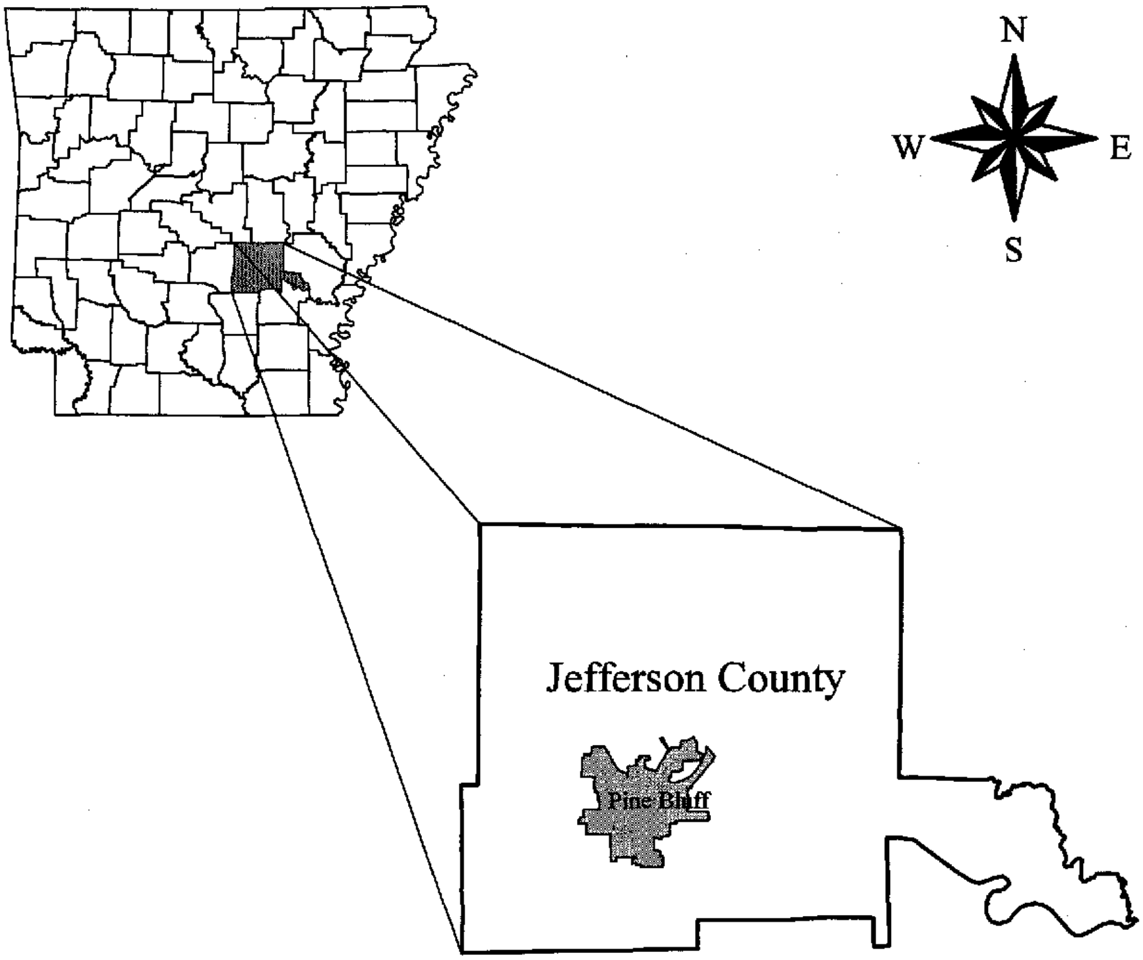
Ground-Water Resources and Water Quality in the Vicinity of Pine Bluff Municipal Area Jefferson County, Arkansas



Arkansas Ambient Ground-Water Monitoring Program

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INTRODUCTION

The Arkansas Department of Environmental Quality (Department) established the Arkansas Ambient Ground Water Monitoring Program in 1985. The objective of the program was to gather background ground-water quality data from fresh-water aquifers in various areas of the state. In addition to gathering background data, the Department also placed a priority on areas of specific interest, including communities with a large dependence on ground water, communities in a large industrial setting, and agricultural communities. Because each setting is unique with a specific set of potential contaminants, a different set of parameters are analyzed within each monitoring area, and the list of analytes may include nutrients, trace metals, and semi-volatile and volatile organic compounds. Each monitoring area is sampled every three years in order to establish trends in ground-water quality data, which assists the Department in evaluating changes in water quality as a result of growing use and anthropogenic impacts.

The City of Pine Bluff, one of the largest communities within the state using ground water to meet practically all of its needs, was selected for one of ten statewide monitoring areas. In addition, a large cone of depression developed in the Sparta Aquifer as a result of large industrial use in the Pine Bluff area, and monitoring was deemed necessary to detect potential changes in water quality from growing use. Both municipal supply and industrial use in Pine Bluff is entirely dependent on ground water, of which 82% of this ground water is derived from the Sparta Formation (Terry, 1995). Jefferson County is the largest user of the Sparta Aquifer in the State, with the majority of this use in the area of Pine Bluff. In addition to being #1 in use of ground water derived from the Sparta aquifer, Jefferson County ranks 6th in the State for total ground water consumption, based in part on consumption of Sparta ground water by municipal and industrial use and a large consumption of Alluvial ground water to support agricultural needs.

Monitoring in the Pine Bluff area began in December 1987, with subsequent sampling events in December 1990, June 1994, and the most recent sampling in September 1997. The original sampling event consisted of a total of nine wells, seven of which were completed in the Sparta Aquifer, one in the alluvial aquifer, and one in the Cockfield Aquifer. The monitoring program was expanded in 1994 and included eight wells in the Sparta Aquifer, three wells in the Alluvial Aquifer, and one well in the Cockfield Aquifer. This level of monitoring has continued into the most recent sampling event. The program is currently under review to include additional wells in both the Alluvial and Cockfield Aquifers for future sampling events.

SITE CHARACTERISTICS

GEOLOGY

Pine Bluff is located in the south-central portion of Jefferson County, approximately 42 miles south of Little Rock. Geographically, Pine Bluff lies in the Gulf Coastal Plain of Arkansas, where the surface geology consists of clay, silt, sand and gravel of Quaternary age. Outcrops of Tertiary-aged silts and clays of the Jackson Group occur to the west and northwest of Pine Bluff.

The subsurface geology in and near the Pine Bluff area is dominated by unconsolidated rocks of Quaternary and Tertiary age. The thickness of these unconsolidated sediments is greater than 2,000 feet in and around Pine Bluff. However, the only productive zones in terms of fresh ground water are located in the Claiborne Group and younger sediments. A generalized geologic column for Jefferson County is displayed in Table 1. Because the Sparta Formation (lower Claiborne), upper Claiborne Group and Jackson Group (undifferentiated), and the Quaternary Alluvium are the only water-supply production zones in Pine Bluff (and Jefferson County), a brief geological description is provided for these units only in the following paragraphs.

The Sparta Formation consists of white to light-grey, fine to medium-grained massive sands interspersed with beds of clay and sandy clay, which are generally of continental origin. In Jefferson County, the Sparta ranges in thickness from about 450 to 800 feet. In the vicinity of Pine Bluff, the Sparta is approximately 600-650 feet thick and is encountered at a depth of about 470 below sea level (Klein, et al., 1950). The percentage of sand in the Sparta Formation varies from approximately 60-100 percent in and around the Pine Bluff area (Terry, et al., 1979).

The portion of the Claiborne group which lies above the Sparta Formation consists of the Cook Mountain and the Cockfield Formations. The Cook Mountain Formation is typically about 100-150 feet thick and composed dominantly of clay, lignite and thin beds of sand up to a few feet thick (Terry, et al., 1979). Although a minor aquifer for domestic purposes in its outcrop area, the Cook Mountain Formation normally acts as a confining unit between the Sparta and Cockfield aquifer systems. The Cockfield Formation generally consists of fine to medium sand in the basal part, and silt, clay and lignite in the upper part (Hosman, et al., 1968) and contains between 60-80 % sand in the project area (Terry, et al., 1979). However, the sand beds are discontinuous and the Cockfield Formation contains considerable clay throughout Jefferson County. Because of the clay content and the fact that the Cook Mountain contains lenses of sand, it is difficult to determine formation boundaries by the type of material. Also, the upper part of the Cockfield Formation is difficult to distinguish from the overlying Jackson Group because of the same problem in differentiating the clays, silts and sands of one unit from the other. Klein et al. (1950) refers to all of the units as simply the upper Claiborne group and Jackson Group undifferentiated. Terry et al. (1979) lists analyses of water from the Cockfield Formation in Jefferson County and cites Klein et al.(1950) as the source, although Klein et al. (1950) only provide analyses for the Eocene Undifferentiated. Although it is possible that wells drilled into the undifferentiated Eocene deposits derive some water from both the Jackson and/or Cook Mountain Formation, the thicker sand deposits (20 feet or greater) that supply most of the water are most likely in the Cockfield. As such, this report cites all wells below the Quaternary alluvium and above the Sparta Formation as being completed in the Cockfield Formation.

The upper aquifer system in the project area and in Jefferson County is situated in deposits of Quaternary age. The Quaternary deposits consist of Pleistocene terrace and Recent alluvial deposits, which will simply be referred to as the Quaternary deposits. These deposits, which average approximately 150 feet in thickness in the project area, are generally divided into three zones: the basal zone, consisting of sand with layers of coarse sand and gravel; the intermediate zone, consisting of medium and fine sand; and the upper zone, consisting of silt and clay.

Table 1. Generalized geologic column and water-bearing properties for strata of Jefferson County

(Figures show thickness in feet)

Era	System	Series	Group	Formation	Character and water-bearing properties
Cenozoic 2,000 to 3,750	Quaternary 0 to 250	Recent		Alluvium	Generally silt and clay in the upper part; sand and gravel with some silt and clay in lower part; sand and gravel in the lower part yield water freely to wells
		Pleistocene		Terrace Deposits ---Unconformity---	
	Tertiary 2,000 to 3,500	Eocene 1,550 to 3,000		Jackson Formation and upper Claiborne Group (undifferentiated) 300 to 800	Chiefly fine to medium sand, sandy clay and clay in alternating beds and lenses; some lignite and glauconite; sand layers and lenses yield water to small-capacity wells
			Claiborne	Sparta Sand 450 to 800	Massive light-colored fine and medium-grained sand with some clay and sandy clay; yields water freely to wells
				Cane River Formation 150 to 400	Clay, sandy clay, and sand with some lignite and glauconite; probably does not yield water to wells.
				Wilcox Formation 650 to 1,200	Sand, sandy clay, and clay with lignite and glauconite; water generally appears to be salty but in places some sands in the upper part may contain fresh water.
		Paleocene		Midway Formation 460 to 500 ---Unconformity—	Gray and bluish-gray compact clay; calcareous in the lower part; does not yield water to wells.
Mesozoic	Cretaceous	Gulf			Calcareous and glauconitic sand and sandstone with thin beds of shale and limestone; does not yield potable water.
Paleozoic				---Unconformity—	Consolidated and folded beds of sandstone and shale.

Adapted from Klein et al. (1950)

SUBSURFACE HYDROLOGY

There are three aquifer systems in use in the project area and throughout Jefferson County. These are the Sparta, Cockfield and Alluvial aquifer systems. The Sparta and Alluvial aquifer systems supply most of the water used for municipal, industrial and agricultural supply. The Cockfield is primarily used for domestic purposes, and with the growth of municipal water supply systems, operational domestic wells in the Cockfield are few in number.

In the project area, wells sampled from the Sparta Aquifer ranged in depth from approximately 790-1275 feet below the ground surface. Klein et al. (1950) speculate that there are two to three zones in the Sparta aquifer that yield water to wells. The upper sands are more massive and reach thicknesses of 200 feet in places. These sands appear to contain fresh water throughout Jefferson County; however, the lower sands may contain saline water in places (Klein et al., 1950). Sources of recharge to the Sparta are precipitation on the outcrop, leakage from overlying alluvium, and underflow from the Memphis aquifer. The Sparta is a very productive aquifer and large capacity wells yield from a few hundred to more than 2,000 gpm (Hosman et al., 1968). Movement of water is generally southeast, but in and around the project area the flow has changed in response to the large cone of depression developed by heavy use of the aquifer for industrial and municipal purposes In the project area, the Sparta is used for municipal and industrial supply.

Throughout eastern Arkansas the Cockfield is used for domestic, industrial and municipal supply, although the dominant use is for domestic purposes. In the project area, the Cockfield is used solely for domestic purposes. Reports on water use in Arkansas do not cite any production numbers for the Cockfield in Jefferson County after 1985 (Holland, 1987; Holland, 1993). Early production numbers were dominantly from small municipal supplies, and as new wells were drilled, these were completed in the deeper Sparta Aquifer (Terry Holland, personal communication, 1998). However, the water quality in the Cockfield is suitable for all uses and it remains an important water source for present and future needs. Average reported yields in Jefferson County are 5 gpm, although one well had a reported yield of 350 gpm. In the project area, moderate amounts of ground water can be obtained from the Cockfield at depths ranging from 150 - 350 feet, and reported well depths range from approximately 150 - 470 feet below the surface of the land (Klein, et al., 1950). Recharge to the Cockfield is from precipitation on the outcrop and leakage from the Alluvial aquifer, where it overlies the Cockfield (Hosman et al., 1968). Only one well was sampled from the Cockfield for the present study.

The uppermost aquifer system, the Alluvial Aquifer, is situated in the Quaternary deposits; no younger sediments or formations overlie these deposits. These deposits range in thickness from 0 to 250 feet. The productive ground-water zone is located in the sand and gravel deposits in the middle and lower part of the deposits. This aquifer is extensively used in Jefferson County primarily for irrigation. Reported yields in and around the project area average approximately 1,500 gpm, although one well had a reported yield of 3000 gpm (Klein et al., 1950). This well was completed at a depth of 165 feet. Measured depth to water from land surface was as shallow as 7-8 feet in the project area in 1949, with many depths reported at and above a depth of 10 feet. Primarily due to the large growth in rice production beginning in the early and mid-seventies, the Alluvial Aquifer has at the present time become the primary source of ground water in Jefferson County.

HISTORY OF GROUND-WATER USE

One of the primary reasons for the induction of the Pine Bluff area into the monitoring program was the fact that Jefferson County is the largest user of the Sparta Aquifer in the state. As a result of the large dependence on this aquifer, a large cone of depression has developed in the project area and water levels in the Sparta Aquifer dropped over 200 feet from 1955 through 1987 (Kilpatrick and Ludwig, 1990). In addition to the large use of the Sparta for industrial and municipal supply, the dependence on the Alluvial Aquifer has grown in concert with increased use of this aquifer for irrigation needs. It is useful, therefore, to review the historical and present use of these aquifers to understand the growing demand on ground-water resources in the project area and surrounding areas within Jefferson County.

Although shallow wells were in use for domestic and municipal purposes, the Sparta Aquifer was not developed until the turn of the century (Klein et al., 1950); the first well having been drilled in 1898 (U.S. Army, 1977). By 1948 the General Waterworks Corporation, which supplied water to the Pine Bluff municipal area, was pumping approximately 2.7 million gallons/day (mgd). In the project area, the only other large users were the Pine Bluff Arsenal (4.2 mgd) and the St. Louis Southwestern Railroad (0.6 mgd), for a combined total of 7.5 mgd (Klein et al., 1950). By 1948, it is estimated that water levels had dropped approximately 35 feet from the original pre-pumping potentiometric surface in the Pine Bluff area (Bedinger et al., 1960). Municipal water use steadily, but moderately, climbed to a present usage of approximately 11 mgd. However, in the late 1950's, two large paper mills located in the area and began withdrawing large amounts of water from the Sparta (U.S. Army, 1977). In 1958, the total pumpage reported from the Sparta was 37.15 mgd, with municipal use only increasing from 2.7 to 3.6 mgd from 1948 to 1958. The remaining portion was dominantly the result of pumping for both International Paper Company and Dierks Paper Mill. The effects of the increased pumping was demonstrated by Bedinger et al. (1960) in the comparison of drawdown in two wells within the project area. One well declined 14 feet from June 1949 to May 1958, but declined an additional 43 feet from May 1958 to July 1959. Another well declined 115 feet from April 1958 to May 1959. Figure 1 depicts the production by major users from 1955 to 1995. After the large initial declines associated during the late 1950s, the total amount of withdrawal by industry increased at a more moderate pace to the present time, especially in consideration of the rapid change from the production prior to the late 1950s to the start-up of the paper mills.

Figure 2 displays the cone of depression developed from water-level measurements made in 1997. Using an approximate elevation of 180 feet above mean sea level (msl) for the pre-pumping potentiometric surface in the project area and the lowest value of head (-71 msl) listed in Joseph (1998), water levels have dropped approximately 250 feet since development of the Sparta Aquifer in the project area. However, this decline has not been steady as demonstrated by the large initial decline between 1958 and 1959. Water levels in conjunction with water use have fluctuated over the years, with some years showing increases. Figure 3 depicts a hydrograph over a 40 year period from water levels in a well within the project area. The hydrograph shows the reverse pattern observed in Figure 1, and demonstrates that during periods of declines in use (1980-1985), there was a rise in the water level as depicted in Figure 3. Conversely, there are decreases in the water level during periods of increased production from the Sparta within Jefferson County.

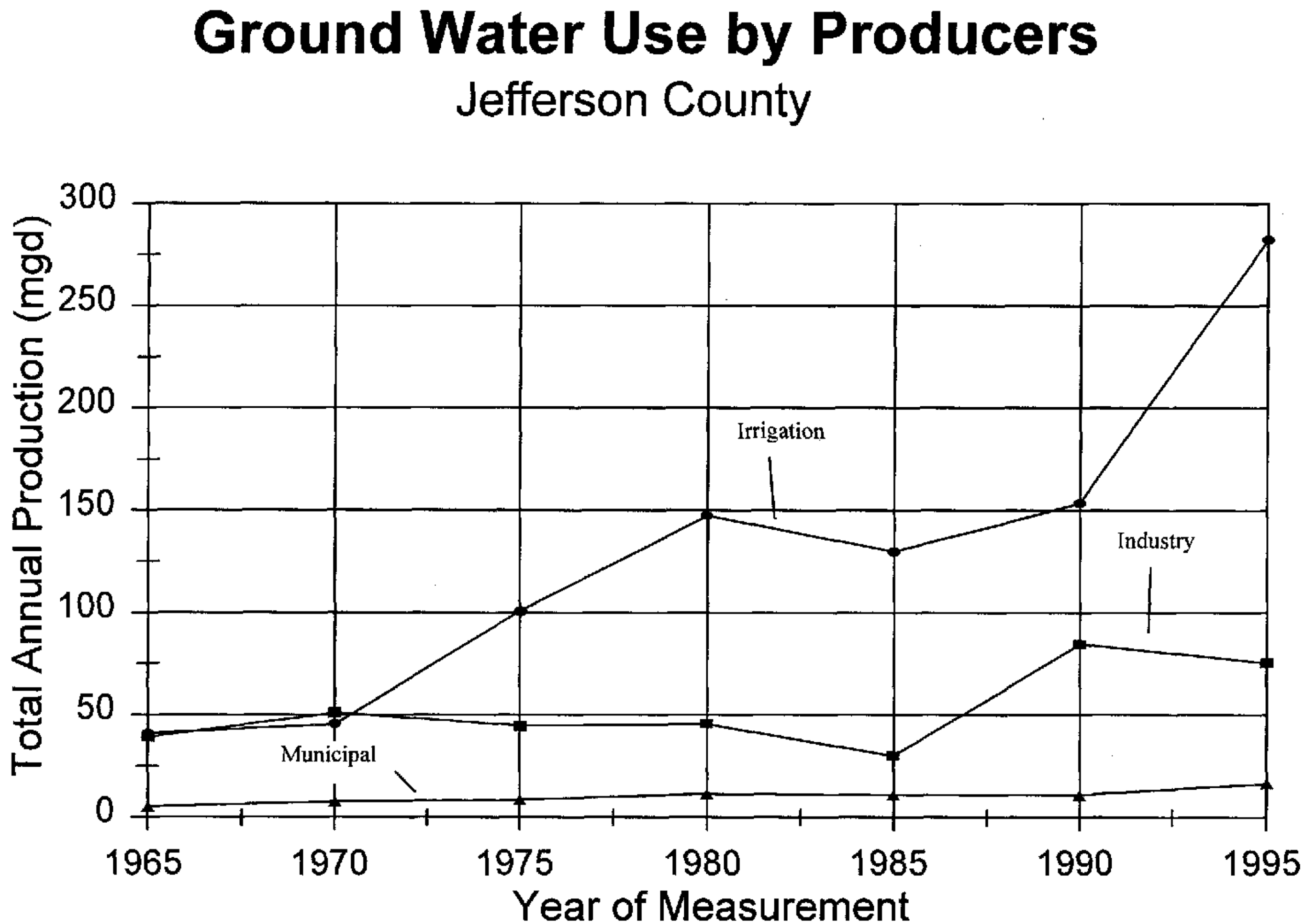


Figure 1. Total ground-water production in millions of gallons per day for major producers in Jefferson County.

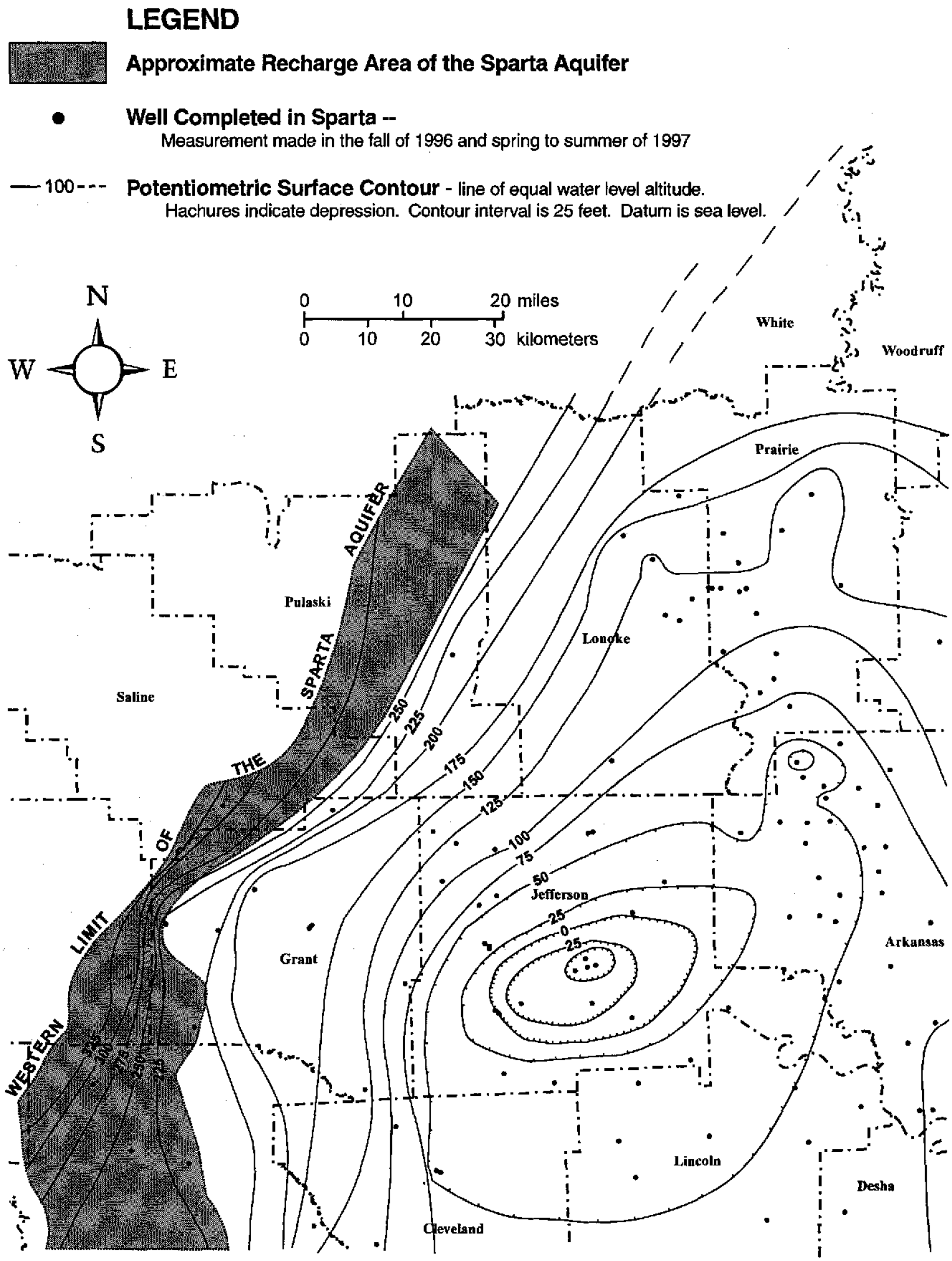


Figure 2. Potentiometric surface of the Sparta Aquifer in eastern and south-central Arkansas (Adapted from Joseph, 1998).

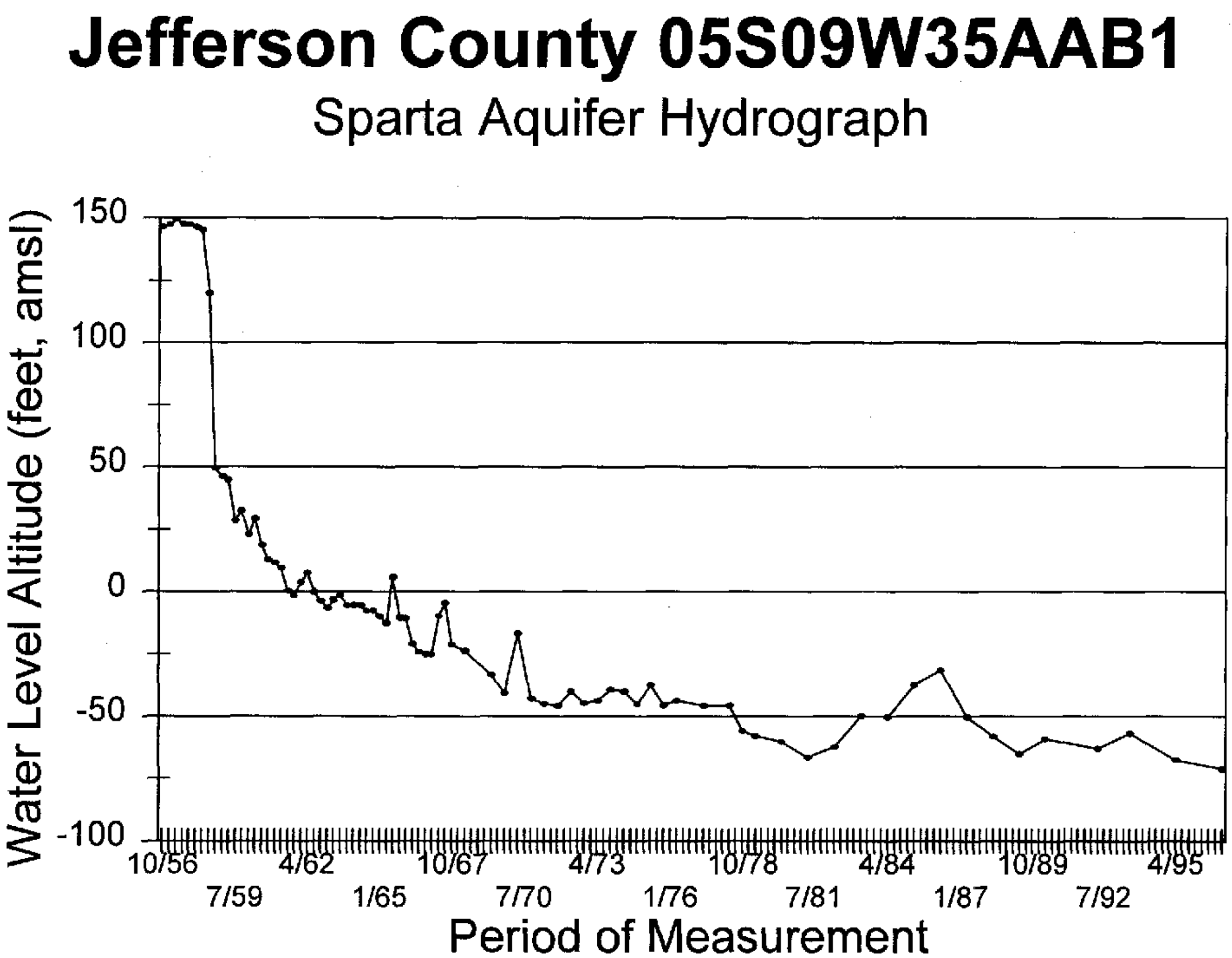


Figure 3. Hydrograph of water level versus time for well in Sparta Formation in project area.

Until the period between 1970 and 1975, the Sparta was the most important aquifer in Jefferson County in terms of total production, and remains the most productive and important source of ground water in the project area. However, as demonstrated in Figure 4, total usage from the Alluvial Aquifer in Jefferson County more than doubled from 51.6 mgd in 1970 to 106.8 mgd in 1975, making it the most heavily used aquifer in Jefferson County. Use of the Alluvial Aquifer continued to grow and total use from the Alluvial Aquifer in 1995 was approximately 265 mgd. Similarities are noted between the general shape of the irrigation curve (Figure 1) to the Alluvial use curve in Figure 4. Similarities also exist between the shape and values for the combined municipal and industrial usage curves (Figure 1) to that of the Sparta usage curve in Figure 4. These graphs alone strongly denote agricultural use of the Alluvial Aquifer as the reason for the rise in development of this aquifer. Figure 5 further demonstrates that both the increase in irrigation and pumpage from the Alluvial Aquifer was directly tied to the production of rice in Jefferson County.

Difficulties arise when attempting to assess patterns of use associated with the Cockfield Aquifer system. Early reports list production values ranging from 0.17 to 0.31 mgd from 1965 to 1980. These values, when compared to ranges in production from both the Sparta (42.4 to 78.5 mgd) and the Alluvial Aquifer (42.0 to 174.7 mgd), demonstrate that the Cockfield is of far lesser importance in terms of usage than the Sparta and Alluvial aquifers. Production values for the Cockfield were no longer provided for water use reports beginning in 1985 and subsequent years, although many wells are still in use for domestic purposes. This lack of reporting is mainly due to the difficulty in finding operational wells as a result of municipalities drilling deeper replacement wells over time and lack of obtaining reliable data on domestic use. It is sufficient to state that present production values have probably declined from the 1980 value of 0.23 mgd as a result of the changes in use.

METHODOLOGY

As stated above, the inclusion of the Pine Bluff municipal area in the monitoring program was its prominence as the largest city dependent on ground water for all of its needs, and the development of a large cone of depression in the Sparta Aquifer in the project area as a result of large industrial and municipal use. As a result, most of the wells sampled for this study are competed in the Sparta Aquifer. For the present sampling period, seven wells were sampled from the Sparta Aquifer. In addition, three samples were taken from wells completed in the Alluvial Aquifer and one from the Cockfield Aquifer. Because the Alluvial Aquifer is the shallow-most aquifer in the project area and the fact that the project area is in an industrial setting, the Alluvial Aquifer is more vulnerable to impacts from surface activities. The sample from the Cockfield Aquifer provides both water quality data for this aquifer system and assists in determining potential interconnections from the overlying Alluvial Aquifer and underlying Sparta Aquifer. Figure 6 depicts the location of all the wells sampled for this period and past sampling events.

Sampling sites were originally located within the Pine Bluff municipal area and north to northwest of the city. In 1994 two additional wells were located to the east of the city, closer to the center of the cone of depression to better monitor changes in water quality as a result of reversal of flow downgradient toward the center of the cone. The three alluvial wells were chosen according to a random grid in the municipal area.

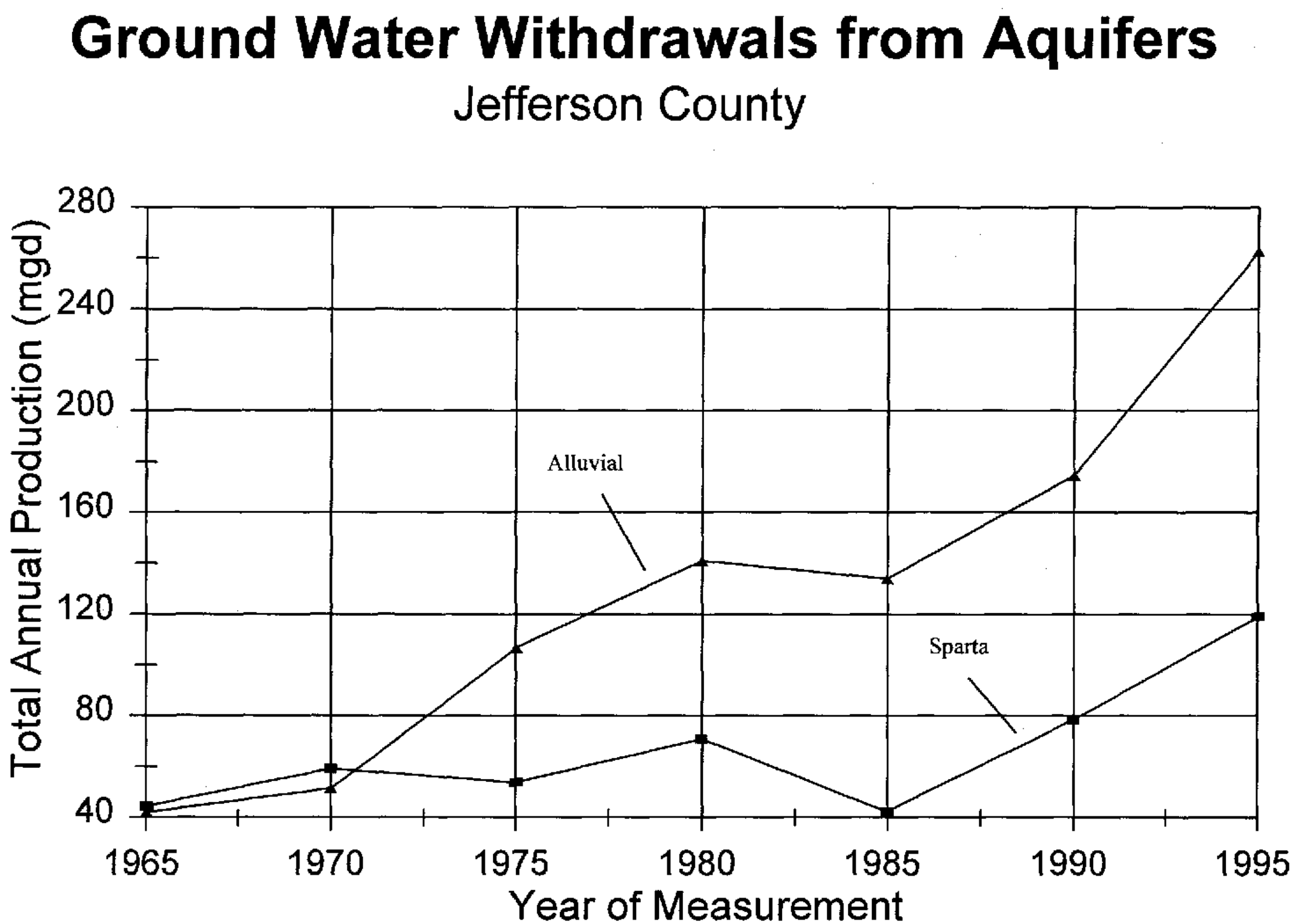


Figure 4. Annual production in millions of gallons per day for the Alluvial and Sparta aquifers. Figures compiled every five years. Data taken from following sources: Holland, 1999; Holland, 1993; Holland, 1987; Holland and Ludwig, 1981; Halberg, 1977; Halberg, 1972; and Halberg and Stephens, 1966.

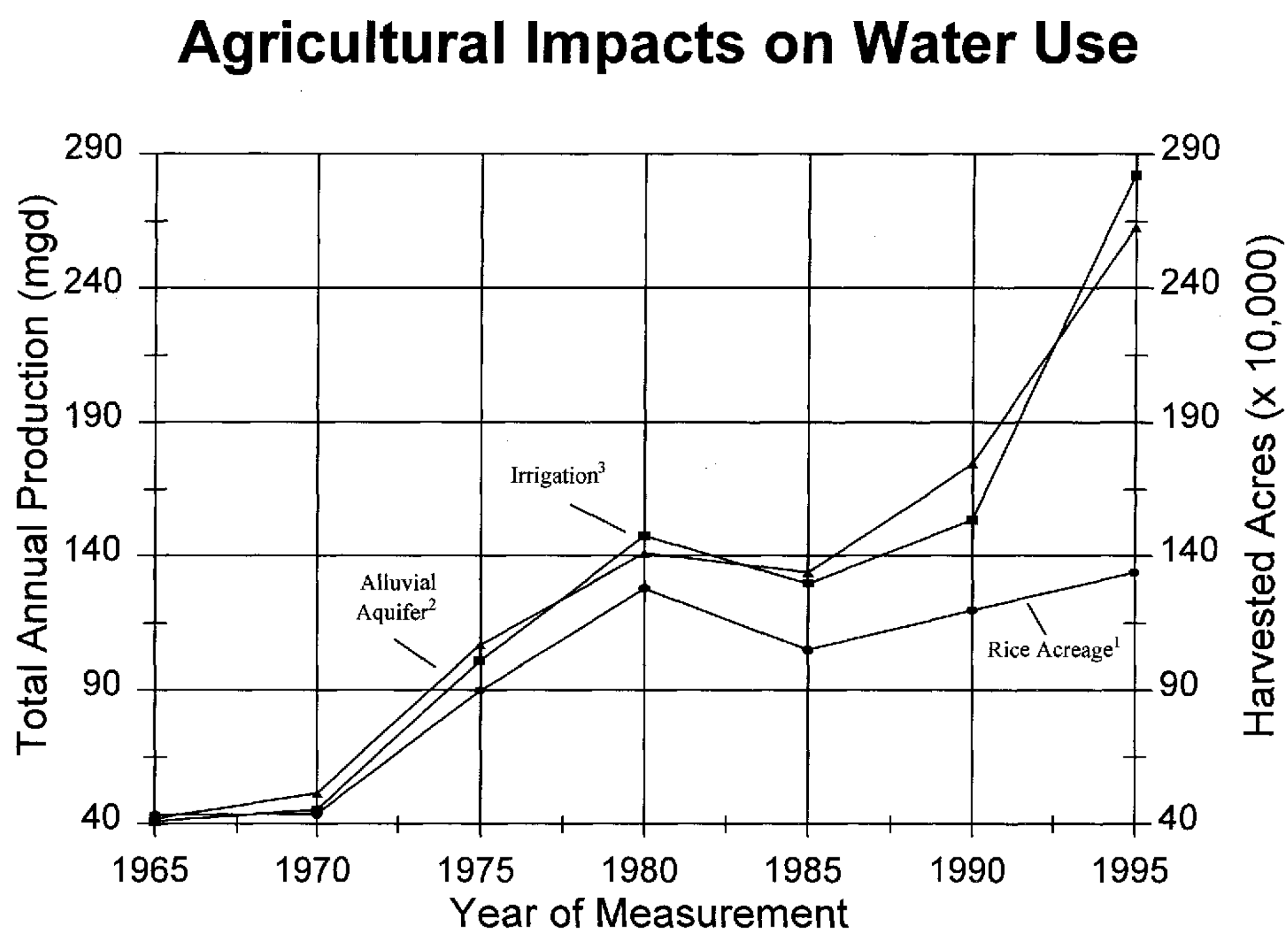


Figure 5. Graph showing the relationship of production from the Alluvial Aquifer to usage for irrigation and rice production. [1]Production of rice is for entire state and is graphed by harvested acres x 10,000 for purpose of comparison and best fit. Production from the [2]Alluvial Aquifer and for purposes of [3]Irrigation are listed in millions of gallons per day.

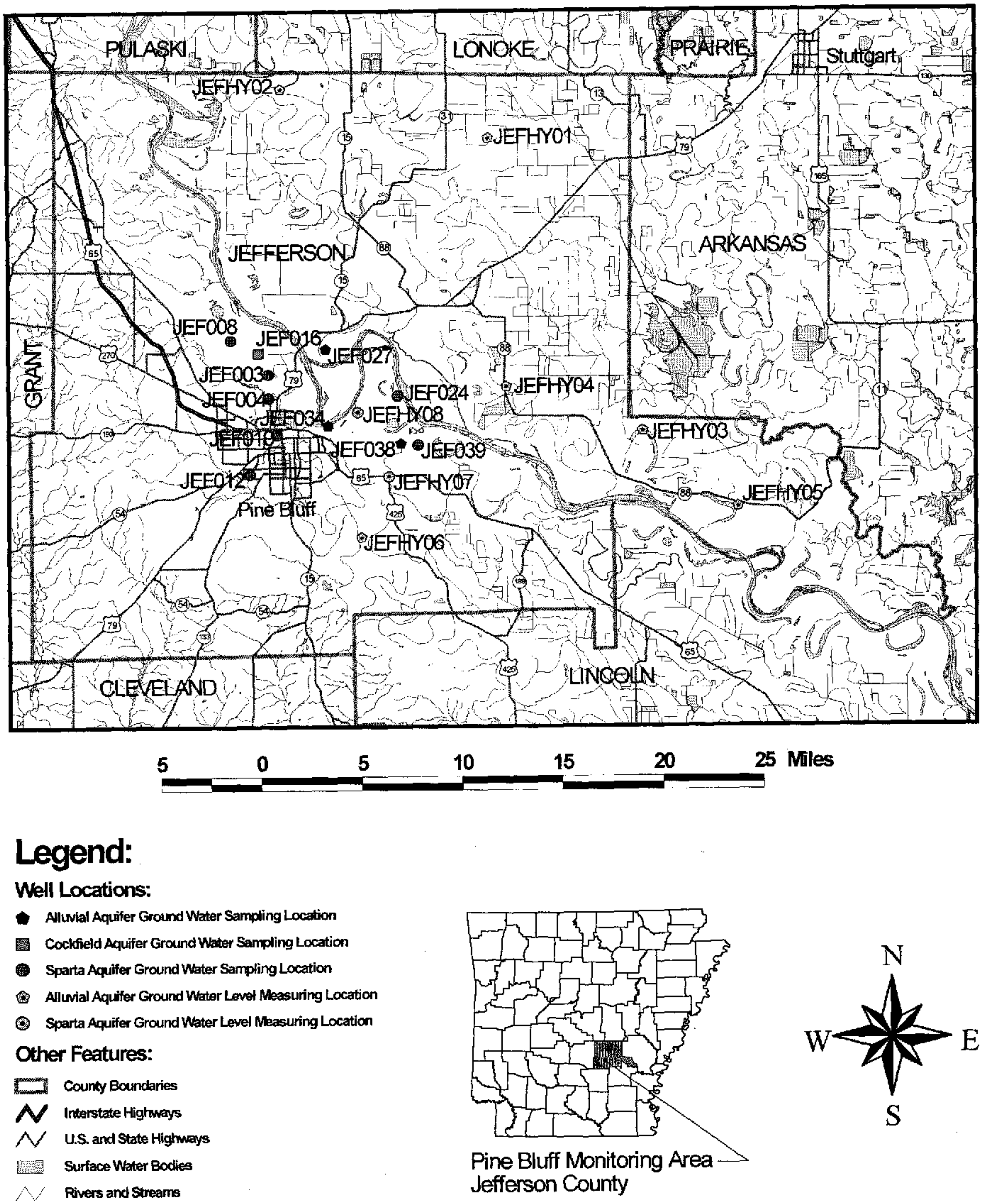


Figure 6. Pine Bluff monitoring area sampling locations

The wells were sampled on February 9, 1997. All wells were sampled as near to the wellhead as possible through available faucets. Each well was allowed to run for a minimum of ten minutes until field-measured parameters had stabilized prior to sampling. All samples were collected in approved containers for the selected parameters. Samples were filtered through disposable 0.45 μm pore-sized membrane in the field for metal analyses and preserved with nitric acid. All other samples were unfiltered samples, stored on ice, and delivered to the Department laboratory under chain-of-custody requirements by the sampling team.

All samples were analyzed for major and minor cations, major and minor anions, and trace metals. Samples from the Alluvial and Cockfield aquifers were also analyzed for volatile organics. Analyses for pH, conductance and temperature were performed in the field at the time of sampling. The analyses are represented in the report by a numbering system, which is prefaced by an abbreviation for the county (Jefferson), followed by the number of the well.

WATER QUALITY ANALYSES

Interpretation of water-quality analyses was performed by evaluating general water quality, detection of volatile organics, and geochemistry including graphical and statistical methods. Individual parameters were compared to federal drinking water standards to evaluate the general water quality for use as a drinking water source. The analyses were also compared to historic data to detect changes in water quality over time. No volatile organic compounds were detected in any of the samples analyzed for these compounds. Results of all analyses including laboratory QA/QC, represented by duplicate and spike analyses, are located in Appendix I.

GENERAL WATER QUALITY

In general, the water quality from all three aquifers is acceptable for most uses. The water from both the Sparta and Cockfield aquifers is a sodium-bicarbonate type water. Sodium accounted for over 50% of the total cations in all eight wells and averaged 61% of the total cations. The remaining total was comprised of dominantly calcium and potassium with minor amounts of magnesium. Bicarbonate accounted for over 50% of the total anions for all well-water samples including the Alluvial aquifer samples, and averaged 87 % of the total anions. The remaining percentage was relatively evenly divided between chloride and sulfate ions, except for JEF038, an Alluvial Aquifer water sample, in which chloride equaled 131 mg/L and comprised 23 % of the total anions for the sample. The samples from the Alluvial Aquifer denote a calcium-carbonate type water. Calcium accounted for over 50% of the cations in all three samples and averaged 65 % of the total cations. The remaining total for the Alluvial Aquifer samples was dominantly comprised of magnesium and sodium cations with trace amounts of potassium.

The analyses demonstrate that all parameters are below primary and secondary drinking water standards except for iron and total dissolved solids (TDS). JEF038 has a TDS concentration of 829 mg/L, which exceeds the secondary maximum concentration level (MCL) of 500 mg/L TDS. The secondary MCL for iron (0.3 mg/L) was exceeded in all samples; however, both iron and TDS are secondary standards, which are unenforceable federal guidelines related primarily to aesthetic effects of drinking water.

Table 2 lists selected analyses for the major cations, anions, and TDS for each of the aquifer systems sampled for the present study. A cursory review of the data show differences in the quality of the water between all three aquifers. The TDS for the Sparta Aquifer ranges from 74 to 103 mg/L; the lowest TDS for any of the aquifers. Individual parameter concentrations varied only slightly for all of the parameters for the Sparta samples, demonstrating a very consistent water quality throughout the project area. The Sparta Aquifer also contained negligible magnesium concentrations, in stark contrast to the Alluvial and Cockfield aquifer samples. Analysis of the sample from the Cockfield differs from the Sparta results mainly in the elevated TDS value, and differs from the Alluvial results in that it, similar to the Sparta Aquifer, is a sodium-bicarbonate type water. Additionally, the sulfate concentration for the one Cockfield sample is elevated relative to both the Alluvial and Sparta aquifer samples. Analyses of Alluvial Aquifer samples can clearly be differentiated from either the Cockfield and/or Sparta analyses based on the water type; calcium-bicarbonate versus sodium-bicarbonate water type. Additionally, the Alluvial Aquifer water exhibits significantly higher calcium to bicarbonate ratios and lower calcium to magnesium ratios (see section entitled "Geochemistry of Project Area Ground Water").

COMPARISON TO HISTORICAL WATER QUALITY

Because of the changes in use documented above (see History of Ground Water Use), comparing present analyses to older data sets is useful for detection of long-term changes in water quality. Klein et al. (1950) provide water-quality analyses for all three aquifer systems in Jefferson County including many sites in the project area. In addition, because this is the fourth sampling of the Pine Bluff area, trends in water quality were analyzed over a 12 year period.

Tables 3 compares historical data to present analyses for the Sparta Aquifer. A review of Table 3 shows that mean and median values for the historical data compare very well to the values for the present study. Statistical comparisons (Appendix IV) reveal significant differences in both iron and magnesium, which can be attributed to changes in analytical technologies rather than to changes in water quality (Richard Thompson, personal communication,1998). However, TDS data offer a basic criterion of general water quality that is less subject to changing methodology and variation between sites, and indeed show excellent agreement between the two data sets. Other parameters, excluding chloride, which is basically very low in both data sets, also reveal no statistical differences between the data sets. In general, interpretation of the data supports a conceptual model in which water quality has not changed significantly in the past 50 years. This is especially noteworthy in view of the large use and the development of the cone of depression dating to the late 1950s.

Table 4 compares the analyses of the one sample from the Cockfield Aquifer (JEF016) to historical values from eight wells in and near the project area. Most all the parameters listed for JEF016 are within the range of values for the historical data. The sulfate concentration is slightly lower than the lowest value listed for the historical data; however, this supports the hypothesis that elevated sulfate concentrations assist in identifying water from the Cockfield solely by water chemistry. Terry et al. (1979) lists the Cockfield as a sodium-bicarbonate water type for the area of use in the Gulf Costal Plain Province. The analyses for JEF016, as mentioned above, is a sodium-bicarbonate water, which together with the elevated sulfate and reported depth, substantiates the well as being completed in and receiving water from the Cockfield Aquifer.

Table 2. Selected water-quality analyses for Pine Bluff monitoring area wells.

Well Number	Aquifer System	Fe mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SiO_2 mg/L	Cl mg/L	SO_4 mg/L	HCO_3 mg/L	TDS mg/L
JEF003	Sparta	2.37	4.8	0.03	4.3	13.0	15.6	2.57	3.82	32.9	74
JEF004	Sparta	6.64	4.3	0.03	4.1	14.3	15.8	2.48	2.65	65.9	81
JEF008	Sparta	2.80	6.1	0.03	4.2	10.9	14.1	2.25	3.09	63.4	77
JEF010	Sparta	2.22	6.7	0.2	5.2	12.6	16.0	1.9	2.74	74.4	84
JEF012	Sparta	1.57	8.3	0.6	5.1	15.8	17.9	1.63	2.8	83.0	93
JEF024	Sparta	2.23	6.9	0.1	5.1	19.9	16.7	1.87	8.06	85.4	101
JEF039	Sparta	1.59	7.1	0.4	4.7	206	17.3	2.09	5.28	90.3	103
JEF016	Cockfield	1.17	16.1	3.7	4.4	85.2	34.5	16.4	31	247.7	318
JEF027	Alluvial	5.95	91.2	14.9	1.1	16.7	23.9	2.71	9.06	369.7	397
JEF034	Alluvial	11.8	75.9	11.9	1.2	11.9	28.5	13.5	17.6	345.2	342
JEF038	Alluvial	19.0	143	12.8	1.9	118.4	25.2	131	22.9	708.8	829

Table 3. Statistical analyses for selected parameters for wells in Sparta Formation

	Minimum		Maximum		Mean		Median	
	ADEQ[1]	USGS[2]	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS
Fe (mg/L)	1.57	0.170	6.64	14.00	2.77	2.41	2.23	1.60
Ca (mg/L)	4.3	4.9	8.3	11.0	6.3	7.0	6.7	7.0
Mg (mg/L)	0.03	1.6	0.6	3.3	0.2	2.1	0.1	2.1
K (mg/L)	4.1	1.9	5.2	7.2	4.7	4.1	4.7	3.8
Na (mg/L)	10.9	6.6	20.6	25	15.3	14.9	14.3	14.0
SiO_2 (mg/L)	14.1	12.0	17.9	20.0	16.2	14.4	16.0	14.0
Cl (mg/L)	1.6	2.5	2.6	5.5	2.1	3.7	2.1	3.8
SO_4 (mg/L)	2.6	0.6	8.1	10.0	4.0	5.1	3.1	4.6
HCO_3 (mg/L)	33	38	90	94	71	67	74	65
TDS (mg/L)	74	60	103	117	88	86	84	85

[1] Statistical analyses performed on seven samples taken in September, 1997 (ADEQ, present study)
[2] Statistical analyses performed on seventeen samples taken in various months in 1949 (Klein, et al., 1950)

Table 4. Statistical analyses for selected parameters for wells in Cockfield Formation

U.S. Geological Survey[1] - 8 wells in Cockfield Formation										
	TDS	Cl	SO_4	Ca	Fe	K	Mg	Na	HCO_3	SiO_2
Range	293-449	10-17	34-216	4.2-41	0.07-1.4	0.2-7.3	1.2-8.7	65-130	148-301	11-43
Mean	352	12	94	14	0.486	2.9	3.4	107	224	27
Median	328	12	78	11	0.462	2.8	2.1	116	228	24
Arkansas Department of Environmental Quality[2] - 1 well in Cockfield Formation										
Value	318	16.4	31	16	1.17	4.4	3.7	85.2	248	34.5

[1] Data from Terry et al., 1979 (1949 data)
[2] Data from ADEQ present study (1997 data)

Table 5. Statistical analyses for selected parameters for wells in Alluvial Aquifer

	Minimum		Maximum		Mean		Median	
	ADEQ[1]	USGS[2]	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS
Fe (mg/L)	5.95	0.43	19.0	13	12.3	7.7	11.8	5.3
Ca (mg/L)	75.9	8	143	162	103.4	61	91.2	43
Mg (mg/L)	11.9	2.3	14.9	39	13.2	18.9	12.8	17
K (mg/L)	1.1	0.2	1.9	6.6	1.4	2.3	1.2	1.9
Na (mg/L)	11.9	29	118.4	206	49.0	69.3	16.7	56
SiO_2 (mg/L)	23.9	11	28.5	53	25.9	35	25.2	43
Cl (mg/L)	2.71	20	131	100	49	64	13.5	74
SO_4 (mg/L)	9.06	6.5	22.9	294	16.1	77.8	17.6	30
HCO_3 (mg/L)	345.2	2.0	708.8	562	474	277	369.7	118
TDS (mg/L)	342	214	829	551	523	495	397	403

[1] Statistical analyses performed on three samples taken in September, 1997 (ADEQ, present study)
[2] Statistical analyses performed on seven samples taken in various months in 1949 (Klein, et al., 1950)

Table 5 compares the analyses of the three Alluvial Aquifer samples to historical data from 7 wells in Jefferson County sampled in 1949. The analyses demonstrate the large range of concentrations for various water-quality parameters. Specific statements cannot be made regarding fingerprinting of the Alluvial Aquifer based on water chemistry, except for the fact that the water type is dominantly calcium-bicarbonate. This may be the only consistent distinction between water derived from the alluvial aquifer and water derived from the Cockfield and Sparta aquifer systems.

The chloride concentration of 131 mg/L for JEF038 is higher than the maximum concentration listed for the historic data; however, isolated areas of elevated chloride concentrations are found in the Alluvial Aquifer throughout the Mississippi Embayment. Kresse et al. (1997) lists a chloride concentration of 184 mg/L for an alluvial well in Jefferson County. Currently, there is no one theory to explain the source for these elevated chlorides. The Arkansas River has historically exhibited chloride concentrations exceeding 1,000 mg/L and present-day concentrations can exceed 200 mg/L; however, there is no definitive pattern of contamination to isolate the river as anything more than a potential source. Although the one elevated chloride concentration noted for the present study is higher than any of the listed historic levels, caution must be exercised when interpreting trends in water quality based on individual analyses. In a separate study, Kresse et al. (1997) sampled 18 alluvial wells in Jefferson County as part of a nonpoint source investigation and compared the data to 32 alluvial well-water analyses from Klein et al. (1950). Except for iron and magnesium, all mean analyses were in close agreement. The mean TDS, similar to many of the individual parameters, was slightly lower for the 1997 data (395 mg/L) than for the historical data (417 mg/L). Mean chloride concentrations were 35 mg/L for the 1997 data set compared to 39 mg/L for the historical data.

The 1997 data were also compared to analyses from the previous three sampling events conducted 1987, 1990, and 1994. Appendix II lists all data collected to date for the Pine Bluff area. Because some of the wells sampled in 1987 are no longer in service and the new wells were added to the program in 1984, some wells have been sampled only two times since inception of the program. Only one well, JEF012, has been sampled on all four occasions. However, because there were a limited set of parameters analyzed during the first two sampling events, trend analyses is still limited to two events for most of the parameters for this well. No detectable trends are evident from review of the data. Two of the wells, JEF019 and JEF038, exhibit elevated chloride concentrations, with increasing concentrations over the respective sampling periods. Scheduled sampling in 2000 should provide more information concerning possible trends for these wells.

In summary, the analyses of the water samples taken for the present study indicate that the water quality of the Sparta, Cockfield and Alluvial aquifer systems is acceptable for most all uses. The Cockfield and Sparta aquifers yield a sodium-bicarbonate type water; whereas, the Alluvial Aquifer produces a calcium-bicarbonate type water. Elevated chlorides are present in the Alluvial Aquifer in isolated areas and may be related to the influence of the Arkansas River, although no study has thoroughly investigated sources for the isolated chloride concentrations. Water analyses for the present study compare well to analyses from other studies in the general area. Comparison of the analyses of the Sparta aquifer for the present study to analyses presented in Klein et al. (1950) demonstrate that water quality has remained virtually unchanged in the last 50 years. This finding is encouraging based on historical and present production from the Sparta and the development of a large cone of depression in the project area.

GEOCHEMISTRY OF PROJECT AREA GROUND WATER

Least-Squares linear regression analyses was applied to the water quality data using QuattroPro in order to compare the relationships between various chemical parameters. This analysis method tests the variance between a set of independent and dependent variables. The coefficient of determination (R^2) explains the variation within the linear model, and represents the reliability of the regression with a value between zero and unity. The linear relationship is more reliable as R^2 approaches unity. Graphical, including generation of Piper diagrams, and statistical methods were also employed to describe the geochemistry of the three aquifer systems in the project area.

Figure 7 depicts a Piper diagram constructed from milliequivalent concentrations of the major cations and anions in all of the samples. The difference in water type discussed in the previous section regarding the Alluvial versus the Sparta and Cockfield aquifers is easily discernable in the center diagram, which graphically depicts the calcium-carbonate and sodium-carbonate water types for the respective aquifer systems. It is interesting to note that the one sample representing the Cockfield Aquifer plots in an overlapping fashion with the Sparta Aquifer samples, although clear distinctions are noted in a review of the water quality analyses presented in Table 2. For instance, chloride and sulfate concentrations for the Cockfield averaged 8 times higher than those for the Sparta, calcium averaged approximately 3 times higher in the Cockfield than in the Sparta, and sodium concentration was approximately 6 times higher in the Cockfield than in the Sparta. However, Table 6 demonstrates that actual ion ratios indicate a water chemistry for the Cockfield which is very similar to the Sparta, especially when compared to the ratios for samples from the Alluvial Aquifer. The piper diagram graphically depicts this close similarity between water type and water chemistry for the Cockfield and Sparta aquifer samples.

Difficulties arise when performing linear regression analyses on water quality analyses which are derived from different aquifer systems or on analyses in which one sample serves as an outlier with a vastly different TDS concentration from the other samples. For example, Figures 8 & 9 display ion-pair relationships between calcium+magnesium versus bicarbonate and sodium versus chloride, respectively. Both graphs show strongly positive relationships with corresponding r^2 values of 0.93 and 0.73, respectively, for all analyses. However, the Sparta well samples vary little in their ionic composition and clump into a tight grouping. This situation combined with the fact that one alluvial sample has elevated concentrations of all major ions and serves as an outlier produces a graph which is similar to drawing a line through two points (or tight groupings) with the only major deviation being the other two Alluvial and one Cockfield well samples. Because of this situation, illustrating individual ion-pair relationships using only the data from the Sparta Formation samples is a more appropriate process. However, an interesting relationship using all analyses is displayed in Figure 10, which investigates the relationship between two ion ratios: sodium divided by chloride and calcium + magnesium divided by bicarbonate; all in milliequivalent concentrations. A water whose source of these ions is derived directly from the dissolution of calcite and halite and in the absence of transformation processes would have ion-pair ratios of those provided in Figure 10 approximating unity. Figure 10 demonstrates that ion exchange or other chemical transformation processes have increased the sodium concentrations for the Sparta and Cockfield samples at the expense of calcium. This is evident from the fact that decreases in calcium (+ magnesium) /bicarbonate ratios correlate with increasing sodium/chloride ratios.

Pine Bluff Monitoring Area

Piper Diagram

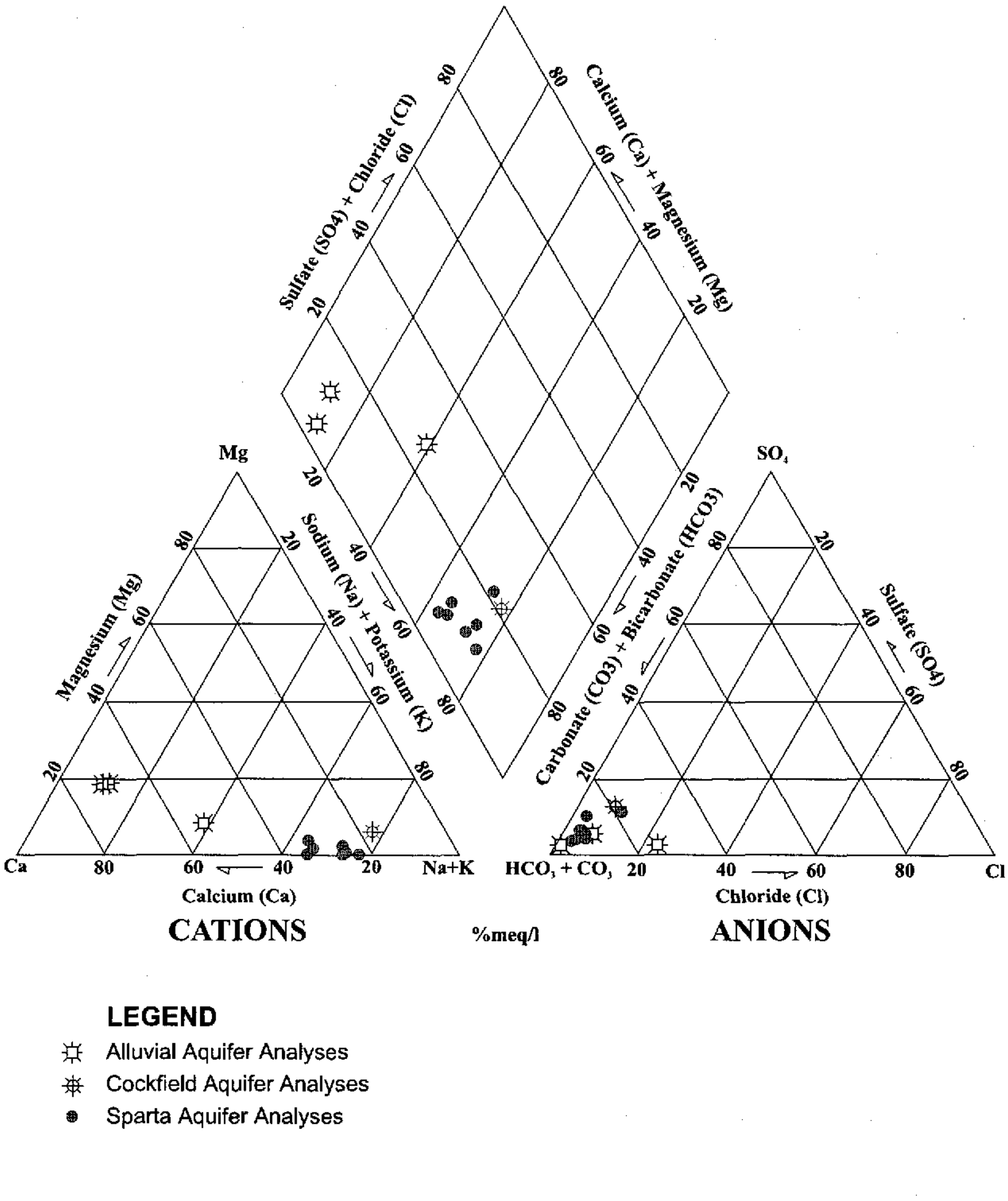


Figure 7. Piper diagram of Pine Bluff monitoring area

Table 6. Selected ionic ratios for Pine Bluff monitoring area well analyses.

Well Number	Aquifer System	Ca/Cation %	Mg/Cation %	K/Cation %	Na/Cation %	HCO_3/Anion %	Cl/Anion %	SO_4/Anion %	CaMg/ HCO_3	Na/Cl	Na/ HCO_3
JEF003	Sparta	26.11	0.27	11.99	61.64	78.01	10.49	11.51	0.45	7.80	1.05
JEF004	Sparta	22.73	0.26	11.11	65.90	89.62	5.80	4.58	0.20	8.89	0.58
JEF008	Sparta	34.26	0.28	12.09	53.37	89.05	5.44	5.51	0.30	7.47	0.46
JEF010	Sparta	32.40	1.59	12.89	53.12	91.68	4.03	4.29	0.29	10.23	0.45
JEF012	Sparta	32.32	3.85	10.18	53.64	93.15	3.15	3.71	0.34	14.95	0.51
JEF024	Sparta	25.53	0.61	9.67	64.19	86.39	3.26	10.36	0.25	16.41	0.62
JEF039	Sparta	25.24	2.35	8.57	63.85	89.76	3.58	6.67	0.26	15.20	0.61
JEF016	Cockfield	16.31	6.18	2.28	75.23	78.56	8.95	12.49	0.27	8.01	0.91
JEF027	Alluvial	69.67	18.77	0.43	11.12	95.81	1.21	2.98	0.95	9.50	0.12
JEF034	Alluvial	71.26	18.42	0.58	9.74	88.33	5.95	6.72	0.84	1.36	0.09
JEF038	Alluvial	53.30	7.87	0.36	38.47	73.58	23.40	3.02	0.70	1.39	0.44

Note: All ratios formulated using meq/L, including individual parameters and total cations and anions.

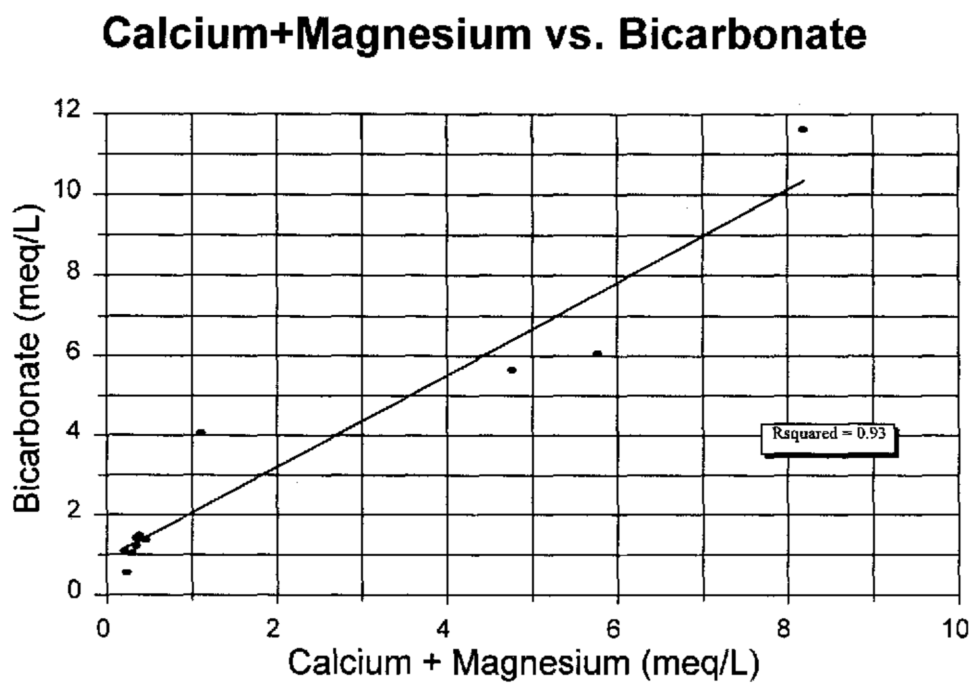


Figure 8. Linear relationship of calcium plus magnesium versus bicarbonate for all wells in Pine Bluff monitoring area. Goodness of fit represented by r^2 value.

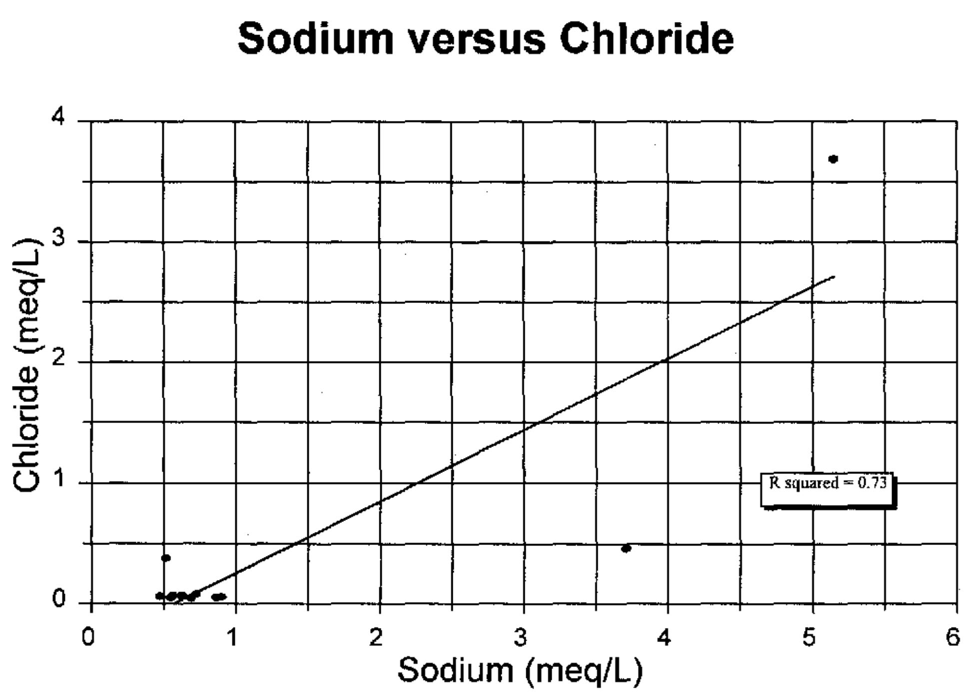


Figure 9. Linear relationship of sodium versus chloride for all wells in Pine Bluff monitoring area. Goodness of fit represented by r^2 value.

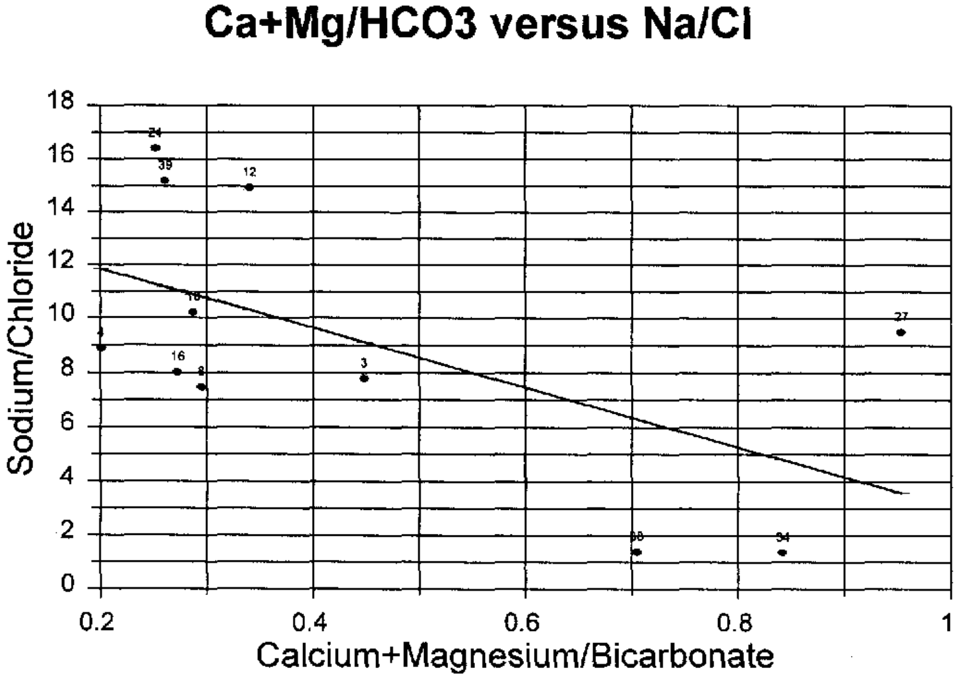


Figure 10. Graph of the relationship of sodium divided by chloride to calcium plus magnesium divided by bicarbonate. Ratios were calculated using equivalent weights for all parameters.

Figures 11, 12 and 13 display ion relationships using only data from the Sparta aquifer. Figure 11 depicts the relationship between sodium versus chloride. Although regression analyses performed on all samples for sodium versus chloride (Figure 9) had demonstrated a strongly positive relationship, a weakly negative relationship is noted using only Sparta well data. Because sodium has been increased as a result of ion exchange, it is reasonable that increases in sodium do not result in net increases in chloride concentrations. Figure 11 also supports the above discussion that care must be exercised when using regression analyses for interpreting ion-pair relationships. Use of all the analyses in the construction of the ion-pair relationships, would have falsely suggested that a positive relationship exists between sodium and chloride in the Sparta aquifer.

Figures 12 and 13 depict weakly positive relationships between calcium and sodium versus bicarbonate, respectively. A cursory review of both figures, in addition to Table 6, reveal that in addition to the low r^2 values, the ratios of both sodium and calcium to bicarbonate are less than one. The fact that both ratios are less than one, and that sodium/bicarbonate ratios are higher than those involving calcium, is one additional indicator that ion exchange processes in the evolution of the chemistry of the Sparta Aquifer has increased sodium concentrations in the water at the expense of calcium. Figure 14 graphically displays the results of simply adding sodium to both calcium and magnesium and relating the sum of the concentrations to bicarbonate. In addition to the r^2 value for Figure 14 improving over the values provided in Figures 12 and 13, the relationship between the sum of the cations and bicarbonate is closer to a one-to-one ratio.

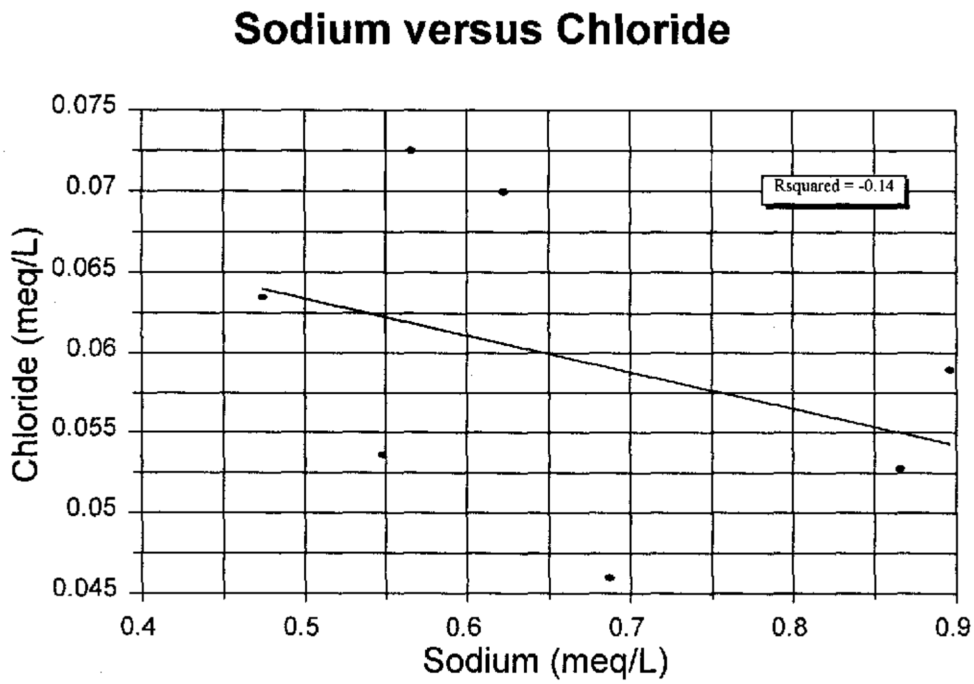


Figure 11. Linear relationship between sodium and chloride for Sparta Formation well samples. Goodness of fit represented by r^2 value.

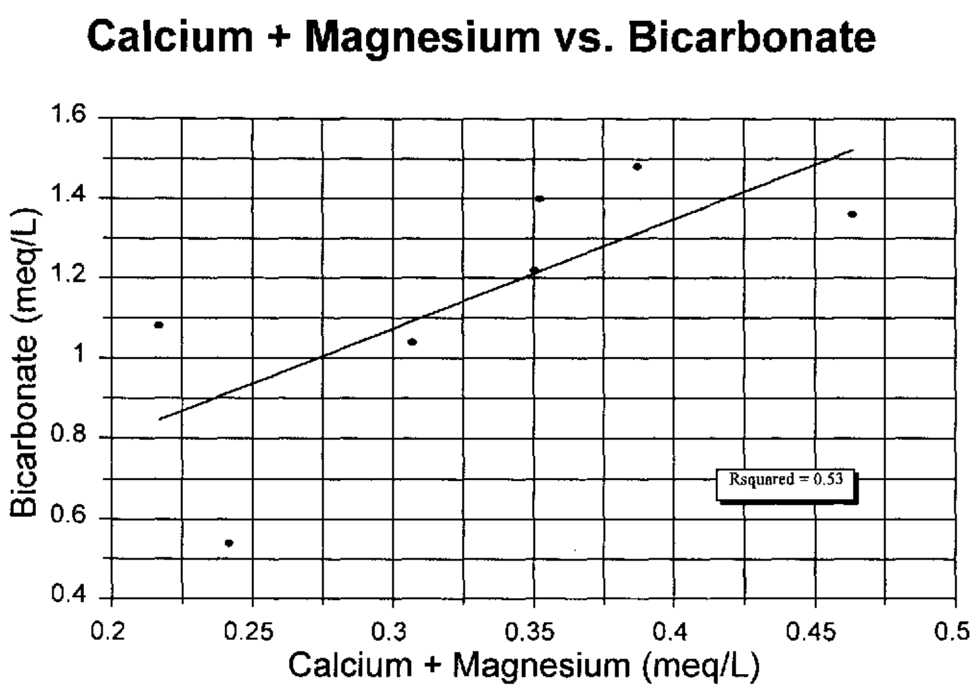


Figure 12. Linear relationship of calcium plus magnesium versus bicarbonate for Sparta Formation well samples. Goodness of fit represented by r^2 value.

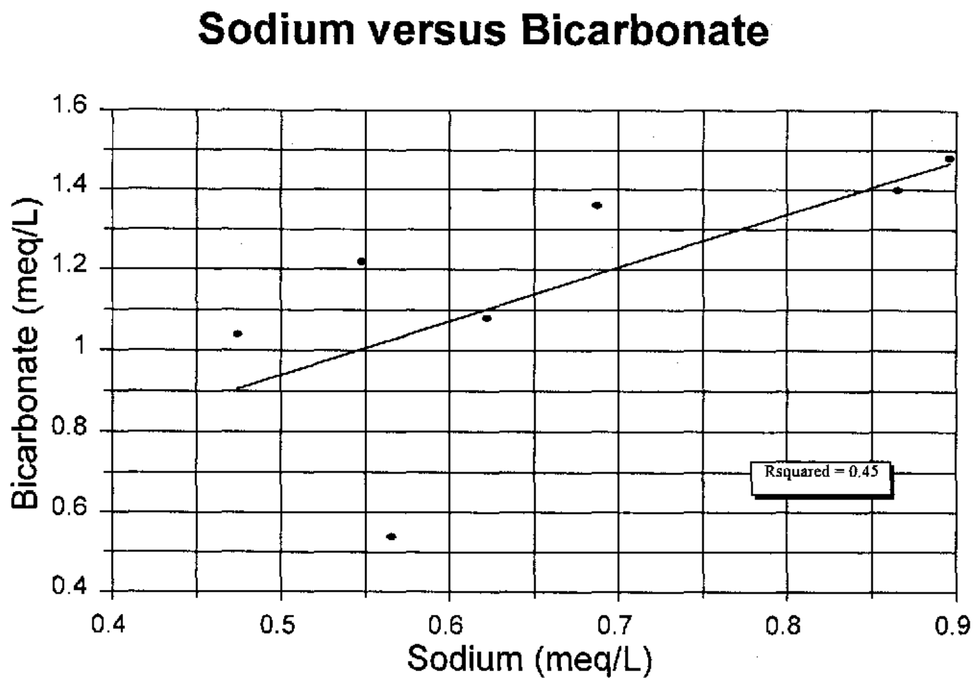


Figure 13. Linear relationship of sodium versus bicarbonate for Sparta Formation well samples. Goodness of fit represented by r^2 value.

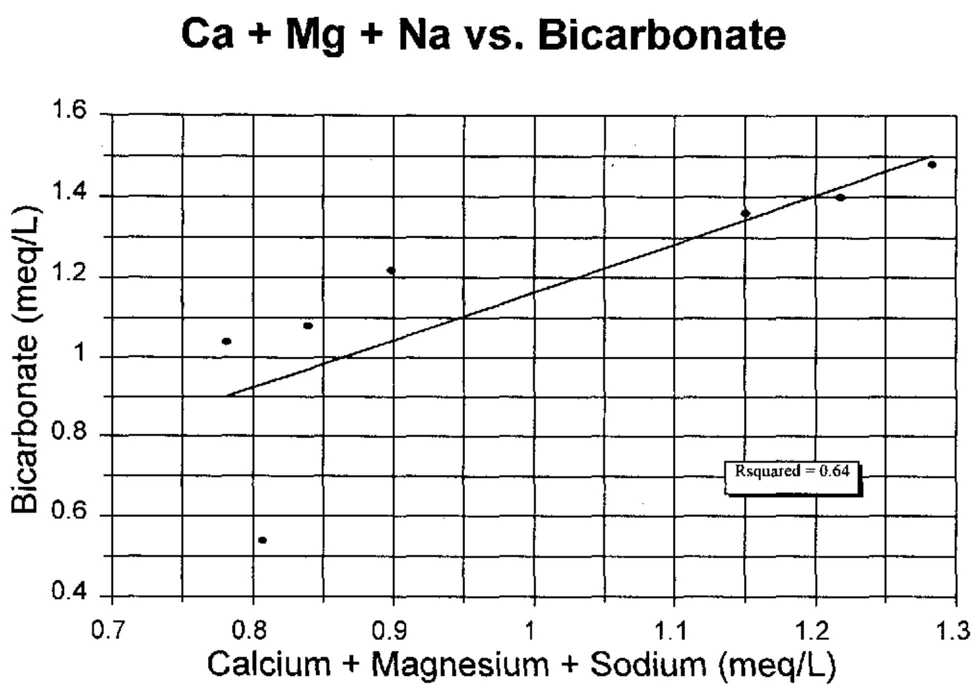


Figure 14. Linear relationship of calcium and magnesium plus sodium versus bicarbonate for Sparta Formation well samples. Goodness of fit represented by r^2 value.

A review of the water-quality analyses, Piper diagram, equivalent ratios and regression analyses demonstrates that fingerprinting the aquifers based on differences in water type, TDS and individual parameters appears to be valid for the study area and throughout Jefferson County. Statistical analyses indicate that the Cockfield is chemically very similar to the Sparta Aquifer. However, the Cockfield can be differentiated by its higher TDS with concomitant increases in individual parameters, especially sulfate, magnesium and sodium. Although Alluvial well samples vary over a wide range in individual ion concentrations, it is differentiated from the Sparta and Cockfield aquifers by its calcium-bicarbonate water type, and, to a lesser degree, by its increased magnesium concentrations, increased calcium/bicarbonate ratios, and decreased calcium/magnesium ratios.

FACTORS AFFECTING AQUIFER RECHARGE

Continuous and increasing use of both the Sparta and Alluvial aquifer systems in Jefferson County has led to substantial declines in water levels over the years. Water-level data for six Alluvial and two Sparta wells (Figure 6) dating to 1955 were obtained from the USGS, and from these data eight hydrographs were produced and are located in Appendix III. Although water levels have declined over the years, all of the hydrographs depict years with notable increases in the water levels. Four of the Alluvial wells (JEFHY03-06) are located east of the Pine Bluff municipal area and are within a 25 mile radius of one another. These four wells have similar hydrographs (Appendix IIIc and IIIf) and display both rises and declines over approximately a forty year period with total declines of only 2-4 feet, although differences from the highest to lowest level range from 8 - 11 feet. Figure 15 displays one of these hydrographs, which represents the conditions in this part of the Alluvial Aquifer. The other two Alluvial hydrographs (Appendix IIIa and IIIb), represented by Figure 16, are north of the municipal area and affected by steep hydraulic gradients imposed by a cone of depression developed in Arkansas and Prairie counties (Figure 17); therefore, these hydrographs show an almost continual decline in water levels with total declines of 11 - 15 feet. Figure 18 represents changes in the potentiometric surface for the Sparta Aquifer (Appendix IIIg-h) and graphically depicts the conditions discussed in previous sections concerning the large decline of the potentiometric surface in 1958 and subsequent continual, but less severe, decline since that period of time. Although water levels in Sparta wells within the project area have drastically declined from pre-pumping levels, it is apparent from Figure 18 that there have been periods of major and minor increases in water levels within some years. It is useful to review the factors controlling the changes in water levels to better understand the relationship between recharge and withdrawal from the two aquifer systems. The following discussion focuses mainly on the Alluvial Aquifer, which is affected to a larger degree by seasonal and yearly changes in water flux, both in regard to recharge and harvesting of the water. Explanations are also provided for changes in the water levels in the Sparta aquifer wells.

Several factors affect the rise and fall of water levels in wells completed in the Alluvial Aquifer. Although each well site is unique in that individual owners may start the well at different times, use different amounts, and grow crops which differ in their water demand, the four well hydrographs represented by Figure 15 display close similarities to major, and even minor, rises and declines in water level. Precipitation events result in water level rises, but are highly dependent on both frequency and intensity of rain events. Where wells are situated close to and in hydraulic communication with a river, the river stage is also a critical factor in the recharge of the water table.

Jefferson County 07S08W06BAA1

Alluvial Aquifer Hydrograph

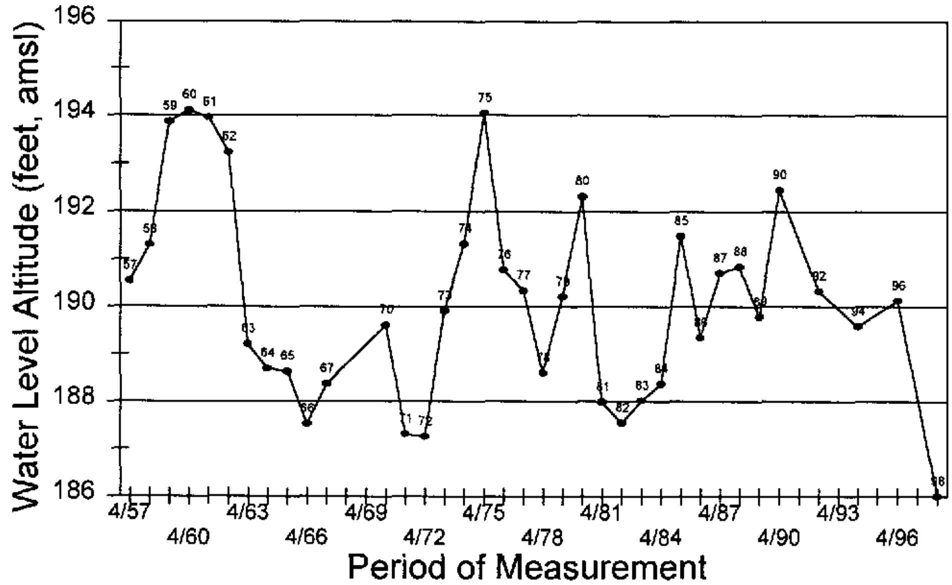


Figure 15. Graph of water level versus time for alluvial well in central part of project area. All measurements shown were taken in Spring of each year. Some data are missing as the frequency of measurements changed in recent years. See Appendix III for complete set of hydrographs.

Jefferson County 03S09W06DDA1

Alluvial Aquifer Hydrograph

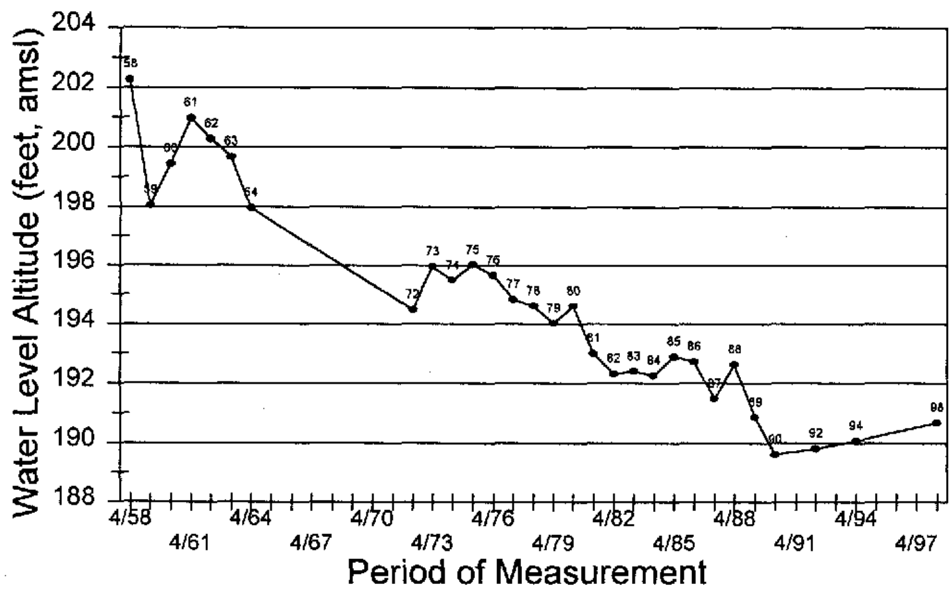
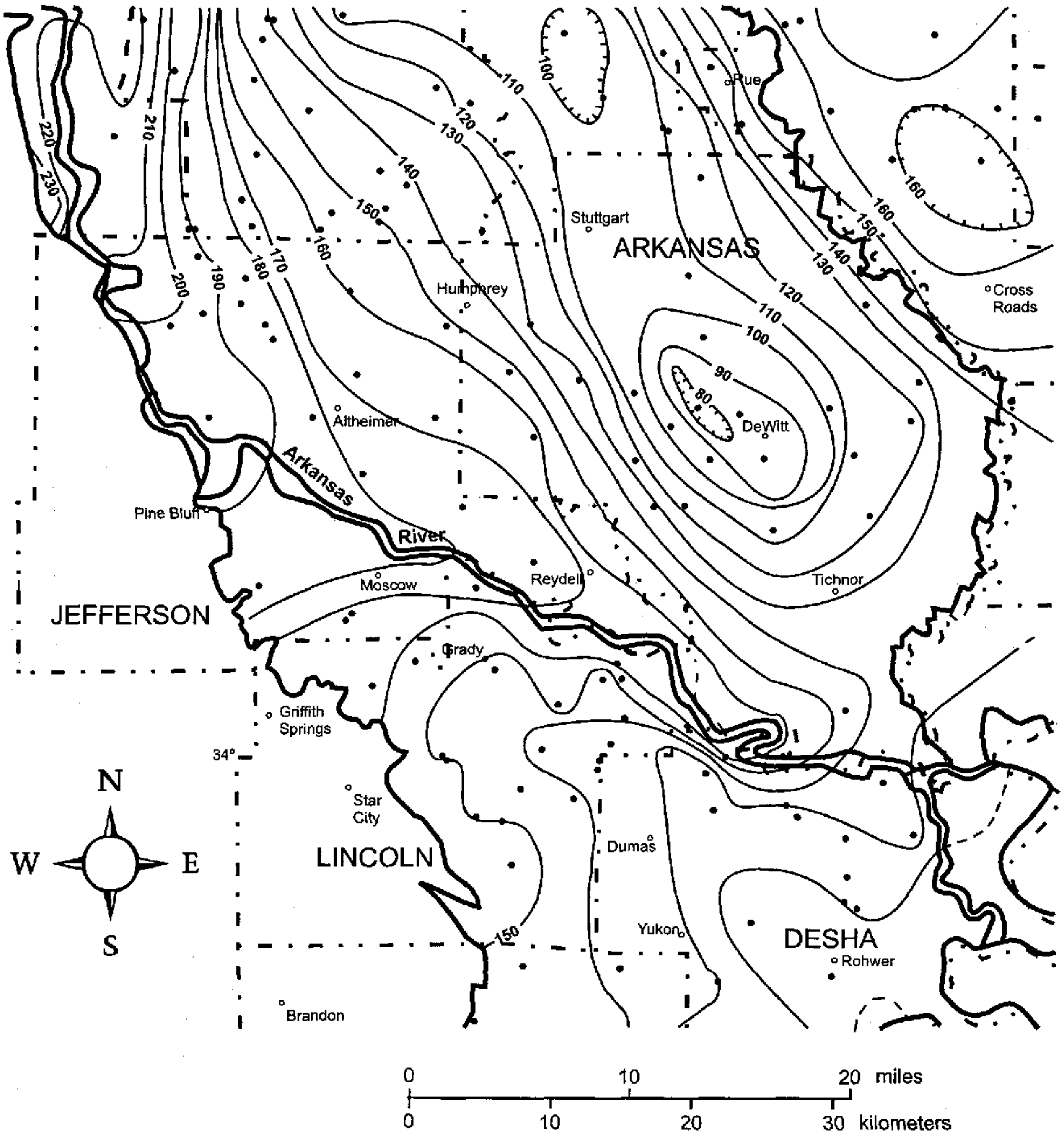


Figure 16. Graph of water level versus time for alluvial well on extreme northern edge of project area. All measurements taken in spring of each year. Some data are missing as frequency of sampling changed in later years.



LEGEND

● **Well Completed in Alluvial --**
Measurements made from March through June, 1998.

—100--- **Potentiometric Surface Contour –** line of equal water level altitude.
Hachures indicate depression. Contour interval is 25 feet. Datum is sea level.

Figure 17. Potentiometric surface of the Alluvial Aquifer, spring 1998 (Adapted from Joseph, 1999).

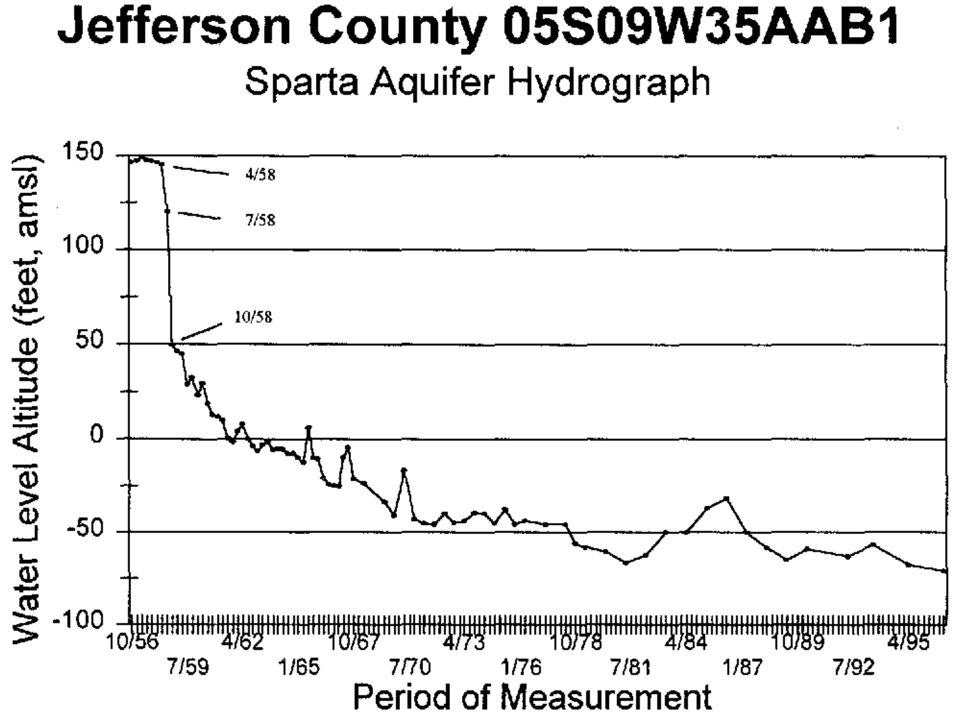


Figure 18. Graph of water level versus time for a Sparta Formation well in the project area. Dates shown indicate rapid drawdown between April and October, 1958, in which potentiometric surface dropped nearly 100 feet in less than six months.

Although river stage is sometimes related to local precipitation data, floods can occur during periods of intense rainfall during one season, whereas the annual precipitation for the flood year may be an average or below-average precipitation year. Floods can also be caused by heavy rains outside of the recording station or even in another state. Although factors affecting water-level declines would include evapotranspiration and natural discharge to rivers in combination with long periods of no recharge, the dominant factor affecting declines, as evidenced by the correlation presented in Figure 6, is pumping of ground water to meet irrigation needs.

To investigate the effects of precipitation on alluvial water levels, precipitation data from Stuttgart, Arkansas, were gathered for 1955-1996 and compared to Figure 15 as representing changing conditions in the Alluvial Aquifer in the study area. Because the precipitation data included total daily inches of rainfall for each day of the year, both summer (June-August) and yearly totals were compared to water-level data. The use of yearly totals only can be misleading if most of the rain fell during the non-growing seasons. Although the total precipitation for any one year may greatly exceed mean values, lack of rain during the growing season necessitates large ground-water withdrawals, which may result in a net water-level decline for the year. For example, the mean annual and summer precipitation for years 1955-1996 for the Stuttgart area was 48.9 inches and 9.8 inches, respectively. In 1962, the annual total of 42.35 inches was below normal, although the summer total of 12.57 was well above normal; conversely, in 1973 the annual total was 60.95 inches with only 5.73 inches falling during the summer months. A combination of events may greatly affect water levels in the Alluvial Aquifer. High annual precipitation values in combination with frequent summer rainfall would result in the highest potential for water-level increases by potentially adding to recharge and decreasing the demand on pumping for irrigation needs. Conversely, low annual and summer precipitation amounts would combine to produce low recharge with high irrigation demand, resulting in net water-level declines. In between these two extremes would lie different combinations possibly affecting water levels to a lesser degree.

Graphs were produced using the Stuttgart precipitation data for annual totals, summer (June-August) totals, and a combination of each. The graphs for annual and summer totals are represented by total inches of precipitation for 1955-1996 and are shown in Figures 19 & 20, respectively. For Figure 21, the summer and annual totals were converted to percent deviation from the mean value for each data set, and then added together for the total percent deviation. As such, the mean value is set at zero for ease of comparison; values above zero showing total percent deviation above the mean, and the negative values represent values below the mean. Because different variables exist which affect water levels, no exact match between precipitation and water level hydrographs should be expected. In fact, although the four hydrographs represented by Figure 15 are similar, slight differences exist between individual peaks and troughs (Appendix III). However, marked similarities in the hydrographs include below-average levels (1st notable trough) in the mid-to-late sixties with the low in 1966-67; a minor peak in 1970 followed by a drop in 1971-72; subsequent rise to a high peak in 1975; a decrease in the late seventies rising to a minor peak in 1980 (1979 on one graph); below-average levels in the early 1980's (2nd notable trough), similar to that in the mid sixties; and finally a peak in 1985 (1984 on one graph; 1986 on one graph). Variations in the years in which peaks or troughs occurred, such as the 1979-1980 peaks and the 1984-1986 peaks, can occur as a result of different variables including; recharge lag time as a result of different hydraulic conductivities and distance from recharge source, variations in local rain patterns and well distance from river, differences in irrigation usage amount, and other variables. In spite of these variables, the overall shape and pattern of the hydrographs, are remarkably similar.

Figures 19 & 20 appear to have only vague similarities to the Alluvial well hydrograph in Figure 15. The annual precipitation values (Figure 20) do not have a peak in 1970, and the peak in 1980 is higher than that in 1975. The trough in the sixties is virtually nonexistent, except for the fact that there are below-average values in 1963, '64, '66, and '67. The summer precipitation values (Figure 19) display a series of lows in the sixties, which more closely resembles the trough in Figure 15, but shows a high value in 1966. Also the peak value is in 1970 instead of 1975, and the 1980 value is the lowest value, instead of resembling a minor peak. Figure 21, which displays the added deviations from both the summer and annual mean precipitation values, more closely resembles the general shape of the hydrograph (Figure 15) than either precipitation graph does separately. A visible trough is observed for the period between 1962 and 1970. However, the highest peak is in 1974 and although the general shape more closely resembles that in Figure 15, the peaks in 1971 and 1974 appear to be off by one year. The trough in the early eighties is now visible; however, the values for 1986 and 1988 are actually lower than that in Figure 15. The better fit for the combination of the annual and summer precipitation values support the theory stated above that rain distribution in addition to annual values is important from the standpoint of reducing stresses imparted by production from the aquifer during the summer months.

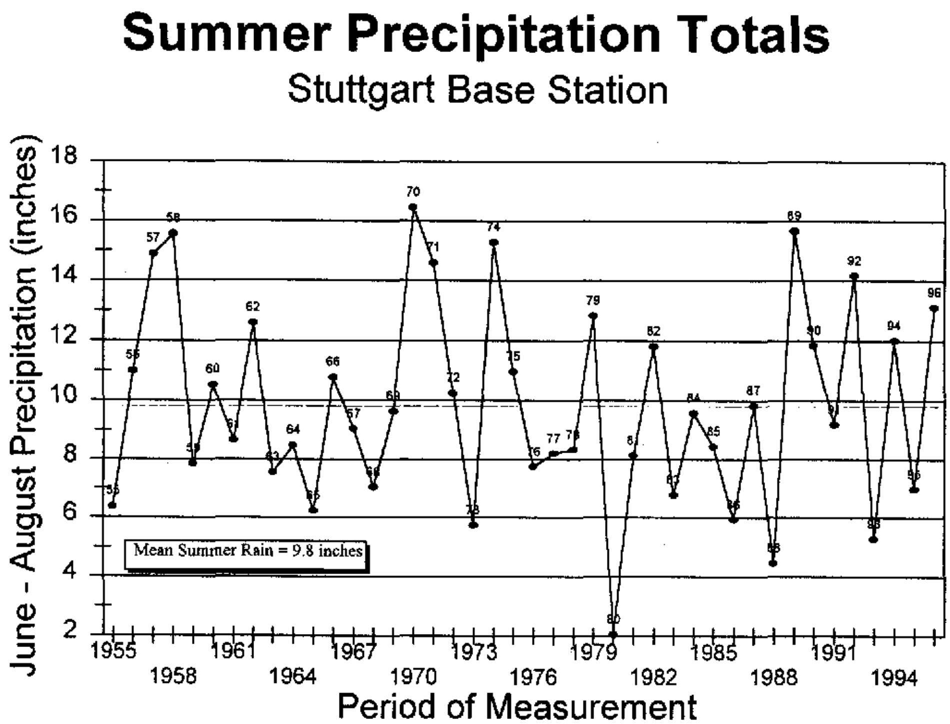


Figure 19. Summer (June - August) precipitation totals from 1955-96 (Precipitation data provided by University of Arkansas Center for Advanced Spatial Technology).

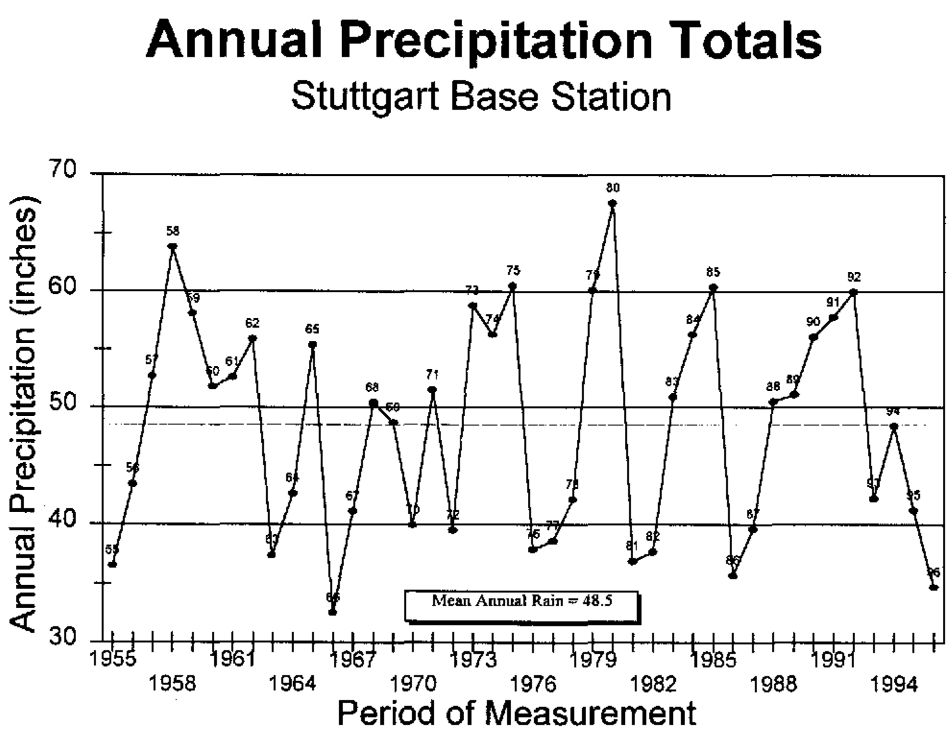


Figure 20. Annual precipitation totals for years 1955 - 1996 (Precipitation data provided by University of Arkansas Center for Advanced Spatial Technology).

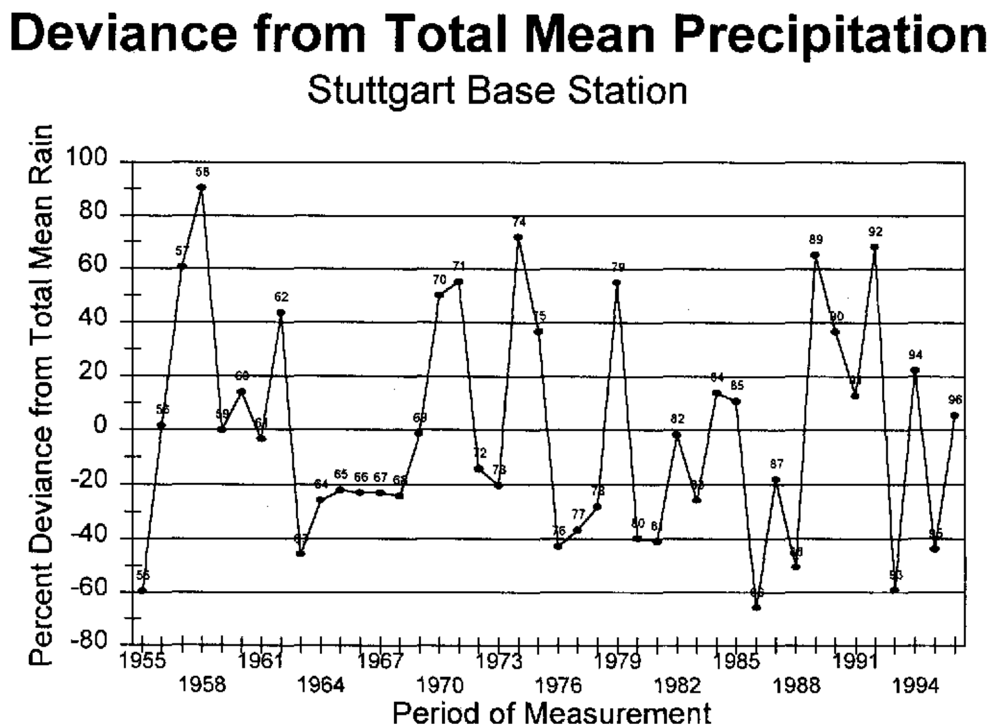


Figure 21. Percent deviance from combined annual and summer precipitation totals for years 1955-96. Deviation in inches from the mean summer and annual precipitation values were converted to percentages and added for total percent deviation.

The installation of lock and dams on the Arkansas River has strongly affected ground-water flow patterns and potential recharge of the Alluvial Aquifer. Previous to the installation of these structures, the river dominantly served as a discharge source for the Alluvial Aquifer. During times of flood conditions, the river temporarily served as a recharge source; however, this temporary influx of water only affected bank-storage ground water to distances of approximately two or more miles inland from the river. Construction of the locks provided a constant-head boundary for ground water recharge by artificially raising the level of the pooled water above the adjacent ground water level. In combination with increased production from the Alluvial Aquifer for irrigation purposes, it appears that the river serves as a constant recharge source along most of its stretch. Because the installation of Lock & Dam #4 (Lock #4) most directly affects levels in the four wells represented by Figure 15, data for the elevation of the tailwater from Lock #4 was gathered from the Arkansas Corps of Engineers. The data dates to 1969, which was the completion date for Lock #4. Figure 22 graphically depicts the years with the greatest potential for recharge from the river. For construction of Figure 22, the total days exceeding 190 feet amsl were tabulated for each year for the years 1969-1996. An elevation of 190 feet corresponds to a release of about 100,000 cfs, which is associated with flood releases from the projects in Oklahoma (Glen Raible, written communication,1999).

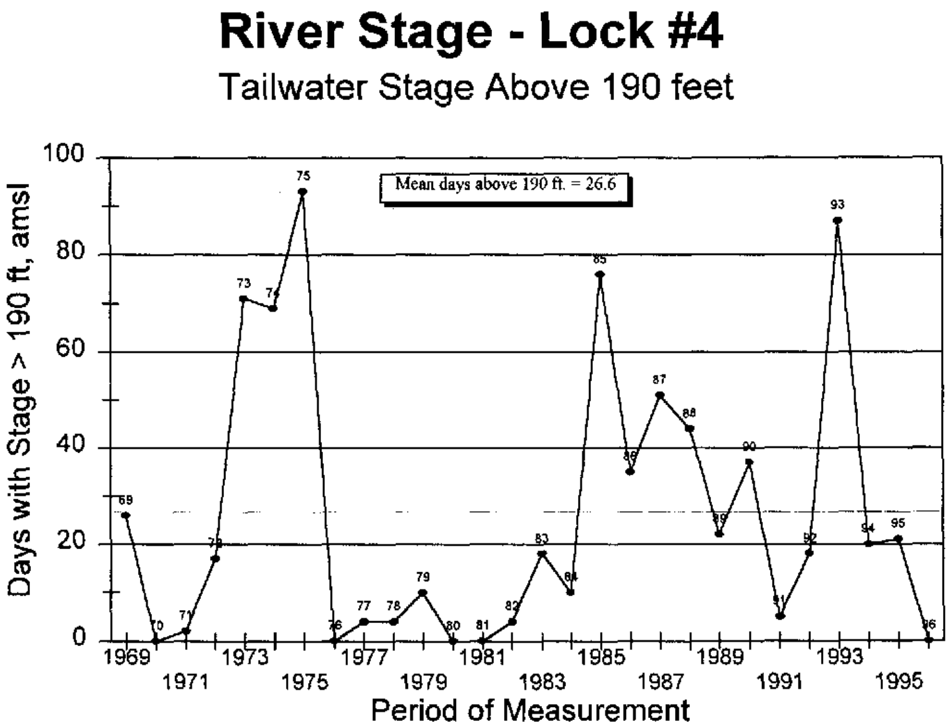


Figure 22. Total days of stage exceeding 190 feet amsl at Lock #4 from 1969-96.

A cursory inspection of Figure 22 immediately reveals that the highest number of days with elevations exceeding 190 feet occurred in 1975, followed by a trough and another peak in 1985. The high number of days for elevated stage from 1973 - 1975 correlates to the rise in water level elevations in all four hydrographs from 1973-1975. This correlation suggests that river stage was most likely responsible for the increases during this period of time and has been a dominant recharge source since 1969. Figure 23 represents the combination of recharge inputs, derived from adding all deviations from the mean, for summer and annual precipitation events and river stage. This combination of recharge sources appears to best fit the conditions depicted in Figure 15. A well-defined trough is evident between 1962 and 1970 with a major peak following in the period between 1974-75. Two secondary troughs are noted for the late seventies and early eighties; broken only by the peak in 1979. After the later decline in the early eighties, a sharp rise in the combined inputs results in the peak in 1985. Because the period of measurement changes from annually to once every two years in 1988, it is difficult to effectively correlate the data past the 1985 period. Because the hydrographs differ somewhat in the exact year a high or low water level occurred, it is difficult to ascertain if a mathematical model or ranking system (for weighting input sources) would significantly improve the correlation. It is sufficient to state that the correlations discussed above between the resource inputs and the water-level hydrographs appear to strongly indicate that

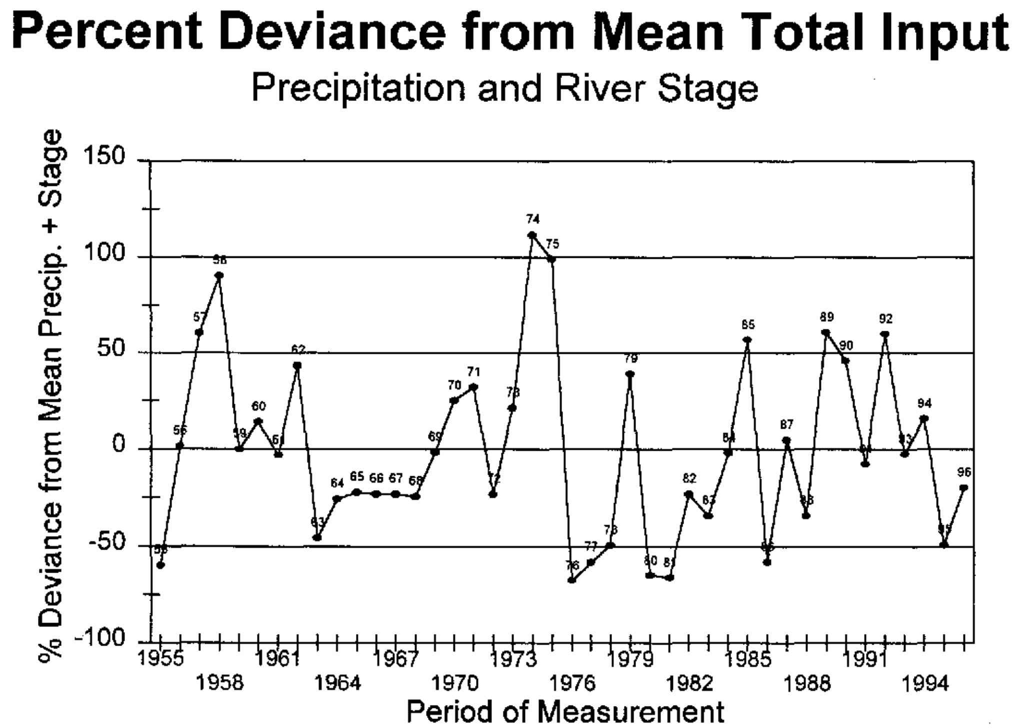


Figure 23. Total deviation from summer and annual precipitation values combined with river stage. Percent deviation from the mean for each input was summed for the total deviation for the combined input sources.

previous to 1969 the combination of annual and summer precipitation were critical in providing ground-water recharge. After installation of Lock #4 in 1969, elevated river stage, as determined by number of days exceeding 190 feet amsl, becomes a dominant source of recharge in combination with precipitation. Because the two alluvial wells to the north appear to be unaffected by either precipitation or river stage, additional factors would include proximity to the river, local precipitation, and proximity to cones of depression developed from large ground-water withdrawal.

Because the remaining two Alluvial hydrographs and the two Sparta hydrographs (Appendix III e-g) illustrate continual declines over the same period of time, there would appear to be little correlation to precipitation and stage as described in the previous paragraphs. In addition to the continual decline, there is minimal hydraulic communication between the Alluvial and Sparta aquifers. The Alluvial Aquifer is dominantly a water table aquifer, whereas the Sparta is confined; and neither river stage or precipitation should affect the Sparta Aquifer to the degree that the Alluvial Aquifer is impacted, especially in view of the drastic decline in water levels in the Sparta Aquifer. However, close inspection of Figure 16, which represents conditions in the Alluvial Aquifer in northern Jefferson County, reveals a pattern of peaks and troughs, similar to those illustrated in Figure 15. Although years 1965-71 are missing, a decline in water levels is evident after 1961 with a subsequent rise in 1975 (and also 1973). A clearly defined trough exists in the early eighties culminating in a peak in 1985. It is evident that the same recharge events were occurring in this part of the Alluvial Aquifer, although the impacts from production in Arkansas and Prairie counties severely affected the water levels in this area. Figure 24 lists water levels for both Sparta wells for spring measurements only. A distinct peak is evident in 1970, although an earlier peak occurs in 1967, followed by a declines in levels until a rise to a peak in 1975. A large trough is evident in the early eighties, followed by a large rise in water levels to a peak in 1986. The fact that the largest peak does not occur in 1975 is evidence that river stage does not affect recharge to the Sparta, and correlations can only be made to precipitation as the recharge input. Another possibility for the similarities to the alluvial hydrographs is that increases in water level in the Alluvial Aquifer result in increased pressure upon the lower stratigraphic units, and this pressure could result in notable increases in the hydraulic head pressure within the Sparta Aquifer.

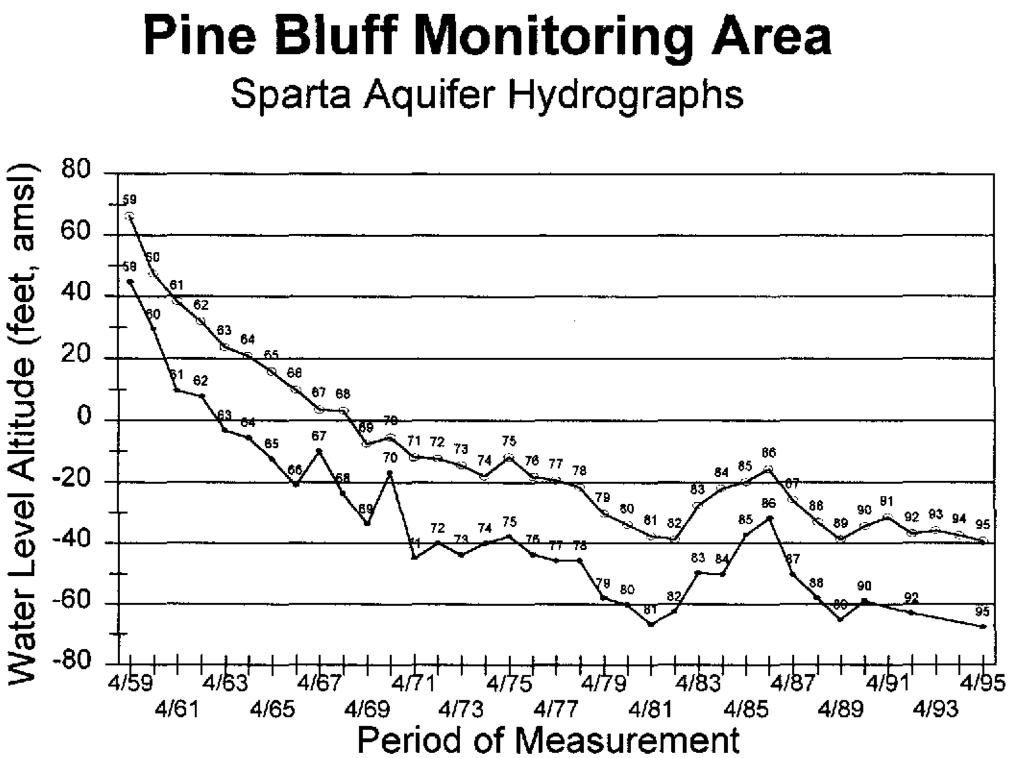


Figure 24. Water level versus time for both Sparta Formation wells illustrated in Appendix III. Period of time ranges from 1959 - 1995. Some data missing as frequency of monitoring changed in later years.

SUMMARY AND CONCLUSIONS

The fourth sampling of the Pine Bluff Monitoring Area was conducted in September, 1997. Seven Sparta, one Cockfield, and three Alluvial Aquifer well samples were collected and analyzed for major and minor cations and anions, including trace metals, and volatile organic compounds. Analyses from all three aquifers demonstrate very good water quality. Samples derived from the Sparta and Cockfield aquifers reveal a sodium-bicarbonate water type; whereas, the Alluvial Aquifer produces a calcium-bicarbonate water type. All parameters were below primary and secondary drinking water standards with the exception of iron levels, which were exceeded in all samples, and TDS, which was exceeded in one Alluvial Aquifer sample. However, both iron and TDS are secondary standards, which are unenforceable guidelines related to aesthetic effects of drinking water and pose no health risks. Water in the Sparta Aquifer is especially soft, with TDS concentrations ranging from 74 to 103 mg/L.

A review of historical to present water usage demonstrates that the largest drop in water levels within wells completed in the Sparta Aquifer occurred in the latter part of 1958. The water level in one well dropped approximately 115 feet from April, 1958 to May, 1959. The Sparta Aquifer was pumped at a higher annual production rate than either the Alluvial or Cockfield, until sometime between 1970 and 1975, at which point the total gallons pumped from the Alluvial Aquifer had more than doubled, making it the highest-use aquifer in Jefferson County. In the study area, however, the Sparta remains the most heavily-pumped aquifer, and Jefferson County is #1 in the total gallons of water produced from the Sparta Aquifer.

Water-quality analyses from the present study were compared to historical data gathered in 1949 (Klein, et al., 1950) for all three aquifers. Basically, water quality in all three aquifers shows no evidence of increases in major cations and anions when compared to historic data. Median TDS values for the Sparta Aquifer were within 1 mg/L, which is encouraging in view of the fact that a large cone of depression has developed in the Sparta with water levels having dropped approximately 250 feet from pre-pumping water levels to the present date. Fingerprinting of all three aquifer systems appears to be valid based on water quality and geochemical relationships.

Six Alluvial well hydrographs and two Sparta well hydrographs were used to investigate the impacts of recharge inputs including river stage and precipitation. Total inches of precipitation were tabulated for both annual and summer (June-August) totals. An elevation of 190 feet amsl for the tailwater from Lock #4 was used to denote high river stage, and the total number of days exceeding this amount was tabulated for each year. Four of the Alluvial hydrographs east of the Pine Bluff municipal area showed both increases and decreases in water level, with very little overall declines dating to 1957. This observation suggests that there exists more of a balance between production and recharge, and comparisons to graphs of precipitation and river stage over the same period of time demonstrated close similarities to increases in recharge inputs and well-water levels. A graph representing the total of annual and summer precipitation fit the hydrograph pattern better than individual comparisons of either precipitation ranges investigated independently of one another.

The graph representing days of elevated river stage indicated that river stage was a dominant influence for large increases in well-water levels after 1969; the completion date for Lock and Dam #4. The best fit was achieved when both precipitation inputs were combined with river stage, which reflects the importance of both sources in affecting increases in water levels for the Alluvial Aquifer.

Graphs of precipitation and river stage were also compared to the remaining two Alluvial well and two Sparta well hydrographs. The two Alluvial wells are north of the Pine Bluff municipal area, and the well hydrographs show an almost continual decline in water levels as a result of a large cone of depression developed in Arkansas County. Similarly, the two Sparta wells reveal continual declines in water levels over time. However, all hydrographs revealed patterns similar to the graphs for the recharge inputs, and suggest that even in cases of over-production, periods of regionally-increased recharge resulted in increased water levels.

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APPENDIX I

Water-Quality Analyses

Well Descriptions - Pine Bluff Monitoring Area

Wells Sampled During Fourth Sampling Event

Sample ID	T/R Location	Latitude	Longitude	Date	Depth	Aquifer	Use	Owner	Owner Designation
JEF003	05S09W19BAA1	34 16 08.0	92 01 29.0	9-27-97	820'	Sparta	Industrial	Gaylord Container Corp.	
JEF004	05S09W30DBA1	34 15 06.0	92 01 29.0	9-27-97	792'	Sparta	Irrigation	UAPB	
JEF008	05S10W11ACA1	34 17 40.0	92 03 24.0	9-27-97	992'	Sparta	Municipal	Pine Bluff Arsenal	3
JEF010	06S09W04BAB2	34 13 30.5	92 01 06.0	9-27-97	865'	Sparta	Municipal	United Water Works ?	10
JEF012	06S09W17CCC1	34 11 49.0	92 02 29.0	9-27-97	848'	Sparta	Municipal	United Water Works ?	19
JEF016	05S09W07CCC1	34 17 05.0	92 01 58.0	9-27-97	265'	Cockfield	Domestic	Elijah Coleman	
JEF024	05S08W30AAB1	34 15 07.5	91 54 46.0	9-27-97	@900'	Sparta	Industrial	International Paper	18
JEF027	05S09W10CCA1	34 17 14.8	91 58 29.8	9-27-97	110'	Alluvial	Irrigation	Jim Danaher	
JEF034	05S09W34CAB1	34 13 54.0	91 58 25.0	9-27-97	102'	Alluvial	Industrial	Pine Bluff Sand & Gravel	
JEF038	06S08W09ACC1	34 13 05.0	91 54 38.0	9-27-97	165'	Alluvial	Industrial	International Paper	2S
JEF039	06S08W10CAA1	34 12 59.0	91 53 44.0	9-27-97	1020	Sparta	Industrial	International Paper	23

Previously Sampled Wells:

Sample ID	T/R Location	Latitude	Longitude	Date	Depth	Aquifer
JEF001	04S10W29ADC1	34 20 23.0	92 06 22.0	6-6-94	651'	Sparta
JEF005	05S09W31DCA1	34 13 42.0	92 01 10.0	2nd	859'	Sparta
JEF007	05S10W02CDD1	34 18 07.0	92 03 34.0	2nd	1,085'	Sparta
JEF011	06S09W04BAB1	34 13 30.5	92 01 10.0	2nd	864'	Sparta
JEF019	05S10W12ADD1	34 17 32.0	92 02 00.0	6-6-94	54'	Alluvial

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	Date	Time	Cd µg/L	Cr µg/L	Pb µg/L	As µg/L	Se µg/L	pH	Alkalinity mg/L	HCO_3 mg/L	Conductivity µS/cm	Br mg/L	Cl mg/L
JEF003	WGX	970902	1345	<.04	<.4	<.4	<5.0	<5.0	6.54	27	32.9	121	<0.03	2.57
JEF004	WGX	970902	1255	<.04	<.4	<.4	<5.0	<5.0	6.73	54	65.9	165	<0.03	2.48
JEF008	WGX	970903	1020	<.04	<.4	<.4	<5.0	<5.0	6.76	52	63.4	119	<0.03	2.25
JEF010	WGX	970902	1150	<.04	<.4	<.4	<5.0	<5.0	6.43	61	74.4	133	<0.03	1.9
JEF012	WGX	970902	1215	<.04	<.4	<.4	<5.0	<5.0	6.96	68	83	147	<0.03	1.63
JEF016	WGX	970902	1615	<.04	<.4	<.4	<5.0	<5.0	6.78	203	247.7	534	0.05	16.4
JEF024	WGX	970902	930	<.04	<.4	<.4	<5.0	<5.0	6.96	70	85.4	168	0.1	1.87
JEF027	WGX	970902	1425	<.04	<.4	<.4	<5.0	<5.0	6.68	303	369.7	691	0.51	2.71
JEF034	WGX	970902	1105	<.04	<.4	<.4	<5.0	<5.0	6.63	283	345.3	630	0.06	13.5
JEF038	WGXO	970902	955	<.04	<.4	<.4	<5.0	<5.0	6.86	581	708.8	1462	0.14	131
JEF039	WGX	970902	905	<.04	<.4	<.4	<5.0	<5.0	6.92	74	90.3	173	<0.03	2.09
JEF038	WGXD	970902	1005	<.04	<.4	<.4	<5.0	<5.0	6.86	576	702.7	1462	0.14	132
JEF038	WGXS	970902	1005	0.53	8.66	3.28	5.48	<5.0					0.13	188
JEF038	WGXS	970902	1005	0.46	8.02	2.82	<5.0	<5.0					0.13	188
TRIP BLANK	WGXB	970902	1200											

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	F mg/L	SO_4 mg/L	Al µg/L	Cu µg/L	Ca mg/L	Fe µg/L	K mg/L	Mg mg/L	Mn µg/L	Na mg/L	Zn µg/L	Hardness mg/L	Ni µg/L	B µg/L
JEF003	WGX	0.08	3.82	20.1	<2	4.8	2370	4.3	<0.06	49.6	13	2.3	11	<5	20.3
JEF004	WGX	0.07	2.65	23.4	<2	4.3	6640	4.1	<0.06	81.1	14.3	<2.0	<	<5	15.9
JEF008	WGX	0.07	3.09	18.9	<2	6.1	2800	4.2	<0.06	62	10.9	<2.0	14	<5	23.9
JEF010	WGX	0.1	2.74	<16	<2	6.7	2220	5.2	0.2	62.3	12.6	31.6	18	<5	26.1
JEF012	WGX	0.1	2.6	<16	<2	8.3	1570	5.1	0.6	72.8	15.8	2.4	23	<5	34.5
JEF016	WGX	0.16	31	<16	3.2	16.1	1170	4.4	3.7	233	85.2	6	55	<5	328.9
JEF024	WGX	0.09	8.06	<16	<2	6.9	2230	5.1	0.1	56.4	19.9	14.9	18	<5	43.9
JEF027	WGX	0.09	9.06	<16	<2	91.2	5950	1.1	14.9	385	16.7	6	289	<5	25.5
JEF034	WGX	0.17	17.6	<16	<2	75.9	11800	1.2	11.9	260	11.9	3.2	239	<5	16.7
JEF038	WGXO	0.11	22.9	<16	<2	143	19000	1.9	12.8	1130	118.4	9.2	410	<5	34.9
JEF039	WGX	0.11	5.28	30.4	<2	7.1	1590	4.7	0.4	53.1	20.6	9.6	19	<5	44.5
JEF038	WGXD	0.11	22.9	<16	<2	143	19200	2.1	13.3	1120	120	3.5	412	<5	34.9
JEF038	WGXS	0.1	73.7	710.9	99.7	159	18900	22.2	31.9	1150	135.8	79.8	528	150.7	236.8
JEF038	WGXS	0.1	69.9	686.6	99	159	18800	21.3	31.9	1150	136.2	79.8	528	148.9	236.7
TRIP BLANK	WGXB														

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	Be µg/L	Ba µg/L	Co µg/L	V µg/L	SiO_2 mg/L	NH_3-N mg/L	NO_3-N mg/L	O-PHOS mg/L	T-PHOS mg/L	TOC mg/L	TSS mg/L	TDS mg/L
JEF003	WGX	<2	125.2	<3	<5	15.6	0.249	0.06	0.023	0.144	<1	<1	74
JEF004	WGX	<2	117.6	<3	<5	15.8	0.286	0.083	0.029	0.126	<1	<1	81
JEF008	WGX	<2	119.1	<3	<5	14.1	0.234	0.07	0.023	0.136	<1	<1	77
JEF010	WGX	<2	125.3	<3	<5	16	0.258	0.068	0.023	0.154	<1	<1	84
JEF012	WGX	<2	88.2	<3	<5	17.9	0.291	0.051	0.024	0.182	<1	<1	93
JEF016	WGX	<2	50	<3	<5	34.5	0.69	<0.010	0.058	0.248	1.8	5	318
JEF024	WGX	<2	113	<3	<5	16.7	0.291	0.092	0.023	0.154	<1	<1	101
JEF027	WGX	<2	376.2	<3	<5	23.9	0.526	0.084	0.054	0.512	1.5	8	397
JEF034	WGX	<2	366.9	<3	<5	28.5	0.693	<0.010	0.053	0.814	1.7	23.5	342
JEF038	WGXO	2.1	560.5	<3	<5	25.2	0.841	<0.010	0.083	0.994	8.5	46	829
JEF039	WGX	<2	86.4	<3	<5	17.3	0.3	<0.010	0.025	0.174	<1	<1	103
JEF038	WGXD	2.2	568.1	<3	<5	25.3	0.812	<0.010	0.043	1.022	8.6	47	834
JEF038	WGXS	19.8	1335	194.6	192.1	25.1	1.4	0.603	0.699	1.526	13.8		
JEF038	WGXS	19.8	1336	195.3	192.4	25.2	1.398	0.603	0.701	1.416	13.8		
TRIP BLANK	WGXB												

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	Dibromofluoromethane(Surr.) µg/L	Toluene-d8(Surr.) µg/L	4-Bromofluorobenzene(Surr.) µg/L	1-1-Dichloroethene µg/L	Methylene_chloride µg/L
JEF003	WGX					
JEF004	WGX					
JEF008	WGX					
JEF010	WGX					
JEF012	WGX					
JEF016	WGX	114.25	98.463	94.012	<1.0000	<1.0000
JEF024	WGX					
JEF027	WGX	102.48	97.166	95.85	<1.0000	<1.0000
JEF034	WGX	105.2	92.54	94.348	<1.0000	<1.0000
JEF038	WGXO	112.53	97.982	96.656	<1.0000	<1.0000
JEF039	WGX					
JEF038	WGXD	102.96	98.999	95.341	<1.0000	<1.0000
JEF038	WGXS	102.1	96.343	99.045	102.51	
JEF038	WGXS	107.39	95.456	102.1	86.465	
TRIP BLANK	WGXB	104.79	96.896	95.567	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	trans-1-2-Dichloroethene µg/L	1-1-Dichloroethane µg/L	cis-1-2-Dichloroethene µg/L	2-2-Dichloropropane µg/L	Bromochloromethane µg/L
JEF003	WGX					
JEF004	WGX					
JEF008	WGX					
JEF010	WGX					
JEF012	WGX					
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX					
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX					
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS					
JEF038	WGXS					
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	Chloroform µg/L	1-1-1-Trichloroethane µg/L	1-2-Dichloroethane µg/L	1-1-Dichloropropene µg/L	Benzene µg/L	Carbon_Tetrachloride µg/L
JEF003	WGX						
JEF004	WGX						
JEF008	WGX						
JEF010	WGX						
JEF012	WGX						
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX						
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX						
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS					99.335	
JEF038	WGXS					92.115	
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	1-2-Dichloropropane µg/L	Trichloroethene µg/L	Dibromomethane µg/L	Bromodichloromethane µg/L	cis-1-3-Dichloropropene µg/L	Toluene µg/L
JEF003	WGX						
JEF004	WGX						
JEF008	WGX						
JEF010	WGX						
JEF012	WGX						
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX						
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX						
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS		90.376				92.942
JEF038	WGXS		80.408				80.382
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	trans-1-3-Dichloropropene µg/L	1-1-2-Trichloroethane µg/L	1-3-Dichloropropane µg/L	Dibromochloromethane µg/L	Tetrachloroethene µg/L
JEF003	WGX					
JEF004	WGX					
JEF008	WGX					
JEF010	WGX					
JEF012	WGX					
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX					
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX					
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS			90.23		
JEF038	WGXS			82.371		
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	1-2-Dibromoethane µg/L	Chlorobenzene µg/L	1-1-1-2-Tetrachloroethane µg/L	Ethylbenzene µg/L	m+p_Xylene µg/L	Styrene µg/L	o-Xylene µg/L
JEF003	WGX							
JEF004	WGX							
JEF008	WGX							
JEF010	WGX							
JEF012	WGX							
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX							
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX							
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS		102.02					
JEF038	WGXS		87.79					
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	1.5002	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	Bromoform µg/L	1-1-2-2-Tetrachloroethane µg/L	Isopropylbenzene µg/L	1-2-3-Trichloropropane µg/L	Bromobenzene µg/L	2-Chlorotoluene µg/L
JEF003	WGX						
JEF004	WGX						
JEF008	WGX						
JEF010	WGX						
JEF012	WGX						
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX						
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX						
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS						
JEF038	WGXS						
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	n-Propylbenzene µg/L	4-Chlorotoluene µg/L	1-3-5-Trimethylbenzene µg/L	tert-Butylbenzene µg/L	1-2-4-Trimethylbenzene µg/L
JEF003	WGX					
JEF004	WGX					
JEF008	WGX					
JEF010	WGX					
JEF012	WGX					
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX					
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX					
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS					
JEF038	WGXS					
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	1-3-Dichlorobenzene µg/L	sec-Butylbenzene µg/L	1-4-Dichlorobenzene µg/L	p-Isopropyltoluene µg/L	1-2-Dichlorobenzene µg/L	n-butylbenzene µg/L
JEF003	WGX						
JEF004	WGX						
JEF008	WGX						
JEF010	WGX						
JEF012	WGX						
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX						
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX						
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS						
JEF038	WGXS						
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

Water Qualtiy Analyses - Pine Bluff Monitoring Area

Description	Samp_type	1-2-Dibromo-3-chloropropane µg/L	1-2-4-Trichlorobenzene µg/L	Naphthalene µg/L	Hexachlorobutadiene µg/L	1-2-3-Trichlorobenzene µg/L
JEF003	WGX					
JEF004	WGX					
JEF008	WGX					
JEF010	WGX					
JEF012	WGX					
JEF016	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF024	WGX					
JEF027	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF034	WGX	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXO	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF039	WGX					
JEF038	WGXD	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000
JEF038	WGXS					
JEF038	WGXS					
TRIP BLANK	WGXB	<1.0000	<1.0000	<1.0000	<1.0000	<1.0000

WGX - Original Sample; WGXO - Original with Duplicate; WGXD - Duplicate; WGXS - Spike; WGXB - Blank; Surr. - Surrogate

APPENDIX II

Inorganic Water-Quality Analyses for all Sampling Periods

Appendix II. Inorganic water quality analyses from all sampling periods.

Well Number	Date of Sample	pH	Temp. °C	Conduct. $\mu S/cm$	Alkalinity mg/L $CaCO_3$	Hardness mg/L $CaCO_3$	NH_3-N mg/L	NO_3-N mg/L	O-Phos. mg/L	T-Phos. mg/L	K mg/L
JEF001	Dec. 1987				39.0	18.0	0.170	0.10K	0.060	0.030	-
	Dec. 1990				-	-	0.100	0.02K	0.030	-	-
	June 1994				56.0	28.5	0.306	0.021	0.03K	0.041	-
JEF003	Dec. 1987	-	-	-	60.0	36.0	0.190	0.01K	0.060	0.130	-
	June 1994	6.87	27.7	157	60.0	33.0	0.082	0.054	0.110	0.128	-
	Sept. 1997	6.54	25.4	121	27.0	11.0	0.249	0.060	0.023	0.144	4.3
JEF004	Dec. 1987	-	-	-	59.0	26.0	0.290	0.010	0.090	0.100	-
	June 1994	-	23.3	192	74.0	13.2	0.392	0.036	0.088	0.061	-
	Sept. 1997	6.73	22.9	165	54.0	10.0	0.286	0.083	0.029	0.126	4.1
JEF005	Dec. 1987				56.0	26.0	0.240	0.010	0.080	0.100	-
	Dec. 1990				-	-	-	0.02K	0.150	-	-
JEF007	Dec. 1987				52.0	22.0	0.170	0.01K	0.020	0.020	-
	Dec. 1990				-	-	0.190	0.02K	0.030	-	-
JEF008	June 1994	-	-	92	60.0	22.5	0.250	0.028	0.058	0.091	-
	Sept. 1997	6.76	26.5	119	52.0	14.0	0.234	0.070	0.023	0.136	4.2
JEF010	June 1994	-	-	-	62.0	20.4	-	0.02K	-	0.101	-
	Sept. 1997	6.43	27.4	133	61.0	18.0	0.258	0.068	0.023	0.154	5.2
JEF011	Dec. 1987				56.0	24.0	0.230	0.010	0.080	0.110	-
	Dec. 1990				-	-	-	0.02K	0.080	-	-
JEF012	Dec. 1987	-	-	-	68.0	32.0	0.240	0.020	0.070	0.140	-
	Dec. 1990	-	-	-	-	-	-	0.020	0.140	-	-
	June 1994	-	-	-	72.0	26.7	-	0.023	-	0.181	-
	Sept. 1997	6.96	26.8	147	68.0	23,0	0.291	0.051	0.024	0.182	5.1

- Continued -

Well Number	Date of Sample	pH	Temp. °C	Conduct. $\mu S/cm$	Alkalinity mg/L $CaCO_3$	Hardness mg/L $CaCO_3$	NH_3-N mg/L	NO_3-N mg/L	O-Phos. mg/L	T-Phos. mg/L	K mg/L
JEF016	Dec. 1987	-	-	-	250.0	30.0	0.710	0.040	0.170	0.130	-
	June 1994	-	-	-	200.0	59.1	0.481	0.028	0.244	0.719	-
	Sept. 1997	6.78	21.3	534	203.0	55.0	0.690	0.01K	0.058	0.248	4.4
JEF019	Dec. 1987				104.0	182.0	0.020	1.70	0.010	0.460	-
	Dec. 1990				-	-	0.05K	1.54	0.050	-	-
	June 1994				115.0	194.0	0.096	1.13	0.03K	0.101	-
JEF024	June 1994	-	-	-	73.0	18.0	-	0.026	-	0.171	-
	Sept. 1997	6.36	23.8	168	70.0	18.0	0.291	0.092	0.023	0.154	5.1
JEF027	Sept. 1997	6.68	18.6	691	303.0	289.0	0.526	0.084	0.054	0.512	1.1
JEF034	June 1994	-	-	-	292.0	273.0	-	0.034	-	0.889	-
	Sept. 1997	6.63	20.4	630	283.0	239.0	0.693	0.01K	0.053	0.814	1.2
JEF038	June 1994	-	-	-	73.0	440.0	-	0.025	-	1.040	-
	Sept. 1997	6.86	19.0	1462	581.0	410.0	0.841	0.01K	0.083	0.994	1.9
JEF039	June 1994	-	-	-	77.0	26.7	-	0.023	-	0.151	-
	Sept. 1997	6.92	25.4	173	74.0	19.0	0.300	0.01K	0.025	0.174	4.7

Well Number	Date of Sample	Ca mg/L	Na mg/L	Mg mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	SiO_2 mg/L	F mg/L	Fe mg/L	TDS mg.L
JEF001	Dec. 1987	1.5	7.0		48	3.0	6.0			2.30	-
	Dec. 1990	-	-		-	6.0	3.0			3.70	-
	June 1994	7.4	21.9		68	4.1	22.9			2.90	16.0
JEF003	Dec. 1987	5.4	12.0	-	73	2.0	4.0	-	-	2.30	-
	June 1994	9.8	11.0	-	73	2.8	5.5	-	-	2.01	84.0
	Sept. 1997	4.8	13.0	0.06K	33	2.5	3.8	15.6	0.08	2.37	74.0
JEF004	Dec. 1987	4.7	11.0	-	72	2.0	5.0	-	-	3.40	-
	June 1994	4.0	16.1	-	90	4.2	1.9	-	-	1.62	94.0
	Sept. 1997	4.3	14.3	0.06K	66	2.5	2.7	15.8	0.07	6.64	81.0
JEF005	Dec. 1987	2.4	13.5		68	3.0	4.0			2.20	-
	Dec. 1990	-	-		-	3.0	5.0			-	-
JEF007	Dec. 1987	3.6	9.0		68	3.0	4.0			2.20	-
	Dec. 1990	-	-		-	6.0	3.0			2.10	-
JEF008	June 1994	6.3	11.8	-	73	3.3	2.9	-	-	33.4	80.0
	Sept. 1997	6.1	10.9	0.06K	63	2.3	3.1	14.1	0.07	2.80	77.0
JEF010	June 1994	6.6	13.1	-	76	2.9	3.9	-	-	2.40	87.0
	Sept. 1997	6.7	12.6	0.20	74	1.9	2.7	16.0	0.10	2.22	84.0
JEF011	Dec. 1987	2.3	16.8		68	2.0	3.0			2.10	-
	Dec. 1990	-	-		-	4.0	5.0			-	-
JEF012	Dec. 1987	3.6	18.0	-	83	2.0	2.0	-	-	2.10	-
	Dec. 1990	-	-	-	-	3.0	4.0	-	-	-	-
	June 1994	7.5	16.1	-	88	2.6	3.9	-	-	2.20	99.0
	Sept. 1997	8.3	15.8	0.60	83	1.6	2.6	17.9	0.10	1.57	93.0

- Continued -

Well Number	Date of Sample	Ca mg/L	Na mg/L	Mg mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	SiO_2 mg/L	F mg/L	Fe mg/L	TDS mg/L
JEF016	Dec. 1987	7.7	128.0	-	305	13.0	52	-	-	0.40	-
	June 1994	16.0	66.0	-	244	18.8	14	-	-	2.90	305
	Sept. 1997	16.1	85.2	3.7	248	16.4	31	34.5	0.16	1.17	318
JEF019	Dec. 1987	24.0	65.0		127	145	8.0			8.60	-
	Dec. 1990	-	-		-	148	8.0			2.10	-
	June 1994	44.0	58.0		140	196	5.9			19.7	557
JEF024	June 1994	7.0	20.0	-	89	3.3	8.7	-	-	2.90	108
	Sept. 1997	6.9	19.9	0.10	85	1.9	8.1	16.7	0.09	2.23	101
JEF027	Sept. 1997	91.2	16.7	14.9	370	2.7	9.1	23.9	0.09	5.95	397
JEF034	June 1994	79.0	14.3	-	356	13.6	19.7	-	-	12.3	390
	Sept. 1997	75.9	11.9	11.9	345	13.5	17.6	28.5	0.17	11.8	342
JEF038	June 1994	136	103.0	-	89	103	27.5	-	-	16.4	747
	Sept. 1997	143	118.4	12.8	708	131	22.9	25.2	0.11	19.0	829
JEF039	June 1994	7.5	20.8	-	94	2.2	5.9	-	-	1.70	108
	Sept. 1997	7.1	20.6	0.40	90	2.1	5.3	17.3	0.11	1.59	103

Well Number	Date of Sample	Mn µg/L	Zn µg/L	Ni µg/L	B µg/L	Be µg/L	Ba µg/L	Co µg/L	Cd µg/L	V µg/L	Cu µg/L
JEF001	Dec. 1987	-	-	-	-	-	-	-	0.5K	-	165
	Dec. 1990	70.0	-	-	-	-	-	-	-	-	-
	June 1994	59.0	8K	-	-	-	128	-	0.5K	6K	162
JEF003	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	June 1994	33.8	2K	2K	-	-	119	-	1.6K	-	2K
	Sept. 1997	49.6	2.3	5K	20.3	2K	125	3K	0.04K	5K	2K
JEF004	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	30.0
	June 1994	187	8K	-	-	-	127	-	0.5K	6K	4K
	Sept. 1997	81.1	2K	5K	15.9	2K	118	3K	0.04K	5K	2K
JEF005	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	Dec. 1990	-	-	-	-	-	-	-	-	-	-
JEF007	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	Dec. 1990	50.0	8K	-	-	-	-	-	0.5K	-	25K
JEF008	June 1994	63.0	8K	-	-	-	126	-	0.5K	-	11.0
	Sept. 1997	62.0	2K	-	23.9	2K	119	3K	0.04K	5K	2K
JEF010	June 1994	63.0	43.0	10K	-	-	126	-	0.5K	6K	4K
	Sept. 1997	62.3	31.6	5K	26.1	2K	125	3K	0.04K	5K	2K
JEF011	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	22.0
	Dec. 1990	-	-	-	-	-	-	-	-	-	-
JEF012	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	Dec. 1990	-	-	-	-	-	-	-	-	-	-
	June 1994	74.0	8K	-	-	-	92	-	0.5K	6K	4K
	Sept. 1997	72.8	2.4	5K	34.5	2K	88	3K	0.04K	5K	2K

- Continued -

Well Number	Date of Sample	Mn µg/L	Zn µg/L	Ni µg/L	B µg/L	Be µg/L	Ba µg/L	Co µg/L	Cd µg/L	V µg/L	Cu µg/L
JEF016	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	June 1994	352	46.0	-	-	-	50	-	0.5K	6K	4K
	Sept. 1997	233	6.0	5K	328.9	2K	50	3K	0.04K	5K	3.2
JEF019	Dec. 1987	-	-	-	-	-	1000K	-	0.5K	-	15K
	Dec. 1990	40K	170	-	-	-	-	-	0.5K	-	25K
	June 1994	1500	960	10K	-	-	101	-	0.5K	6K	6.7
JEF024	June 1994	54.0	8K	10K	-	-	116	-	0.5K	6K	4K
	Sept. 1997	56.4	14.9	5K	43.9	2K	113	3K	0.04K	5K	2K
JEF027	Sept. 1997	385	6.0	5K	25.5	2K	376	3K	0.04K	5K	2K
JEF034	June 1994	268	9.0	10K	-	-	375	-	0.5K	6K	4K
	Sept. 1997	260	3.2	5K	16.7	2K	367	3K	0.04K	5K	2K
JEF038	June 1994	1100	8K	10K	-	-	497	-	0.5K	6K	4K
	Sept. 1997	1130	9.2	5K	34.9	2.1	561	3K	0.04K	5K	2K
JEF039	June 1994	51.0	8K	10K	-	-	93	-	0.5K	6K	4K
	Sept. 1997	53.1	9.6	5K	44.5	2K	86	3K	0.04K	5K	2K

Well Number	Date of Sample	Al µg/L	Cr µg/L	Pb µg/L	As µg/L	Se µg/L	Br mg/L	Hg µg/L	TSS mg/L	TOC mg/L
JEF001	Dec. 1987	-	1.0	1.0	5K	5K	-	0.5K	-	0.4
	Dec. 1990	-	-	-	-	-	-	-	-	-
	June 1994	-	1K	2K	10K	10K	-	-	-	1K
JEF003	Dec. 1987	-	1.0	1K	5K	5K	-	0.5K	-	2.6
	June 1994	-	2.6	2K	10K	10K	-	-	-	0.5
	Sept. 1997	20.1	0.4K	0.4K	5K	5K	0.03K	0.025K	1K	1K
JEF004	Dec. 1987	-	1.0	9.0	5K	5K	-	0.5K	-	3.0
	June 1994	-	1K	2K	10K	10K	-	-	-	1K
	Sept. 1997	23.4	0.4K	0.4K	5K	5K	0.03K	-	1K	1K
JEF005	Dec. 1987	-	1K	7.0	5K	5K	-	0.5K	-	3.6
	Dec. 1990	-	-	-	-	-	-	-	-	-
JEF007	Dec. 1987	-	1K	1K	5K	5K	-	0.5K	-	3.0
	Dec. 1990	-	1K	2K	-	-	-	-	-	-
JEF008	June 1994	-	1K	2K	10K	10K	-	-	-	1K
	Sept. 1997	18.9	0.4K	0.4K	5K	5K	0.03K	-	1K	1K
JEF010	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.03K	-	1K	1K
JEF011	Dec. 1987	-	1K	12.0	5K	5K	-	0.5K	-	3.1
	Dec. 1990	-	-	-	-	-	-	-	-	-
JEF012	Dec. 1987	-	1K	1.0	5K	5K	-	0.5K	-	1.8
	Dec. 1990	-	-	-	-	-	-	-	-	-
	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.03K	-	1K	1K

- Continued -

Well Number	Date of Sample	Al $\mu g/L$	Cr $\mu g/L$	Pb $\mu g/L$	As $\mu g/L$	Se $\mu g/L$	Br mg/L	Hg $\mu g/L$	TSS mg/L	TOC mg/L
JEF016	Dec. 1987	-	1K	1K	5K	5K	-	0.5K	-	1.6
	June 1994	-	1K	2K	10K	10K	-	-	-	4.9
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.05	-	5.0	1.8
JEF019	Dec. 1987	-	1.0	1K	44.0	5K	-	0.5K	-	7.9
	Dec. 1990	-	1K	2K	10K	-	-	-	-	-
	June 1994	-	1K	2K	37.0	10K	-	-	-	3.0
JEF024	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.10	-	1K	1K
JEF027	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.51	-	8.0	1.5
JEF034	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.06	-	23.5	1.7
JEF038	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	16K	0.4K	0.4K	5K	5K	0.14	-	46.0	8.5
JEF039	June 1994	-	1K	2K	10K	10K	-	-	-	-
	Sept. 1997	30.4	0.4K	0.4K	5K	5K	0.03K	-	1K	1K

APPENDIX III

Alluvial and Sparta Formation Hydrographs

(See Figure 6 for location of wells used for water measurement)

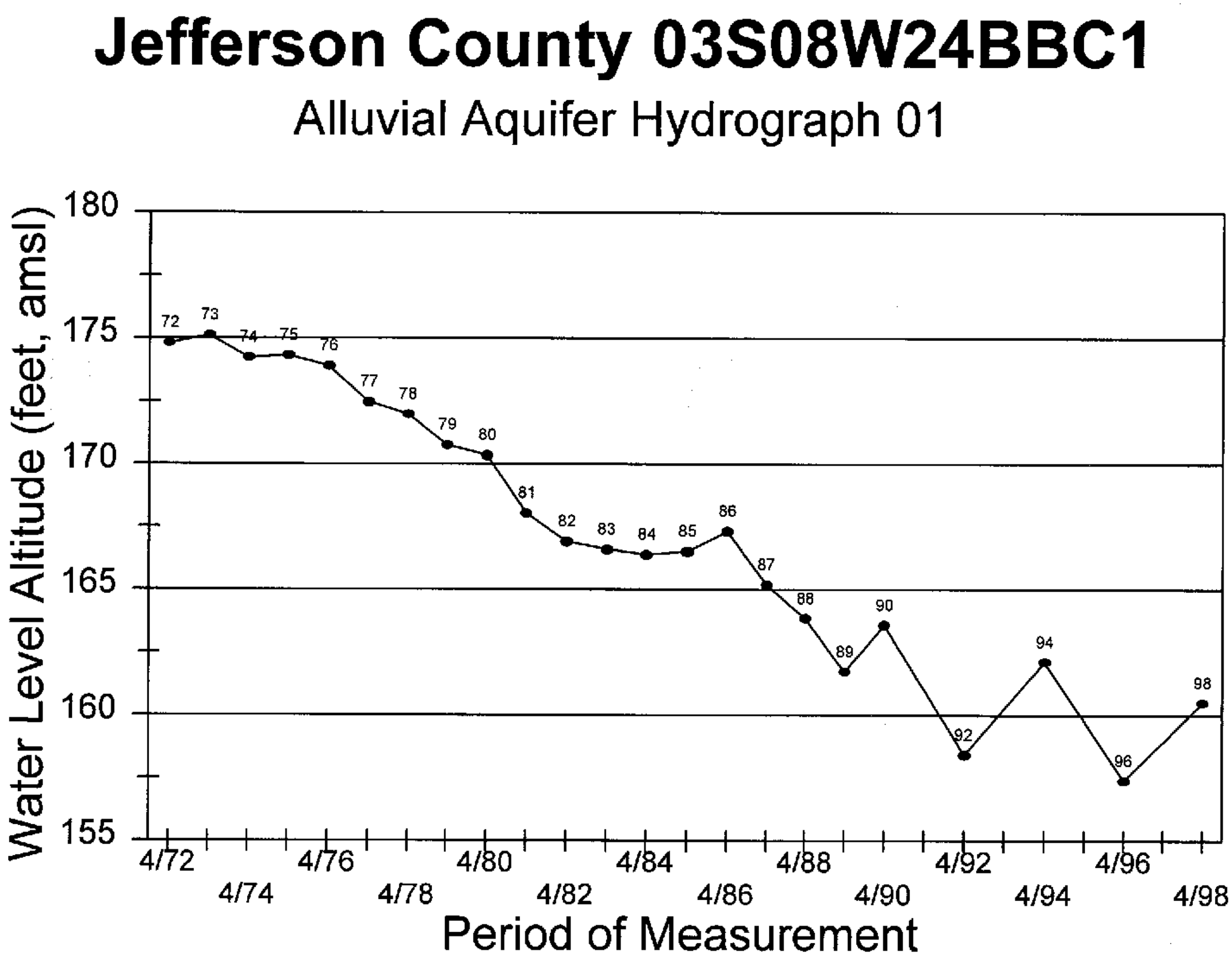

Figure IIIa. Water level hydrograph from Alluvial well located in northern Jefferson County (See Figure 6).

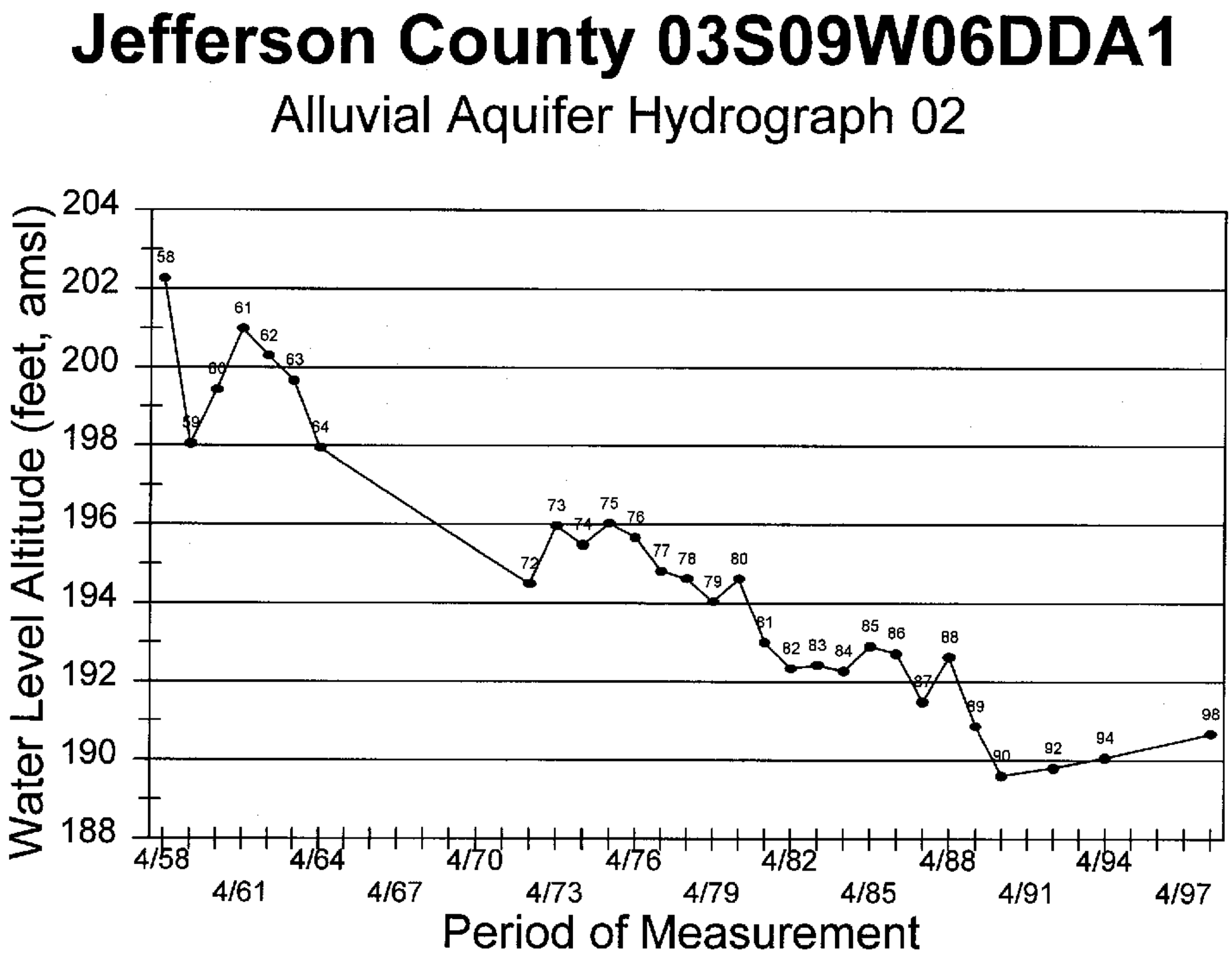

Figure IIIb. Water level hydrograph from Alluvial well located in northern Jefferson County (See Figure 6).

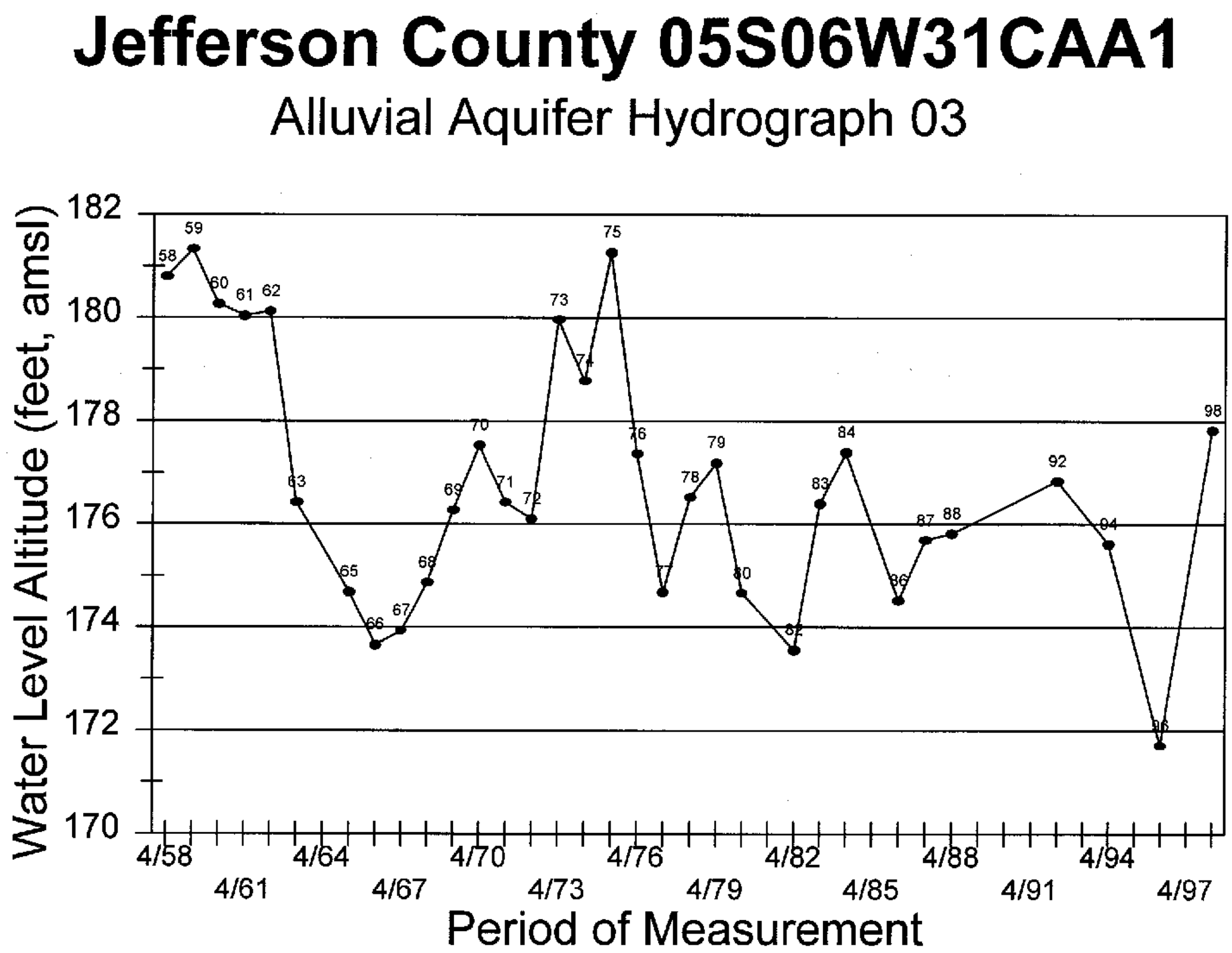

Figure IIIc. Water level hydrograph from Alluvial well located in central Jefferson County (See Figure 6).

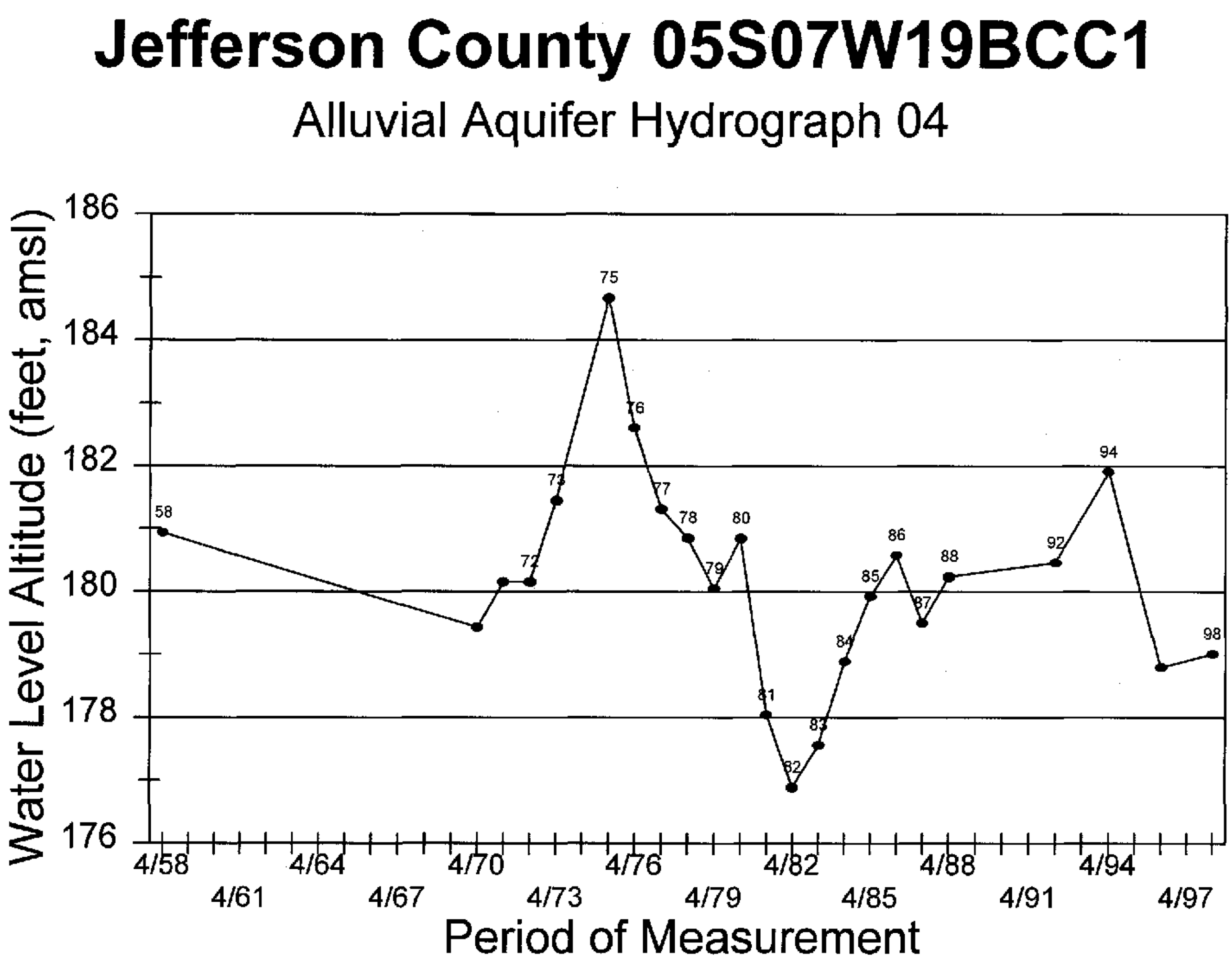

Figure IIId. Water level hydrograph from Alluvial well located in central Jefferson County (See Figure 6).

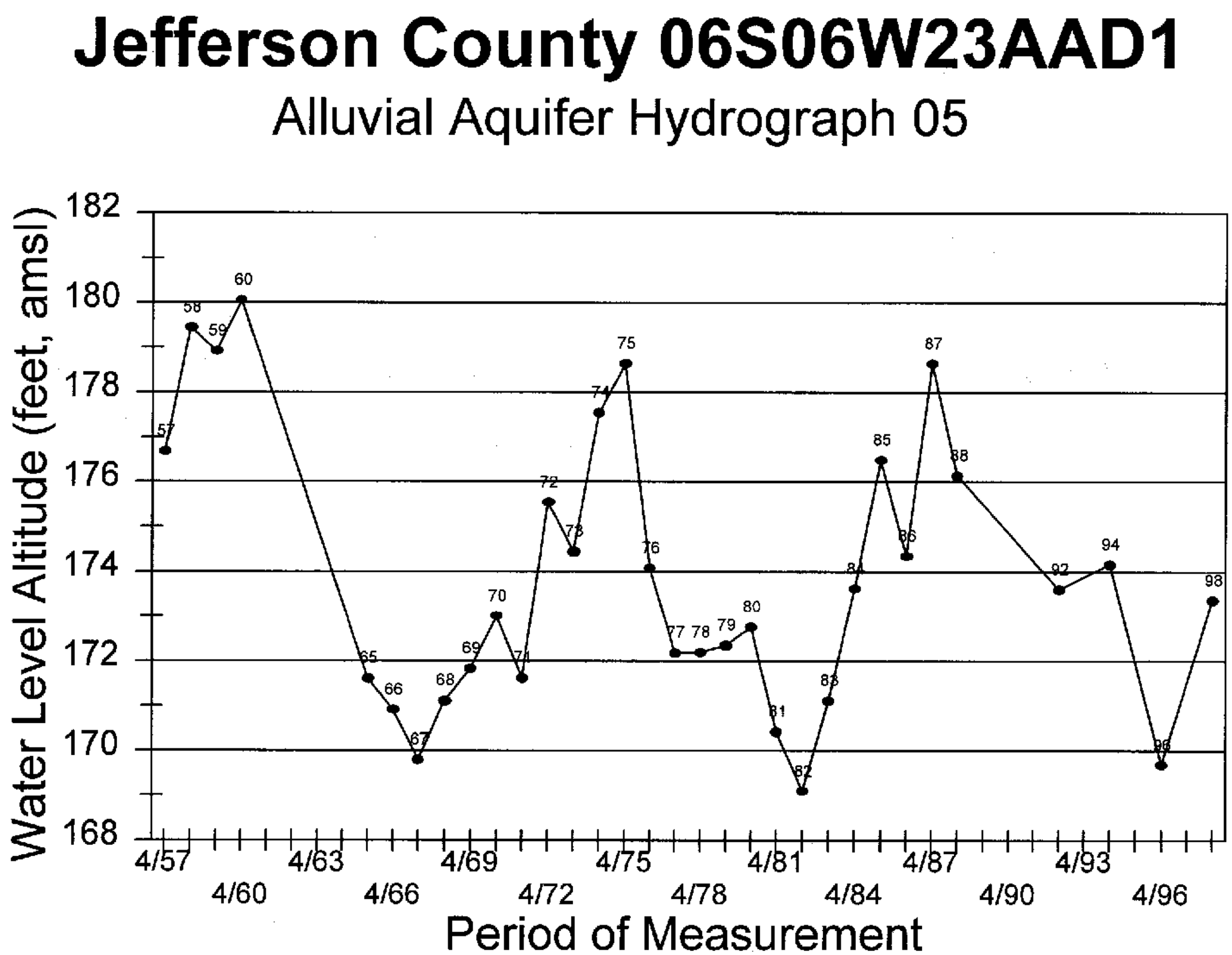

Figure IIIe. Water level hydrograph for Alluvial well located in central Jefferson County (See Figure 6).

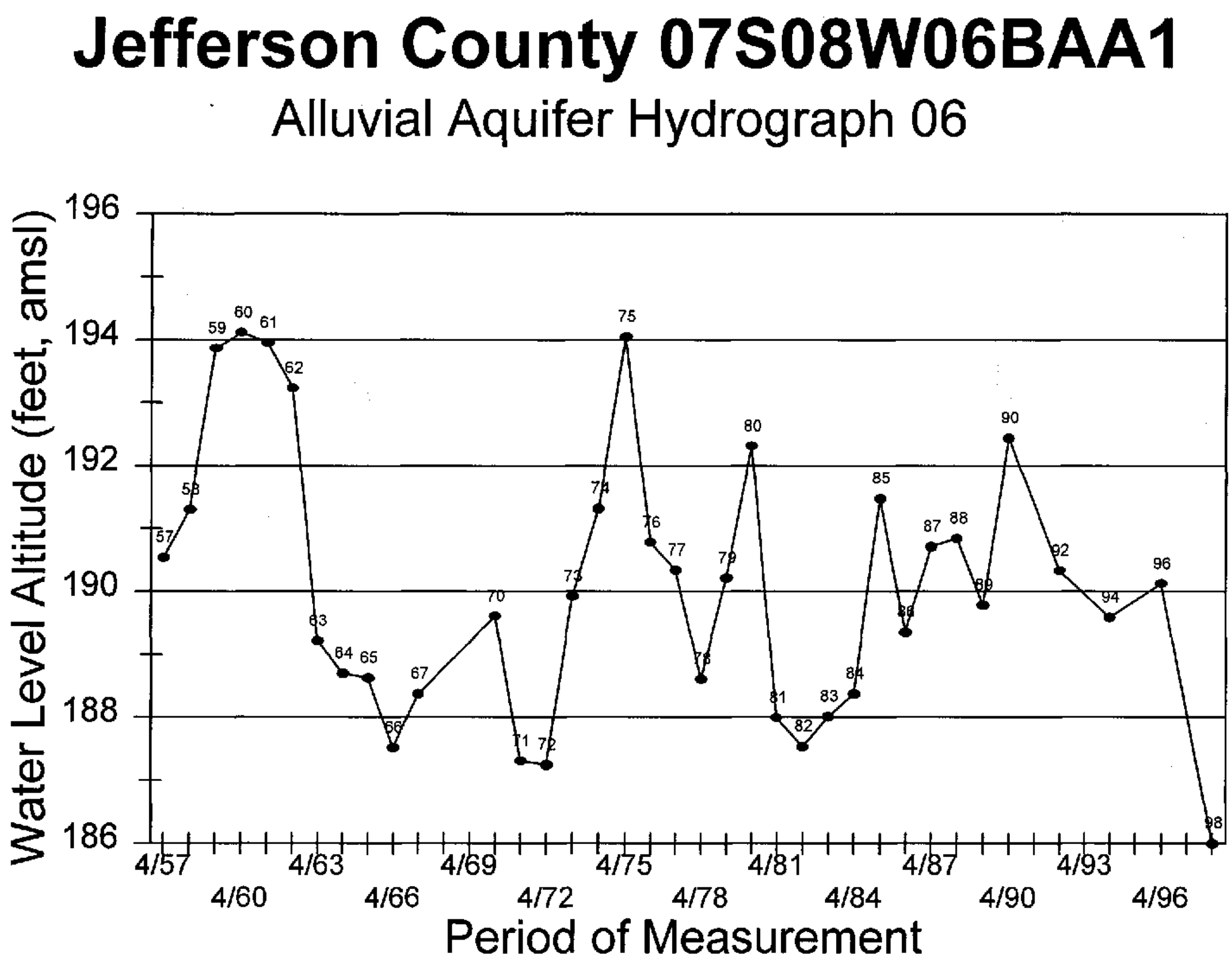

Figure IIIf. Water level hydrograph for Alluvial well located in central Jefferson County (See Figure 6).

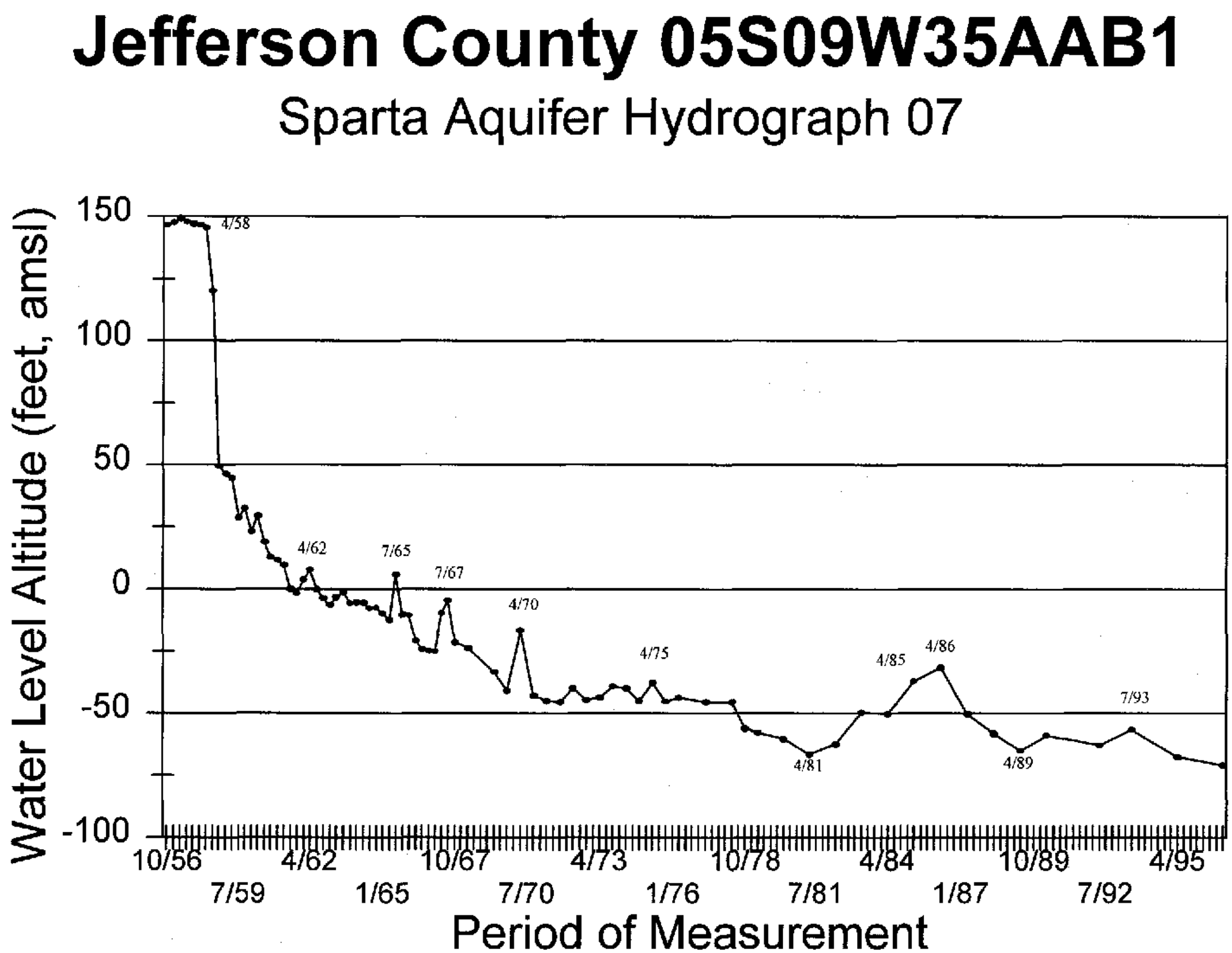

Figure IIIg. Water level hydrograph for Sparta Formation well in central Jefferson County (See Figure 6).

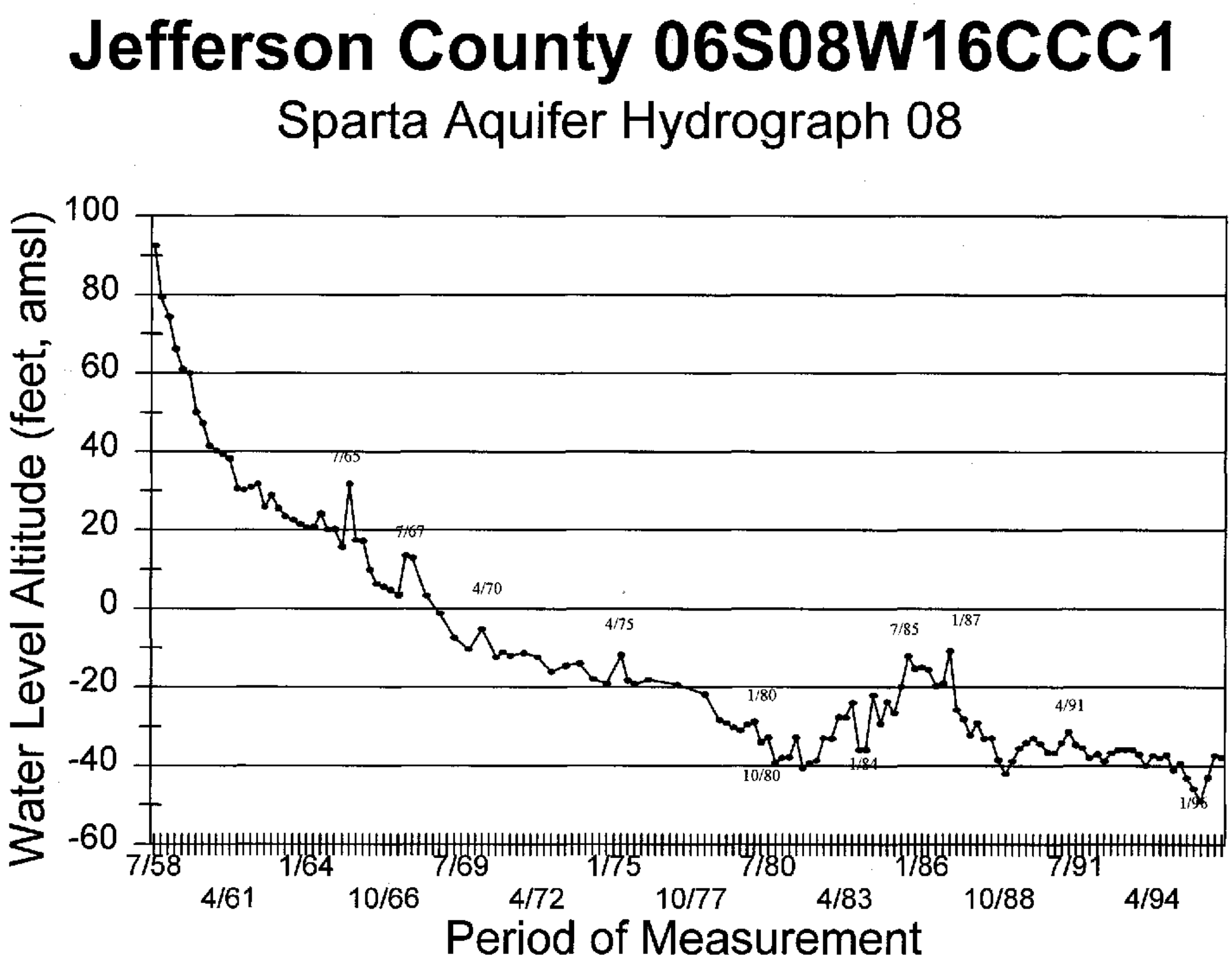

Figure IIIg. Water level hydrograph for Sparta Formation well in central Jefferson County (See Figure 6).

APPENDIX IV

Statistical Analyses of Historical versus Present Data for Sparta Aquifer

Sheet 1. F-Test Analyses
Sheet 2. Mann-Whitney Analyses

(Sheet 1)

Results of *F*-Test Analyses

TDS

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	87.57143	85.70588
Variance	133.2857	286.4706
Observations	7	17
df	6	16
F	2.149297	
P(F<=f) one-tail	0.103745	
F Critical one-tail	2.178329	

Bicarbonate

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	70.75714	66.76471
Variance	378.3962	309.1912
Observations	7	17
df	6	16
F	1.223826	
P(F<=f) one-tail	0.344887	
F Critical one-tail	2.741311	

Chloride

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	2.112857	3.676471
Variance	0.116757	0.595662
Observations	7	17
df	6	16
F	5.101716	
P(F<=f) one-tail	0.004199	
F Critical one-tail	2.178329	

Sodium

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	15.3	14.85882
Variance	13.74	29.24007
Observations	7	17
df	6	16
F	2.128099	
P(F<=f) one-tail	0.106575	
F Critical one-tail	2.178329	

Sulfate

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	4.034286	5.111765
Variance	4.057395	6.411103
Observations	7	17
df	6	16
F	1.580103	
P(F<=f) one-tail	0.216573	
F Critical one-tail	2.178329	

Iron

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	2.774286	2.405882
Variance	3.094029	9.621076
Observations	7	17
df	6	16
F	3.109563	
P(F<=f) one-tail	0.032478	
F Critical one-tail	2.178329	

Calcium

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	6.314286	7.011765
Variance	1.908095	2.637353
Observations	7	17
df	6	16
F	1.382191	
P(F<=f) one-tail	0.280651	
F Critical one-tail	2.178329	

Magnesium

F-Test: Two-Sample for Variances

	Variable	*Variable 2*
Mean	0.198571	2.111765
Variance	0.049448	0.168603
Observations	7	17
df	6	16
F	3.409728	
P(F<=f) one-tail	0.023149	
F Critical one-tail	2.178329	

(Sheet 2)

Mann-Whitney Test

Mann-Whitney U Test Group 1 - 7 variables Group 2 - 17 variables										
Variable	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-level	Z adjusted	p-level	Valid N Group 1	Valid N Group 2	2*1sided exact p
Cl	142.50	3178.50	22.50	-5.745	0.00000	-6.177	0.00000	15	66	0.00000
SO_4	435.00	2886.00	315.00	-2.188	0.02838	-2.192	0.02838	15	66	0.02804
Ca	458.00	2863.00	338.00	-1.909	0.05597	-1.911	0.05597	15	66	0.05651
K	845.50	2475.50	264.50	2.802	0.00499	2.808	0.00498	15	66	0.00429
Mg	120.00	3201.00	0.00	-6.018	0.00000	-6.044	0.00000	15	66	0.00000
Na	667.00	2654.00	443.00	0.632	0.52724	0.633	0.52643	15	66	0.53499
HCO_3	688.00	2633.00	422.00	0.888	0.37479	0.889	0.37382	15	66	0.38183
TDS	661.00	2660.00	449.00	0.559	0.57598	0.560	0.57516	15	66	0.58172
Fe	823.00	2498.00	287.00	2.529	0.01144	2.541	0.01105	15	66	0.01061