations from the surficial wells. Sampling of well 9F-2 ceased in late 1999. Concentrations from well 9F-1 show an increasing trend after early 2000.

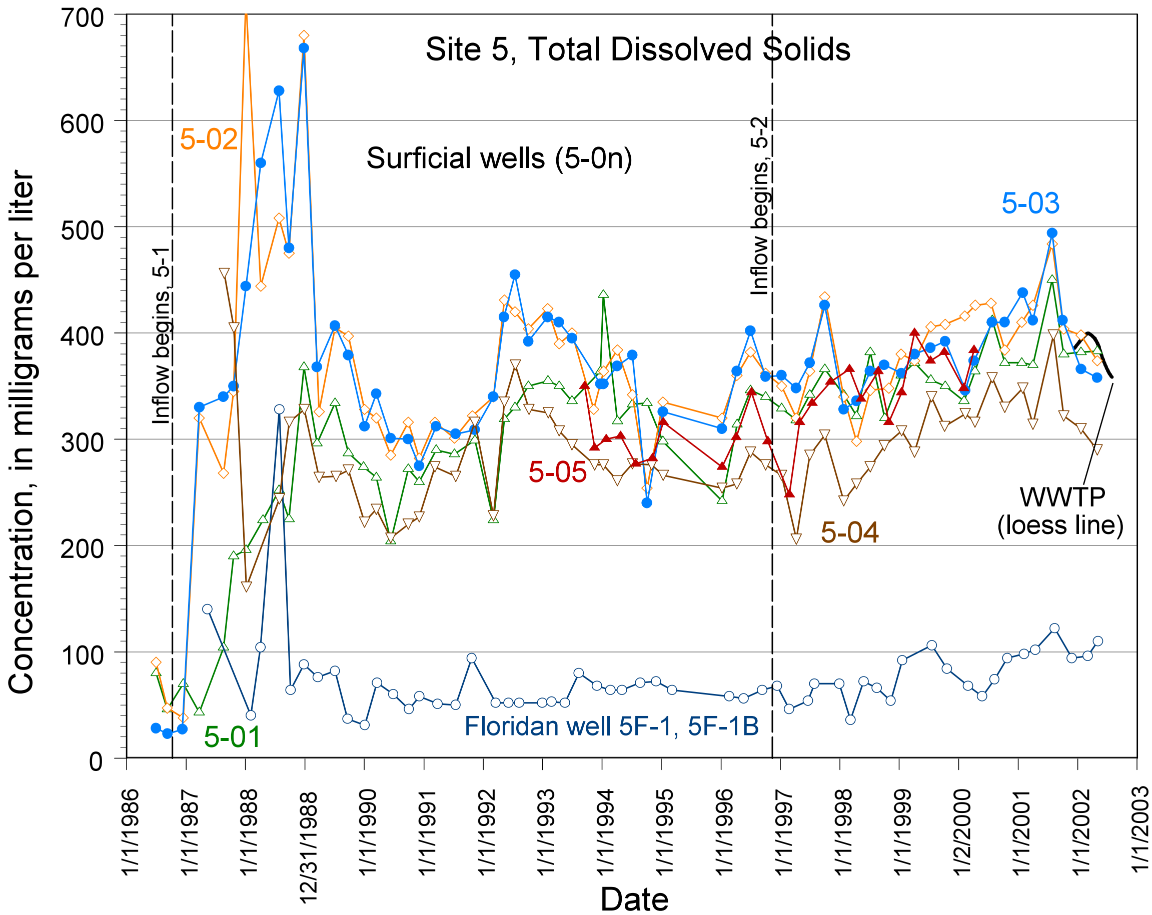

Figure 53. Total dissolved solids concentrations from five surficial and one Upper Floridan monitor well at RIB site 5 and from the wastewater treatment plant (2001–2002)

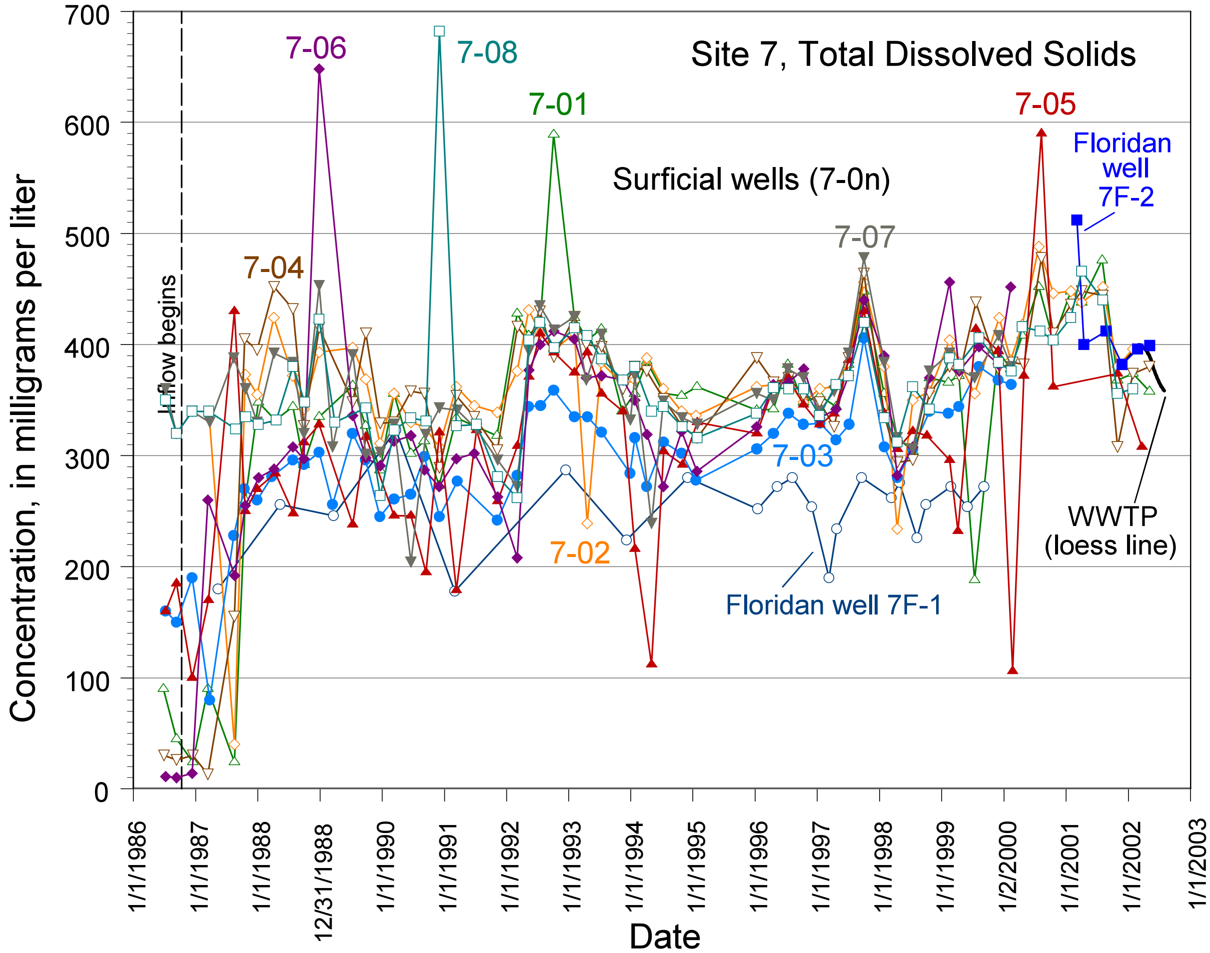

Figure 54. Total dissolved solids concentrations from eight surficial and two Upper Floridan monitor wells at RIB site 7 and from the wastewater treatment plant (2001–2002)

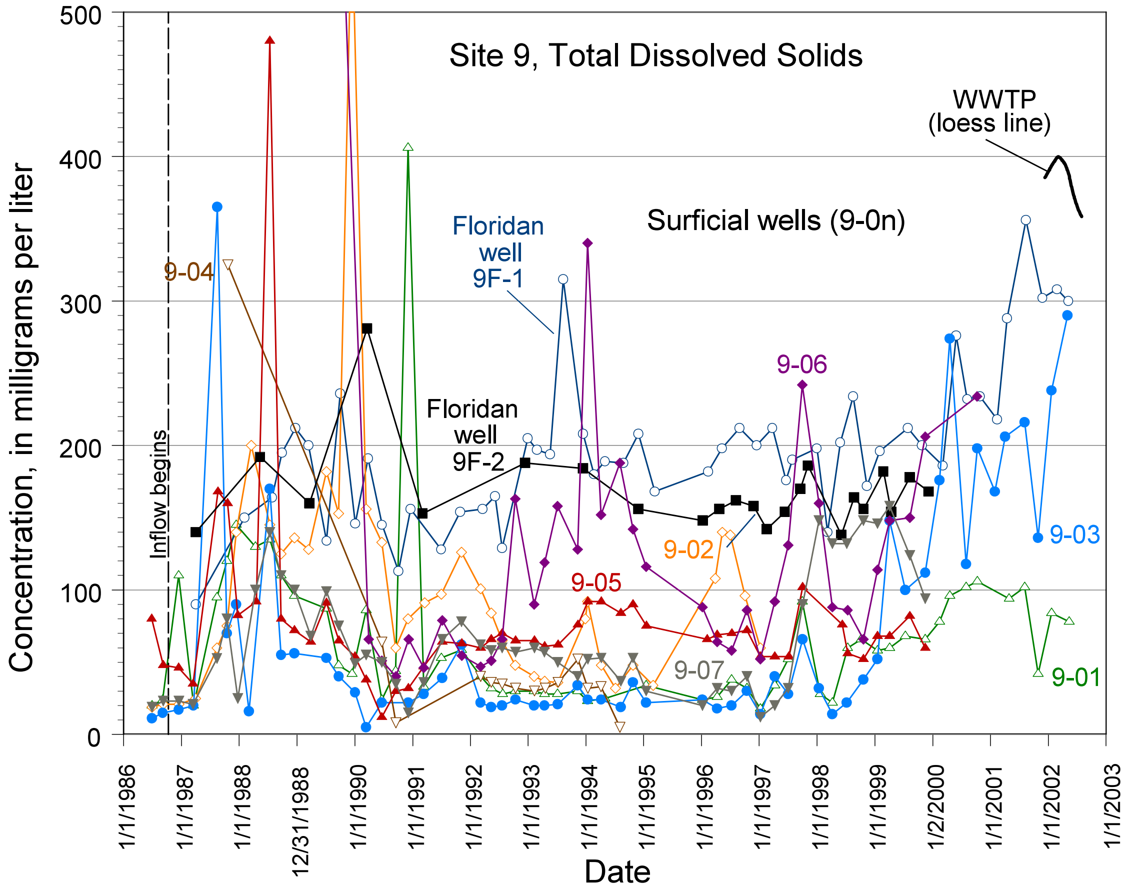

Figure 55. Total dissolved solids concentrations from seven surficial and two Upper Floridan monitor wells at RIB site 9 and from the wastewater treatment plant (2001–2002)

Nitrate Nitrogen

Plots are provided showing nitrate nitrogen concentrations in water samples from surficial and Upper Floridan monitor wells for RIB sites 5, 6, 7, and 9 (Figures 56–61).

At all surficial wells in RIB sites 6 and 9, water samples collected before discharge to the RIB cells began in October or December 1986, had nitrate nitrogen concentrations less than 2 mg/L. Initial samples from surficial wells at sites 5 and 7 had nitrate nitrogen concentrations less than 3 mg/L. Later samples at nearly all wells had nitrate concentrations that varied widely,

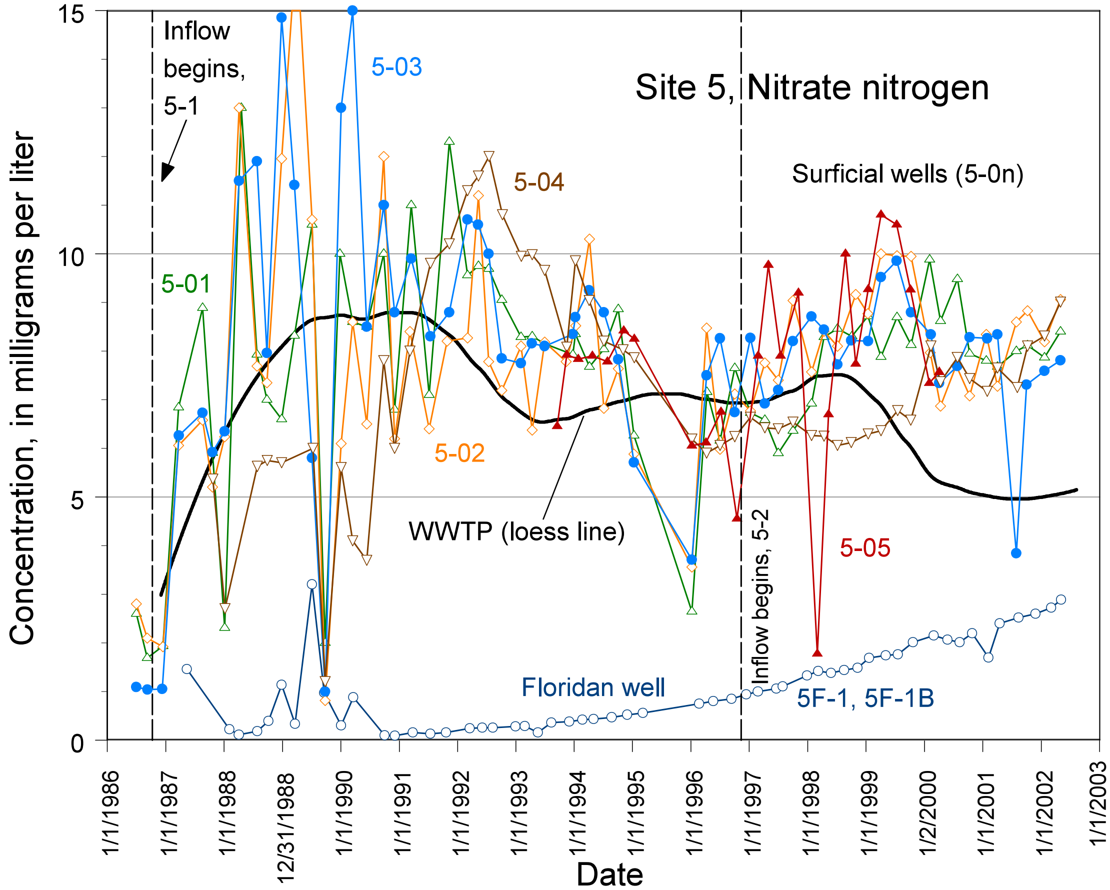

Figure 56. Nitrate nitrogen concentrations from five surficial and one Upper Floridan monitor well at RIB site 5 and from the wastewater treatment plant (1986–2002)

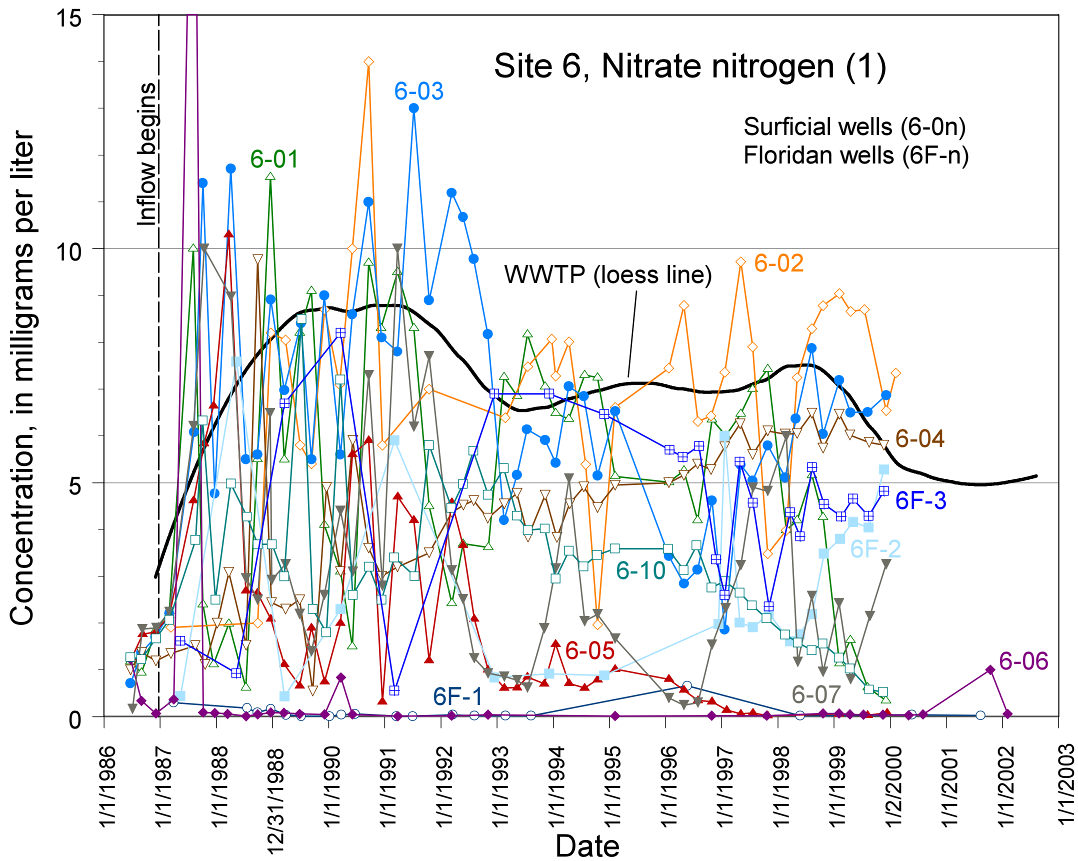

Figure 57. Nitrate nitrogen concentrations measured at nine surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

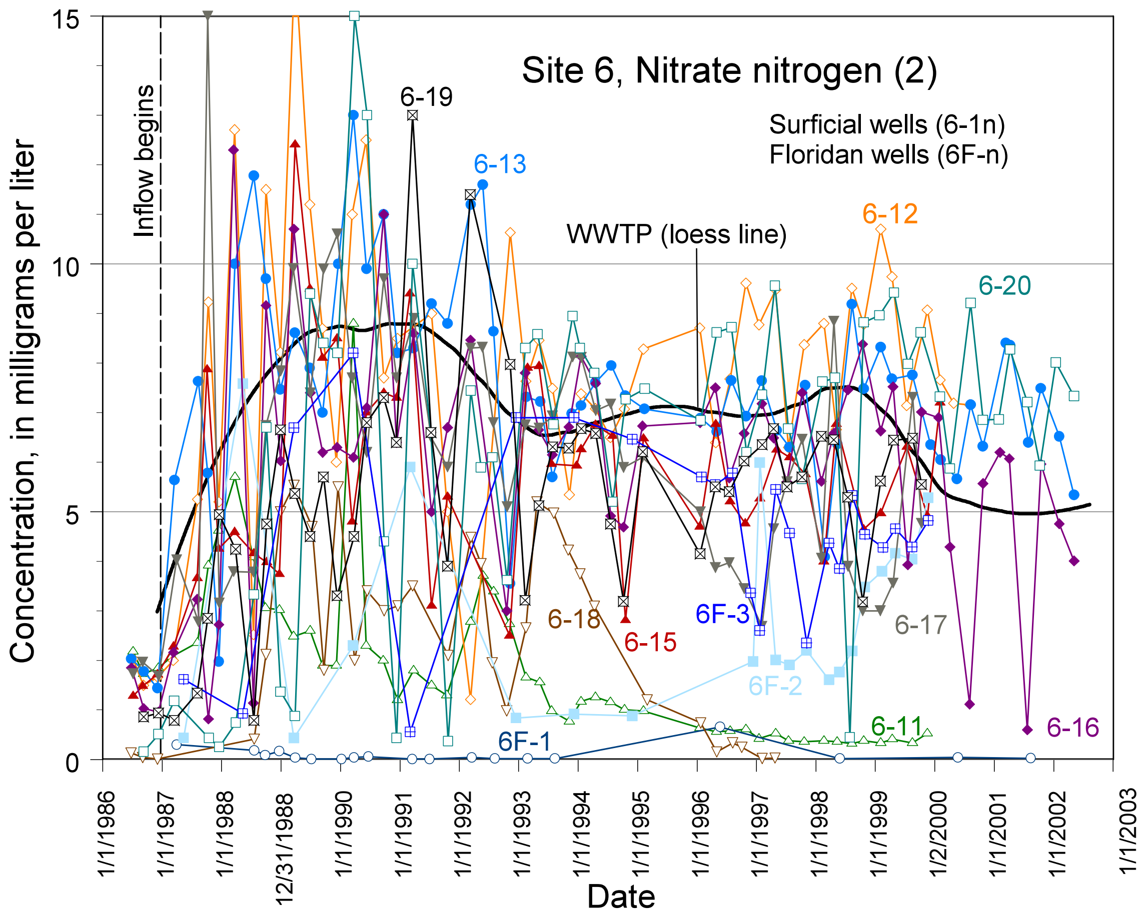

Figure 58. Nitrate nitrogen concentrations measured at nine surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

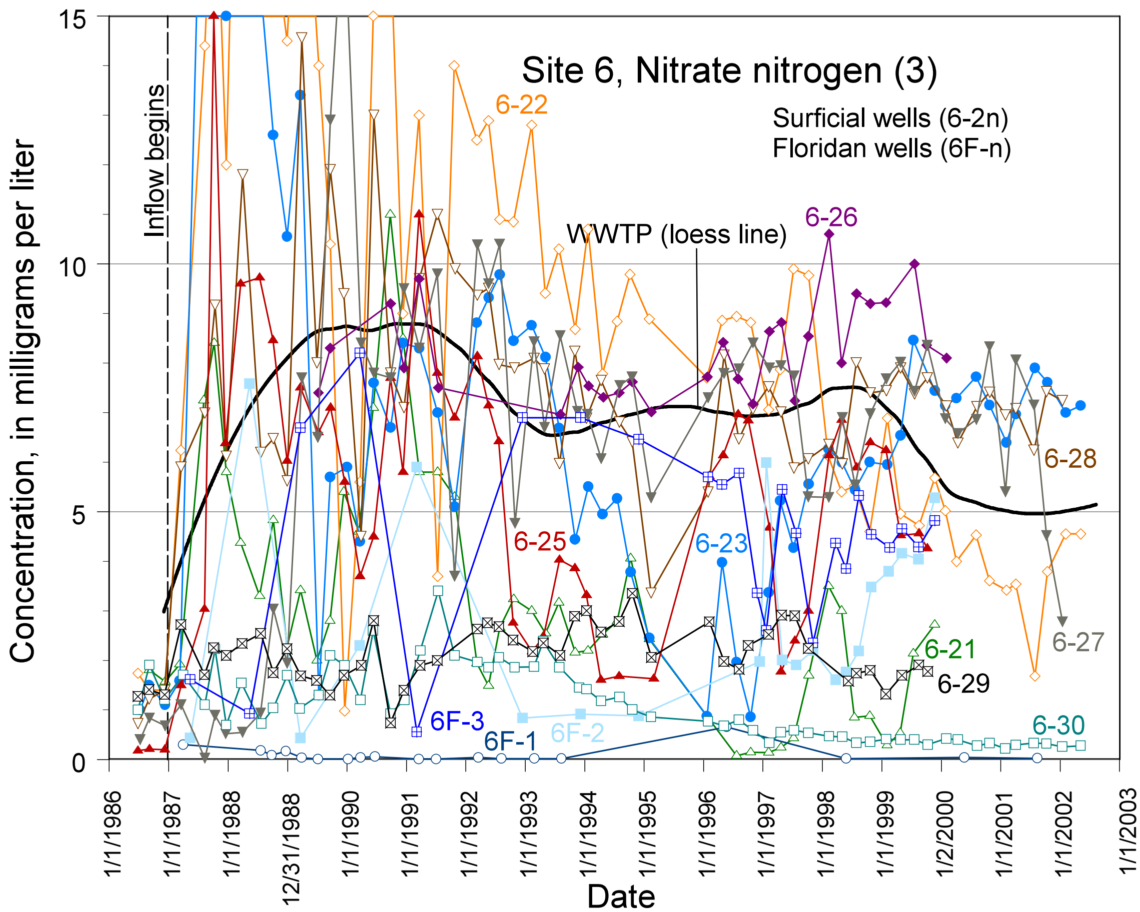

Figure 59. Nitrate nitrogen concentrations measured at ten surficial and three Upper Floridan monitor wells at RIB site 6 and at the wastewater treatment plant, 1986–2002

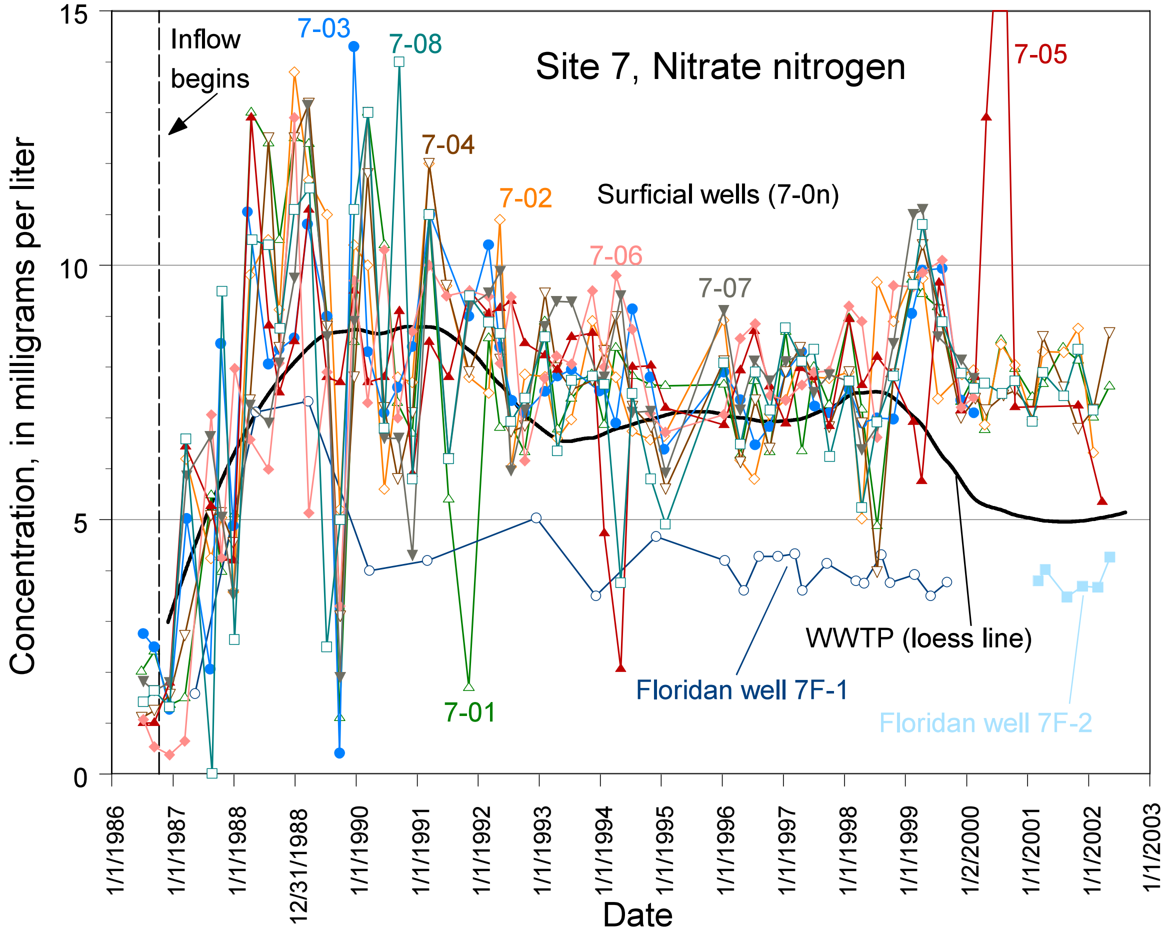

Figure 60. Nitrate nitrogen concentrations measured at eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

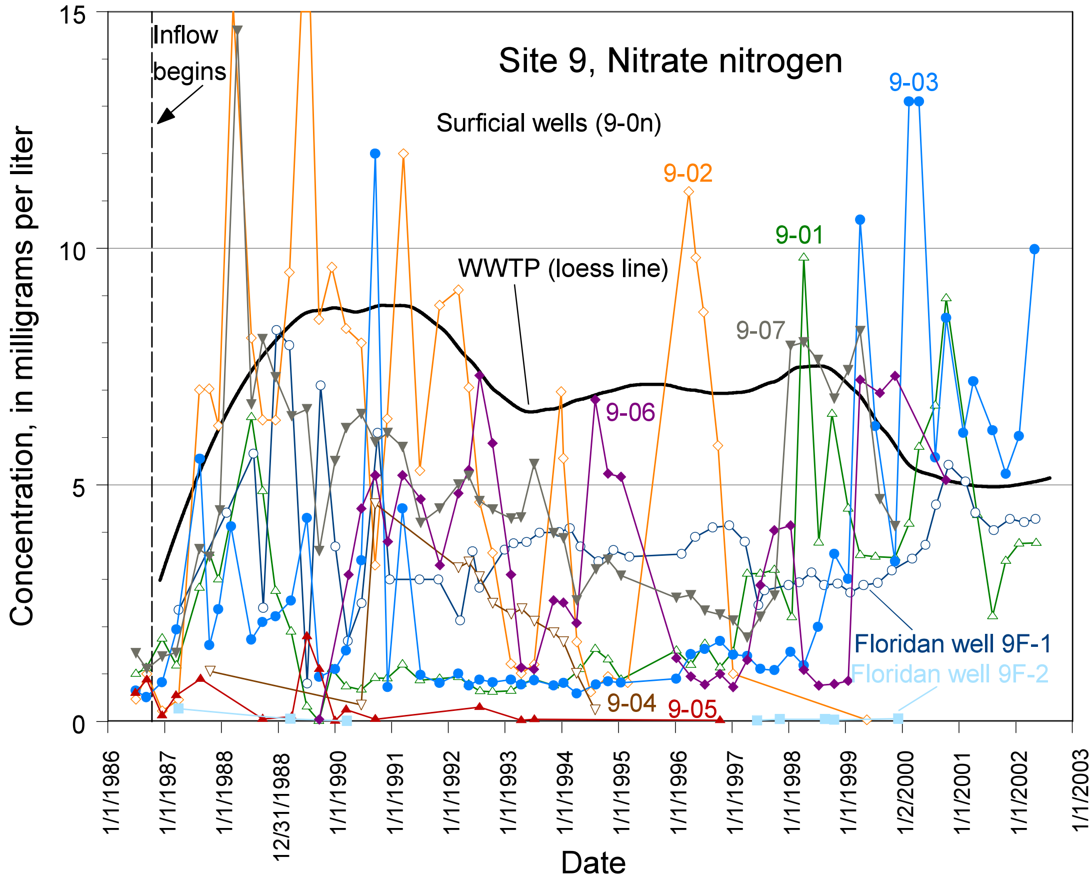

Figure 61. Nitrate nitrogen concentrations measured at seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

especially between 1987 and 1992, about the local regression (loess) line for nitrate samples from the WWTP effluent. The latter varied between 5 and 10 mg/L.

At RIB site 6, water samples from two surficial wells (6-05 and 6-06) had nitrate nitrogen concentrations less than 0.10 mg/L (the natural upper limit for pristine areas) for lengthy periods of time. This was also the case for water samples from well 9-05 at RIB site 9. At other surficial wells (6-10, 6-11, 6-21, 6-29, and 6-30) the nitrate nitrogen concentrations in water samples remained well below the WWTP sample concentrations, although they were above the natural limit for pristine areas.

The behavior of nitrate nitrogen concentrations in Upper Floridan aquifer wells is best viewed in Figure 62, which shows only Upper Floridan water samples and the WWTP loess line.

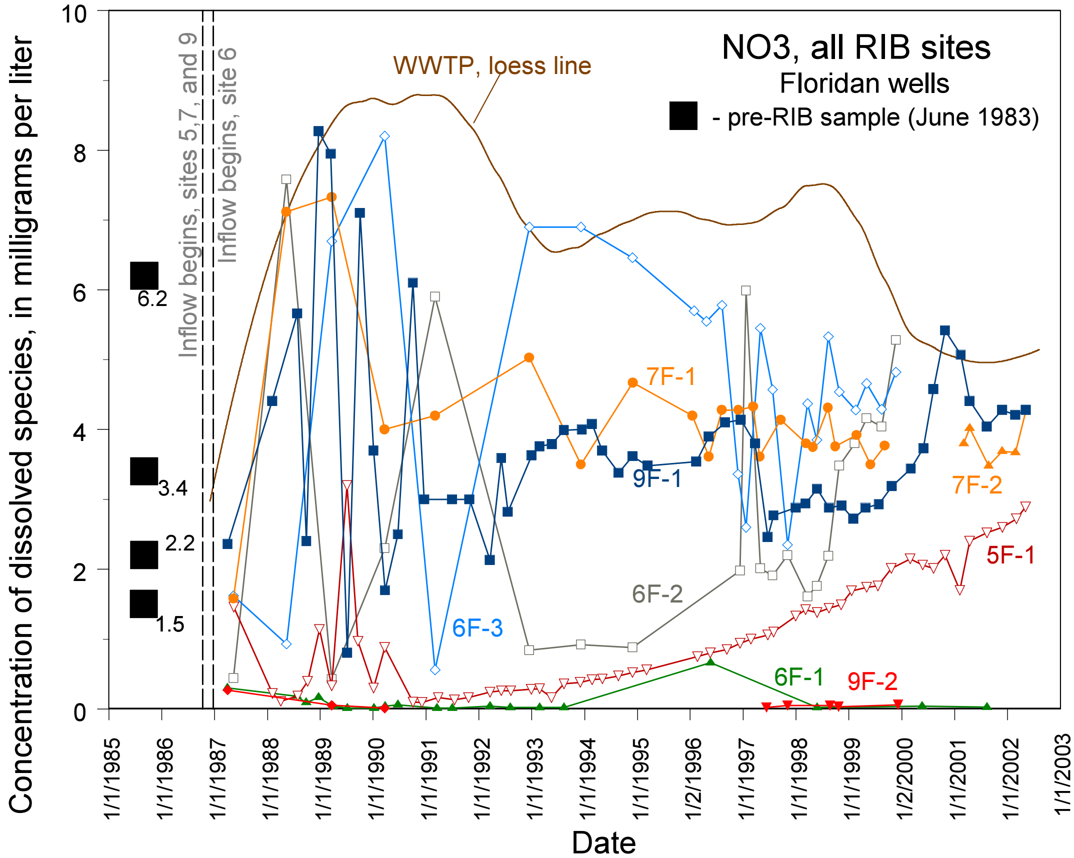

Figure 62. Nitrate nitrogen concentrations measured at Upper Floridan aquifer monitor wells at RIB sites 5, 6, 7, and 9 and the local average of nitrate nitrogen concentrations in wastewater treatment plant samples

Illustrated in the figure are the nitrate nitrogen concentrations in samples obtained in 1983 from four wells in the Floridan aquifer used for nursery or grove irrigation. The sampling date precedes the discharge to RIB basins by more than two years, but concentrations are well above those characterizing a pristine natural environment. As discussed earlier in this report, such concentrations might be characteristic of some sections of agricultural areas where irrigation and the use of nitrogen fertilizers are common practices. These practices are a means to maintain orange groves and nurseries that have been common in the study area for many decades.

At RIB site 5, the nitrate nitrogen concentration in samples from Upper Floridan well 5F-1was at a pristine natural level of 0.10 mg/L in October 1990. Since that time, there has been a steady increase to 2.89 mg/L in May 2002. However, this concentration is still appreciably less than the local smoothed average of nitrate nitrogen concentrations in reclaimed water from the WWTP (about 5 mg/L in May 2002).

At RIB site 6, nitrate nitrogen concentrations in all samples except one from 6F-1 are within the pristine natural background range. However, nitrate nitrogen concentrations in samples from wells 6F-2 and 6F-3, wells pumped regularly for irrigation to the north of the RIB site (Figure 3), are appreciably higher than pristine background levels. Concentrations at well 6F-3 oscillated about an average of 4 to 5 mg/L after 1996. At well 6F-2, a pattern of rapid increase, from 1.6 mg/L to over 5 mg/L, occurs between March 1998 and November 1999, when sampling at both 6F-2 and 6F-3 ceased.

At RIB site 7, nitrate nitrogen concentrations in samples from Upper Floridan well 7F-1 stabilized at about 4 mg/L after 1990. Sampling from this off-site well, pumped regularly for irrigation, ceased in September 1999. Sampling began again at onsite Upper Floridan monitor well 7F-2 in March 2001, and nitrate nitrogen concentrations remained at the same level as previously found in samples from 7F-1.

At RIB site 9, nitrate nitrogen concentrations in samples from onsite Upper Floridan monitor well 9F-1 exhibited a period of strong oscillations during 1987-90 and stabilized thereafter at an average concentration of between 3 and 4 mg/L. There seems to be an increasing trend beginning in 1999. Concentrations in samples from well 9F-2, about 4,350 ft to the southeast of site 9 and hydraulically upgradient in the Upper Floridan aquifer, have remained, with one exception, within the pristine natural background range.

Total Phosphorus

Concentrations of total phosphorus in samples from surficial and Upper Floridan monitor wells at RIB sites 5, 7, and 9 are presented in Figures 63–65.

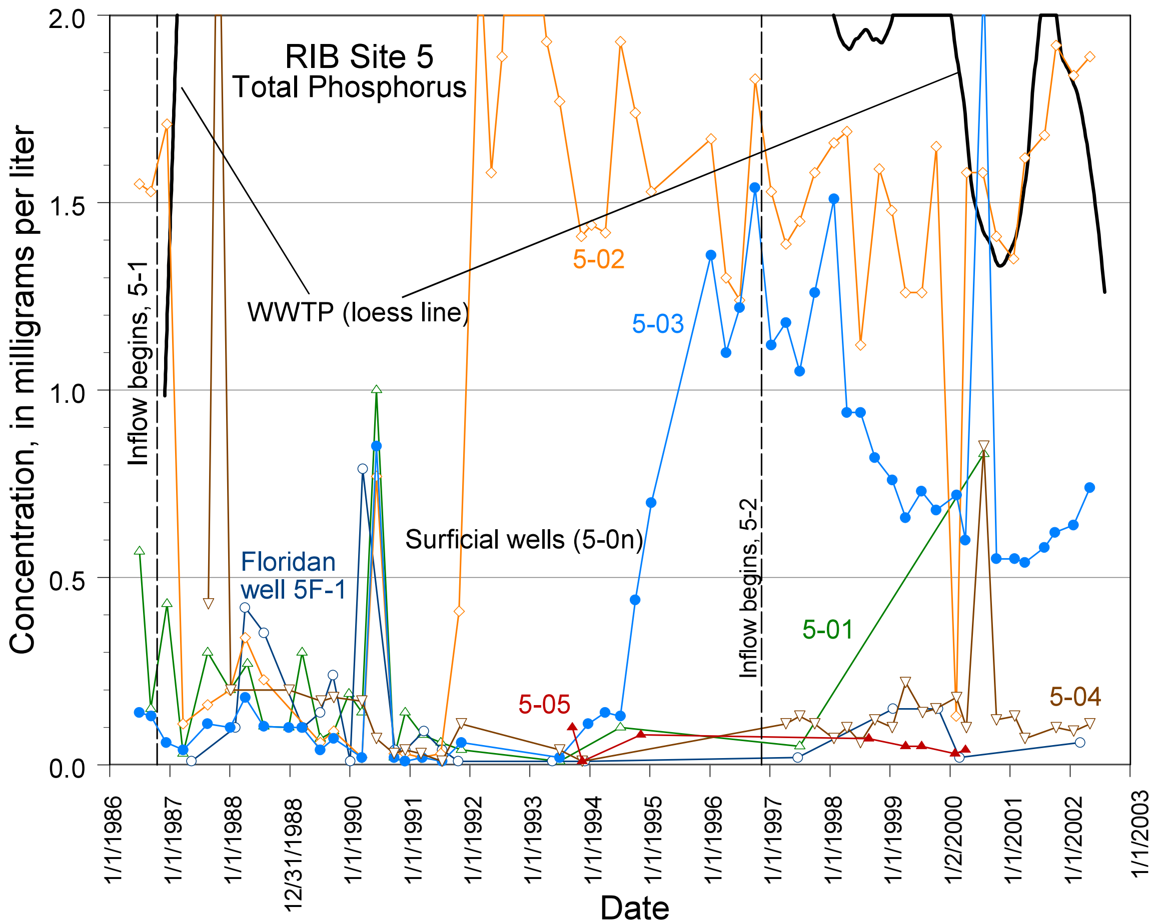

Figure 63. Total phosphorus concentrations from five surficial and one Upper Floridan monitor well at RIB site 5 and from the wastewater treatment plant (1986–2002)

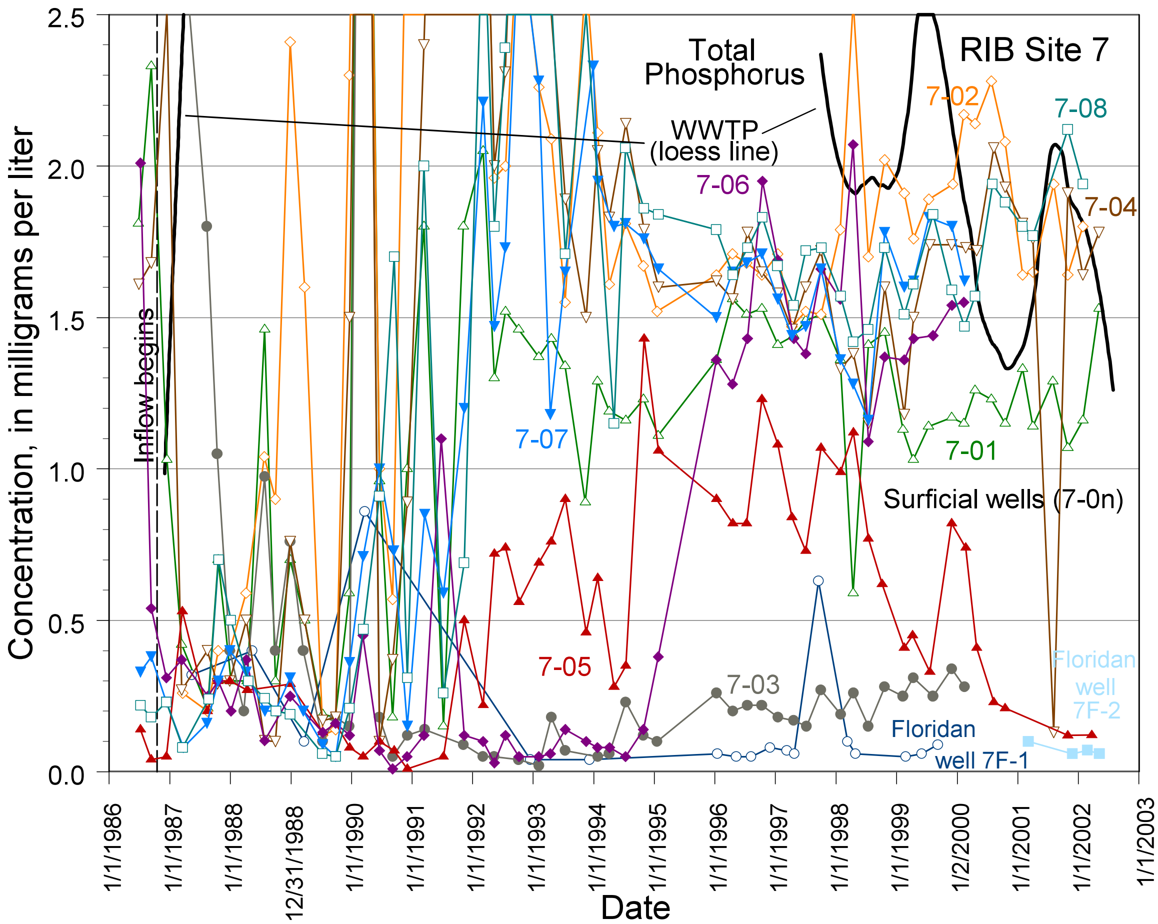

Figure 64. Total phosphorus concentrations measured at eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

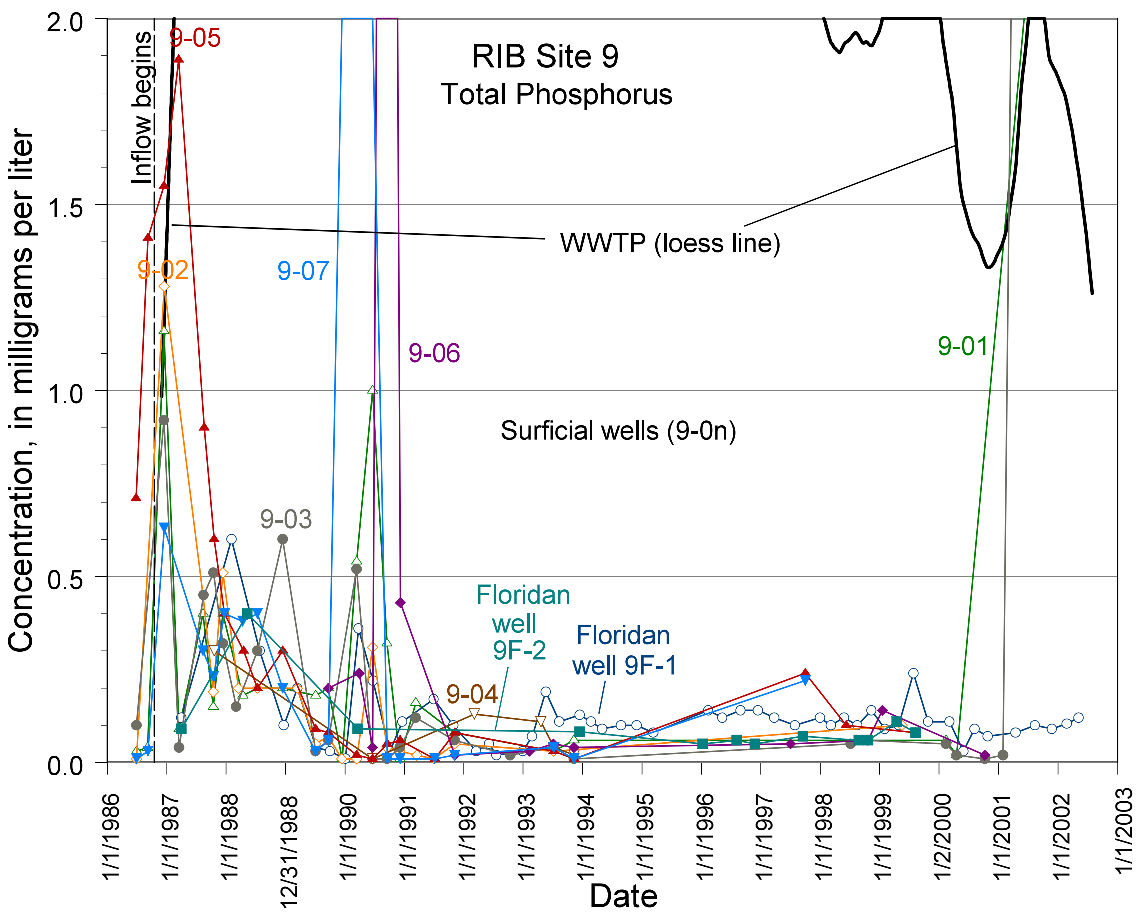

Figure 65. Total phosphorus concentrations measured at seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

At RIB site 5, concentrations of total phosphorus from surficial wells 5-01, 5-04, and 5-05 have increased above the natural background limit (0.10 mg/L) only occasionally since 1991. In October 1991, total phosphorus concentrations from well 5-02 abruptly increased into a range of 1.0 to 2.0 mg/L. In October 1994, total phosphorus concentrations from well 5-03 abruptly increased 1.0-1.5 mg/L, but declined after 1997 into a range of 0.5–1.0 mg/L.

At RIB site 7, only at well 7-03 have concentrations of total phosphorus remained within or slightly above the natural range. Concentrations of total phosphorus for well 7-05 were in the natural range before 1992 and have returned to it since 2001. Concentrations of total phosphorus for the other six monitor wells exhibited wide variations before 1992, and have been roughly comparable to total phosphorus concentrations in the reclaimed water since that time.

At RIB site 9, total phosphorus concentrations at surficial monitor wells have risen appreciably above the natural range only after the short period of discharge to the basin that occurred in early 1987. The fluctuations in 1990 are unexplained. The period of discharge in early 1997 raised total phosphorus concentrations only slightly at wells 9-05 and 9-07. The period of discharge in early 2001 seems to have caused high concentrations of total phosphorus to be measured at wells 9-01 and 9-03.

The behavior of total phosphorus concentrations at Upper Floridan monitor wells at RIB sites 5, 6, 7, and 9 is illustrated in Figure 66.

In June 1983, before any discharges to the RIB cells, water samples were collected for analysis from four grove and nursery irrigation wells in the CONSERV 2 area. Three samples had phosphate phosphorus concentrations equal or nearly equal to zero, but one sample had a concentration of almost 1.0 mg/L.

Total phosphorus concentrations for the Upper Floridan wells have remained well below the local smoothed average of orthophosphate phosphorus concentrations measured in the reclaimed water since 1986. In the years 1986–1990, all of the Upper Floridan wells provided some total phosphorus concentrations substantially higher than the natural, background range. After mid-1990, however, only well 9F-1 provided many concentrations greater than the natural range, and those concentrations were only slightly greater than the natural range. Single high concentration values from wells 6F-1 and 7F-1 could possibly represent decimal point errors.

Biochemical Oxygen Demand

The 5-day biochemical oxygen demand (BOD) values obtained from analysis of water samples from surficial and Upper Floridan wells in RIB sites 5, 7, and 9 are shown in Figures 67–69. The pattern of variation of BOD values is the same at all surficial and Upper Floridan sites. Before 1991, the data is characterized by substantial variation and the occurrence of high and low values. From 1991 through 1997, measured values are less than the local smoothed average (loess) of the measurements on reclaimed water samples. After 1997, measured values are generally similar to the values from reclaimed water samples.

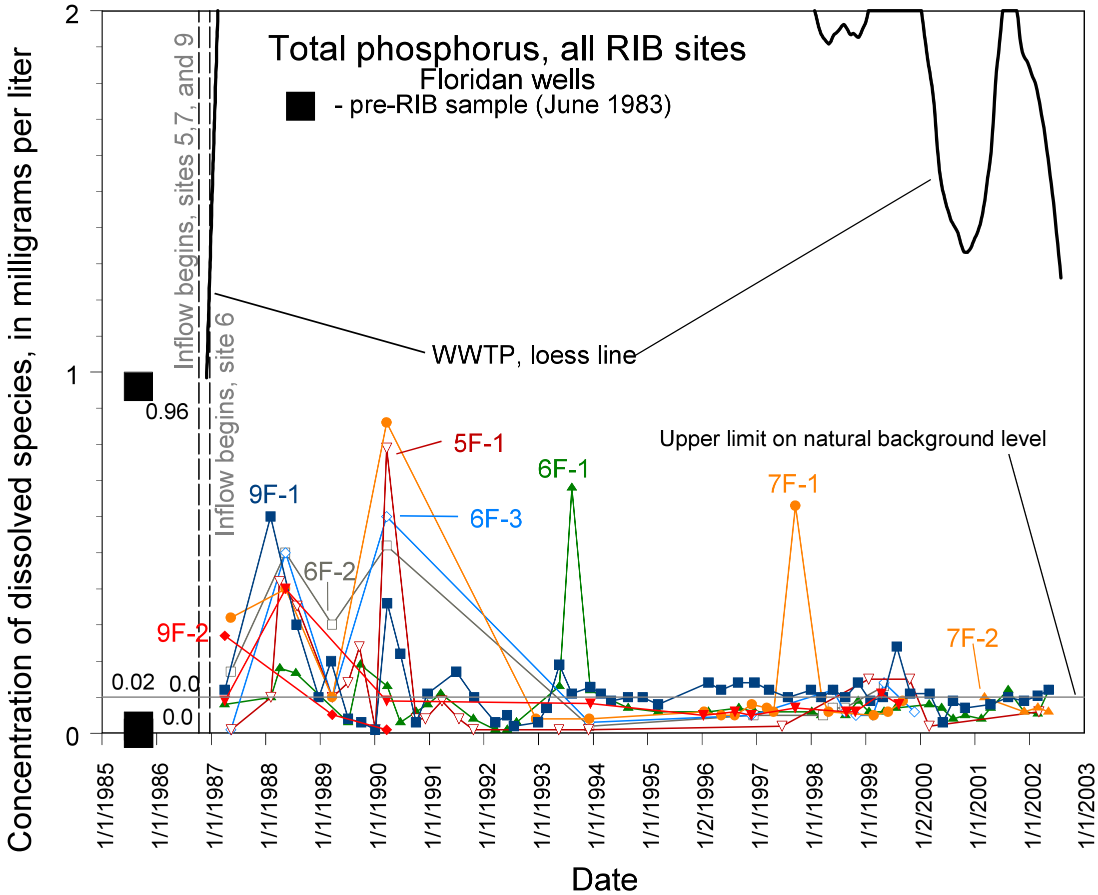

Figure 66. Total phosphorus concentrations measured at Upper Floridan aquifer monitor wells at RIB sites 5, 6, 7, and 9 and the local average of nitrate nitrogen concentrations in wastewater treatment plant samples

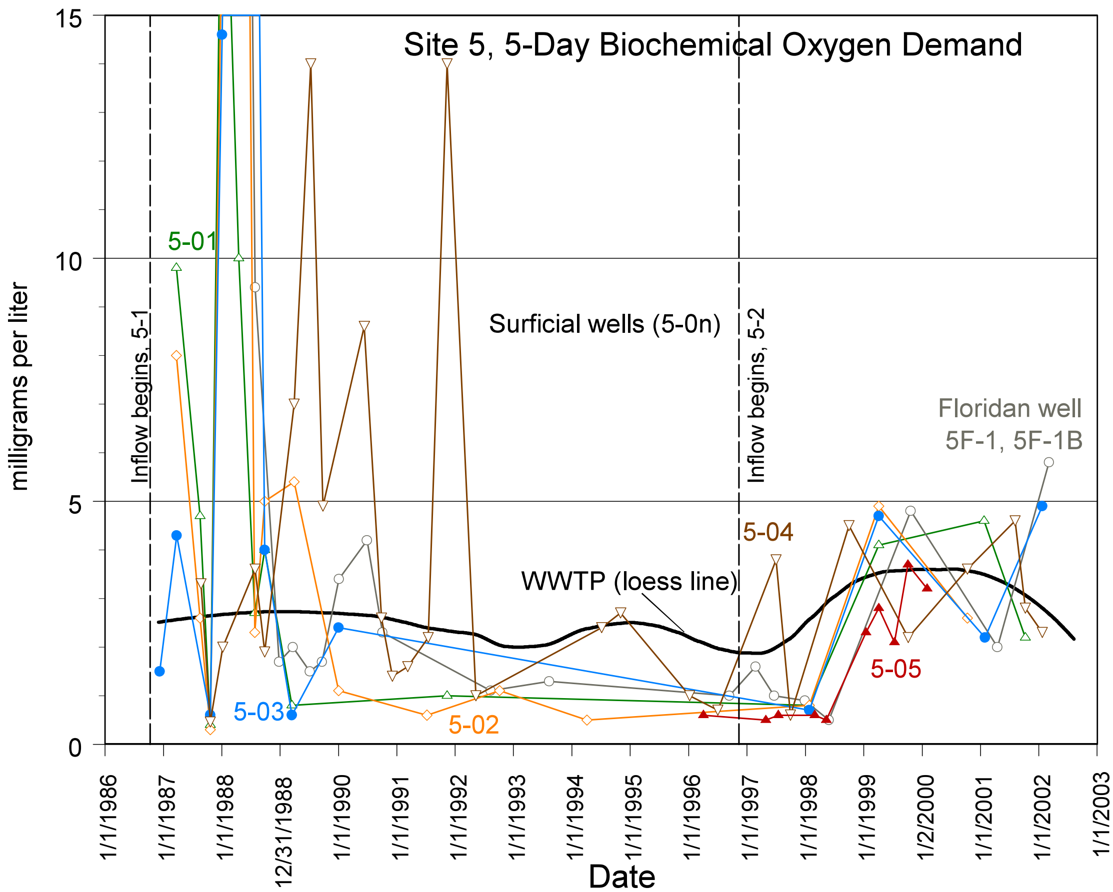

Figure 67. 5-day biochemical oxygen demand determinations from five surficial and one Upper Floridan monitor well at RIB site 5 and from the wastewater treatment plant (1986–2002)

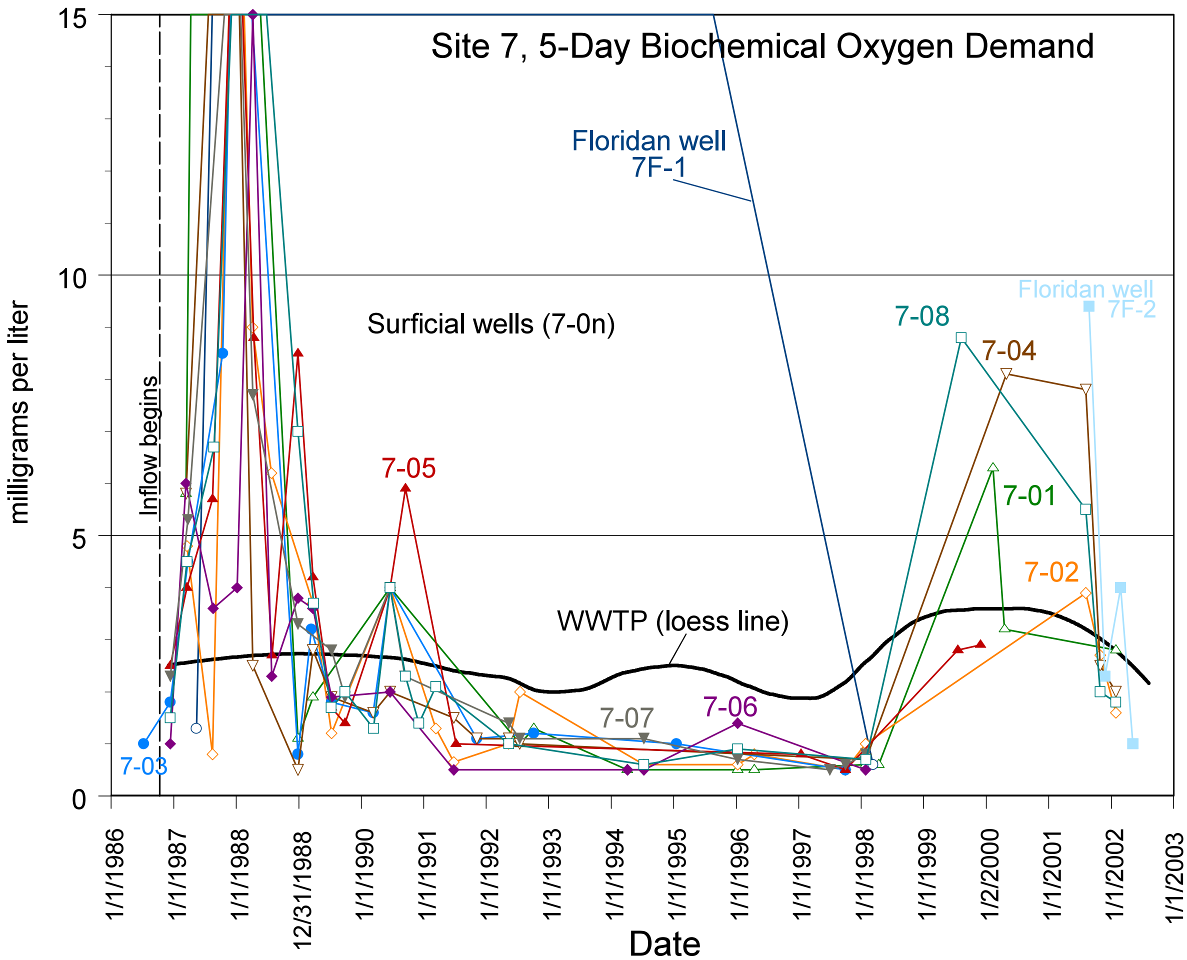

Figure 68. 5-day biochemical oxygen demand determinations from eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

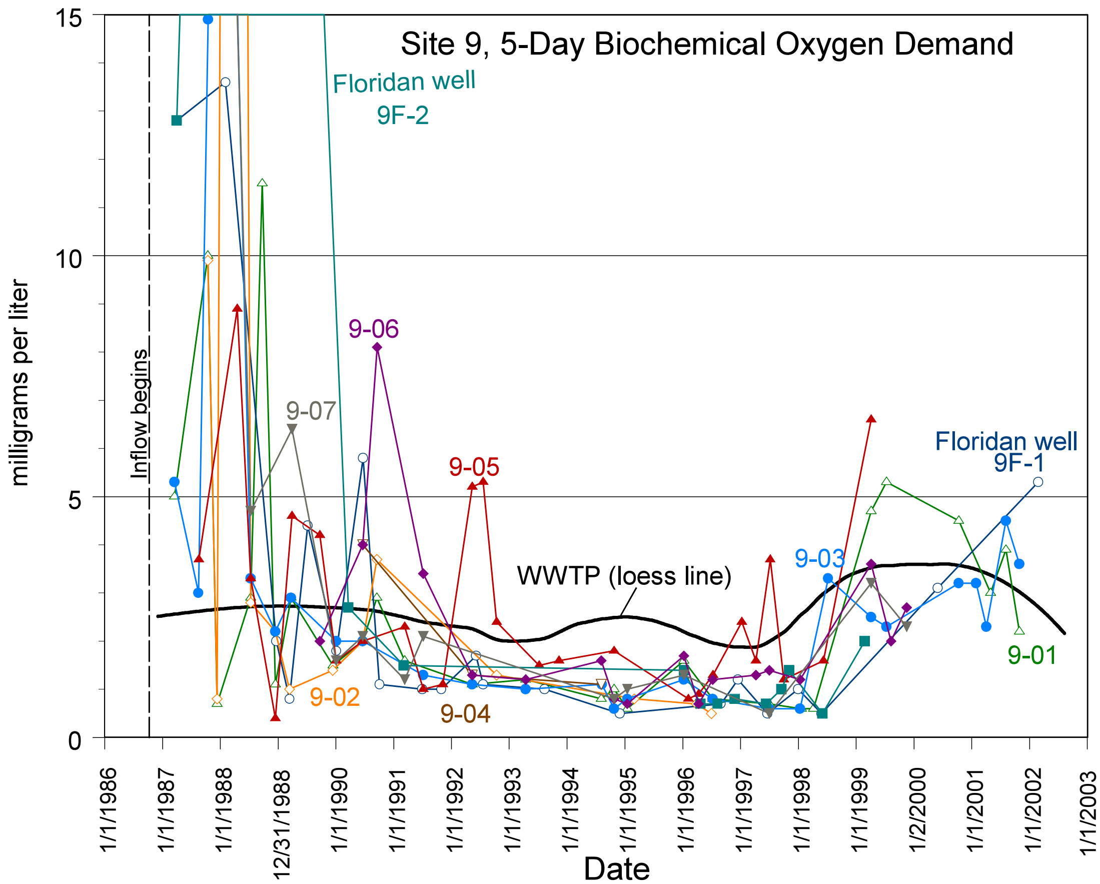

Figure 69. 5-day biochemical oxygen demand determinations from seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

pH

Measurements of the pH of water samples from surficial and Upper Floridan wells at RIB sites 5, 7, and 9 are shown below in Figures 70–72. Measurements of pH in the reclaimed water from 1986 to 2002 average (7.09) slightly above neutral (7.0), although there is some temporal variation of the loess line (Figure 17). A clear distinction is noted between surficial and Upper Floridan monitor wells in their characteristic pH measurements. The pH measurements from the surficial wells tend to be quite acidic, ranging as low as 4.0 at well 5-01 (site 5) and at many wells on site 9. At the latter site, all pH measurements from surficial wells after 1990 are below 6.0. At several wells on site 5, the pH at several wells is only slightly acidic after 1991. The pH measurements of water samples from surficial wells at site 7 generally are only slightly acidic, and occasionally become slightly alkaline.

The acidic tendency of pH measurements of water from the surficial wells is probably explained by the influence of rainfall, which tends to be acidic. On the other hand, the pH of water in the Upper Floridan aquifer is influenced by the soluble carbonate rock matrix, which tends to make the water alkaline, and this is evident in the depiction of pH measurements of samples from the Upper Floridan monitor wells in Figures 70-72. At site 5, pH measurements from well 5F-1 range as high as 10.0. In contrast, pH measurements from two Upper Floridan wells at site 7 generally range from 7.0 to 8.0.

The rate of leakage between the surficial and Upper Floridan aquifers probably influences the pH of the waters resident in each. Leakance estimates previously cited for the confining layer at site 5 were much lower than estimates cited for site 7 and 9. The greater rate of leakage beneath site 7, at which volumes of discharge are greatest of all the RIB sites, means that greater volumes of acidic water from the surficial aquifer will percolate to the Upper Floridan at site 7, reducing the alkalinity of the resident water.

Total Trihalomethanes

Total trihalomethanes (TTHM), the sum of concentrations of chloroform, bromodichloromethane, dibromodichloromethane, and bromoform, were measured in water samples from surficial and Upper Floridan monitor wells at RIB sites 5 and 7 (Figures 73–74). Only one to three measurements of this parameter were made on samples from each surficial well at sites 6 and 9, and on samples from all but two of the surficial wells at site 7. The plots below only show TTHM measurements from surficial wells where a sufficient number of TTHM measurements were made to show trends over a period of years. Total trihalomethanes were not measured in the reclaimed water stream from the treatment plant.

It is assumed that the four substances comprising the total trihalomethanes parameter are not present in natural waters in Florida. Any occurrence of these substances in the surficial or Upper Floridan aquifers would have a source in anthropogenic activities. At the RIB sites, the source is assumed to be the reclaimed water from the wastewater treatment plant. The concentrations at surficial wells at site 5 indicate the lateral movement of the

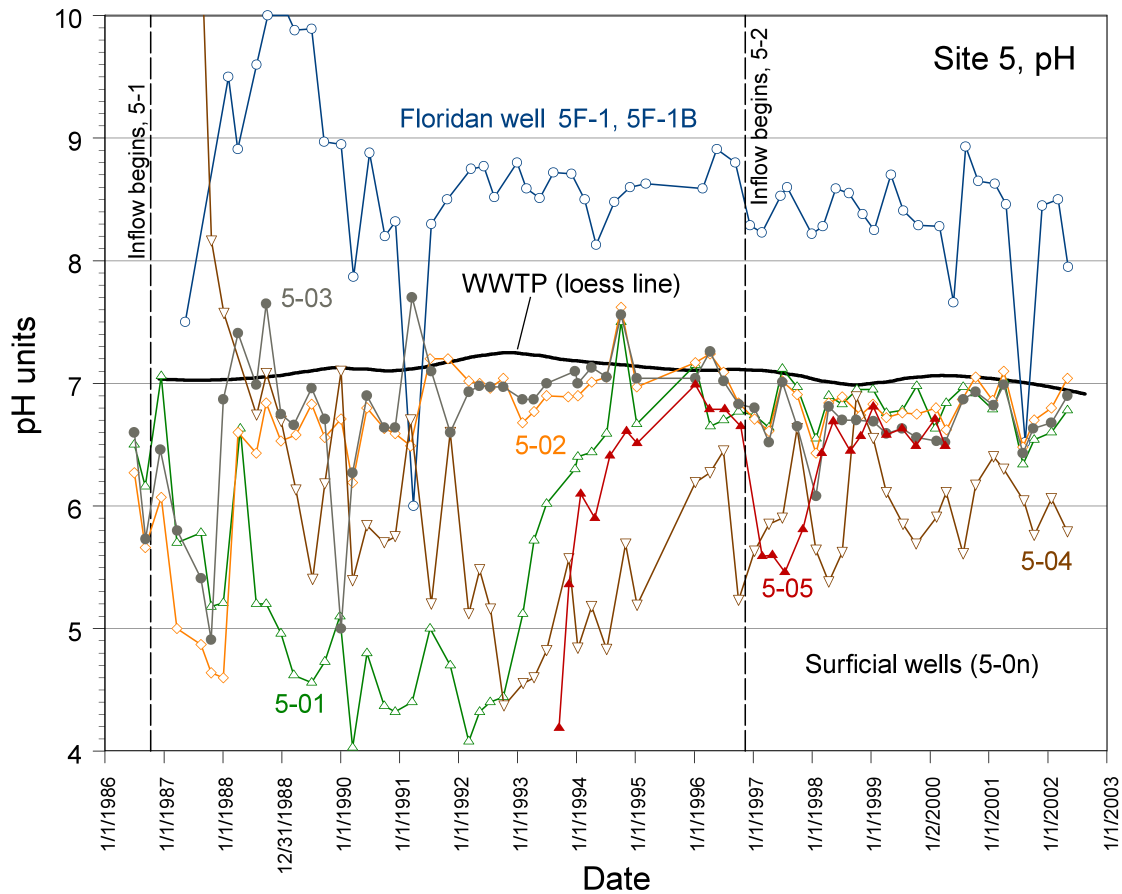

Figure 70. pH measurements from five surficial and one Upper Floridan monitor well at RIB site 5 and from the wastewater treatment plant (1986–2002)

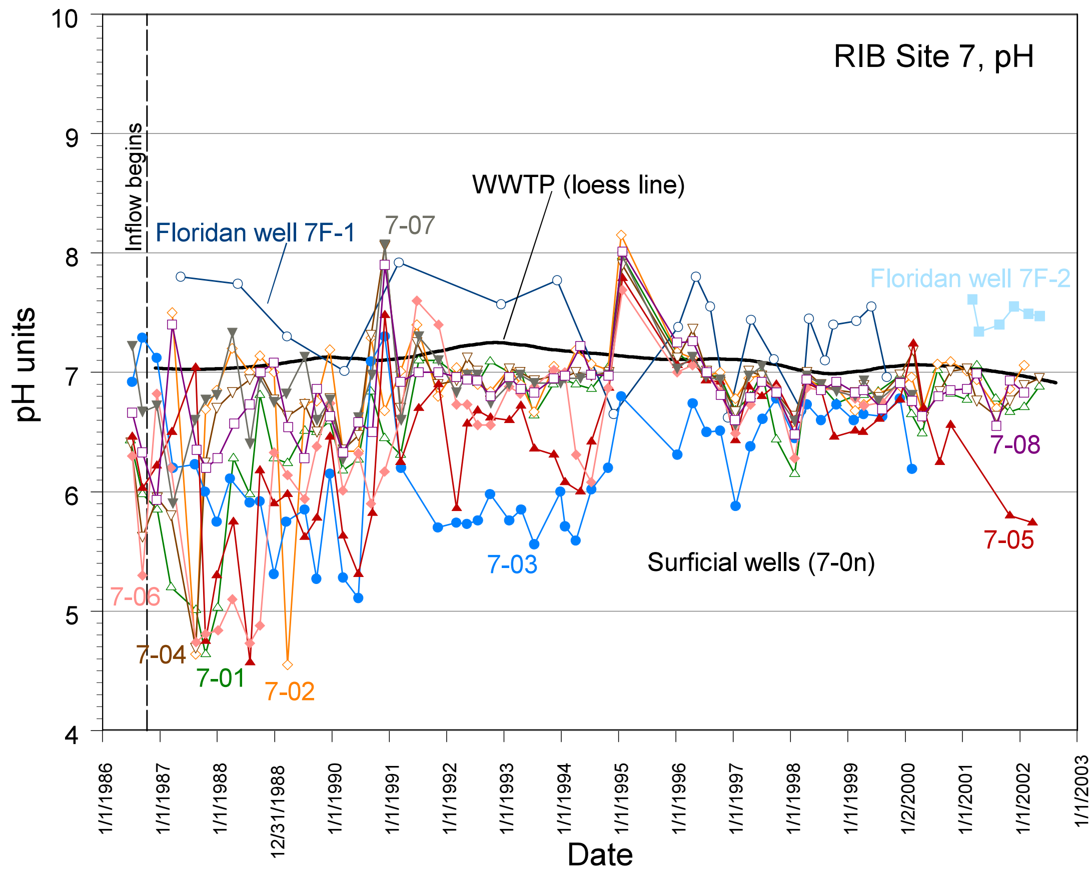

Figure 71. pH measurements from eight surficial and two Upper Floridan monitor wells at RIB site 7 and at the wastewater treatment plant, 1986–2002

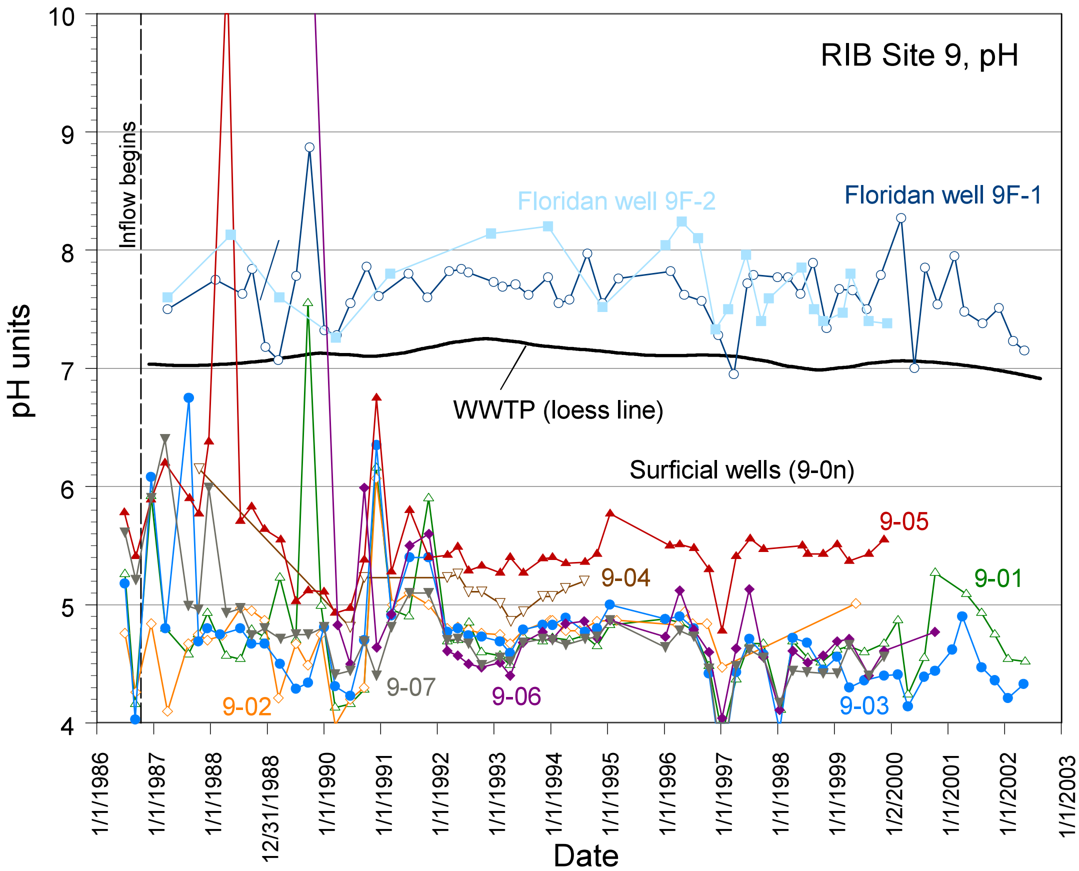

Figure 72. pH measurements determinations from seven surficial and two Upper Floridan monitor wells at RIB site 9 and at the wastewater treatment plant, 1986–2002

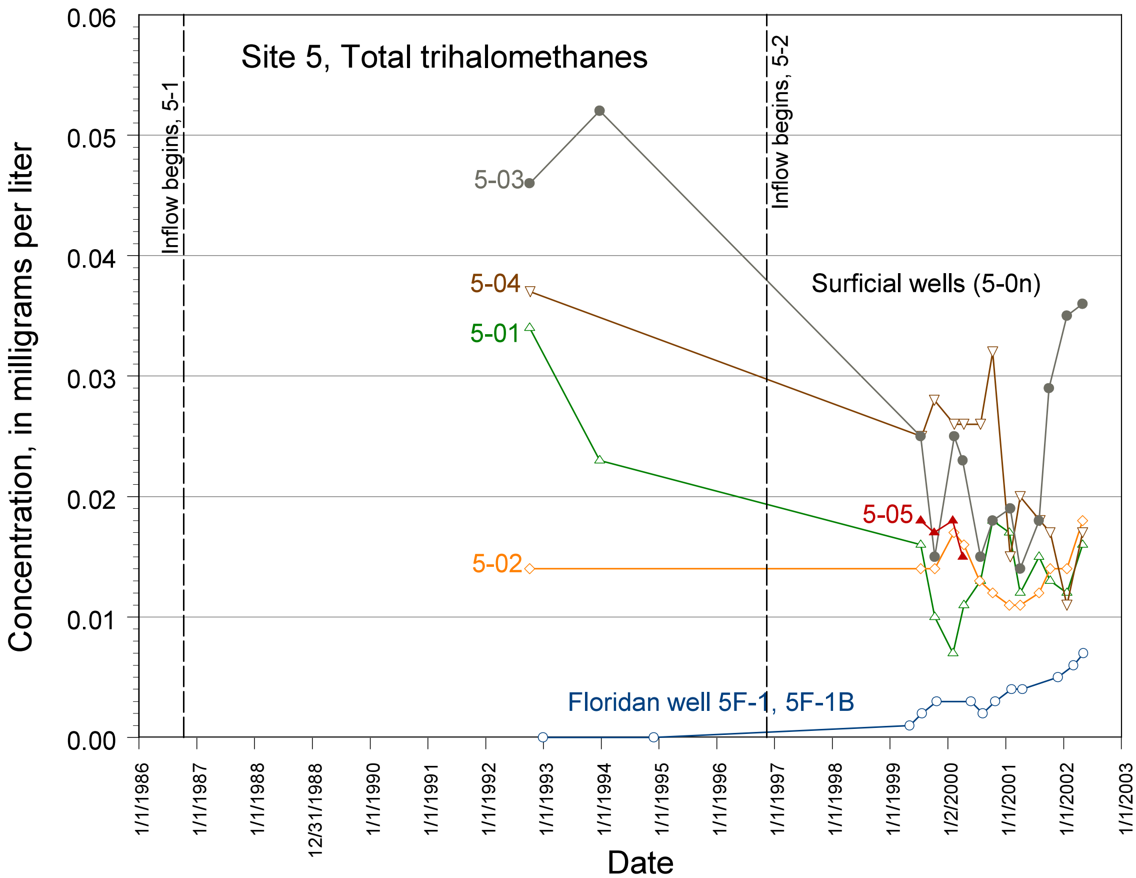

Figure 73. Total trihalomethane concentrations from five surficial and one Upper Floridan monitor well at RIB site 5 (1992–2002)

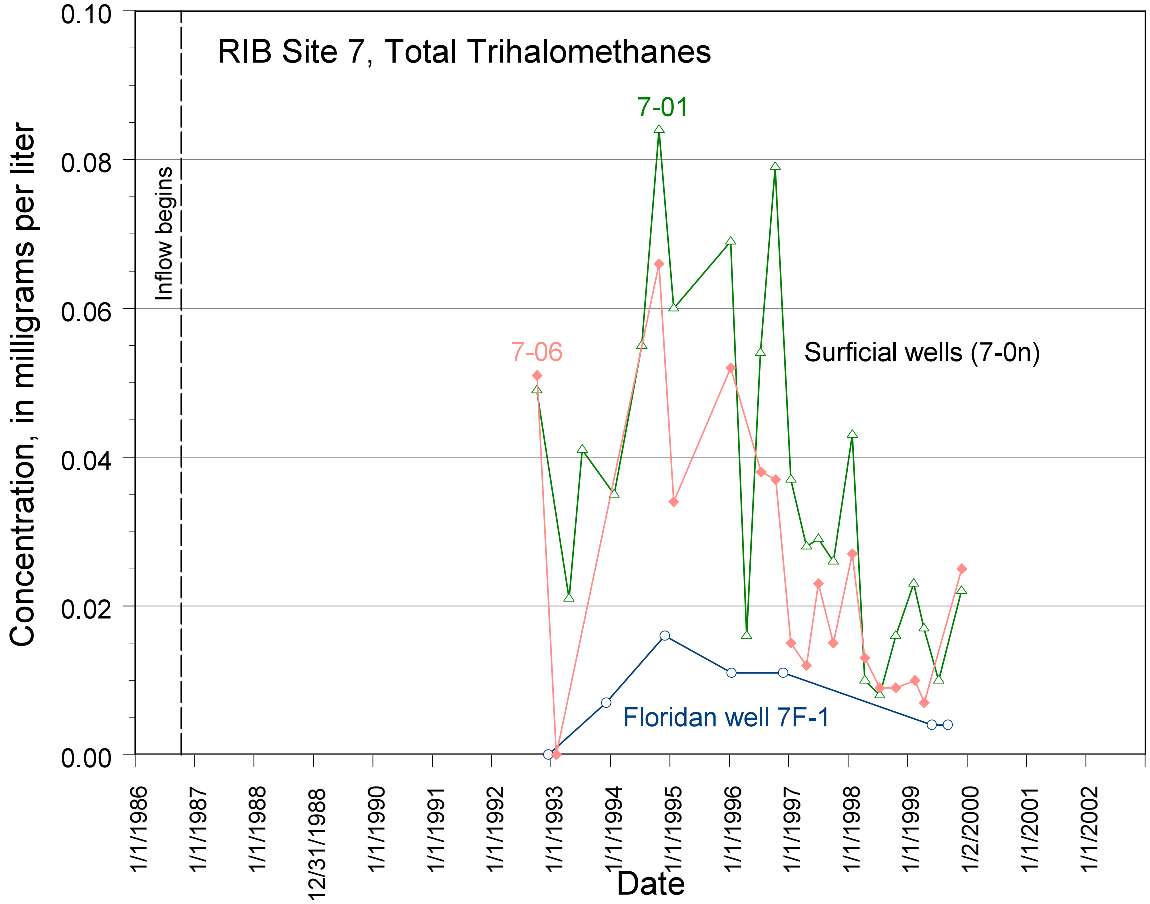

Figure 74. Total trihalomethane concentrations from two surficial and one Upper Floridan monitor well at RIB site 7 (1992–2002)

reclaimed water in the surficial aquifer. Although the concentrations in samples from the Upper Floridan aquifer well 5F-1 are lower than those in samples from the surficial wells, the steady increase in 1999–2002 indicates a small but increasing concentration of reclaimed water in the Upper Floridan aquifer near this well.

Measurements of total trihalomethanes at two surficial monitor wells at site 7 also indicate the presence of reclaimed water. Measured concentrations peaked in 1995 before decreasing through 1999. The same pattern, though more subdued, is evident in the record of measurements in samples from

Upper Floridan well 7F-1. In comparison with the data from site 5, this pattern suggests a more direct connection by downward leakage through the confining layer at site 7 than at site 5.

A sufficient number of measurements of total trihalomethane (Figure 75) are available from Upper Floridan monitor wells at sites 5, 6, 7, and 9 to make possible comparisons among all four RIB sites.

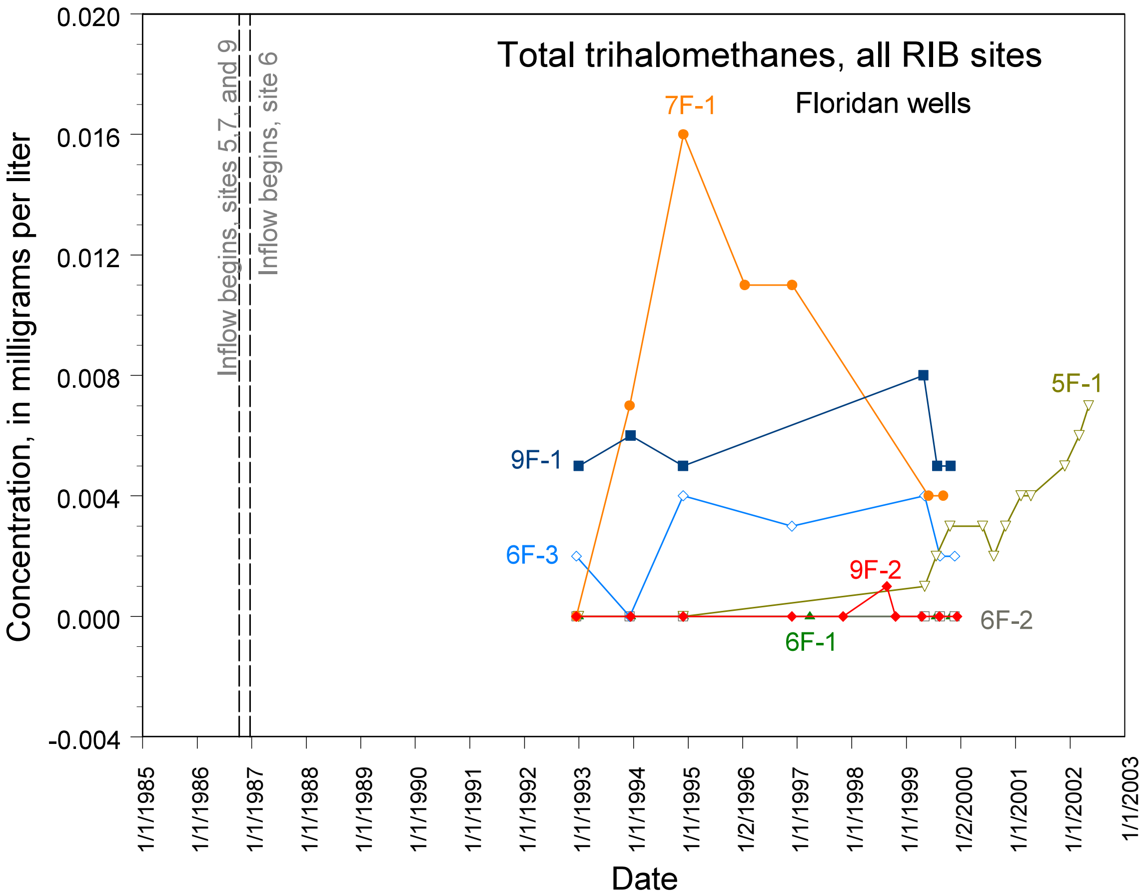

Figure 75. Total trihalomethane concentrations measured at Upper Floridan aquifer monitor wells at RIB sites 5, 6, 7, and 9

Shown again is the steady increase of trihalomethanes at the Upper Floridan aquifer monitor well 5F-1 at site 5, and the presence of trihalomethanes in the Upper Floridan aquifer monitor well 7F-1 at site 7. The trihalomethane measurements in samples from Upper Floridan wells at sites 6 and 9 show significant trends. Measurements at well 6F-1 near the eastern boundary of site 6 remain at zero. Concentrations were higher at pumped Upper Floridan grove irrigation well 6F-3. Trihalomethane measurements from well 6F-2, however, were all zero.

Concentrations of chemical substances in water from well 9F-2 appear to be representative of pristine background conditions in the Upper Floridan aquifer in this area. Total trihalomethane concentrations, except for one measurement, were zero. Total trihalomethanes, however, are present in appreciable concentrations at onsite Upper Floridan monitor well 9F-1.

WATER TABLE ALTITUDES AND POTENTIOMETRIC HEADS

Monitoring the effects of discharging reclaimed water to the RIB cells included recording water levels in the surficial and Upper Floridan monitor wells and in a network of piezometers completed in the surficial aquifer. The piezometers were used solely for water level measurements.

RIB Site 5

At RIB site 5, water level data of appreciable record length were obtained from the five monitor wells and from five piezometers (Figures 76–78). At four of the monitor wells, one to several water level readings were obtained before the discharge of reclaimed water began in late 1986. Water level measurements from the piezometers at site 5 began in July 1996, a few months before the RIB site was extended eastward with construction of cell 5-2. Most of the piezometers are located in the new section.

The first water levels recorded at monitor wells 5-01, 5-02 and 5-03 range from 139.5 to 142 ft. Fifteen values were measured at 5-04 before the beginning of discharge; all are about 120 ft. Water levels were obtained from the eastern part of site 5 in May-June 1983 by a contractor working for CDM (1983). Interpolating from their contour map to the locations of these four monitor wells indicates values of 134–137 ft, suggesting an increase of 3-6 ft from June 1983 to August 1986. However, a reading of the daily record of water levels for the Lake Oliver shallow well (Figure 5) shows a decrease of about 1 ft between these same dates. This discrepancy is irresolvable given present data. The CDM water table contours are somewhat nonintuitive, as a water table depression is indicated in an area of high land elevation.

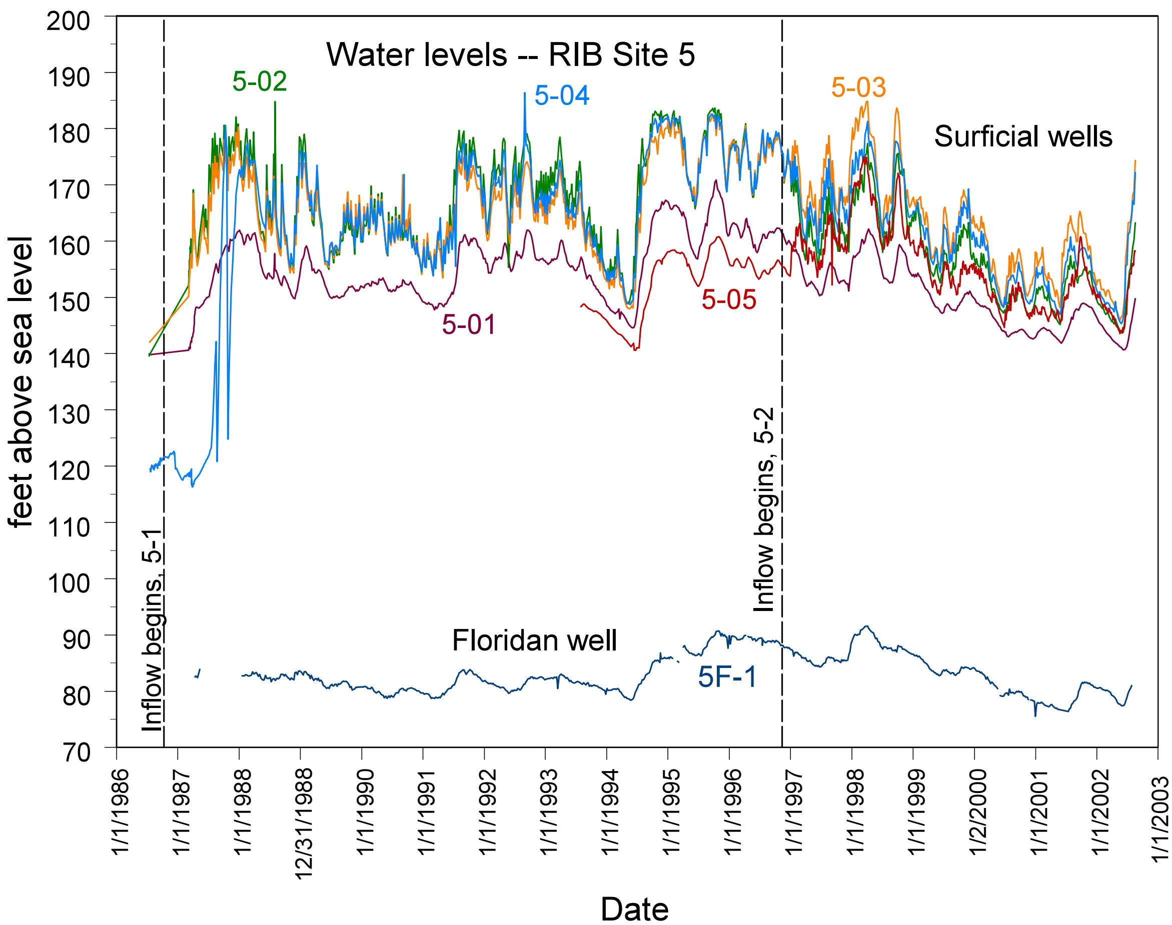

Figure 76. Water-level measurements from surficial monitor wells 5-01, 5-02, 5-03, 5-04, and 5-05 at RIB site 5

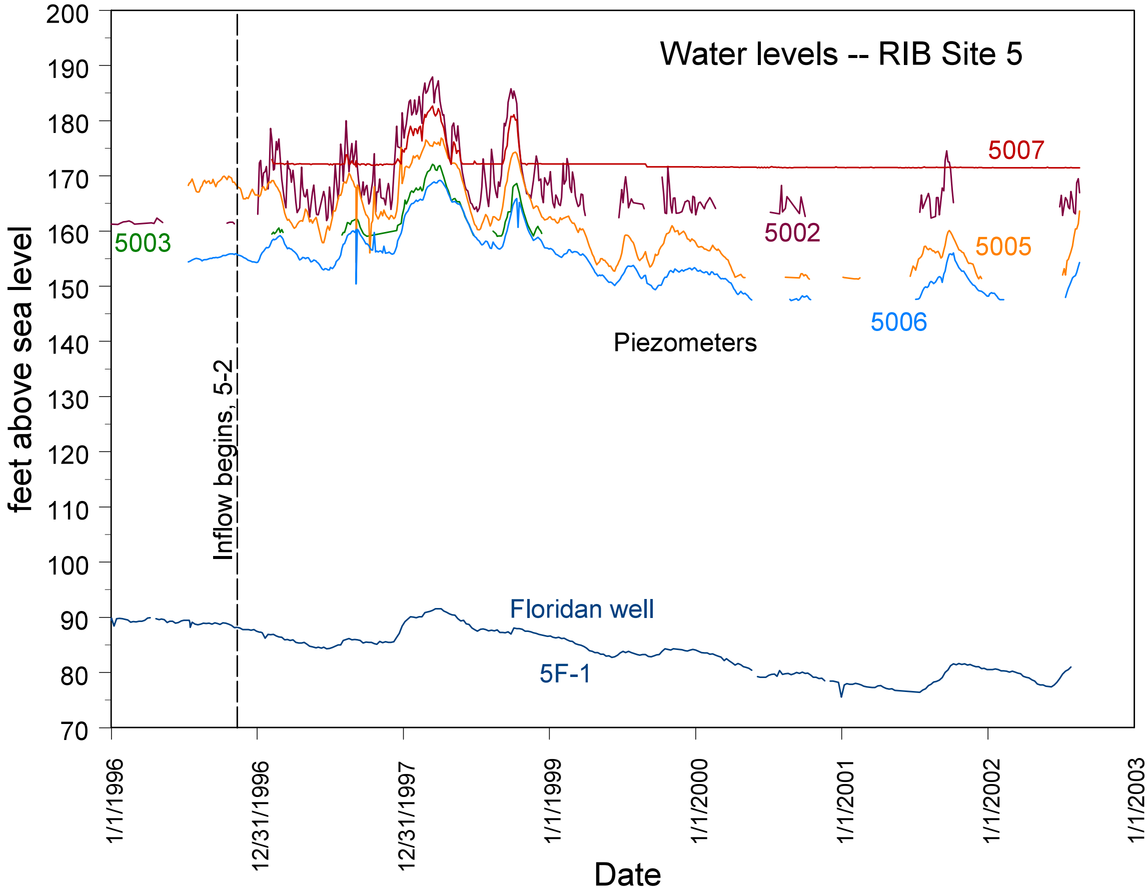

Figure 77. Water evel measurements from piezometers 5002, 5003, 5005, 5006, and 5007 at RIB site 5

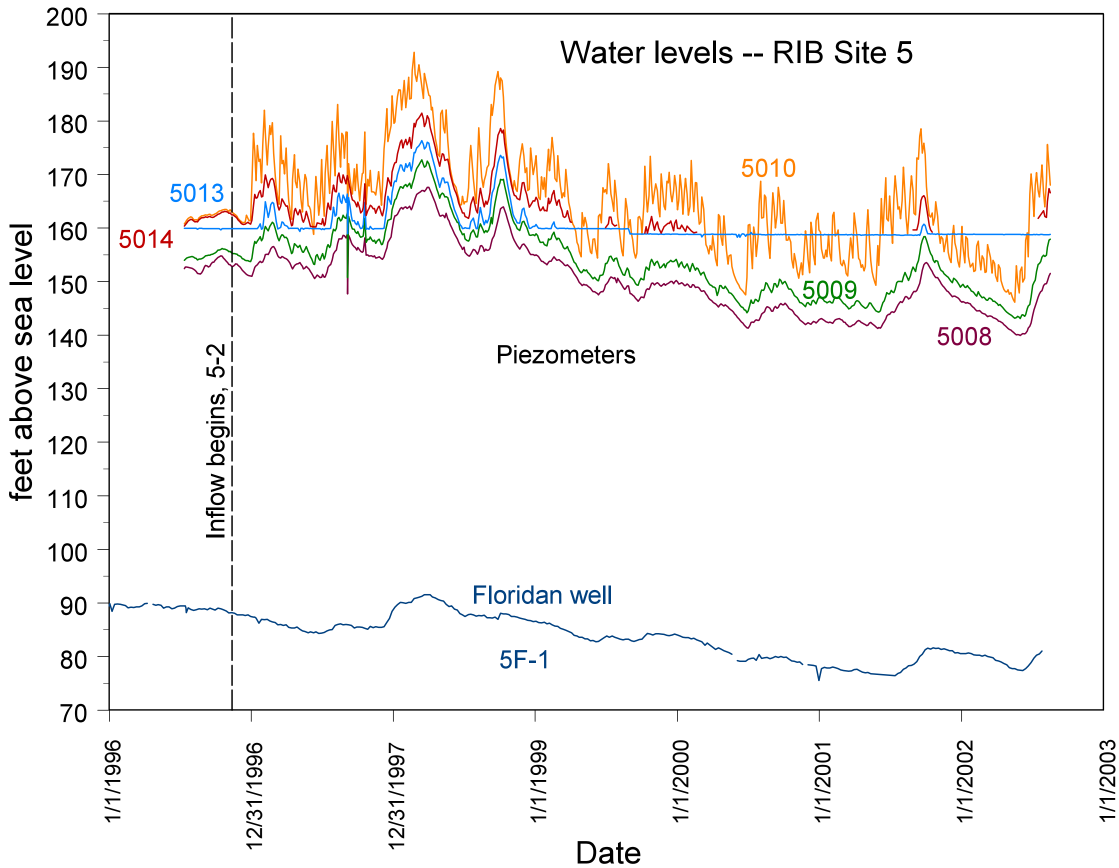

Figure 78. Water-level measurements from piezometers 5008, 5009, 5010, 5013, and 5014 at RIB site 5

For purposes of this study, it was decided to accept the early 1986 values in the long-term database for determining water level increases during reclaimed water discharges, based on the likelihood that the datum for conversion of depth to water to sea level elevation would be consistent throughout the period of record. This was not the case at well 5-04, however, where the abrupt increases of August through October 1987 probably represent a datum correction, and subsequent water levels at this well resemble those at 5-02 and 5-03. At wells in the eastern extension of the RIB site where no predischarge information is available, the predischarge water table altitude will be inferred to be in the 140–145 ft range.

Water levels as high as 183–185 ft were measured at wells 5-02, 5-03, and 5-04 between 1994 and 1998. These values represent an increase of as much as 45 ft from predischarge values, far more than the natural range of variation of 4–5 ft and clearly indicating the hydraulic effect of the reclaimed water discharges at the site. These three wells are located near (about 100 ft) RIB cells. Wells 5-01 and 5-05 were located at greater distances (700 and 1,300 ft, respectively) from grid cells, and water level rises in 1994–1995 were only 29 and 21 ft, respectively But well 5-05 was located only 170 ft from the expansion RIB cell 5-2 which began to receive reclaimed water discharges in late 1996. After this date, the water levels at well 5-05 resembled those at wells 5-02, 5-03, and 5-04.

Water levels from the piezometers have a similar interpretation relative to discharge of reclaimed water at the expansion RIB cell. Water levels that show mainly longer-term variations, such as 5006, 5008, and 5009, are from piezometers located at a distance from RIB cells. Those that show marked short-term oscillations (5002 and 5010) are from piezometers close to RIB cells. In fact, 5010 is located near the center of a RIB cell and shows the highest water levels and the maximum short-term water level variation for the site.

The head variation in Upper Floridan well 5F-1 shows a range of variation of 15 ft from 1987 to 2002. Although no head data from 5F-1 predate the reclaimed water discharges, it appears that the predischarge head difference between the surficial and Upper Floridan aquifers is about 55 ft. After discharges began, the head difference approaches 100 ft at some of the monitor wells. There is probably a pressure-loading effect from variations in the water table, but it would have virtually no relation to the localized water level variations in the surficial wells at site 5. A measurable degree of pressure loading at Upper Floridan aquifer wells occurs only in response to regionally extensive water table variations.

RIB Site 6

At RIB site 6, water level data of appreciable record length was obtained from 42 monitor wells (Figures 79–84) and from 170 piezometers. The earliest record is for December 1991, five years after the beginning of discharges at site 6. Early data from 6-01 probably contains a datum error that was corrected in 1995.

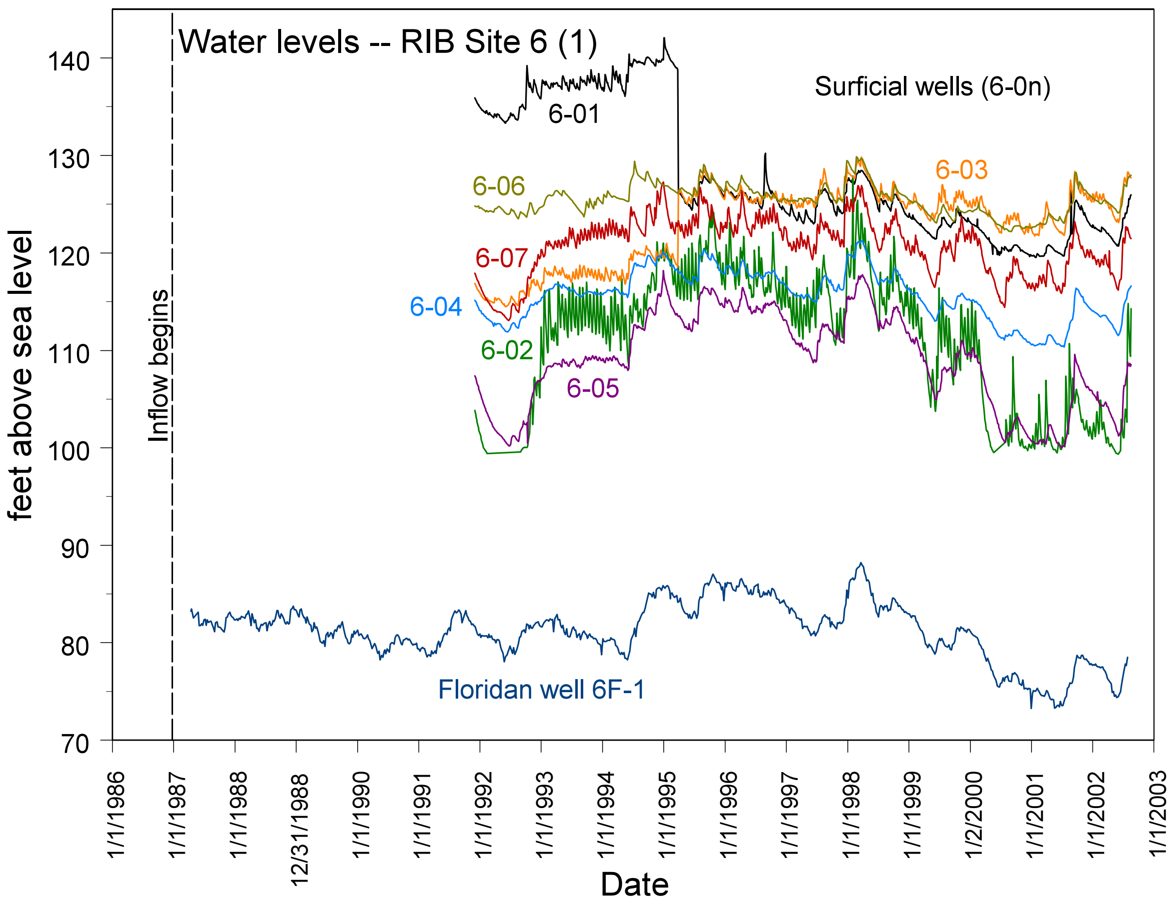

Figure 79. Water levels measured in monitor wells 6-01, 6-02, 6-03, 6-04, 6-05, 6-06, and 6-07 at RIB site 6 and the head measured in Upper Floridan well 6F-1

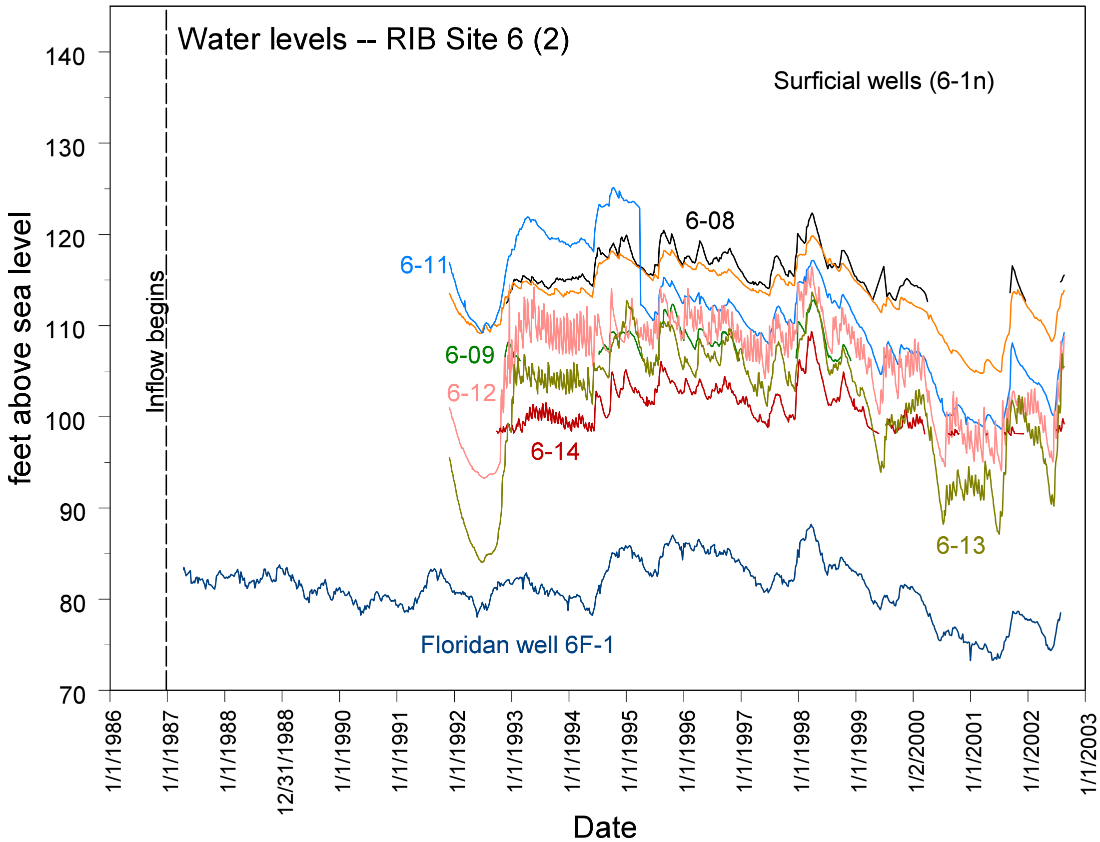

Figure 80. Water levels measured in monitor wells 6-08, 6-09, 6-10, 6-11, 6-12, 6-13, and 6-14 at RIB site 6 and the head measured in Upper Floridan well 6F-1

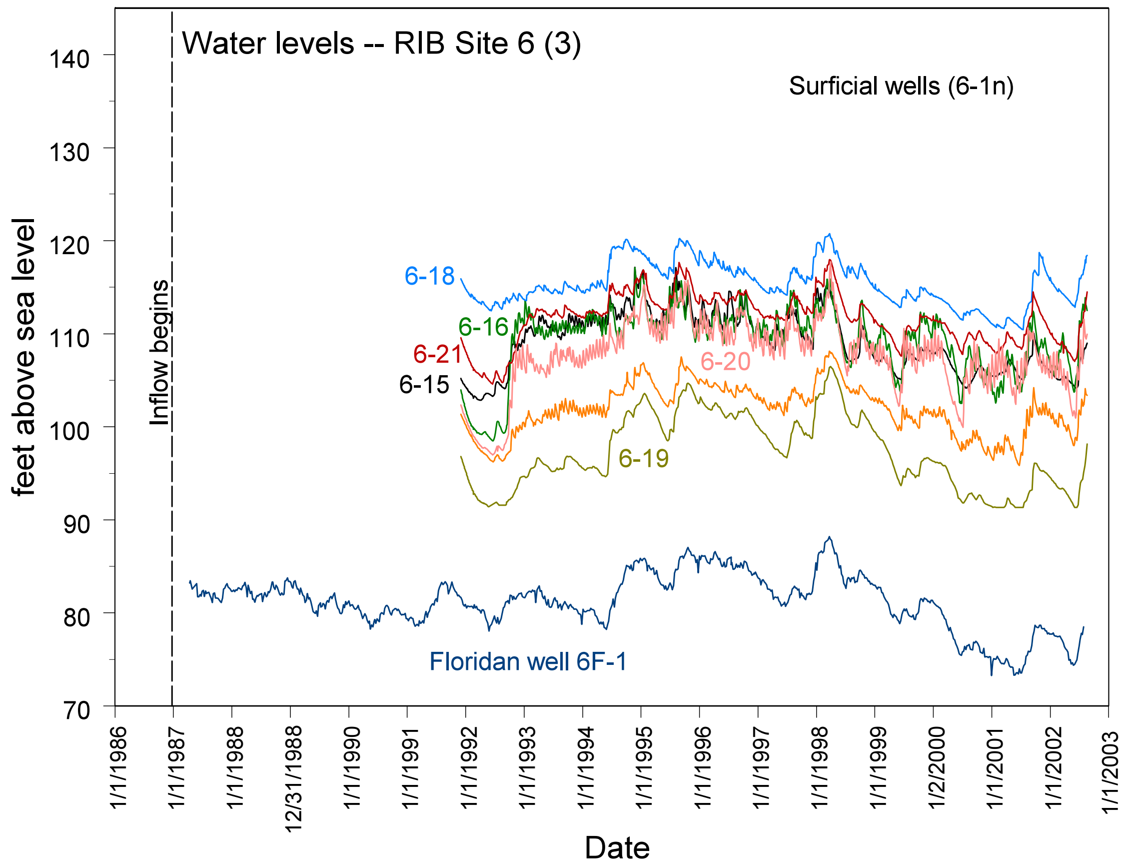

Figure 81. Water levels measured in monitor wells 6-15, 6-16, 6-17, 6-18, 6-19, 6-20, and 6-21 at RIB site 6 and the head measured in Upper Floridan well 6F-1

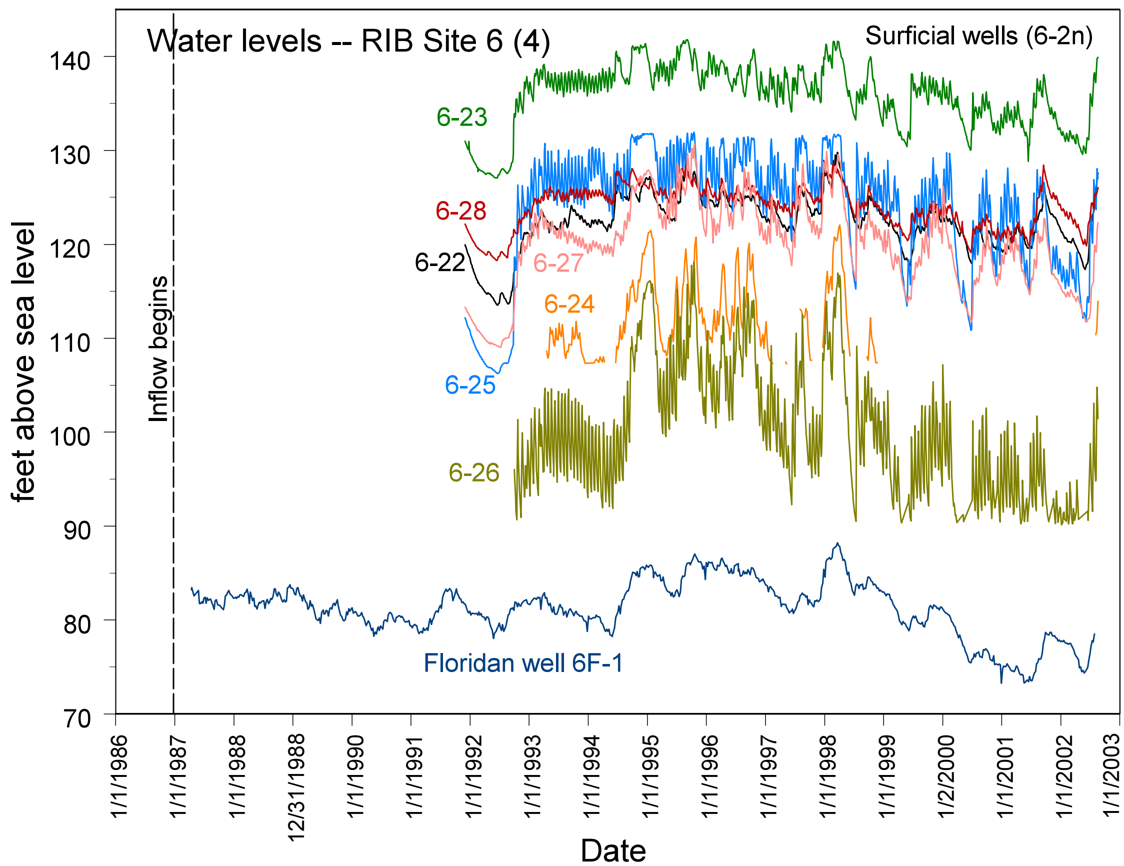

Figure 82. Water levels measured in monitor wells 6-22, 6-23, 6-24, 6-25, 6-26, 6-27, and 6-28 at RIB site 6 and the head measured in Upper Floridan well 6F-1

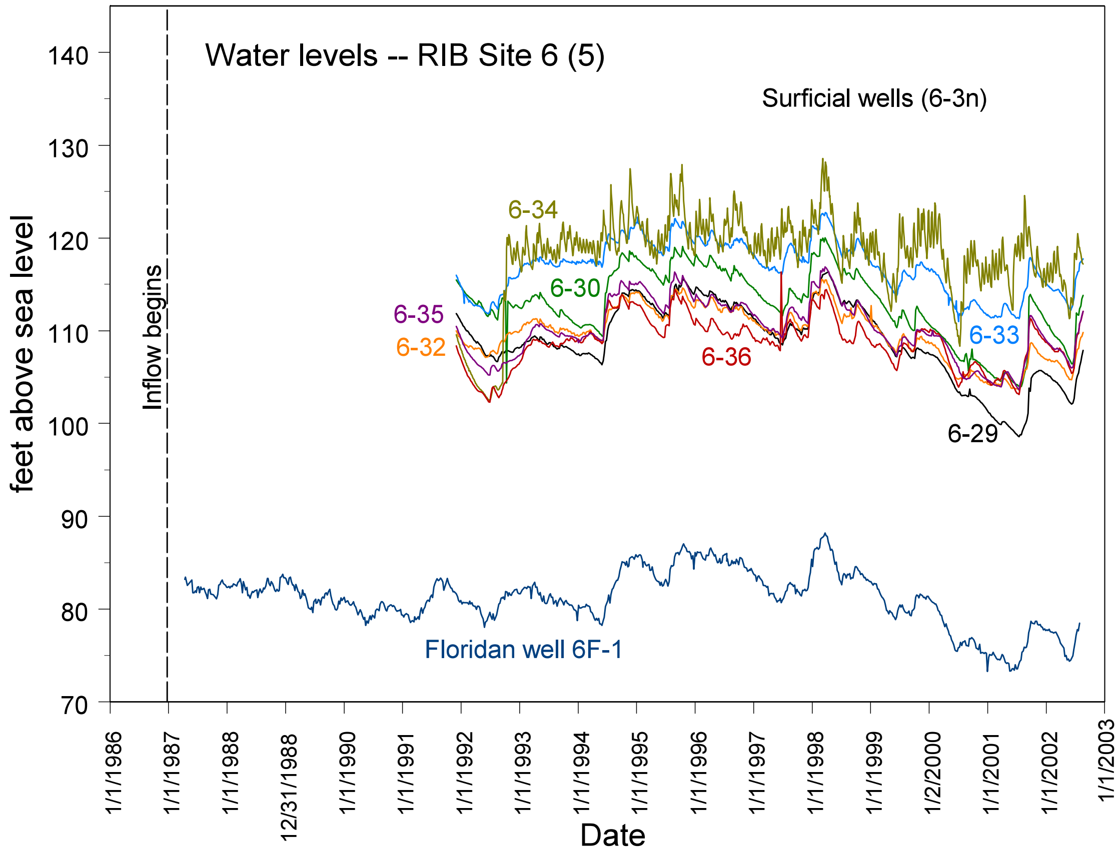

Figure 83. Water levels measured in monitor wells 6-29, 6-30, 6-32, 6-33, 6-34, 6-35, and 6-36 at RIB site 6 and the head measured in Upper Floridan well 6F-1

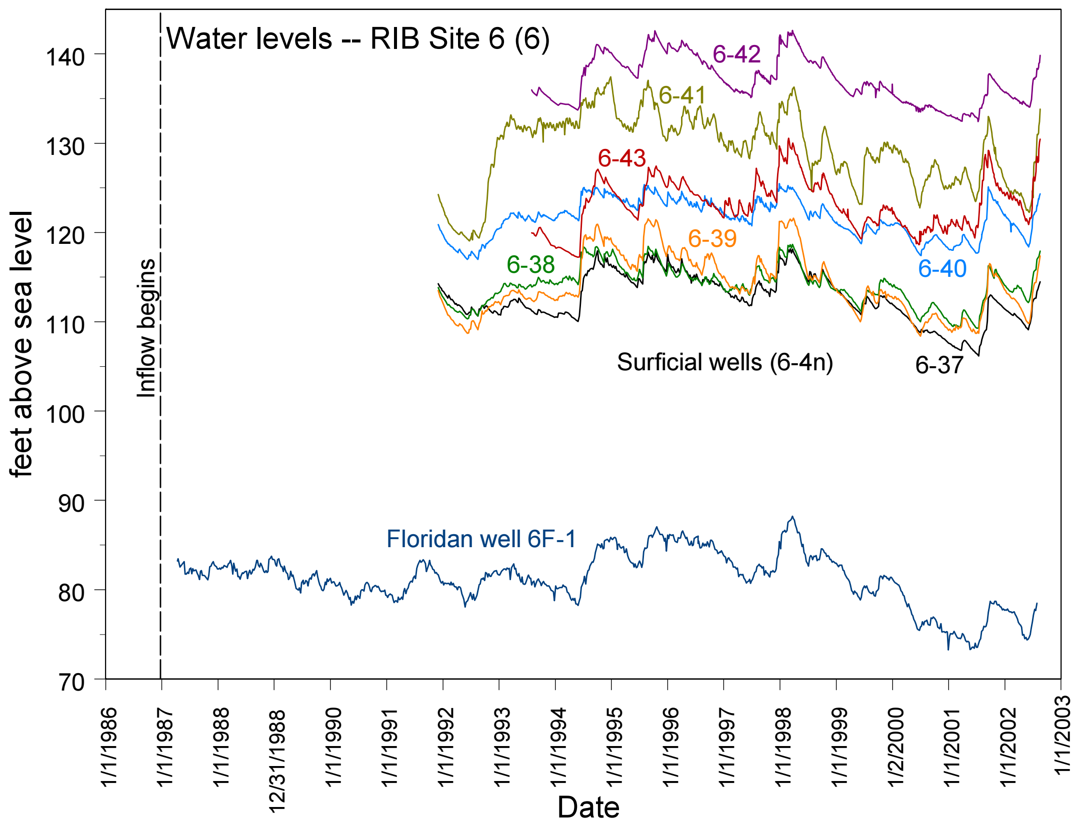

Figure 84. Water levels measured in monitor wells 6-37, 6-38, 6-39, 6-40, 6-41, 6-42, and 6-43 at RIB site 6 and the head measured in Upper Floridan well 6F-1

Heads were also measured at two Upper Floridan wells (6F-1 and 6IW). These two wells were located only about 800 ft from one another, so the measured heads were nearly identical and only heads from 6F-1 are shown in Figures 79–84. Measurements at 6F-1 began in April 1987; about 3.5 months after discharge to the RIB cells began in December 1986.

The depth to water was measured during core borings from April to July 1983, and the altitude of the water table was contoured by CDM (1983). The contour levels in site 6 range from 100 to 125 ft, and it is possible to interpolate predischarge surficial water levels at individual well locations. However, because water level measurements immediately before the beginning of the discharge of reclaimed water were not obtained as part of the principal database, it is not possible to make a direct correlation between the two sets of data.

Each monitor well shows the local response of the water table to discharges of reclaimed water at the RIB cells nearest to the monitor well. As an illustration of how these responses vary, water levels from wells 6-08, 6-10, 6-11, 6-12, 6-13, and 6-14 are plotted for the 12-month period from July 1993 to June 1994 (Figure 85). During this period, discharges to RIB cells close to the locations of wells 6-12, 6-13 and 6-14 were made during one week out of three, so that a 2-3 week rest period (of no discharges) separated periods of discharge. The periodic discharge volumes were generally uniform. Water levels from the three cited wells reflect this discharge schedule, with water level peaks every three weeks, separated by periods of declining water levels. Over the yearly period, there is no cumulative increase in water level at any well. The surge in water levels at the end of this one-year period was caused by heavy rainfall in June 1994.

Wells 6-08 and 6-10 were located close to and on opposite sides of a RIB cell that was only used on a few occasions during the period shown in Figure 85. Both show a nearly natural pattern of subdued water table altitude variation.

The water level data from the 170 piezometers is not portrayed because of space limitations. The interpretation of the piezometer data is similar to that of the monitor well data.

RIB Site 7

At RIB site 7, water level data of appreciable record length was obtained from 11 monitor wells (Figures 86–87). Two wells (7-06 and 7-09) provide record from July 1986, before the beginning of RIB cell discharges in October 1986. The predischarge water levels are about 89.5 and 90.5 ft above sea level, respectively. Water levels were measured during the core boring program that took place during the summer of 1983 (CDM, 1983). Maps contouring the water table were prepared independently for the northwestern and southeastern sections of site 7 (Figure 4). There is an unexplained water level shift of 3 ft where the maps adjoin. The northwestern section shows contours ranging from 88 to 93 ft above sea level; the southeastern section shows contours ranging from 94 to 98 ft above sea level. Interpolating to the locations of 7-09 leads to a value of about 89 ft above sea level. Well 7-06 is off both section maps, and the interpolated value could range from 90 to 94 ft above sea level. The water level in the Lake Oliver shallow well varied by no more than a foot during the summer of 1983 and decreased by about a foot between May 1983 and August 1986. Assuming that water levels from 7-06 and 7-09 showed a similar lack of variation over this time period, values in the database from 7-06 and 7-09 will be considered valid for purposes of this study.

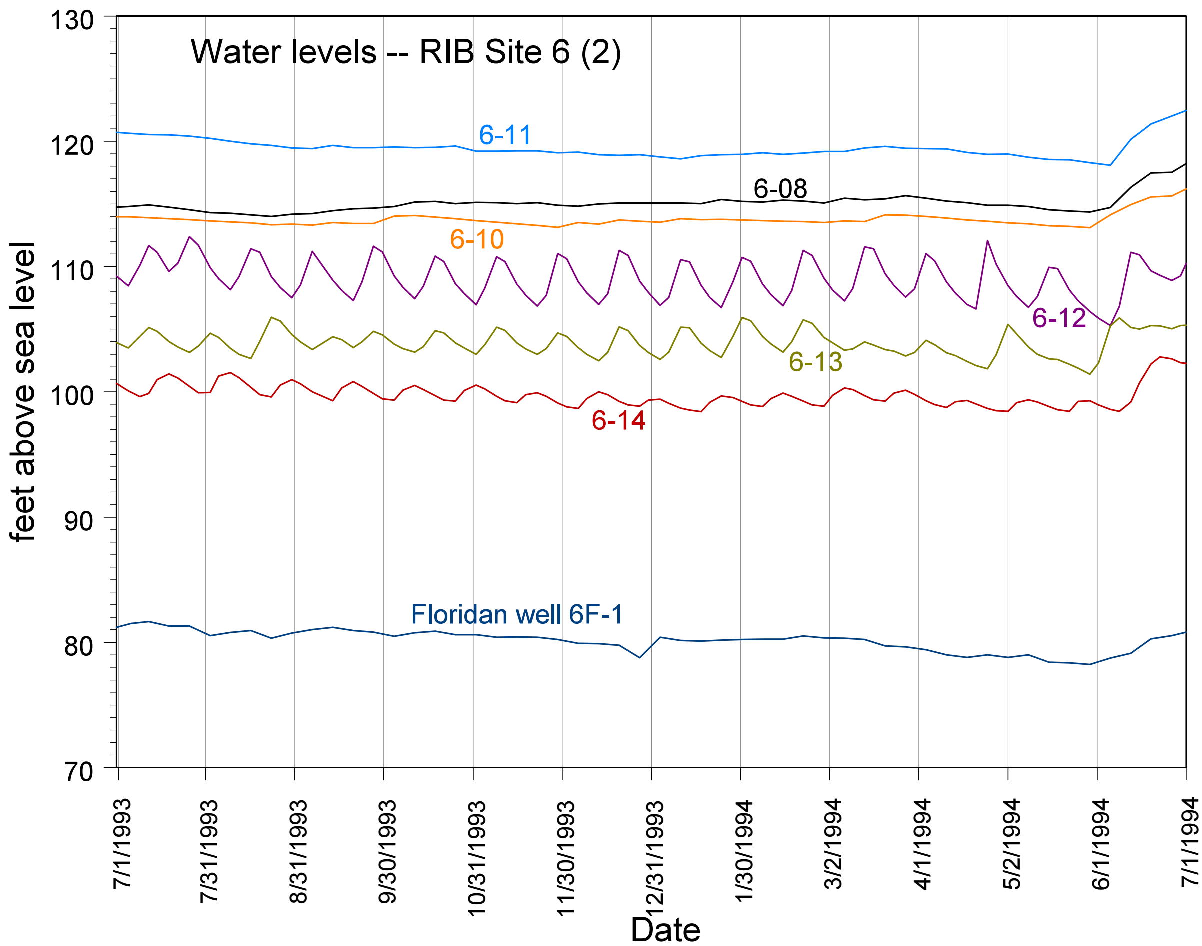

Figure 85. Water levels measured in monitor wells 6-08, 6-09, 6-10, 6-11, 6-12, 6-13, and 6-14 at RIB site 6 and the head measured in Upper Floridan well 6F-1 during a one-year period from July 1993–June 1994

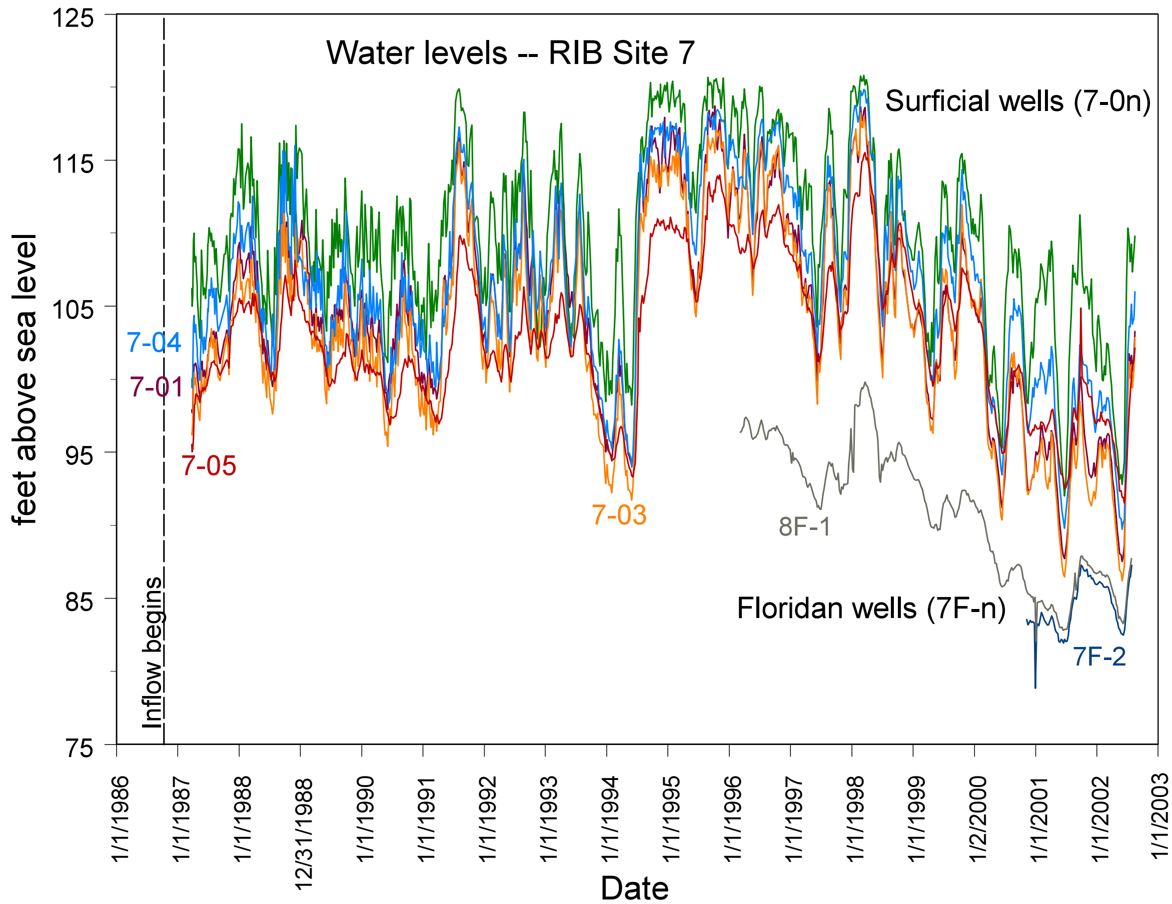

Figure 86. Water levels measured in monitor wells 7-01, 7-02, 7-03, 7-04, and 7-05 at RIB site 7 and the head measured in Upper Floridan wells 7F-2 and 8F-1

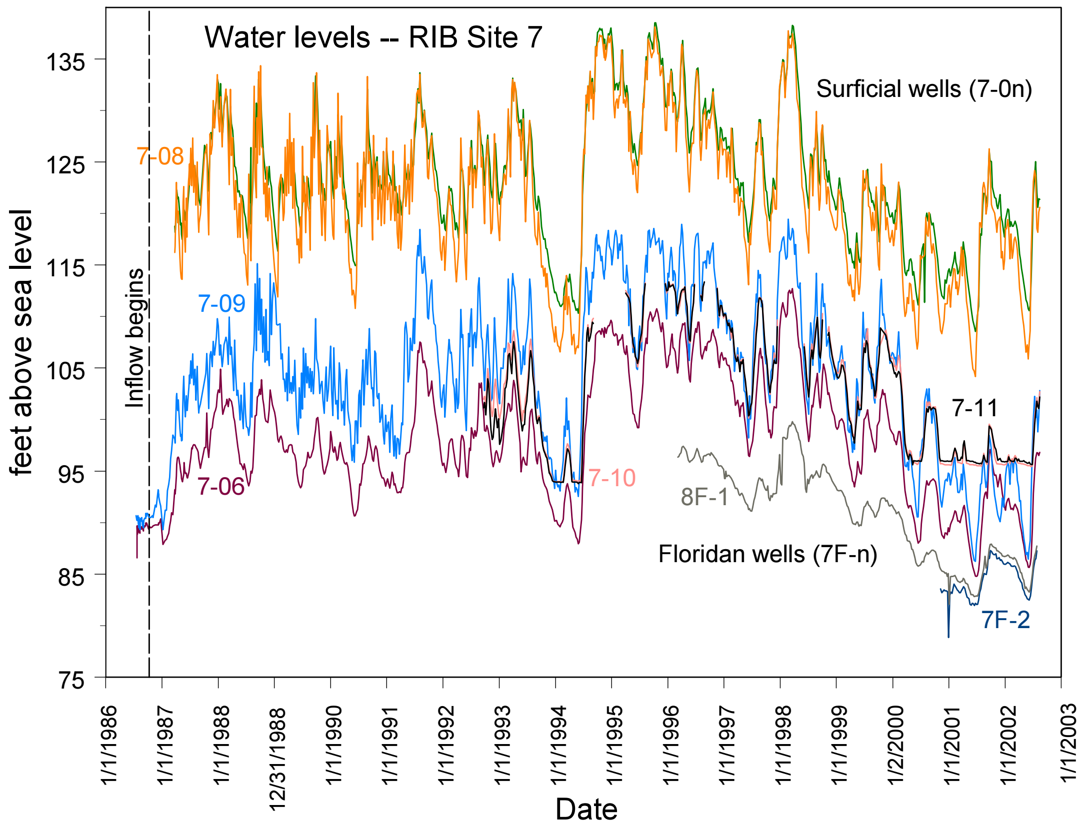

Figure 87. Water levels measured in monitor wells 7-06, 7-07, 7-08, 7-09, 7-10, and 7-11 at RIB site 7 and the head measured in Upper Floridan wells 7F-2 and 8F-1

All monitor wells provide data that clearly indicate the hydraulic effect of RIB cell discharges. RIB site 7 is not large in areal extent, but receives a greater volume of recharge than any other RIB site. Wells 7-07 and 7-08 are near a RIB cell in the part of the site with the highest land elevation and highest pre-RIB water table elevation, and water levels higher than 138 ft have been recorded at each. CDM (1983) indicates that the predischarge water levels in 7-07 and 7-08 should have been about 98 and 97 ft, respectively, in the summer of 1983. At wells 7-01, 7-02, 7-03, 7-04, 7-05, and 7-09, water levels during the discharge period (1986-present) have reached 115 to 120 ft. Pre-RIB water table elevations are indicated to range from 88 to 94 ft at all wells except 7-05, which is not within the CDM map area. Of the cited wells, 7-05 is at the furthest distance from a RIB cell and has the lowest average water level during the discharge period.

Well 7-09 is also at some distance from a RIB cell, and water levels during the discharge period do not exceed 112 ft. Wells 7-10 and 7-11 are located near each other in a depressional area bounded by four groups of RIB cells. Maximum water levels are slightly greater than 113 ft.

Heads were not recorded at Upper Floridan well 7F-2 until November 2000. However, Upper Floridan head measurements were made starting in March 1996 at well 8F-1, located on new RIB site 8. Well 8F-1 is about 1,800 ft west of well 7F-2, and heads differ only slightly during the period of overlapping record.

RIB Site 9

Water levels recorded at six surficial monitor wells and one Upper Floridan monitor well are shown in Figure 88. Virtual no water level data were obtained from well 9-06. This well was completed in a layer of clay, and the data obtained from it were anomalous.

Predischarge water levels are shown at five surficial monitor wells, and are about average in altitude relative to those from the period of record (1986–2002) that follows. Because appreciable volumes of discharge to this RIB site only occurred in early 1987, early 1997 and the first part of 2001, the surficial water levels reflect natural conditions for most of the period of record. The natural fluctuations shown (Figure 88) range from 6 to 10 ft. Water level fluctuations in the surficial wells are similar to those at the Upper Floridan well, though the heads are separated by about 10 ft, probably illustrating a pressure-loading effect modified by some variation in downward percolation. During the three periods of discharge, abrupt water level increases of 3 to 5 ft are noted at several surficial monitor wells.

Upper Floridan Wells

All measured heads in Upper Floridan wells, except those from 6IW, which virtually duplicate heads from 6F-1, are illustrated in Figure 89. Head variations are nearly identical at all wells, and are probably the result of regionally distributed influences, such as pressure loading from changes in the water table caused by rainfall. It is unlikely that there would be pressure-loading effects from localized processes such as hydraulic mounding at RIB sites. However, the hydraulic influences of RIB recharge and regional pumping could cause relatively small head variations that would be generally similar in the records from all of the Upper Floridan wells.

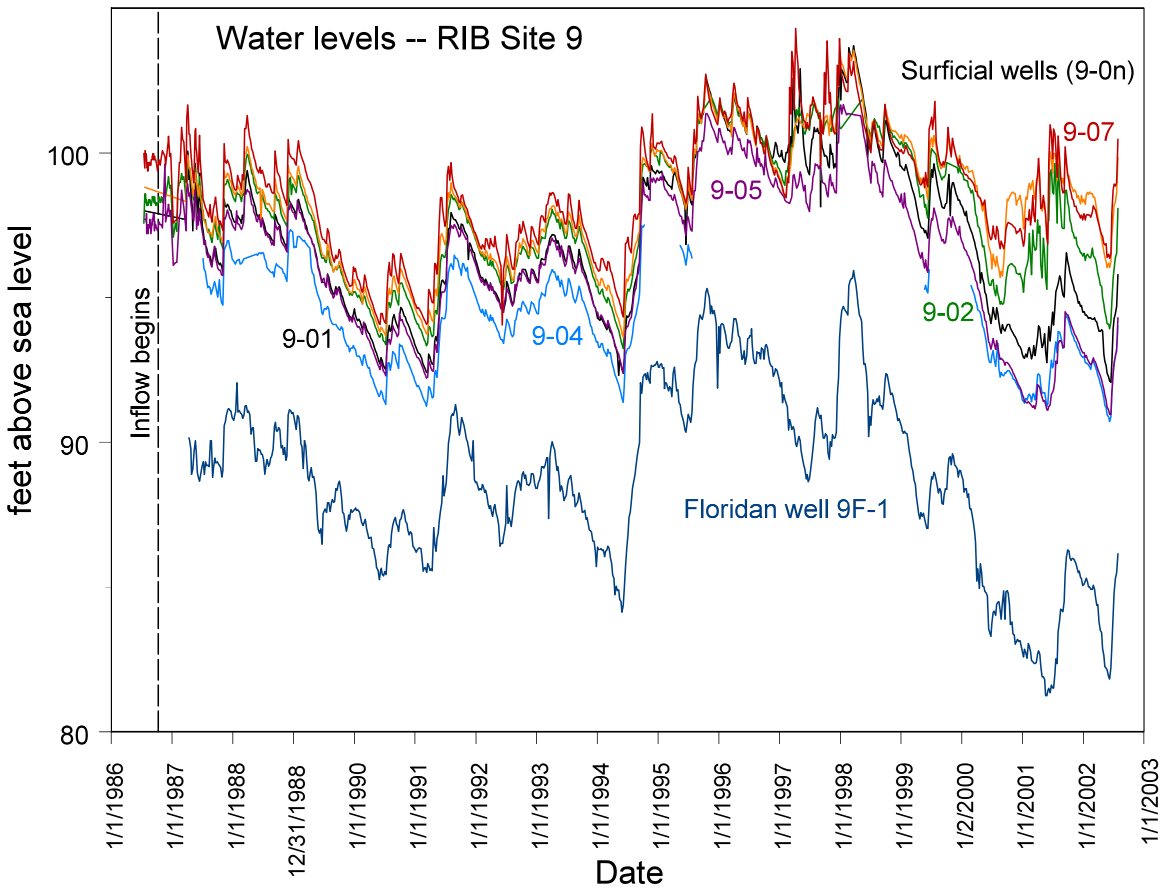

Figure 88. Water levels measured in monitor wells 9-01, 9-02, 9-03, 9-04, 9-05, and 9-07 at RIB site 9 and the head measured in Upper Floridan well 9F-1

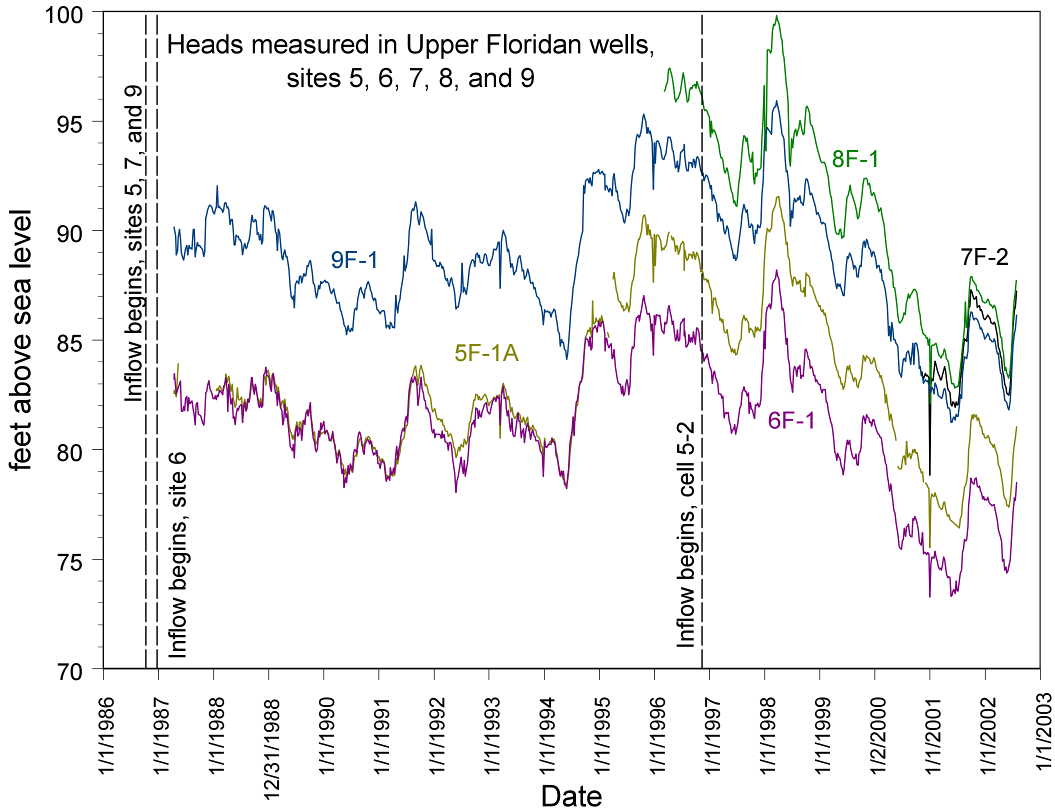

Figure 89. Heads measured at Upper Floridan wells 5F-1A, 6F-1, 7F-2, 8F-1, and 9F-1 in the Water Conserv II area, April 1987 – July 2002

An exception to the similarity between head variations is the abrupt shift in the relation between heads from 5F-1A and 6F-1 that occurs in March 1995. This shift is not related to discharges to the expansion RIB cells that began at site 5 in November 1996. Most likely, a datum correction was made in March 1995, as the depth to water readings are relatively continuous through this period, but the head increases by exactly 3 ft between two sequential readings at the end of March.

Also needing explanation are the sudden and temporary drops in head at all Upper Floridan wells providing data on March 15, 1993, December 26, 1995, and December 31, 2000. Possible explanations might include heavy short-term pumping as might take place for freeze protection of the groves during a night of freezing temperatures. In fact, the latter two dates do correspond to nights of freezing temperatures in central Florida.

Recently, David McIntyre (PB Water, written and oral communs., 2005) has noted changes in the relations of some upper Floridan aquifer heads with those at other sites. As previously noted (Figure 89), upper Floridan heads vary with the regional water table by areawide pressure loading but tend to have the same relations with one another over time because the main differences between them are caused by the regional head gradient and the different geographical locations of the upper Floridan wells. Slight head changes near RIB sites owing to RIB discharges are difficult to detect in the hydrographs of individual wells. However, if upper Floridan heads at one site do not change, slight head changes at other upper Floridan sites can be detected by observing slight but consistent changes in the head differential between active RIB sites and the inactive RIB site where heads do not change.

In this study, upper Floridan heads did not change for long periods of time at RIB site 9 because it was inactive except during short periods of time. Because upper Floridan heads were not measured until April 1987, data are not available to determine head differential changes for RIB sites 5, 6, or 7. However, when recharge began at RIB sites 3 and 4 in early 2002, head differential changes of about 2 ft were observed at the upper Floridan monitor well 5F-1 at nearby RIB site 5. In addition, comparison of later head data at upper Floridan well 3F-1 with early data measured in March 2002 appears to show a head differential increase of about 2.5 ft.

These observations are consistent with the results of model studies by O’Reilly (1998), which indicated upper Floridan head mounding of as much as 3 ft in the vicinity of RIB site 5 and as much as 4 ft in the vicinity of RIB site 7 when recharge initially began in 1986. These head changes are small compared to changes in the altitude of the water table near these RIB sites.

RECHARGE OF THE UPPER FLORIDAN AQUIFER

In this section, the water quality and head data presented and evaluated in the previous sections are used for interpretations related to the possible augmentation of recharge to the Upper Floridan aquifer that might be caused by discharge to the RIB basins.

HYDRAULIC ESTIMATES OF RECHARGE

Large volumes of reclaimed water discharged to the shallow subsurface in a RIB basin can either be removed by evapotranspiration or percolate through the unsaturated zone to the water table. After the reclaimed water reaches the water table, the excess volume of water in the surficial aquifer (a mixture of RIB discharge and rainfall recharge) can either remain in place or be removed by one or more of four processes: (1) lateral movement in the surficial aquifer; (2) additional downward percolation to the Upper Floridan aquifer through the confining layer underlying the surficial aquifer; (3) additional evapotranspiration from the water table; or (4) ground water seepage to bodies of surface water.

Whether or not RIB basin discharges increase the rate of evaporation is a matter of debate and its resolution is beyond the scope of this report. However, it is likely that, if RIB cell discharges raise the water table nearly to land surface, that the volume of evapotranspiration would increase.

There are no bodies of flowing surface water within the hydraulic influence of the Water Conserv II RIB sites. However, some depressional (seepage) lakes are located as near as 2,400 ft from RIB sites 5, 6, and 7, and Lake Hartley is on the southeastern boundary of RIB site 6.

The additional recharge reaching the water table will create a local mound in the water table because of the relatively low permeability of the silty sands comprising the surficial aquifer. The water table mound will tend to gradually dissipate by lateral movement of the water in the surficial aquifer. However, continued discharges to the basin will augment the mound. A theoretical evaluation of the likely height and extent of a mound about a RIB cell caused by steady discharge (CDM 1983) showed that the mound height tended to stabilize with time at a height great enough that the lateral flow of water nearly balanced the rate of discharge. The CDM analysis did not account for downward percolation (seepage through the confining layer) to the Upper Floridan aquifer, another process that also helps to stabilize the mound height.

The downward percolation of water from the surficial aquifer to the Upper Floridan aquifer is governed by the downward hydraulic gradient (difference between the water table altitude and the head in the Upper Floridan) and the leakance of the intervening confining layer. The latter is not altered by the discharge to the RIB cells, but changes do occur to the hydraulic gradient. Generally, head fluctuations in the Upper Floridan are related to changes in pressure loading caused by rainfall-related changes in the regional water table, and are not affected, in terms of pressure loading, by localized effects such as recharge in the RIB basins. The relatively small hydraulic effects of the RIB recharge and regional pumping are generally not identifiable by inspection in the record of head data from the Upper Floridan, possibly because of the high permeability of the aquifer and the areal distribution of the RIB recharge cells. Therefore, to perform the necessary analysis, the head change in the Upper Floridan will be approximated as zero, and it is mainly necessary to define the hydraulic effects of RIB basin discharges in the surficial aquifer.

As reclaimed water is discharged, the rates of lateral flow, vertical percolation to the Upper Floridan aquifer, (possibly) some ground water discharge to lakes, and (under certain conditions) the rate of evapotranspiration, will tend to increase until a balance is reached between the discharge rate and the volumetric rates of the processes removing the excess volume of water, if the hydrologic system is not stressed beyond its capacity to adapt.

The following sections will evaluate the changes in these three hydrologic processes caused by the RIB cell discharges at the four sites that have been in use since late 1986.

RIB Site 5

Originally, RIB site 5 was the western half of the area of the area shown in Figure 90 and four surficial monitor wells (5-01, 5-02, 5-03, and 5-04) were used for monitoring water table altitudes and water quality. Monitor well 5-05 began to provide water level data in July 1993. Some of the piezometers (designated 50nn) began to provide data in July 1996, as the site was extended eastward with the construction of cells 5-2A and 5-2B, which began receiving reclaimed water in November 1986. The two small cells named 5-TB were the test basins used for pilot discharge studies in 1983 (CDM, 1983).

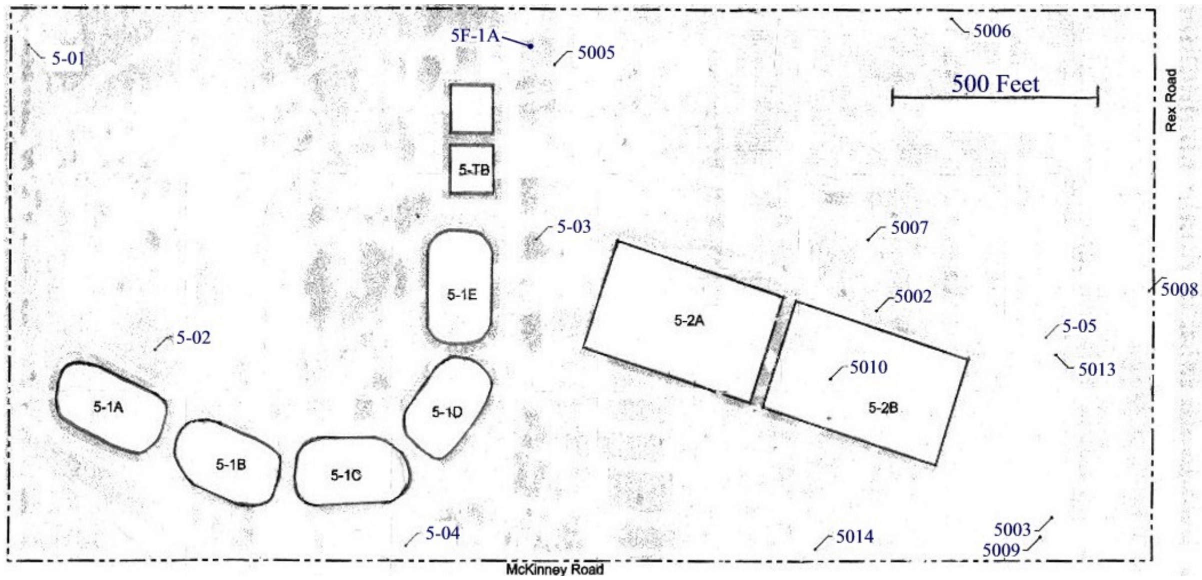

Figure 90. RIB cells, monitor wells, and piezometers at RIB site 5

By the end of 2002, 1.436 x 10^{10} gallons of reclaimed water had been discharged to the RIB cells at site 5. The area of the site is approximately 3.563 x 10^6 ft^2. If the water discharged by the end of 2002 formed a pool of open water enclosed by walls around the site perimeter, the depth of water in the pool would be 538.7 ft. However, water levels stabilized below land surface and even declined during the drought years of 1998–2001. It is evident that discharged water has been effectively removed from the surficial aquifer in the vicinity of RIB site 5 by the processes described above.

Examination of water level records show that the water table reached within 2 ft of land surface at one monitor well (5-02) and at two piezometers (5002 and 5010). The near-surface water levels persisted for some months at 5-02, but only for a short period of time at the piezometers. Qualitatively, it appears that the rate of evapotranspiration may have been increased, but only slightly.

In order to evaluate the augmentation of downward percolation and lateral flow, time-averaged water levels are computed for some of the five monitor wells and 10 piezometers for four time periods: (1) July 1986–November 1996 (four monitor wells); (2) July 1993–November 1996 (five monitor wells); (3) November 1996–August 2002 (five monitor wells and three piezometers); and (4) November 1996–May 2000 (five monitor wells and five piezometers). The remaining piezometers have long breaks in the record that would invalidate mutual comparisons. The original water level data are shown in Figures 76–78. Results of the averaging are in Table 9.

The time-averaged water levels are not used to define time averages of the hydraulic potential for downward percolation through the confining layer to the Upper Floridan aquifer, because the head in the Upper Floridan also varies and it is the difference that determines the rate of leakage. However, because the individual surficial wells and piezometers are mutually similar in their water level responses to changes in atmospheric recharge and RIB cell loading, time-averaged heads and their increase over predischarge levels can be mutually compared to determine local variations in the water table mounding caused by the RIB cell discharges.

The natural water table altitudes might vary by less than 5 ft over a period of years, as was noted for the Lake Oliver shallow well. Water levels in piezometers 3008 and 3014, 3,600 ft away in RIB site 3, before discharge began in January 2002, decreased by 15–16 ft from the high of the El Niño winter of 1997–1998 to the drought of 2000–2001. Water levels in piezometers 4005 and 4007, 2,700 ft away in the northern part of RIB site 4 also showed a similar variation in the same time period. This might indicate that the natural rate of water level variation is greater in the Water Conserv II area than at Lake Oliver, but it seems likely that these water levels have been affected by the RIB discharges at site 5.

For purposes of this study, the predischarge water levels and estimates are also assumed to represent long-term time averages. The first comparison is for head buildup during the period before site expansion occurred in November 1996. Head buildups in monitor wells 5-02 and 5-03, each about 100 ft from a grid cell, were about 28 and 24 ft, respectively. The head buildup at 5-01, about 740 ft from any RIB cell, was about 15 ft, just a little more than half that noted at the other wells. Since 5-01 is in the northwestern corner of the RIB site, this strongly indicates that the water table mounding from the RIB cell discharges of this period extended well beyond the northern and western boundaries of the site.

Considering only data from July 1993 to the time of the plant expansion, it is possible to bring two more monitor wells into the comparison. Average head buildups at 5-02, 5-03, and 5-04, all about 100 ft from the nearest RIB cell, are about 32, 28, and 29 ft, respectively, assuming a pre-RIB water level of 142 ft at 5-04. At 5-01, 740 ft away, the head buildup is about 19 ft. Assuming a value in the range of 142-145 ft for the pre-RIB head at 5-05, 1,330 ft away, the head buildup at 5-05 would be in the 8.5-11.5 ft range, about one-third that observed close to the RIB cells. This indicates that the hydraulic effect of the RIB cell loading probably extended more than twice the distance of the width of the original RIB site (before November 1996).

An examination of monitor well and piezometer data from the expanded site (after November 1996) permits comparisons with average water levels recorded in a piezometer (5010) located within a RIB cell, possibly measuring the near-maximum degree of water table mounding. Discharge rates at expansion cells 5-2A and 5-2B were comparable to discharge rates at the five-cell RIB 5-1. Both rates diminished slightly during the drought years 1998-2001. For simplicity and in lieu of any data, predischarge water table altitudes at monitor wells 5-04 and 5-05 and the five piezometers are all estimated to be 142 ft.

In the November 1996–May 2000 period, the average water level buildup at 5010 would be 29 ft. At the various wells and piezometers (distances from RIB cells in parentheses), the water level buildups were 23 ft at 5-02 (90 ft), 22ft at 5-04 (110 ft), 26 ft at 5-03 (115 ft from one cell and 175 ft from another), 21 ft at 5005 (155 ft), 17 ft at 5-05 (200 ft), 16 ft at 5009 (300 ft), 12 ft at 5008 (460 ft), 14.5 ft at 5006 (735 ft), and 13 ft at 5-01 (740 ft).

Available data do not support an accurate depiction of the extent of the area where the water table is increased appreciably by discharge to the RIB cells at site 5 or an estimate of the mean water table altitude increase. Based on a rough extrapolation of water level buildups near the RIB cells, it is estimated that the affected area is approximately 4.7 times the north-south dimension of the site and 3.0 times the east-west dimension, or 14.1 times the site area (4.276×10^7 ft^2). This area would include piezometers 3008 and 3014 at RIB site 3 and piezometers 4005 and 4007 at RIB site 4 near the southern and southeastern boundaries. The actual area of hydraulic influence will expand and contract as RIB discharges change. The head buildup decrease near the boundary tends to zero exponentially, and the finite boundary is an approximation used for this analysis.

Computation of the recharge to the Upper Floridan aquifer is by integrating the difference in surficial and Upper Floridan heads times the leakance over space and time. If surficial and Upper Floridan heads (w_i^k and h_i^k) are considered approximately uniform over a subarea A_k and constant over a small time period t_i, then the total recharge between times t_0 and t_f over an area A composed of subareas A_k can be approximated by a finite sum:

$$Q = \sum_k \sum_i \Delta t_i \left(w_i^k - h_i^k\right) L_k A_k = \sum_k L_k A_k \left(t_f - t_0\right)\left(\overline{w}^k - \overline{h}^k\right) = \left(t_f - t_0\right) LA \left(\overline{\overline{w}} - \overline{\overline{h}}\right),$$

where the single bars express summation over time and the double bars express summation over time and space. Leakance L_k is assumed to be areally uniform at a value of L. The time interval for water level measurements Δt_i has been assumed to be uniform, and the sum of time intervals is just the difference between the end and start times (t_f and t_0) of the discharge period considered. Formally, the spatial averaging is performed like the time averaging.

The total volume Q can be divided into components Q^b and Q_0, where Q_0 is the natural recharge that would have occurred given the time-averaged natural head w_0 and Q^b is the additional recharge that occurs as a result of the head buildup w^b, where w^b is defined as:

$$w^b = \overline{\overline{w}} - w_0$$

Then:

$$Q^b = Q - Q_0 = \left(t_f - t_i\right) LA \left[\left(\overline{\overline{w}} - \overline{\overline{h}}\right) - \left(w_0 - \overline{\overline{h}}\right)\right] = \left(t_f - t_i\right) LA w^b$$

It has been assumed that the average Upper Floridan head is not changed as a result of head buildup from RIB cell discharges

The time averages of water levels at the monitor wells and piezometers in Table 9 have been computed with relative precision, assuming that each water level is approximately constant over a one-week period. However, spatial averaging cannot be done precisely because of the random location of the data points, and the lack of data outside the site boundaries. The procedure employed was to assume a spatial average of the time-averaged water level buildups that is about one-half the values at monitor wells close to the RIB cells. Using water table buildup values applying to the entire period of record from wells near RIB cells (28 and 24 ft at monitor wells 5-02 and 5-03), the spatially averaged water table buildup is estimated to be 13 ft. This approximation will define the increased percolation to the Upper Floridan aquifer.

Table 9. Average water levels in feet msl for five monitor wells and five piezometers at RIB site 5

Station	Distance From Nearest RIB Cell (Feet)	Pre-Discharge Water Level in Feet (CDM, 1983)	Pre-Discharge Water Level in Feet (Data Base)	Average Water Level in Feet (July 1986 - November 1996)	Average Water Level in Feet (July 1993 - November 1996)	Average Water Level In Feet (November 1996 - August 2002)	Average Water Level in Feet (November 1996 - May 2000)
5-01	740	137	139.79	155.06	158.68	149.76	153.32
5-02	90	136.2	139.56	167.71	171.35	157.55	162.52
5-03	115	132.7	142.00	166.06	169.83	163.12	168.35
5-04	110	135.5	--	--	170.81	160.62	165.70
5-05	1,330 (till 11/1996); 200 (after11/1996)	--	--	--	153.47	155.13	158.96
5005	155	133.5	--	--	--	--	162.89
5006	735	--	--	--	--	--	156.52
5008	460	--	--	--	--	150.27	154.12
5009	300	--	--	--	--	153.83	157.62
5010	(Inside cell)	--	--	--	--	164.65	169.09

CDM (1983) assumed a confining zone leakance in the RIB site 5 area, excluding any sinkholes, of 0.6×10^{-4} ft^{-1} in a numerical model of the site, but their lower estimates of confining zone thickness elsewhere led to an estimated leakance range of 1.1×10^{-4} to 3.2×10^{-4} d^{-1}. O'Reilly (1998) estimated values for an area including site 5 of between 1×10^{-4} and 5×10^{-4} d^{-1}. Based on O'Reilly's leakance estimate and assuming that an average head buildup of 13 ft has occurred, the water table buildup from the RIB cell discharges at site 5 has increased the rate of leakage per unit area from 13×10^{-4} to 65×10^{-4} ft / d. Over the affected area of 4.276×10^{7} ft^2, this volumetric amount lies between 0.55588×10^{5} and 2.7794×10^{5} ft^3 / d.

Over the time period of the discharge (10 / 10 / 1986 to 12 / 31 / 2002 or 5,926 days), from 0.32941×10^{9} to 1.6471×10^{9} ft^3 additional water would have percolated to the Upper Floridan aquifer. This is equivalent to from 2.464×10^{9} to 12.32×10^{9} gal of additional water, or between 17.2 and 86.0% of the volume discharged to the RIB cells at site 5. Averaged over the estimated affected area and the 16.3-year (yr) period, the recharge rate is equivalent to 5.67 to 28.36 in / yr.

If it is assumed that 5% of the water table mound is removed by evapotranspiration and the other 95% percolates to the Upper Floridan aquifer, the leakance estimate based on the assumptions and approximations made above would be 5.5×10^{-4} d^{-1}. The corresponding rate of leakage would be 31.4 in / yr. If it is additionally assumed that an upper Floridan head buildup of 3 ft has occurred at RIB site 5, an approximation of the average head increase between the water table and the upper Floridan could be 10 ft instead of 13 ft. Using the equations above, the estimated leakance would increase by 23%, to 6.8 x 10^{-4} d^{-1}.

Although these estimates are not independent of the modeling studies, because it uses their vertical hydraulic conductivity or leakance estimates, they are consistent with the known discharge data. O'Reilly (1998) estimates 11.6 in / yr of downward leakage in a regional model that includes the Water Conserv II and RCID RIB basins. In a regional model of east-central Florida, McGurk and Presley (2002) estimate downward leakage to the Upper Floridan aquifer to be over 20 in / yr in an area of model cells that includes the Water Conserv II RIB sites, and state that "recharge to the Floridan aquifer also exceeds 50 in / yr at the locations of several large-scale RIB sites." From the estimates made above, the recharge rate in the immediate vicinity of the RIB cells in site 5 would range from 11.3 to 56.7 in / yr, or 62.8 in / yr if the leakance estimate of 5.5 x 10^{-4} d^{-1} is used.

The remaining process for removing the discharged water can also be analyzed using the data in the table above and the equation for radial flow (*Q(t)*) from a source in a surficial aquifer:

$$Q(t) = K 2\pi r h \; dh / dr ,$$

as given by Lohman (1979, p. 11). *Q(t)* is the rate of outward flow per unit time across a perimeter of radius *r* and height equal to the head *h* and must be integrated over the length of time of the flow process to obtain the total volume of flow. By using time-averaged parameters, this can be done by computing an average *Q* and multiplying by the time interval. *K* is hydraulic conductivity.

Assuming as above that the water table mound is contained within an area 4.7 times the north-south dimension and 3.0 times the east-west dimension of RIB site 5, SPLUS software was used to contour the mound for two time periods, October 1986–November 1996 and November 1996–August 2002, corresponding to the original site configuration and the extended configuration after the second cell was added in November 1996 (Figures 91–92).

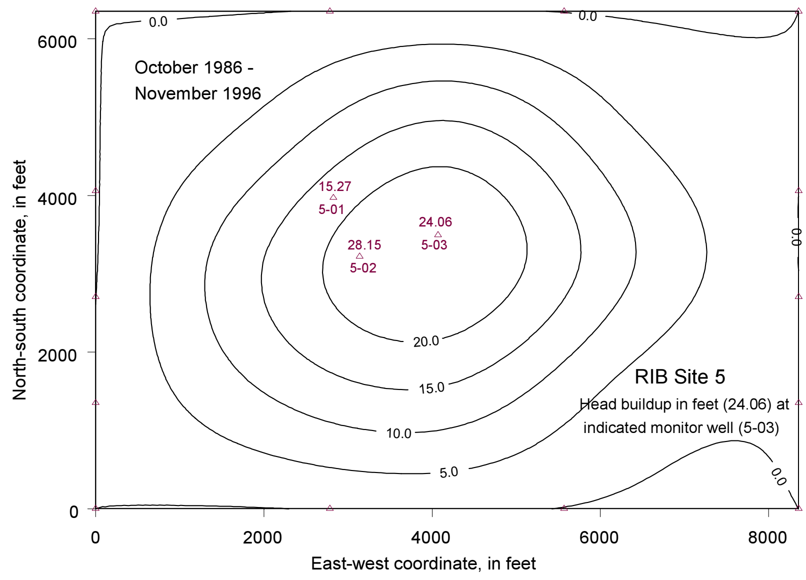

Figure 91. Head buildup contours around RIB site 5, October 1986 – November 1996 averages

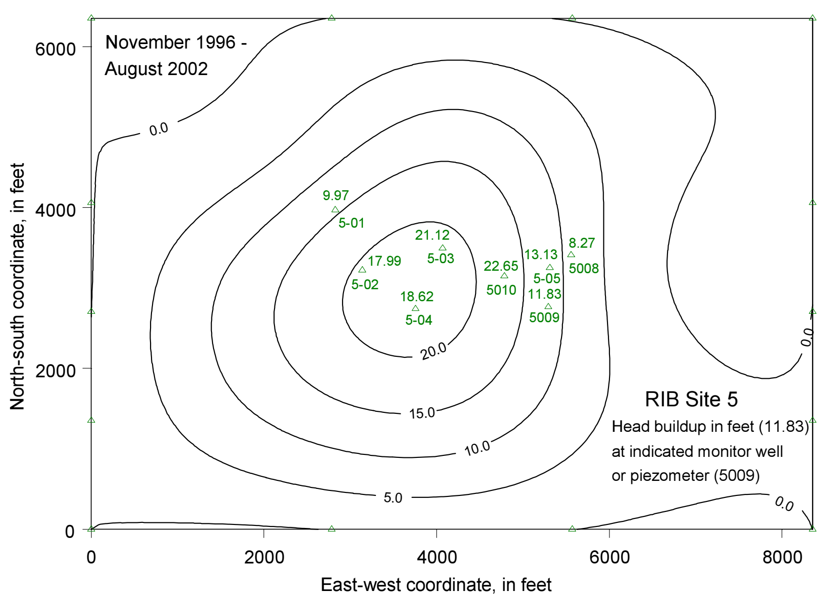

Figure 92. Head buildup contours around RIB site 5, November 1996 – August 2002 averages

The contouring depicted is highly generalized and the contours do not agree closely with all of the data points having high or low values near the center. The contouring could easily have been refined to be more accurate in the neighborhood of the data points. However, because the interpretation depends on lower-level contours, the lack of exact agreement with data points in the center does not hinder interpretation. The spacing of the lower-level contours depends largely on the assumed location of the perimeter of the region of head buildup, where head buildup values were assumed equal to zero. The head gradient was approximated as the finite difference $\Delta h / \Delta r$, where Δh is taken to be 5 ft, Δr is the distance between the 10- and 15-ft contours, *h* is 12.5 ft, and *r* is the distance to the center of the radial segment between 10- and 15-ft contours. Because the contours were somewhat irregular, this was done for several radial segments and results averaged. The hydraulic conductivity (*K*) was assumed to be 30 ft / d.

In the earlier and later time periods, the resulting estimated average Q(t) was 3.207×10^5 gal / d and 2.739×10^5 gal / d. As a result, in the early time period (October 10, 1986–November 11, 1996, 3,654 days), 1.17×10^9 gal flowed across the 12.5-ft contour line. In the later time period (November 12, 1996 - August 18, 2002, 2,272 days), 0.62×10^9 gal flowed across the 12.5-ft contour line. The combined amount for the period of operation until August 18, 2002, is 0.117×10^{10} gal, about 12.5% of the volume of reclaimed water discharged to the RIB site. If the hydraulic conductivity of the surficial aquifer were 50 ft / d instead of 30 ft / d, the amount of lateral flow in the surficial flow across the 12.5-ft contour line, based on observed water levels, would be 20.8% of the discharged reclaimed water.

It is noted that the amount of lateral flow is a function of distance from the source, as with increasing distance from the source, more water percolates to the Upper Floridan aquifer under a larger surface area. Closer to the RIB cells, the lateral outflow would be higher. At the estimated boundary of the mound, there would be no more outflow from water table mounding caused by RIB cell discharges, and all of the mounded water that is not removed by evapotranspiration or ground water seepage to surface-water bodies would have percolated to the Upper Floridan aquifer.

The southeastern corner of the rectangle assumed to represent the region of hydraulic influence just touches Lake Ingram. Because the head buildup at this location is minimal, the volume of additional ground water discharge to the lake is assumed to be negligible.

Recognizing that some small increase in evapotranspiration likely occurs in areas where reclaimed water discharges have temporarily raised the water table to near land surface, it seems probable that the processes of downward percolation, lateral flow, and evapotranspiration account for the removal of a volume of water nearly equivalent to the entire volume of discharged reclaimed water between 1986 and 2002, based on the head buildups observed in the monitor data. Alternatively, given reasonable estimates of hydraulic coefficients such as leakance of the Intermediate Confining Unit and the hydraulic conductivity of the surficial aquifer, the water level data from the monitor wells is consistent with the rate of reclaimed water discharge at RIB site 5 over the nearly 12-year time period studied.

RIB Site 7

Discharge began at RIB site 7 (Figure 93) in the week of October 10, 1986. Two monitor wells (7-06 and 7-09) began to provide water level data in July 1986. Acquisition of data from seven more wells (7-01, 7-02, 7-03, 7-04, 7-05, 7-07, and 7-08) began on March 25, 1987. Two additional monitor wells (7-10 and 7-11) provided data after September 21, 1992.

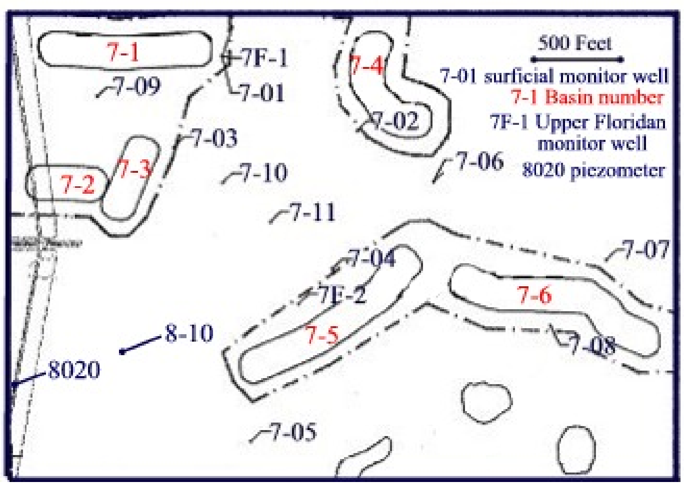

Figure 93. RIB cells and monitor wells at RIB site 7

By the end of 2002, 3.004 x 10^{10} gal of reclaimed water had been discharged. The actual area of the sites is the three sections enclosed in dash-dotted lines shown in the figure. The total area shown in the figure is 1.048 x 10^{7} ft^{2}. If the discharged water formed a pool of open water enclosed by walls around the perimeter of the figure, the depth of water in the pool would be 383 ft. However, water levels (Figures 86–87) stabilized below land surface, except for short time periods, and even declined during the drought years 1998-2001. As at RIB site 5, it is evident that a volume of water in the surficial aquifer nearly equal to the volume of discharged water has been effectively removed from the vicinity of RIB site 7 by the processes of downward percolation to the Upper Floridan aquifer, lateral spreading, discharge to surface-water bodies, or evapotranspiration.

Examination of the water level data shows that the water table reached within 2 ft of land surface, or even rose above land surface, at eight of the monitor wells. These high water table events only persisted for short times, and the water table has been well below land surface during the drought years (1998–2002) at most of the wells (after 2000 at 7-10 and 7-11). As at RIB site 5, it appears that the rate of evapotranspiration at the site may have increased to some degree over the undisturbed rate (if there had been no discharges to the RIB cells) during part of the time period of the RIB cell discharges.

In order to evaluate the augmentation of downward percolation and lateral flow, time-averaged water levels are computed for nine of the monitor wells for the period March 25, 1987 to August 17, 2002. Earlier data from 7-06 and 7-09 were omitted in order to insure the comparability of these averages with those from the other monitor wells that only had data from March 25, 1987. This procedure raised the time averages for these two wells by about 1 foot. Because data from 7-10 and 7-11 began in September 1992, these monitor wells in a frequently inundated area were omitted from the analysis. The time averages computed for the nine wells were considered to be averages for the time period of discharge (October 1986–August 2002), and probably did not differ from the true time averages by more than 1 ft. The averages are shown in Table 10.

The evaluation of water table mounding at the various monitor-well locations follows the procedure used for the site 5 data. Given the scarcity of data, predischarge water levels and estimates are assumed to represent long-term averages.

The highest average water level buildups (over 25 ft) are at monitor wells 7-07 and 7-08, on the north and south sides of RIB basin 7-6. Basin 7-6 received a larger discharge during 1986-2002 than any other basin at this site. Other monitor wells closely adjacent to RIB basins (7-01, 7-02, 7-03, 7-04, and 7-09) also have high average water level buildups (12.97 to 18.87 ft). Monitor wells located further from basins (7-05 and 7-06) have lower average buildups (8.54 to 8.78 ft).

Table 10. Average water levels in feet msl for nine monitor wells at RIB site 7

Monitor well	Time-averaged water level (feet)	Number of measurements	Pre-discharge water level (feet) based on CDM (1983) unless otherwise noted	Average water level increase (feet)
7-01	104.85	812	88.5	16.35
7-02	110.07	812	91.2	18.87
7-03	103.84	812	89.0	14.84
7-04	106.77	812	93.8	12.97
7-05	103.08	812	94.3	8.78
7-06	98.54	812	90.0 (89.40 from data)	8.54 (9.14 from data)
7-07	123.65	814	98.0	25.65
7-08	122.05	814	96.5	25.55
7-09	104.91	803	89.2 (90.24 from data)	15.71 (14.67 from data)

RIB site 7 is bordered on its south side by RIB site 8, which also includes the northeastern and southwestern section of the area shown in Figure 93. Site 8 extends southward to the northern boundary of site 9 (Figure 4), extends eastward and southward on the east and south side of site 9. Water levels at monitor wells in site 9 (Figure 88) have mainly reflected natural conditions, because discharges of appreciable magnitude have occurred only during 3 short periods of a few months each. In the intervening section of RIB site 8 and in its eastern lobe, a number of piezometers were installed between January and June 1992, and several monitor wells were constructed in July 1993. Of these, most have water level records complete through August 2002. This data allows a qualitative evaluation of the extent of the hydraulic influence of the RIB site 7 discharges.

The water level data are not compared directly with the average buildups from site 7 because of the different and variable record lengths and the lack of predischarge water table altitudes. Instead, high and low values from many site 8 and site 9 monitor wells and piezometers were obtained, and a tabulation of the ranges of variation at the various wells was compiled. This range of variation represents the hydraulic effect of discharges at RIB site 7 and net recharge (rainfall minus evapotranspiration). At distance from site 7, the effect of RIB discharges diminishes, and the range of variation will decline with distance until it approaches the natural level caused solely by time-varying net recharge.

Results show a clear trend of diminishing ranges of variation in southward and southeastward directions. Ranges are 21 to 24 ft at 8-10 and 8020 (Figure 93), decreasing to 16 to 17 ft at 8008 and 8010, and decreasing further to 11–15 ft in the eastern lobe of site 8 (Figure 4). The range of variation is only 8.4 ft at 8-03 in the southeastern corner of the eastern lobe of site 8 (Figure 4), and 9 to 11 ft at monitor wells 9-01 and 9-02 in the northern part of site 9 (Figure 4). On this basis, the extent of appreciable hydraulic influence of the RIB site 7 discharges is considered to end in the northern part of RIB site 9 and at the eastern boundary of the eastern lobe of site 8.

The east-west and north-south dimensions of the area shown in Figure 93 are 3,940 ft and 2,700 ft. Hydraulic effects of the RIB cell discharges are estimated to extend northward and southward by another 3,000 ft, and to extend eastward and westward by another 3,000 ft. The total area of hydraulic influence is estimated to be 0.8352×10^{8} ft^{2}. Because of the somewhat lower head buildups, compared to RIB site 5, the average head buildup in the extended area is estimated to be 6 ft.

It is noted that parts of Lake Hancock and Lake Ingram are included on the periphery of this rectangular area where the water table buildup is small. Although this small water table increase will cause a small increase of ground water inflow into the lakes, it is unlikely that the volume of increased inflow, averaged over the area of the lakes, would cause lake stage increases that would be evident in graphs of lake stage (Figures 27–28).

The regional model of CDM (1983) includes RIB site 7 in a subregion where the confining layer is 90 ft thick and has a vertical hydraulic conductivity of 0.005 ft/d, equivalent to a leakance of 0.56×10^{-4} d^{-1}. However, O'Reilly (1998) includes most of site 7 in an area having a leakance of more than 50×10^{-4} d^{-1}, though the site is bounded on the east and south by areas assigned lower leakances. To the east, the assigned leakance is 0.5×10^{-4} to 1×10^{-4} d^{-1}, and the southeastern part of site 7 is included in this zone. To the south, the assigned leakance is 5×10^{-4} to 10×10^{-4} d^{-1}.

Because the volumes of discharge are higher than for site 5, while the head buildup is lower, it is likely that the leakance is higher than at site 5. Assuming a leakance value of 50×10^{-4} d^{-1}, the leakage rate would be 0.03 ft/d. Over the estimated area of hydraulic influence (0.8352×10^{8} ft^{2}), the rate would be 0.2506 x 10^7 ft^3/d. Over the time period of the discharge (10/10/1986 to 12/31/2002 or 5,926 days), 1.48 x 10^{10} ft^3, or 11.11 x 10^{10} gal, of additional water would have percolated to the Upper Floridan aquifer. This volume is equivalent to 130.5 in/yr, and is 3.7 times the amount known to have been discharged to RIB site 7.

Either the average water table buildup (6 ft) or the leakance (50 x 10^{-4} d^{-1}) has been overestimated, possibly both. If the leakance were only 10 x 10^{-4} d^{-1}, the volume of additional percolation would be 2.221 x 10^{10} gal, or 74% of the amount of reclaimed water discharged. This is equivalent to 26.1 in/yr, consistent with the leakage estimate made by McGurk and Presley (2002) of over 20 in/yr in an area of model cells including the Water Conserv II RIB sites. If it is assumed that 5% of the water table mound is removed by evapotranspiration, and the remaining 95% leaks to the Upper Floridan aquifer, the leakance estimate must be revised to 12.85 x 10^{-4} d^{-1}, and the rate of leakage to 33.5 in/yr.

If it is additionally assumed that an upper Floridan head buildup of 4 ft has occurred at RIB site 7, an approximation of the average head increase between the water table and the upper Floridan could be 2 ft instead of 6 ft. Using the equations above, the estimated leakance would increase by 200%, to 38.5 x 10^{-4} d^{-1}.

Despite the uncertainty of assigning a leakance rate, the analysis has demonstrated that the measured water table mounding and available leakance estimates are generally consistent with the removal of a volume of water equivalent to the volume of reclaimed water discharged to RIB site 7.

An analysis similar to the one for RIB site 5 is used to estimate the amount of lateral movement from RIB site 7. As before, SPLUS software was used to draw water-level buildup contours, assuming zero values on the periphery of the rectangular area (Figure 94). As before, the accuracy of the contouring near the data points could easily have been enhanced, but the purpose of the exercise, to estimate outflow near the periphery of the water table mound, was served by the contouring shown in Figure 94. The resulting contours are skewed by the high buildup values at wells 7-07 and 7-08.

Despite the variability of the spacing of the 5-ft and 10-ft contours around the center, using the center of the 30-ft contour as a center, the values of $r/\Delta r$ computed along numerous radii (3.9 to 7.3) vary by less than a factor of two. The resulting range of values for outflow per time across the 7.5-ft contour is

5,513.5 to 10,602.9 ft^3/d. Multiplying this average value by period (5,926 days) of discharge to the end of 2002, 0.336 x 10^8 to 0.628 x 10^8 ft^3 flowed across this perimeter. This is equivalent to 2.51 x 10^8 to 4.70 x 10^8 gal, or from 0.84% to 1.56% of the volume of reclaimed water recharge.

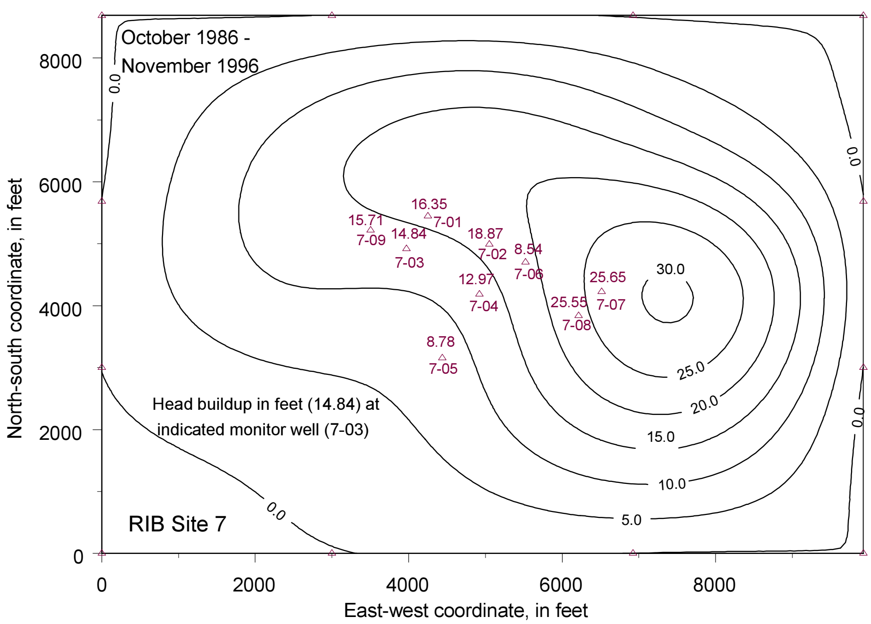

Figure 94. Head buildup contours around RIB site 7, October 1986 – August 2002 averages

It is again noted that the volume of outward lateral flow decreases with distance from the source, as additional water percolates to the Upper Floridan aquifer with increasing distance from the source. The lateral flow ceases at the boundary of the hydraulic influence of the RIB discharge. Within this boundary, all water within the mound, except that removed by evapotranspiration or ground water seepage to lakes, will percolate to the Upper Floridan aquifer. It is again noted that some of the recharged reclaimed water is probably removed by additional evapotranspiration, because the recharge raises the water table to near land surface during some periods of time.

RIB Sites 6 and 9

The discharge of appreciable volumes of reclaimed water took place at RIB site 9 only in three limited periods, early 1987, early 1997, and in 2001. During most of the 1986–2002 time period, variations in measured water levels at the site (Figure 88) were influenced solely by natural stresses. Pre-discharge water levels were measured in the six monitor wells having record of appreciable length. Water levels measured through mid 1994 were generally lower than the initial levels. Water levels from mid 1994 through early 2000 were generally higher.

During the three major discharge periods, elevated and rapidly fluctuating water levels occurred in wells 9-02, 9-03, and 9-07. Because of the limited amount discharged (0.029 x 10^{10} gal) and the corresponding limited hydraulic effects, a hydraulic analysis of site 9 data was not done.

Of all the RIB sites, only site 7 has received a greater volume of reclaimed water recharge than site 6. However, the discharge volume at site 6 (2.035 x 10^{10} gal) has been distributed over a substantially greater number of RIB cells over a substantially greater area (about 0.57 x 10^8 ft^2, or about 2.0 mi^2). A detailed hydraulic analysis of RIB site 6 (Figure 95) was considered beyond the scope of this report, because of the scarcity of data and because the large size of the site has dispersed the effects of the reclaimed water discharges into a large number of localized processes that are difficult to analyze individually.

Water-level data collection did not begin until 1991, so that five years of the water table response to recharge were not documented. Water levels from 1991 through 2002 are shown in Figures 79-84. Pre-discharge water level measurements for monitor wells in the database were not made, although water table contours with a 5-ft interval were prepared earlier by CDM (1983). The degree of accuracy to which these contours allow predischarge water levels to be inferred at monitor-well locations varies from well to well. Qualitatively, certain individual well responses can be compared with the predischarge water levels inferred from the CDM maps, and interpretations about the water table response in the vicinity of the wells can be made.

Certain monitor wells show little response to RIB cell discharges, while others show a strong and marked response. Well 6-19 is an example of the former. The predischarge water level is inferred to be 110 ft. However, the later record from December 1991 to August 2002 contains only water levels less than 110 ft. Well 6-19 is relatively distant (535 ft) from the nearest RIB cell (the no longer used 6-18) compared to many other monitor wells.

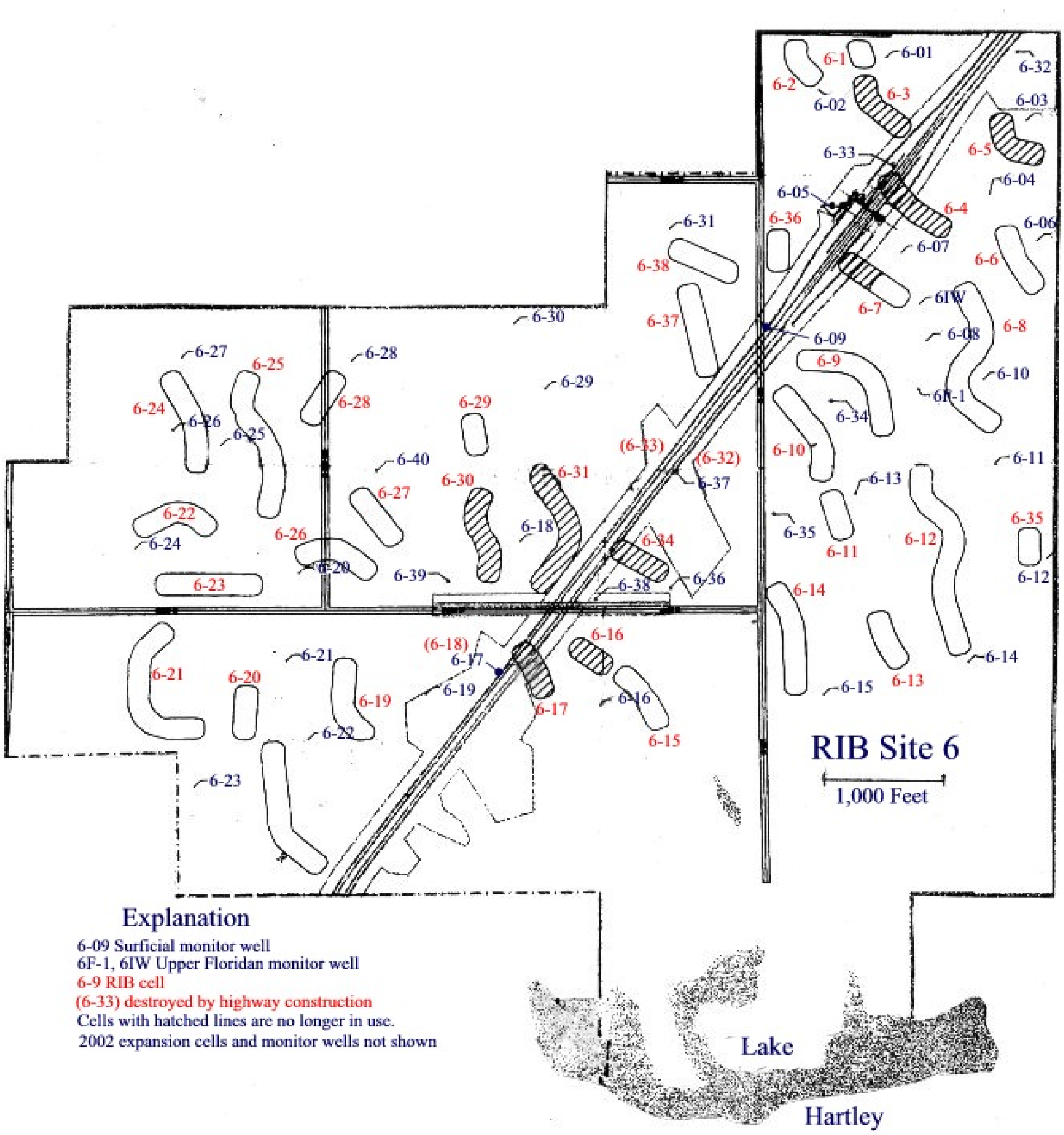

Figure 95. RIB cells and monitor wells at RIB site 6

In contrast are the water level records from monitor well 6-25 (Figure 82), which shows a clear response to discharges at nearby cells 6-24 and 6-25. The predischarge water level was inferred to be 105 ft. After 1993, the recorded water level in well 6-25 was generally between 115 and 130 ft. During parts of this period, particularly during 1993, discharges occurred during one week out of three, and an oscillatory pattern of water level variation was established, as has been noted previously (Figure 85). During the periods between discharges, water was removed from the water table by processes of lateral flow in the surficial aquifer and downward percolation to the Upper Floridan aquifer.

The pattern indicated is of many localized water table mounds about RIB cells. The calibrated model of O'Reilly (1998) shows RIB site 6 to be underlain by four different zones of confining-zone leakance, ranging in value from less than 0.5×10^{-4} to 50×10^{-4}. Likely, the relation between lateral flow and downward percolation is as spatially variable as the leakance parameter.

EVIDENCE OF RECHARGE FROM WATER QUALITY DATA

The presence of reclaimed water in the Upper Floridan aquifer can be inferred from the measurements of various dissolved substances, including those measured at the RIB sites in the period 1986-2002 and illustrated earlier in this report (Figures 43–75). The available parameters of particular interest are chloride (and the often closely correlated specific conductance and total dissolved solids), nitrate nitrogen, total phosphorus, and total trihalomethanes. As previously noted, little is known about the construction of wells providing long-term record from the Upper Floridan, so the discussion must proceed without reference to details about the vertical extent of the well capture zone.

Chloride is present in appreciable concentrations in the reclaimed water (Figure 14), based on measurements beginning in 1997. The mean concentration of these measurements was 87.5 mg/L. In contrast, the chloride concentration in natural waters of the Upper Floridan aquifer is normally less than 25 mg/L, and measurements of less than 10 mg/L are common. Even where substantial downward percolation of water in agricultural areas has occurred for decades, and traces of nutrient species from fertilizers are evident, there is usually no noticeable increase in chloride. Thus, increases in chloride in Upper Floridan wells used to monitor the RIB sites are considered indicative of the downward percolation of reclaimed water discharged at the sites.

Nitrate nitrogen is also present in appreciable concentrations as a dissolved constituent in the reclaimed water (Figure 15). Measured since discharge of reclaimed water began in 1986, the mean measured concentration of nitrate nitrogen in the reclaimed water has been 6.91 mg/L. Nitrate nitrogen can be removed by the process of denitrification after discharge to the basins, but, if it is not removed, some of the nitrate-rich reclaimed water can percolate downward to the Upper Floridan aquifer. Sumner and others (1998), in a study of nutrient transport and transformation beneath an infiltration basin, note “removal of nitrogen from infiltrating water by denitrification was negligible beneath the basin, probably because of subsurface aeration.”

The natural concentration of nitrate nitrogen in pristine natural waters of the Upper Floridan aquifer is close to zero, or less than 0.1 mg/L. However, decades of irrigation and fertilization of citrus groves and plant nurseries in the study area has led to downward percolation of nitrate-rich waters in scattered parts of the study area. Background concentrations of nitrate nitrogen measured before the discharges to RIB basins began, or in areas not likely to have been influenced by RIB discharges, have ranged as high as 7.5 mg/L. This fact means that detection of high concentrations of nitrate nitrogen at Upper Floridan monitor wells cannot be regarded as verifying the occurrence of downward percolation to the Upper Floridan without further study and possible qualification. Where a gradual pattern of increase is found, it could be evidence of downward percolation of reclaimed water from a RIB basin or of the lateral migration of nitrate-rich water from a nearby section of the aquifer containing water from downward percolation from an agricultural area. Where the increase correlates with that of other constituents present in the reclaimed water, it could be considered as supporting evidence for downward percolation of reclaimed water.

One type of analysis that may help to overcome the uncertainties associated with the interpretation of water quality data is to consider the ratios of certain constituents that are characteristic of a source fluid and tend to remain relatively constant over time. In this study, the ratio of total nitrogen to chloride was studied, and comparisons were made between this ratio in the source (the reclaimed water from the wastewater treatment plant), in water samples from surficial aquifer monitor wells, and in water samples from upper Floridan aquifer monitor wells. This approach was suggested by David McIntyre (PB Water, pers. Comm., 2005).

As previously stated, total nitrogen is computed as the sum of total Kjeldahl nitrogen, nitrite nitrogen, and nitrate nitrogen. It is assumed that the latter species are reported in the database as equivalent weights of nitrogen. Chloride analyses of samples of the reclaimed water available for this study were collected from October 1997 through July 2002. During this period, some variation in the total nitrogen to chloride ratio occurred, but the ratios (Figures 96–98) remained near a value of 0.10. Interpretations at individual RIB sites will be detailed below.

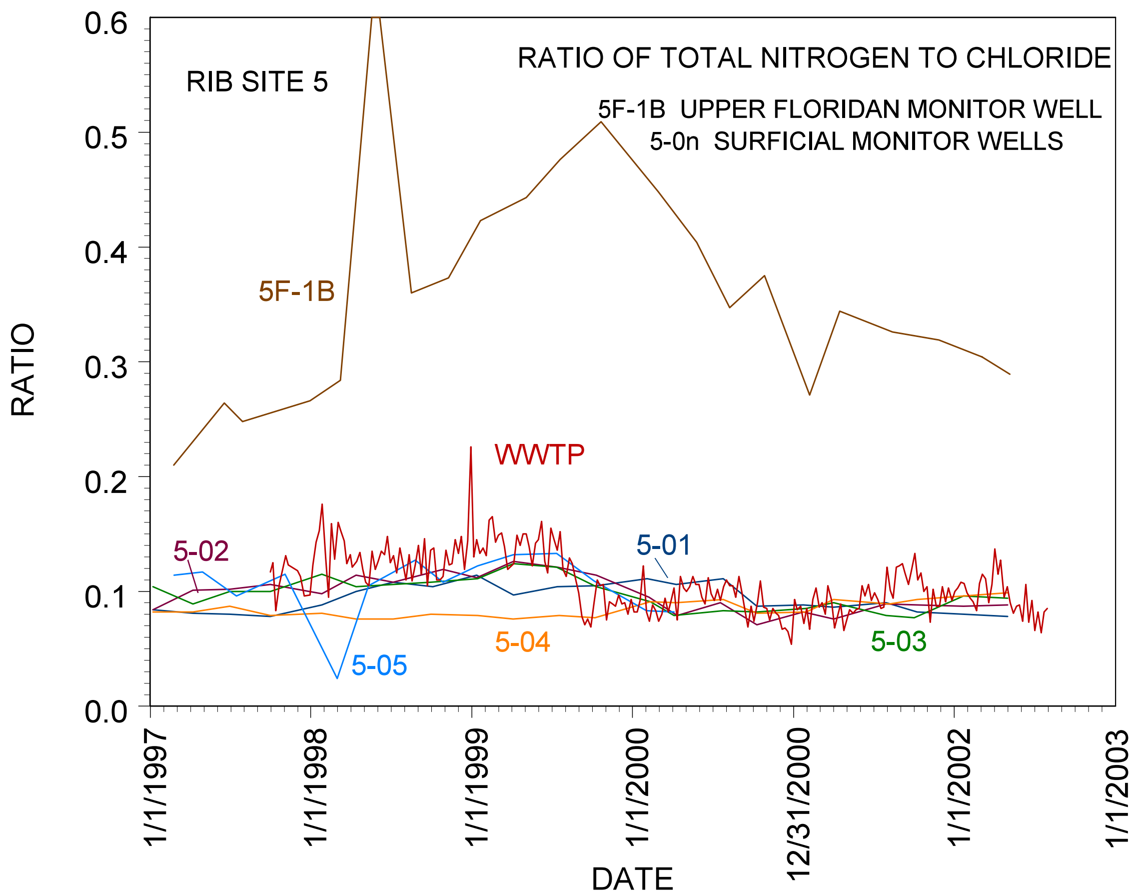

Figure 96. Ratios of total nitrogen and choride in water samples from the WWTP and surficial and upper Floridan monitor wells at RIB site 5.

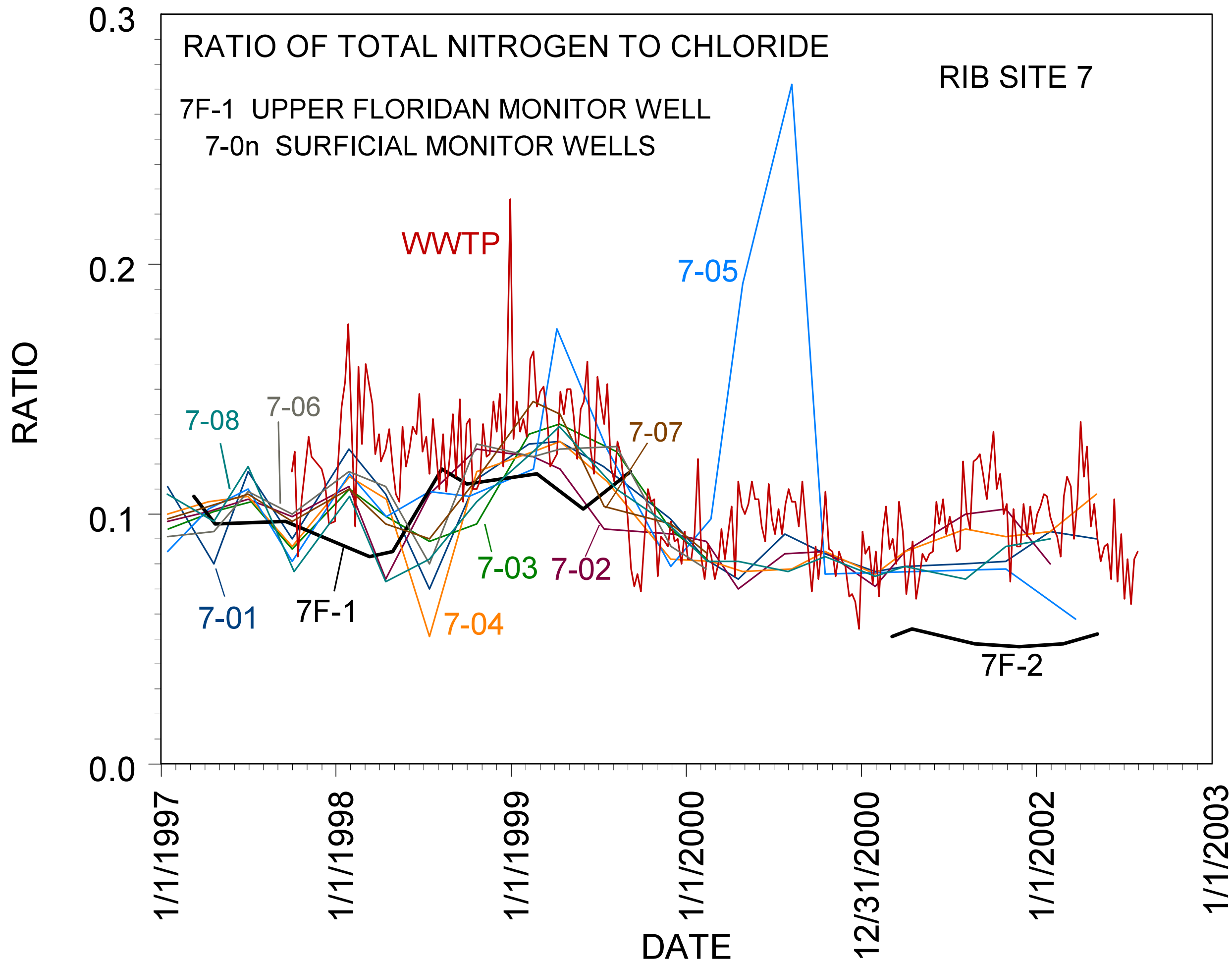

Figure 97. Ratios of total nitrogen and chloride in water samples from the WWTP and surficial and upper Floridan monitor wells at RIB site 7.

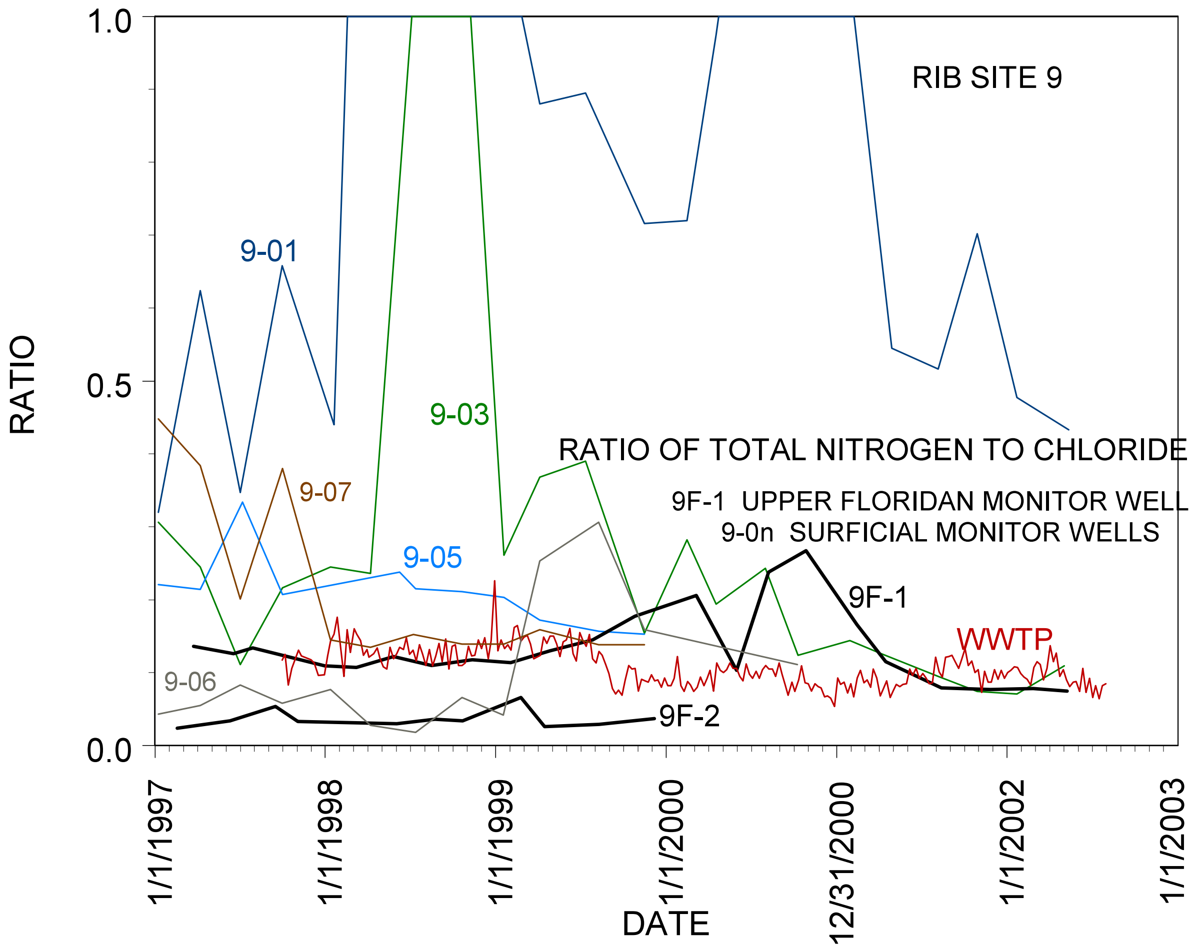

Figure 98. Ratios of total nitrogen and chloride in water samples from the WWTP and surficial and upper Floridan monitor wells at RIB site 9.

Phosphorus is a dissolved constituent found in the reclaimed water, in which the mean concentration measured between 1997 and 2002 was 1.94 mg/L. Phosphorus is also present in fertilizers used in agricultural areas. The natural concentration of phosphorus in pristine natural parts of the Upper Floridan aquifer is near zero, or less than 0.1 mg/L. As with measurements of high concentrations of nitrate nitrogen, consistently high measurements of phosphorus in the Upper Floridan aquifer could also be an indicator of either downward percolation of reclaimed water or of lateral migration from an area of the aquifer containing downward percolation from an area of agricultural activity.

However, as noted by Hem (1985), phosphorus is not very mobile in groundwater, and it is likely that high concentrations will not be found in the Upper Floridan aquifer even where substantial downward percolation of reclaimed water does occur. Sumner and others (1998), in the study of nutrient transport and transformation beneath an infiltration basin, note "approximately 90% of the phosphorus in treated wastewater was removed within the upper 15 ft of the subsurface, primarily by adsorption reactions." They note further "phosphorus that accumulated below the water table was immobilized by adsorption or precipitation during basin rest periods."

Concentrations of the four species included in total trihalomethanes were not known to have been measured in the reclaimed water. However, the reclaimed water is considered to be the source of these dissolved substances, because they are not known to occur naturally in either the surficial or Upper Floridan aquifers or in water percolating downward from agricultural areas. High concentrations or increasing trends of concentration of these species can be considered evidence of downward percolation of the reclaimed water.

RIB Site 5

Water samples from Upper Floridan monitor well 5F-1 on the northern boundary of RIB site 5 (hydraulically downgradient in the aquifer) have shown a steadily increasing trend in chloride concentration (Figure 46) since 2000. This trend correlates with a slow steady increase of specific conductance (Figure 43) since 1998 and a general increase of total dissolved solids (Figure 53) since 1999. The concentration levels reached in 2002 were not above the thresholds of concentrations deemed natural in the aquifer, but the trends are consistent enough to appear significant.

At site 5, there has also occurred a steadily increasing trend of nitrate nitrogen concentrations (Figure 56) since 1991, and concentrations reached 2.89 mg/L) by May 2002 that is considered well above pristine natural conditions, though it would be characteristic of Upper Floridan waters receiving percolation from agriculturally affected areas. Subject to the previously discussed constraints on interpreting nitrate nitrogen data, and noting the correlation with steady increases in other constituents, this may indicate that reclaimed water has percolated downward to the Upper Floridan aquifer. Phosphorus has not increased in water samples and remains at near-zero concentrations.

Total trihlomethanes have also shown a pattern of increase since 1999, reaching a level of 0.07 mg/L. This trend correlates with other increases, and indicates that some reclaimed water has entered the Upper Floridan aquifer.

The total nitrogen to chloride ratios in water samples from the five surficial aquifer monitor wells are similar to those in the reclaimed water (Figure 96). However, the ratios in water samples from the upper Floridan monitor well 5F-1B are substantially higher. This suggests the possibility that nitrate detected at the upper Floridan well could be from an alternative or additional source other than the RIB discharge.

It was previously noted as part of the hydraulic analysis that the confining-layer leakance underneath RIB site 5 was relatively low compared with other RIB sites, which is consistent with a pattern of slow percolation and slowly increasing concentrations of marker constituents at well 5F-1, used for water sampling at a location downgradient in the Upper Floridan aquifer. Subject to the qualification suggested by the nitrogen to chloride ratios, it is concluded that the water quality data does indicate that downward percolation of reclaimed water occurs underneath RIB site 5.

RIB Site 6

Upper Floridan monitor well 6F-1 lies near the eastern boundary of RIB site 6, underneath a section of the confining layer believed by O’Reilly (1998) to have relatively low leakance. The northeastern hydraulic gradient in the Upper Floridan (O’Reilly, 1998) indicates that the monitor well is downgradient of an area overlain by numerous RIB basins. Water samples from well 6F-1 have shown little evidence of the presence of reclaimed water. The concentration of chloride has remained below 10 mg/L, nitrate nitrogen and phosphorus concentrations have remained near zero, and no trihalomethane has been detected.

However, water samples from monitor wells 6F-2 and 6F-3 have shown evidence of chemical changes. These wells (Figure 3) are located north of the western part of the RIB site. Judging from the Upper Floridan hydraulic gradient, these wells are on the western edge of the detection zone of constituents in percolating reclaimed water at RIB site 6. As pumped irrigation supply wells, however, their capture radius might be greater than suggested by this gradient. O’Reilly (1998) shows the well locations as being within the zone of flow paths from site 6. Neither well has been sampled since November 1999.

Analysis of water samples from well 6F-2 has shown a generally increasing trend in chloride concentration, beginning in 1998. Concentration levels, however, are still below 25 mg/L, the assumed limit of natural concentrations. Chloride concentration levels have remained high (at about the 25 mg/L level) since 1992 in samples from 6F-3. Nitrate nitrogen concentration levels have been relatively high during the period of discharge, but samples from 6F-2 have had lower concentration levels, and the concentrations have shown an increasing trend since 1998. Phosphorus concentrations have remained near zero. Total trihalomethane concentrations have remained at zero in samples from well 6F-2, but the concentration levels in five samples from 6F-3 obtained since 1994 have been as high as 0.004 mg/L.

The results of sampling from wells 6F-2 and 6F-3 suggest that downward percolation of reclaimed water has occurred at RIB site 6. The increasing trends of chloride and nitrate nitrogen concentrations in samples from 6F-2 and the trihalomethane concentrations in samples from 6F-3 are the strongest indicators.

RIB Site 7

Upper Floridan monitor well 7F-1 was located in the northern part of the area shown in Figure 93. It was in a good location to detect downwardly percolating constituents from the reclaimed water at one section of RIB site 7. However, because it was technically off-site, sampling was discontinued after September 1999. Well 7F-1 was a pumped irrigation well, which would increase the zone of capture of water, so that constituents characteristic of the reclaimed water would have a better chance of being detected.

The two initial chloride concentrations in 7F-1 during 1997-98 were below 25 mg/L, the upper limit of the natural range for the Upper Floridan aquifer. Since then, chloride concentrations have been consistently above 25 mg/L. From 1995 to 1998, concentrations were over 40 mg/L, though concentrations decreased to 34 mg/L before sampling was discontinued. Specific conductance and total dissolved solids were generally constant from 1995-99.

Similarly, the initial nitrate nitrogen concentration in 1987 was 1.6 mg/L. but since 1990, the nitrate nitrogen concentration has been in the 3-5 mg/L range. Except for one outlier, phosphorus concentrations were all close to zero. Since the first zero measurement in 1992, total trihalomethanes have been above zero, with a maximum concentration of 0.016 mg/L.

These concentrations indicate the likely presence of reclaimed water in the water samples from Upper Floridan monitor well 7F-1. It was shown as part of the hydraulic analysis that the confining-zone leakance underneath RIB site 7 was relatively high compared to the other RIB sites, which would be consistent with the early appearance of trace constituents from the reclaimed water in water samples from 7F-1.

In March 2001, water samples began to be obtained from newly drilled Upper Floridan monitor well 7F-2 (Figure 93). Chloride concentrations were quite high (80–89 mg/L), similar to concentration levels in the reclaimed water. Nitrate nitrogen samples were approximately the same as from well 7F-1. Total phosphorus concentrations were near zero, and no trihalomethane measurements were made.

Total nitrogen to chloride ratios in the reclaimed water, in samples from the seven surficial aquifer monitor wells, and from upper Floridan monitor well 7F-1 (until discontinued in late 1999) were all similar (Figure 97), supporting the conclusion that reclaimed water had percolated to the upper Floridan aquifer near 7F-1. Nitrogen to chloride ratios from 7F-2 (starting in March 2001) were consistent at a value lower than that of the reclaimed water, reflecting the higher measured values of chloride.

The high chloride concentrations in samples from 7F-2 suggest that the area of the Upper Floridan aquifer near the well might have been contaminated with reclaimed water. However, the well completion report shows that the well was developed after completion.

RIB Site 9

Upper Floridan aquifer monitor well 9F-2 was located some distance from RIB site 9 in a direction hydraulically up gradient from the RIB site. The area where the well is located appears to be a pristine, forested area. A lack of constituents that would be tracers of the reclaimed water would be expected in analyses of water samples, and such is indeed the case. Chloride concentrations have not exceeded 10 mg/L, nitrate nitrogen and phosphorus concentrations have been close to zero. Except for one sample, all measurements of trihalomethanes have been zero. Sampling was discontinued after September 1999.

Upper Floridan monitor well 9F-1 is located at the northeastern corner of the RIB site, and hydraulically downgradient of the RIB cells, an excellent location to detect constituents in the Upper Floridan aquifer that would indicate downward percolation of reclaimed water. Despite the fact that the total volume of recharge to the site has been small, and has only occurred in three short time periods, reclaimed water constituents apparently have been detected.

Chloride concentrations averaged about 10 mg/L through 1991, but increased above 25 mg/L in 1996, and have shown a rapidly increasing trend (to 59 mg/L) since 2000. Nitrate nitrogen concentrations have also shown a rapidly increasing trend since 1998, although phosphorus concentrations have remained near zero. Total trihalomethane concentrations have all been higher than 0.004 mg/L. These facts suggest that reclaimed water is being detected in well 9F-1, but PB Water (written commun., 2004) state that the reclaimed water is from an onsite source (a golf course) other than the Water Conserv II RIBs.

Total nitrogen to chloride ratios (Figure 98) from various surficial aquifer and upper Floridan monitor wells are quite variable, indicating that the concentrations of constituents at various wells have a variety of origins, probably different from reclaimed water recharge. This is consistent with the fact that recharge at site 9 only occurred at several discrete time periods. However, ratios in samples from surficial aquifer monitor well 9-07 and upper Floridan aquifer monitor well 9F-1 are very similar to those of the reclaimed water for substantial periods of time. This fact supports conclusions based on the chloride, nitrate, and trihalomethane data indicating that reclaimed water might have been detected at well 9F-1, possibly originating at nearby RIB site 8, where recharge began in July 1999.

RECHARGE ESTIMATES BASED ON WATER QUALITY

Estimates of reclaimed water recharge to the Floridan aquifer at Water Conserv II were determined based on the nitrate and total trihalomethane (TTHM) concentrations in Floridan aquifer monitor wells. The assumption is made that there is little to no nitrate and no TTHM concentrations in the Floridan wells prior to the beginning of the application of reclaimed water. It is further assumed that nitrate and TTHM concentrations in Floridan monitor wells are due to downward seepage of water from the surficial aquifer. The source of nitrates and TTHM in the surficial aquifer is assumed to be from the application of reclaimed water. Nitrate nitrogen concentrations at the WWTP were as high as 18.06 mg/l and had a mean and median concentration of 6.91 mg/l and 6.78 mg/l respectively (Figure 15). TTHM's were not measured at the WWTP. Recharge estimates were determined for two RIBs, 5 and 7. No information is available on the well construction for Floridan monitor wells 5F-1 and 7F-1. Both wells were irrigation wells prior to the application of reclaimed water at Water Conserv II. In fact, 7F-1 remained a pumped irrigation well after Water Conserv II began.

RIB Site 5

Because the concentration of nitrate in reclaimed water applied to RIB Site 5 has varied with time, a period (March 1, 1992 to May 7, 2002) when the concentration was approximately constant was selected. During this period, the nitrate concentrations in Floridan monitor well 5F-1 approximately linearly increased (Figure 56). The increase was statistically significant at the 99% confidence level. The slope for the increase was 0.26 mg/l/yr. During this time, the average nitrate concentration in surficial monitor wells 5-01 (7.90 mg/l), 5-02 (8.00 mg/l), and 5-03 (8.02 mg/l) was 8.0 mg/l (Figure 56).

Since 1995, the ratios of total inorganic nitrogen/chloride in the Floridan monitor well (5F-1) are higher than those in the reclaimed water and in the surficial compliance monitoring wells. This suggests that the reclaimed water applied at RIB 5 is not the source of all of the nitrates measured in the Floridan monitor well 5F-1. The ratios of total inorganic nitrogen/chloride are the same in the surficial aquifer compliance monitor wells as they are in the reclaimed water. However, the following discussion assumes that all of the nitrates in the Floridan monitor well 5F-1 arise from downward seepage of RIB 5 reclaimed water. The fact that all of the nitrates are not due to RIB 5 relaimed water indicates that the amount seeping into the Floridan aquifer is even lower than calculated.

The change in nitrate concentration in the Floridan aquifer can be mathematically expressed as:

$$dc/dt = c_{in}Q_{in}/V - cQ_{out}/V \qquad (1)$$

where dc/dt is the change in nitrate concentration in the Floridan aquifer per time (mg/l/yr), or the slope; c_{in} is the average nitrate concentration in surficial aquifer monitor wells (mg/l); Q_{in} is the volume of reclaimed water entering the Floridan aquifer per time (ft3/yr); Q_{out} is the volume of water in the Floridan aquifer laterally flowing away from the monitor well per unit of time (ft3/yr); and V is a representative volume of water in the Upper Floridan aquifer (ft3). Equation (1) mathematically states that the measured change in concentration in a monitor well equals the difference between what comes in and what goes out of a representative volume of the Upper Floridan aquifer. It also assumes that each concentration is an average value and that the monitor well penetrates the full thickness of the Upper Floridan aquifer. The available information is insufficient to determine if concentration gradients exists with depth or if concentrations vary with depth. The sample was collected at the well head and thus represents the average concentratrion.

As stated earlier, the assumption is made that there is no nitrate nitrogen in the representative volume of the Upper Floridan aquifer prior to the application of reclaimed water and that the presence of nitrate nitrogen is due to the downward percolation of reclaimed water, The fact that initial nitrate nitrogen concentrations are near zero and increase along with chloride after the application of reclaimed water supports this assumption.

The unknowns in equation (1) are $Q_{in,}$ Q_{out}, and V. Assuming all variables except c are independent of time, the solution to equation (1) is

$$c = [c_{in}Q_{in} / Q_{out}](1 – \exp((-Q_{out} / V)t)) \tag{2}$$

Substituting 0.26 mg/l/yr for dc/dt, 8.0 mg/l for c_{in}, and 0.26 mg for c (concentration after one year) in equation (1) and solving for Q_{in} yields

$$Q_{in} \text{ (for one year)} = 0.0325 (V + Q_{out} \text{(for one year)}) \tag{3}$$

The representative volume of the Upper Floridan aquifer (V) is a function of the capture zone for the monitor well. For a homogeneous system, it is the product of the average capture area, the thickness of the Upper Floridan aquifer, and the effective porosity. Assuming an effective porosity of 0.10 (CDM 1983) and a thickness of 400 ft, yields a volume of 40 ft times the average capture area. Assuming an average capture area of 100 ft2, produces an average volume of 4,000 ft3. If Q_{out} is much larger than 4,000 ft3, than equation (3) can be simplified to Q_{in} approximately equals 0.0325 Q_{out}.

Simply put, to estimate the fraction of surficial aquifer water recharging the Floridan at RIB Site 5, the nitrate concentration in the Floridan after one year (0.26 mg/l) was divided by the average concentration (8.0 mg/l) in the three surficial aquifer monitor wells. That fraction was 3.25%. Although it is possible for all of the applied reclaimed water to recharge the Floridan aquifer at RIB Site 5, that scenario seems unlikely because of the large volume of Floridan water that would be required to dilute the concentration to the measured value. However, because of the unknown open-hole interval for 5F-1, that scenario could be possible. Water quality samples could have been diluted during well purging and sample collection.

As a check on the recharge estimate, chloride concentration in 5F-1 for 2000 was calculated. The calculation involved multiplying the recharge estimate (3.25 %) by the chloride concentration in the surficial aquifer in 2000 (90 mg/l) and adding to this quantity the product of the background chloride concentration in 5F-1 prior to 2000 (4 mg/l) multiplied by 96.75 %. The calculated chloride concentration was 6.8 mg/l. It agrees fairly well with a measured chloride concentration of 6.02 to 6.98 mg/l between October 27, 2000 and April 16, 2001 (Figure 46).

Another check on the recharge estimate can be obtained from the TTHM concentration. However, since there is no information on the TTHM concentration in the reclaimed water applied to RIB Site 5, a period (1999–2002), when the applied annual volume of reclaimed water was approximately constant, was selected. During this period, the TTHM concentration in Floridan monitor well 5F-1B approximately linearly increased (Figure 73). The increase was statistically significant at the 99% confidence level. The slope of the increase was 0.0017 mg/l/yr. During this time the average TTHM concentration in surficial monitor wells 5-01, 5-02, 5-03, and 5-04 was 0.0179 mg/l (Figure 73). Substituting 0.0017 for dc/dt, 0.0179 for c_{in}, and 0.0017 for c (concentration after one year) in equation (1) and solving for Q_{in} yields:

$$Q_{in} = 0.0950\ (V + Q_{out}) \tag{4}$$

To estimate a fraction of surficial aquifer water recharging the Floridan at RIB Site 5, the TTHM concentration in the Floridan after one year (0.0017 mg/l) was divided by the average concentration (0.0179 mg/l) in the four surficial aquifer monitor wells. That fraction was 9.50%. The measured TTHM concentration in the above surficial aquifer monitor wells has varied with time. Measured concentrations have differed by more than 0.03 mg/l, suggesting that c_{in} is not well defined. Using the maximum TTHM concentration (0.052 mg/l) measured in surficial aquifer monitor wells (5-03) for c_{in} lowers this fraction to 3.27% of the total quantity of reclaimed water applied. This is the same value obtained for nitrates, suggesting that estimates of recharge based on water quality at RIB Site 5 are consistent.

RIB Site 7

Because the nitrate concentration in reclaimed water applied to RIB Site 7 has varied with time, a period (1/1/92 to 1/1/98) when the concentration was approximately constant was selected. During this period, the average nitrate (Figure 60) and chloride (Figure 50) concentration in Floridan monitor well 7F-1 was 4.17 and 40 mg/l respectively. The average nitrate and chloride concentration in surficial monitor well 7-01 was 7.44 and 77.7 mg/l respectively; in 7-02, the concentration was 7.51 and 80.6 mg/l; in 7-03, the concentration was 7.66 and 80.2 mg/l; in 7-04, the concentration was 7.58 and 80.7 mg/l; in 7-05, the concentration was 7.62 and 71.9 mg/l; in 7-06, the concentration was 8.08 and 78.6 mg/l; in 7-07, the concentration was 8.03 and 78.3 mg/l; and in 7-08, the concentration was 7.29 and 79.5 mg/l (Figures 60 and 50 respectively).

Because there is no increasing trend in nitrate concentration in 7F-1, dc/dt in equation (1) for RIB Site 7 is 0. Substituting 0 for dc/dt in equation (1) and solving for Q_{in} yields:

$$Q_{in} = (c/\ c_{in})\ Q_{out} \tag{4}$$

One reason why there is no trend in water quality in the Floridan monitor well (7F-1) at RIB Site 7 may be because 7F-1 is a pumped irrigation well, and any trends would have been obscured by mixing of water within the Floridan aquifer.

An estimate of the fraction recharging the Floridan aquifer can be obtained by dividing the average nitrate and chloride concentration in 7F-1 by the respective average concentrations in the surficial monitor wells. Those fractions are 0.52 to 0.57 for nitrate and 0.50 to 0.56 for chloride.

Like nitrate, there is no trend in measured TTHM concentrations in the Floridan monitor well (7F-1) at RIB Site 7 (Figure 74). The average measured TTHM concentration in 7F-1 is 0.00883 mg/l. Measured concentrations in the surficial aquifer monitor wells are very variable and average concentrations differ by as much as 0.035 mg/l. Because of this difference, the average THM concentration in each surficial aquifer monitor well at RIB Site 7 is used for c_{in} in equation (4). Substituting the above average TTHM concentration in the Floridan monitor well and the average TTHM concentration in each surficial aquifer monitor well at RIB Site 7, yields fractions ranging from 0.15 to 0.36.

These lower fractions compared to nitrate and chloride are probably due to the variability in the measured TTHM concentrations. The above fractions are the minimum estimate of reclaimed recharge to the Floridan aquifer at RIB Site 7. In fact, because 7F-1 was an irrigation well, the fractions are probably much greater.

At both RIB Sites 5 and 7 nitrate is present in the Floridan monitor wells almost immediately after the commencement of the application of reclaimed water. This suggests that there is little to no delay in the travel time for water to move vertically from the surficial aquifer to the Floridan aquifer at both sites.

COMPARISON OF RECHARGE ESTIMATES CALCULATED FROM HYDROGEOLOGIC DATA AND WATER QUALITY

The previously described minimum fractions of reclaimed water recharging the Floridan aquifer at RIB Sites 5 and 7 are based on water quality. Earlier in this report, Merritt calculated estimates based on hydrogeologic data (i.e. water levels both the surficial and Floridan aquifer, and leakance values for the Upper Confining unit). There is some uncertainty in the actual leakance value for RIB Sites 5 and 7. Because of this uncertainty, Merritt calculated fractions of from 0.172 to 0.860 of reclaimed water recharging the Floridan aquifer at RIB Site 5, and from 0.74 to 1.00 at RIB Site 7. These estimates are consistent with the fractions calculated from water quality, especially since the water quality fractions are minimum estimates.

The difference in the minimum fraction of reclaimed water that was estimated to recharge the Floridan aquifer at RIB Sites 5 and 7 is supported by the difference in the calibrated leakance of the intermediate confining unit (O'Reilly, 1998). RIB Site 7 has a calibrated leakance that is 10 to 50 times higher than that for RIB Site 5.

CONCLUSIONS

In the Water Conserv II area of Orange County, reclaimed water is used to recharge the shallow subsurface by discharges to rapid infiltration basins (RIBs). It was the purpose of this paper to determine whether this recharge of the shallow subsurface with reclaimed water has increased the volume of recharge to the Upper Floridan aquifer. The conclusions reached in this study are as follows.

- By the end of 2002, 3.004×10^{10} gal of reclaimed water had been discharged to RIB site 7, 2.035×10^{10} gal had been discharge to RIB site 6, and 1.436×10^{10} gal had been discharged to RIB site 5. Volumes discharged to other RIB sites were small compared to these volumes.
- It appears that the predominant influence on lake stages is the accumulation of rainfall. While the RIB discharges might have affected lake stages by influencing heads in the Upper Floridan aquifer, the lake stage data do not show readily evident influences from RIB discharges.
- A number of staff gages were used to measure the stages of bodies of water that accumulate in shallow closed depressions near the RIB sites. Stages generally have been measured only during the 1994–99 period, so that they cannot easily be used in conjunction with water level data from monitor wells. However, the stage data from the staff gages is comparable to water level data from monitor wells in showing the influence of RIB discharges. Stages from some staff gages near RIB sites 5 and 7 are appreciably higher than predischarge water table altitudes, and show strong increases in responses to discharges. However, there is no cumulative effect, and stages have decreased strongly during the recent drought years (1998–2002).
- A study of the mounding of the water table near monitor wells and piezometers at RIB sites 5 and 7 was made to assess the mechanisms of removal of volumes of water equivalent to the large volumes of reclaimed water disposed at the sites. Though off-site data describing water table changes were limited, estimates were made of the area hydraulically affected by RIB site discharges. Using estimates of the leakance of the confining zone separating the surficial aquifer and Upper Floridan aquifer derived by previous modeling studies, it was possible to estimate the additional volume of water leaking downward to the Upper Floridan aquifer as a consequence of the RIB cell discharges. Estimates of the additional leakage were comparable to the total volume of discharge,

helping to validate leakance estimates previously used in model studies. The rate of lateral outflow from the water table mound in the surficial aquifer diminished to zero at the assumed boundary of hydraulic influence. Because water levels approached land surface at some well locations, it was inferred that some additional evapotranspiration was caused by the RIB discharges.

- Although the area of hydraulic influence from RIB site 7 is estimated to reach Lakes Ingram and Hancock, the water table increase at those locations would be small. Although some additional water would seep into the lakes, when the additional volumes are averaged over the areas of the lakes, the increases in lake stages would probably be negligible.
- It has been observed in 2002-2003 that stages in lakes to the south and west of the RIB sites have reached high levels (SJRWMD, pers. comm. 2002). However, because the hydraulic influence of the recharge to the RIB sites occurs only for a limited distance in the surficial aquifer, it is unlikely that the RIB recharge could be influencing the lake stages. If lake stages occurring after the drought years of 2000–2002 are actually higher than those of the wet years 1994–98 or of earlier wet periods, a possible explanation could be a change of the pattern or quantity of runoff resulting from increased urbanization (Tibbals 1978).
- A method was developed to evaluate the water quality sample data collected from monitor wells in the Upper Floridan aquifer to determine whether traces of the reclaimed water were present, thereby providing a qualitative estimate of the magnitude of downward leakage to the Upper Floridan aquifer. The tracers used were chloride, nitrate nitrogen, phosphorus, and total trihalomethanes. Even though background concentrations of nitrate nitrogen may be as high as 6 mg/l in the Upper Floridan aquifer beneath areas where nitrogen fertilizers have been used for agricultural purposes, the first water quality samples collected after the application of reclaimed water had nitrate nitrogen concentrations below about 2 mg/l. Natural, background concentrations of chloride were low everywhere, including in the vicinity of agricultural activity. Total trihalomethanes were assumed not to be present except in the reclaimed water. Phosphorus was likely to have precipitated or been absorbed before it could leak to the Upper Floridan aquifer.
- At RIB site 5, slow, steady increases of chloride, nitrate nitrogen, and total trihalomethanes indicated that leakage of reclaimed water has occurred, even though concentration levels of the first two remained below thresholds of natural variation. The slow rates of increase were consistent

with the estimated low leakance of the confining layer at RIB site 5. Because the ratio of total nitrogen to chloride measured in samples from the upper Floridan monitor well is higher than that of the reclaimed water, the possibility exists that the high nitrate levels measured at the well might have an alternative or additional cause other than the RIB site discharge. Recharge estimates based on water quality may be as low as about 3% of applied reclaimed water. For comparison, recharge estimates based on hydrogeology and leakance, range from 17 to 86% of the total reclaimed water applied. These observations probably indicate an off-site source of reclaimed water other than the water Conserv II RIBs.

- At RIB site 6, tracer concentrations in samples from one Upper Floridan monitor well in an area of low estimated confining-zone leakance remained at background levels through 2002. At two off-site pumped irrigation wells, however, concentrations of chloride and nitrate nitrogen were either high or showed increasing trends. Total trihalomethanes were high in samples from one of the wells. These observations were considered as evidence of the probable occurrence of downward leakage of reclaimed water in the vicinity of RIB site 6.
- At RIB site 7, chloride and nitrate nitrogen concentrations in Upper Floridan monitor well samples quickly rose from relatively low initial values and have remained high. Total trihalomethanes have also been present. The ratio of total nitrogen to chloride in samples from the Upper Floridan monitor well are similar to those in the reclaimed water and in samples from the surficial monitor wells. These observations are considered as indicating that downward leakage of reclaimed water has occurred, and the early rise in tracer concentrations is consistent with the estimated high leakance at this site. Recharge estimates based on water quality may be as low as about 52% of applied reclaimed water. For comparison, recharge estimates based on hydrogeology and leakance, range from 74 to 100% of the total reclaimed water applied.
- At RIB site 9, the total volume of discharged reclaimed water is small and occurred in three periods of several months each. Despite this, a rapidly increasing trend of chloride and nitrogen since 1998 in water samples from one Upper Floridan monitor well have been measured. Total nitrogen to chloride ratios at this well are similar to those of the reclaimed water. Total trihalomethanes have also been detected. These observations probably indicate an on-site source of reclaimed water other than the Water Conserv II RIBs or leakage from RIB site 8.

- Available data indicate that an approximate 3-ft mound occurs in the Upper Floridan aquifer beneath RIB site 5 and an approximate 4-ft mound occurs in the Upper Floridan aquifer beneath RIB site 7. This would tend to increase leakage rate estimates, by a small percentage at RIB site 5 and by as much as 200% at RIB site 7.

RECOMMENDATIONS

For the purposes of enhancing research and analysis of the hydraulics and water quality characteristics of RIB site operation, the following modifications to the data collection program would be helpful:

- Either total trihalomethanes or some other conservative tracer unique to the reclaimed water should be used as a tracer for the reclaimed water, and sampling for this tracer for adequate frequency should be made at observation wells and in the stream of reclaimed water.
- Water quality sampling should be initiated at least several months before discharge of reclaimed water begins at a new RIB site.
- Water level measurements should begin at least several months before reclaimed water discharges begin at a new RIB site.
- Piezometers for measuring water levels should be place off-site, at available locations up to a distance of two or three times the site dimension, in order to define the extent of the hydraulic influence of the discharges.
- More Upper Floridan monitor wells might be needed, particularly at RIB site 6, where the existing well is poorly located. Water-quality sampling should resume at off-site wells when and where they are available. Hydraulically up-gradient wells in the Upper Floridan aquifer should also be used for water quality sampling to establish background conditions for comparison with samples from downgradient wells.
- Better estimates of reclaimed recharge to the Floridan aquifer could be obtained from Floridan monitor wells that just penetrate the aquifer and have small (1–5 ft) open hole intervals. In such wells, the reclaimed water recharge water quality would undergo minimum dilution.

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