

**INTEGRATING THE EFFECTS OF THE GREAT FLOOD OF 1993:
CHANGES IN GROUND WATER HYDROLOGY AND QUALITY IN RELATION TO
CHANGES IN SURFACE WATERS**

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ABSTRACT

The Great Flood of 1993 had far-reaching impacts upon surface waters in the State of Missouri. Many stations along the Missouri River were above flood stage for months during the summer of 1993. Researchers conducted extensive sampling during the flood and discovered high levels of agricultural contaminants in many of the samples. This result was surprising, as scientists had previously always assumed that the large volumes of water carried by floods dilute contaminants to lower-than-normal concentrations.

The objectives of this study were to

- ◆ locate a series of wells along the Missouri River that could be used to track hydrological and contaminant trends in the alluvial aquifer,
- ◆ monitor those wells approximately monthly during the period of study,
- ◆ determine hydrological and biological/chemical trends in those wells,
- ◆ relate the monitoring results to water level and biological/chemical quality in the Missouri River, and
- ◆ make predictions with respect to impacts of future floods.

Groundwater samples obtained during the study were analyzed for chemical and biological constituents used to indicate groundwater contamination. Parameters that are used to "fingerprint" waters--cations, anions, pH, conductivity, and temperature--were also determined. These parameters were obtained to determine if unusual amounts of surface waters had entered the groundwater system.

Water level data showed a downward trend that was probably on-going at the beginning of the study. The trend appeared to be in excess of normal seasonal changes. However, there are too few sampling rounds to conclude that the downward trend was solely a remnant of the flood; part of the trend may be normal seasonal variation.

The study showed that there were changes in most of the water quality parameters investigated. Statistical analysis indicated the "after flood" data distribution indicated a different population from the "before flood" data. Analysis also indicated that the aquifer chemistry for wells close to the river more closely resembled the chemistry of the river than did water from wells farther from the river; this pattern did not change over time. During the period of the study, coliforms were detected only intermittently and at low levels; pesticides were not detected.

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I. INTRODUCTION

The Great Flood of 1993 had significant impact upon surface waters in the State of Missouri. Many stations along the Missouri River were above flood stage for months during the summer of 1993. Researchers conducted extensive sampling during the flood and discovered high levels of agricultural contaminants in many of the samples. This result was surprising, as scientists had previously always assumed that the large volumes of water carried by floods dilute contaminants to lower-than-normal concentrations.

Much attention was given to surface water flows and quality during the Great Flood of 1993, but little attention was given to the impacts of the flood on the ground-water quality in the area. Many people depend on the ground water of the Missouri River Alluvium for their water source. Therefore, the maintenance of high water quality in this aquifer is essential to the livelihood of the people who depend on it. This research project was designed to determine if the 1993 flood produced a change in the water quality of the alluvial aquifer.

The specific objectives of this study were to:

- ◆ locate a series of wells along the Missouri River that could be used to track hydrological and contaminant trends in the alluvial aquifer,
- ◆ monitor those wells approximately monthly during the period of study,
- ◆ determine hydrological and biological/chemical trends in those wells,
- ◆ relate the monitoring results to water level and biological/chemical quality in the Missouri River, and

The area of study and the placement of the monitoring wells is shown in Figure 1.

Ground-water quality data of the Missouri River alluvium will also be compared with Missouri River water quality data over a period of time. These data will be compared to look for possible patterns in the transport of contaminants from the surface water to the ground water, and possible lag times between contaminant peaks in surface water and ground water. It is hoped that links between surface water and ground water will lead to the development of a system that will permit use of surface-water quality to predict future ground-water quality.

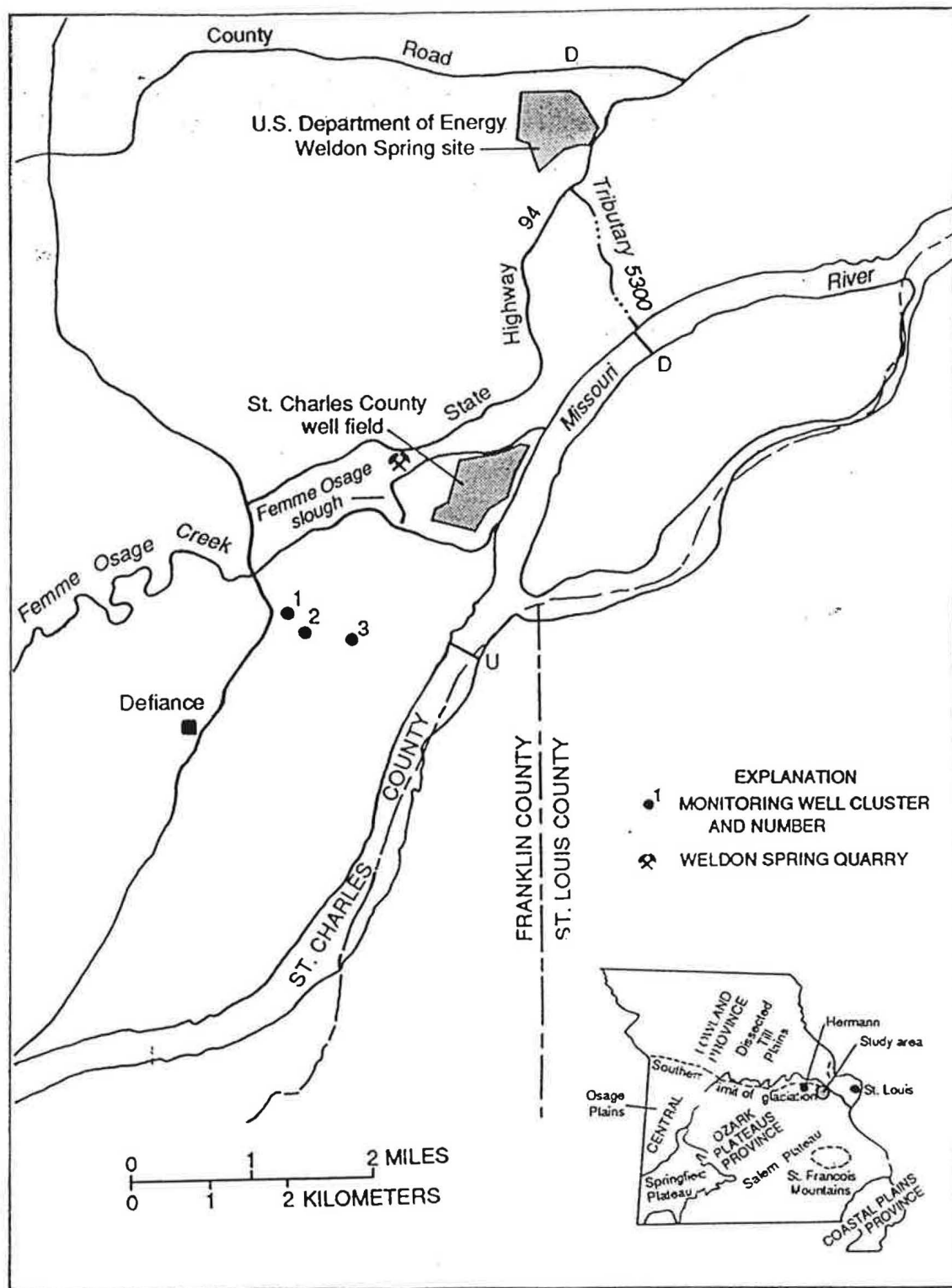


Figure 1. Study area

II. BACKGROUND

A. RELEVANT BACKGROUND OF THE GREAT FLOOD OF 1993:

The Great Flood of 1993 was the result of unprecedented heavy rainfall over a large area of the upper midwest (Brown et al., 1994). In terms of precipitation amounts, record river stages, areal extent of flooding, persons displaced, crop and property damage, and flood duration, this event surpassed all floods in the United States during modern times (Brown et al., 1994).

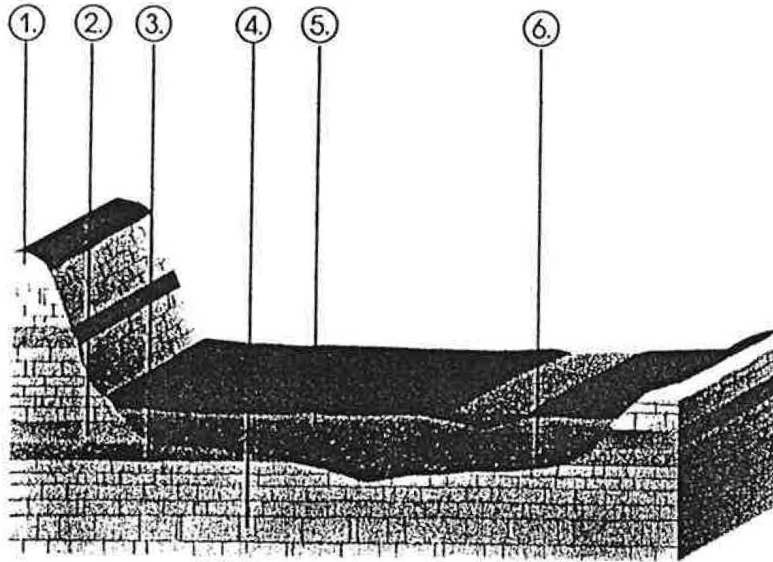
Soil conditions in the upper midwest were near saturation through the winter of 1992-1993. Then, with a rapid spring snow melt and an above average rainfall for the months of April, 1993, and May, 1993, flooding began to be a problem in the northern part of the area (Parrett et al., 1993). Some regions of the Upper Mississippi River Basin received more than twice the normal precipitation during the months of April, 1993, and May, 1993 (Wakl et al., 1993). Heavy rains continued for most of the Upper Midwest throughout the months of June 1993 and July 1993, causing flooding throughout the Upper Mississippi and Missouri River Basins. Most of the area received from 150 percent to 200 percent of the 1961-1990 normal total precipitation from January, 1993, through July, 1993 (Wakl et al., 1993).

The large amount of precipitation occurring throughout the nine state area (Missouri, Illinois, Iowa, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, and Wisconsin) of the Upper Mississippi River Basin exceeded the capacity of the Upper Mississippi and Missouri River Basins, and record flooding occurred throughout the area (Brown et al., 1994). The flood-peak discharges equaled or exceeded the 10-year recurrence interval at 154 streamflow gaging stations, and the flood peak discharges exceeded the 100-year recurrence interval at 45 gaging stations (Parrett et al., 1993). At 41 streamflow gaging stations, the peak discharge was greater than the previous maximum known discharge, and at 15 additional gaging stations, peak discharges exceeded the previous maximum regulated peak discharge (Parrett et al., 1993).

In the state of Missouri, the 1993 flood on the Missouri River set record river stages at 12 locations, and river traffic on the Missouri River had to be closed for most of the Great Flood of 1993 (Brown et al., 1994). The Missouri River was above flood stage for over two months, and crested in the St. Charles area at about two feet above the previous record flood stage (Brown et al., 1994).

B. MISSOURI RIVER ALLUVIUM:

The ground water region known as the Missouri River alluvium is located along the Missouri River. The typical geologic deposits underlying this region consist of weathered bedrock, shale, sandstone, limestone, clay and silt, and sand and gravel as shown in Figure 2. Because of the rapid recharge of the alluvium from rivers in the area, ground water is plentiful, with well yields often exceeding 1,000 gallons per minute (Missouri Department of Natural



1. Weathered Bedrock; 2. Shale; 3. Sandstone;
4. Limestone; 5. Clay and Silt; 6. Sand and Gravel

Figure 2. Typical geologic deposits of the Missouri River Alluvium.
(Missouri Department of Natural Resources, Undated)

Resources, Undated). Some wells in this area have been found to produce yields as large as 3000 gallons per minute (Emmett and Jeffery, 1968). The water table in the area is usually within 20 feet of the ground surface, so ground water may be pumped rapidly from shallow wells. Although the water in the area is usually characterized as very hard (greater than 180 milligrams per liter), and high in iron content (concentration not stated), the overall quality of the ground water is usually suitable for domestic use (Emmett and Jeffery, 1968).

The area being investigated in this project is located on the north side of the Missouri River, near Defiance, Missouri. The monitoring wells are located in an approximately six mile long alluvial bottom of the Missouri River, known as Darst Bottoms. The monitoring wells form an approximate straight line, perpendicular to the Missouri River, about 2000 feet upstream of Missouri River Mile 50, as pictured in Figure 1.

The thickness of the Missouri River Alluvium at the downstream end of Darst Bottoms varies from 89 to 116 feet (Mugel, 1993). The typical composition of the Darst Bottoms alluvium is 10 to 20 feet of fine materials (mostly silts, clays and fine sands) underlain by about 20 feet of fine sands, underlain by about 70 feet of coarser sand, gravel, and boulders; bedrock beneath the alluvium is a dark grey limestone known as the Plattin Formation (Soil Consultants,

Inc., 1988). Typically, there is an exponential increase in sediment grain size, and a general increase in hydraulic conductivity, as depth increases (Grannamann and Sharp, 1979). Maximum variability and smallest average grain size are found in the top stratum; grain size and uniformity increase with depth.

Confined aquifer conditions exist where the upper 10 to 20 feet of overlying material are predominantly clays, and unconfined aquifer conditions exist where sand is predominant near the surface (Mugel, 1993). Water levels in the aquifer are controlled by the stage of the Missouri River, and the water-table elevation fluctuates with changes in the river level. Many of the confined aquifer conditions are marginal. Marginal confined conditions exist where the water level is at or near the bottom of the confining layer (Emmett and Jeffery, 1968). Thus, ground water may be under confined aquifer conditions when the river is at high stage (during the wet seasons), but the aquifer may become unconfined as the water level in the aquifer drops below the confining layer during low river stages (during dry seasons).

The hydrogeology of the study area has been previously investigated. The technical literature on Darst Bottoms contain results from two pump tests performed on the alluvial aquifer. One of the aquifer tests was performed in March, 1967, using one of the wells in the Weldon Spring Ordnance well field (now called the St. Charles County well field), located at the downstream end of Darst Bottoms. The well was pumped at a rate of 2,650 gallons per minute (gpm) for 47 hours. Drawdowns were measured in observation wells that were located at distances of 244 feet, 261 feet, 484 feet, and 502 feet from the pumping well. The test indicated that the coefficients of transmissivity and storativity of the aquifer in the vicinity of the test were approximately 270,000 gallons per day per foot (gpd/ft) and 0.2, respectively (Emmett and Jeffery, 1968). The average hydraulic conductivity was shown to be about 3,000 gallons per day per square foot (gpd/ft²) (Emmett and Jeffery, 1968).

Another aquifer test in the same area was conducted in 1985 by Layne-Western Company, Inc. of Kansas City, Kansas. For this test, an existing well in the St. Charles County well field was used as the pumping well. The well was pumped at a rate of 1500 gpm for approximately 84 hours (Layne-Western Company, Inc., 1986). Water-level measurements were taken at existing monitoring wells, at newly-installed monitoring wells, observation wells in the vicinity of the test well, and at production wells throughout the well field. Stage data from the Missouri River was also obtained (Layne-Western Company, Inc., 1986).

The transmissivity of the aquifer in the vicinity was determined to range from 377,000 gpd/ft to 450,000 gpd/ft of aquifer material (Layne-Western Company, Inc., 1986). The storativity coefficient was estimated to be 0.01 for the short term test (Layne-Western Company, Inc., 1986). The hydraulic conductivity of the aquifer material was found to be 4000 gpd/ft² to 4500 gpd/ft² in the lower, productive portion of the aquifer (Layne-Western Company, Inc., 1986).

The results for the two pump tests are summarized in Table I. The summary of results from the pump tests show some differences. The differences can possibly be explained by

examining the storativity values from the two tests. Typical storativity values for an unconfined aquifer range from 0.02 to 0.30, and typical storativity values for a confined aquifer are usually less than 0.005 (Fetter, 1994). By comparing the storativity values of the two pump test with the typical storativity values for confined and unconfined aquifers, it is likely that the well used in the 1967 pump test was under unconfined conditions at the time of the test and that the well used in the 1985 pump test was probably under partially confined conditions.

Table I. Summary of alluvial aquifer properties for the Darst Bottoms area.

Test Date	Pump Rate (GPM)	Duration (Hours)	Transmissivity (GPD/FT)	Storativity (Dimensionless)	Hydraulic Conductivity (GPD/FT ²)
1967	2650	47	270,000	0.20	3000
1985	1500	84	377,000 to 450,000	0.01	4000 to 4500

Although the Missouri River alluvium has some inhomogeneities, the transmissivity, storativity, and hydraulic conductivity of the aquifer in the area studied should be similar to the aquifer properties of the St. Charles County well field. The zones of the aquifer intercepted by the monitoring wells in this study would be expected to have slightly lower values of transmissivity, storativity, and hydraulic conductivities than the average values of the aquifer, as these wells are much shallower than the production wells in the well field. As mentioned previously, as depth within the aquifer increases, mean grain size of the particles in the alluvium material also increases, resulting in increases in the hydraulic conductivity of the aquifer.

Where the Missouri River flows parallel to the valley wall for a considerable distance, as it does along Darst Bottoms, and when the Missouri River is at normal or low stage, the ground water flows in a downstream direction through the alluvial aquifer before discharging into the Missouri River, (Grannamann and Sharp, 1979) as shown in Figure 3. During periods of high river stage, ground water flow reverses and water from the Missouri River flows into the alluvial aquifer, (Emmett and Jeffery, 1968) as shown in Figure 3. Thus, the river stage not only greatly influences the ground water level; river stage also acts to change the direction of ground water flow. This influence of the river on the ground water is also affected by distances from the river, with the river having greatest influence on ground water near the river and a lesser influence on the ground water some distance from the river (Grannamann and Sharp, 1979). It has been predicted that the alluvial aquifer system normally approaches a steady state condition approximately 72 hours after the occurrence of any major hydrological change (Layne-

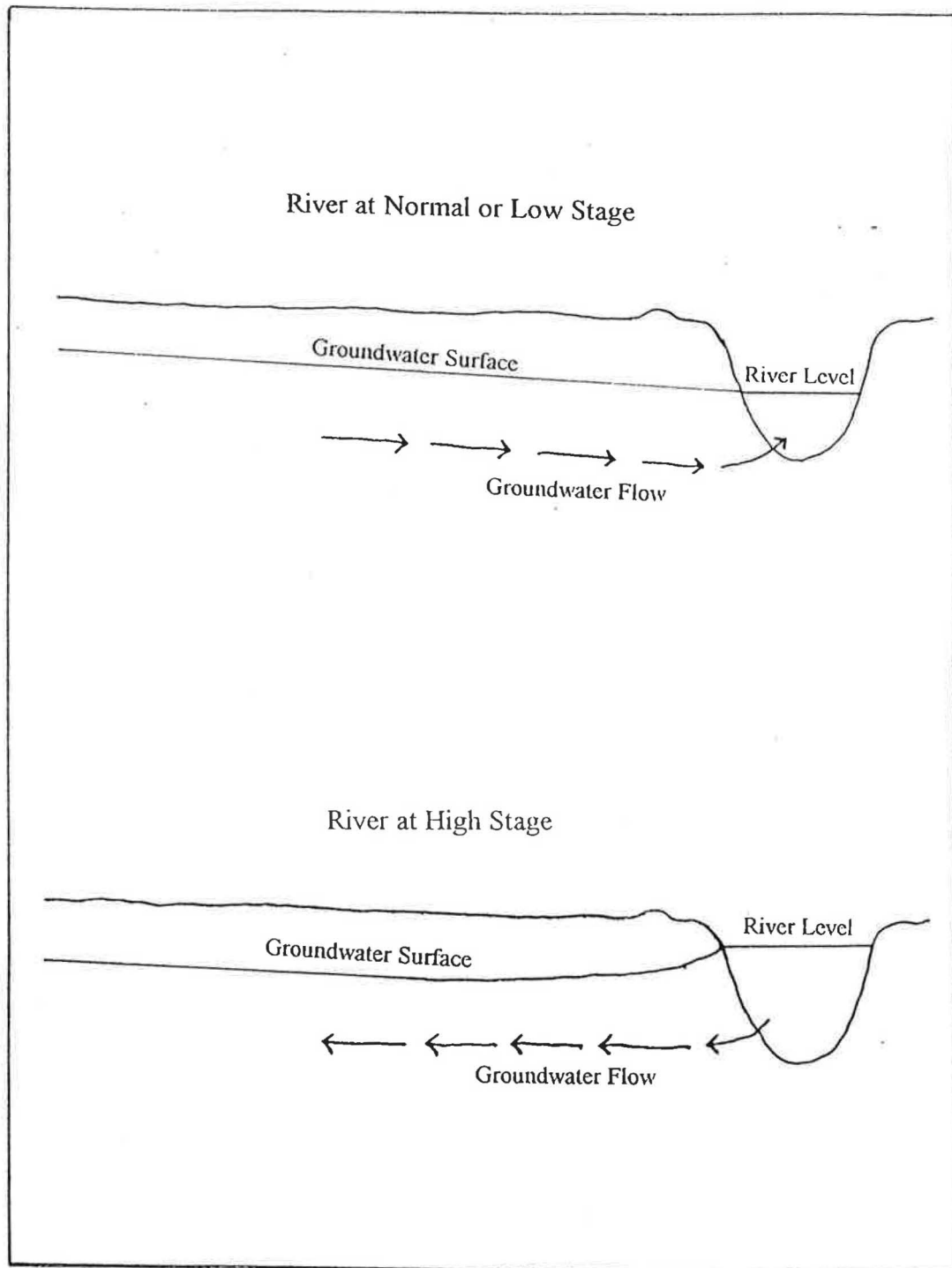


Figure 3. Effects of river stages on ground water flow.

Western Company, Inc., 1986). Researchers have also stated that, near sharp bends in the river, or where tributaries enter the river, ground water levels change more rapidly than on straight reaches, because influent or effluent flow can take place in two directions (Grannamann and Sharp, 1979).

Contributions to the ground water in the alluvial aquifer come from direct precipitation and infiltration, overbank flooding, small amounts from local bedrock aquifers, infiltration from the tributary streams, and, most significantly, from percolation of water from sustained high river stage of the Missouri River (Grannamann and Sharp, 1979). The main discharge of the ground water is seepage to the Missouri River during low stage; and other discharges include pumping from wells, downward movement of water into the bedrock and evapotranspiration (Grannamann and Sharp, 1979).

Layne-Western Company, Inc., performed electronic modeling to determine infiltration of water from the Missouri River during pumping of the St. Charles County well field. Under the normal operating mode of the field, pumping at 10.39 million gallons per day (mgd), the electronic model indicated that 66 percent of the water pumped is a result of direct infiltration from the Missouri River (Layne-Western Company, Inc., 1986). When the pumpage simulation was increased to 16.5 mgd, approximately 75 percent of the total pumpage was derived from direct river infiltration (Layne-Western Company, Inc., 1986). Soil Consultants, Inc. performed a similar model on the St. Charles County well field and found that recharge from the Missouri River ranged from 42.3 to 70.8 percent of the total quantity of water pumped, and that the percentage depended on the quantity of water pumped, what wells were being used, and the river stage at the time of pumping (Soil Consultants, Inc., 1988).

C. MONITORING WELLS:

Information on the installation of the monitoring wells used in this project was taken from U.S. Geological Survey Open-File Report 93-109, entitled *Water-Quality Data for the Missouri River and Missouri River Alluvium near Weldon Spring, St. Charles County, Missouri--1991-1992*, by Michael J. Kleeschulte. The holes for the monitoring well clusters (as shown in Figure 1) were drilled with hollow-stem augers. The deep wells were designed to penetrate the alluvium to the top of bedrock; however, this depth of penetration was only accomplished in Deep Well 1, located farthest from the river. Augering was stopped in the other two deep wells when saturated fine grained sands began sloughing around the auger flights, causing increased drag on the augers. Drilling these holes to bedrock could have resulted in loss of auger flights. Consequently, the shallow wells range from 29.9 to 49.8 feet deep, and the deep wells range from 37.5 to 69.5 ft deep, as shown in Table II.

Table II.-- Well construction data for monitoring wells in Darst Bottoms.
(Kleeschulte, 1993)

Well (Figure 1)	Total depth (feet)	Screened interval (feet)	Drilled hole diameter (inches)	Casing diameter (inches)	Altitude of land surface (feet)	Altitude of top of casing (feet)
Well 1 shallow	29.9	19.9-29.9	8.5	2.0	462.0	463.2
deep	37.5	27.5-37.5	8.5	2.0		463.9
Well 2 shallow	49.8	29.8-49.8	10.5	4.0	465.8	465.8
deep	69.5	49.5-69.5	8.5	2.0		465.9
Well 3 shallow	27.6	27.6-37.6	10.5	4.0	466.7	467.5
deep	52.5	37.5-52.5	8.5	2.0		467.8

The monitoring well riser pipe and screen consisted of flush-wall, schedule 40 polyvinyl chloride (PVC) pipe with O-rings inserted at each pipe joint. The slot size used for the well screen was 0.010 inch. The natural sand pack used around the well screen to a depth of about five feet above the screen was formed by allowing the sands around the auger flights to collapse around the screen as the augers were slowly removed from the hole. In the shallow wells, the native sands did not always slough to fill the annular space; in these instances, 30 to 40 mesh, washed sands were added to a depth of about five feet above the well screen.

The seal above the sand pack was constructed by placing 0.375 inch bentonite chips above the sand pack for a total thickness of about five feet. The remainder of the annular space was sealed by alternating fill materials between natural sands and bentonite chips. This alternating sequence continued to within five feet of the land surface, where the remaining annular space was filled with bentonite chips. Each well was then secured with a metal protective casing and a lockable cap.

During the drilling of the deep wells, core samples were taken with a stainless steel, split-spoon sampler. The core samples were collected at five feet intervals (when possible). Typically, coring was discontinued at a depth of 35 to 40 feet. When the coring bit was removed to insert the coring tool, saturated sands would flow inside the hollow stem auger preventing the coring tool from being reinserted. Grab samples were collected after coring stopped. The core samples are described in Table III.

Table III. Core sample descriptions from deep wells in Darst Bottoms.
(Kleeschulte, 1993)

Depth (ft)	Core sample description
Well 1 Deep	
0 - 9	No sample
10	Light gray, frequent orange-red iron stains, clayey silt; some fine-grained, clear quartz sand
15	Buff to gray, slightly calcareous clayey silt; some very fine-grained white to clear, some orange iron stained, quartz sand; some clear to yellow, subrounded, coarse quartz sand
20	Gray silt, with trace of black organic fragments; some mica fragments (muscovite)
25	Predominantly slightly calcareous silt, with clear to white, very fine-grained, quartz sand; trace of black organic fragments; trace of mica fragments
30	Predominantly slightly calcareous silt, with clear to white, subangular to subrounded, fine-grained quartz sand; trace of black organic fragments
35	Same as 30 feet
36	Possible clay stringer
39	Possible clay stringer
41	Top of bedrock
Well 3 Deep	
0 - 9	No sample
10	Light to dark brown, silty clay; occasional white, angular chert fragments; some very fine-grained, clear, quartz sand
15	Gray silty clay, with frequent orange-red iron stain; some very fine-grained quartz sand
20	Green to brown silt; abundant clear to yellow, very fine grained, subangular, quartz sand; trace of limestone fragments; trace of black organic fragments
25	No recovery
30	Clear, white to yellow, subangular to subrounded, fine- to very fine-grained quartz sand; occasional yellow, subangular to subrounded, medium- to very coarse-grained quartz; frequent black organic fragments
35	Clear to yellow, some orange to red, subangular to subrounded, medium-grained, silty quartz sand; occasional white to yellow, angular to subrounded, coarse- to very coarse-grained quartz sand; general appearance is greenish-brown with frequent black organic fragments
40 - 50	Grab sample--clear to red, rounded to subangular, very fine- to very coarse-grained silty sand; frequent white to red, angular, small chert pebbles; some black organic fragments

Table III. Core sample descriptions from deep wells in Darst Bottoms. (Continued)

Depth (ft)	Core sample description
	Well 2 Deep
0 - 9	No sample
10	Tan to brown, silt clay; occasional fragments of white limestone; subrounded, light green quartz, some iron stain
15	Brown to white, angular, very fine-grained, quartz sand; some mica fragments; occasional white, medium-grained, limestone fragments; trace of black organic fragments
20	Brown to white, angular, very fine-grained silty quartz sand; some small mica fragments; some very fine-grained clear to white, with orange iron stain, quartz; trace of black organic fragments
25	Gray to white silty, very fine-grained quartz sand; some mica fragments; some limestone fragments; trace of black organic fragments
30	White to gray, silty to very fine-grained quartz sand; occasional fine grained, clear, quartz sand; some mica fragments; trace of black organic fragments; some limestone fragments
35	Clear to white, medium to fine-grained, subrounded, quartz sand; occasional angular, coarse-grained, quartz sand; some brown, subrounded, medium-grained chert; trace of black organic fragments
40	Large gravel or cobbles

D. GEOCHEMISTRY:

Impurities in water, including organics, inorganics, anions, cations, and trace metals, come from the natural weathering process of rocks and soil that come in contact with water, and from leaching of improperly disposed of waste. The amount and type of dissolved ions in the water depend upon the types and quantities of minerals that are exposed to the water, solubility of the ion in water, water temperature, pH of the water, and level of dissolved oxygen in the water (Hem, 1992) (Drever, 1988) (Rose et al., 1991).

Impurities can be carried in water as dissolved ions, or may be carried as an adsorbent on suspended colloidal particles. As the temperature and pH of the water change, minerals can dissociate and go into solution with the water. Dissolved ions are then carried in solution with the water, as the water moves through the hydrologic cycle. These dissolved ions can also leave solution, if water conditions change. This process of dissolved ion transport is highly dependent upon the solubility of the minerals in water. Another process that effects the transport of impurities is adsorption and ion exchange onto colloidal particles. Colloidal particles have diameters that range from 0.000001 - 0.001 centimeters; colloids consequently have large surface area for adsorption (Rose et al., 1991). Common natural materials occurring as colloidal

particles include iron and manganese oxides and hydroxides, organic matter, clays, and silica (Rose et al., 1991). These colloidal particles are small enough to remain in suspension in water and are carried with the movement of the water. As the colloidal particle is transported with the water, it is likely to adsorb ions on its surfaces and carry the ions with the particle. It is also possible for colloidal particles carrying ions to flocculate and settle out of suspension and become immobilized in the soil or stream sediment (Rose et al., 1991).

As water flows through soil and rock of alluvial deposits, it can go through different processes that affect the chemistry of the water. Water chemistry is usually not effected by contact with quartz sands, but contact with clay particles can cause cation exchange on the clay particles. Soluble organic material can complex with metals and form soluble organometallic compounds that may be carried with the water through the aquifer. Solid organic material in the aquifer may adsorb metals, effectively removing them from solution. By these processes, ions carried into the aquifer may become trapped in the aquifer materials. When conditions change, the ions may again be released into the aquifer water supply (Rose et al., 1991).

Properties of herbicides and nitrate affect the transport and concentration levels of agricultural chemicals that are found in natural waters. Water solubility of chemicals determines how easily they are washed off soil and crop residues, and how easily the chemicals leach through the soil. Herbicides with solubilities exceeding 30 milligrams per liter are considered to be soluble and are likely to wash off the soil during storms (Goolsby and Battaglin, 1993). A parameter called the *soil sorption coefficient* measures the tendency of herbicides to attach to soil particles. Herbicides with low soil sorption coefficients (less than 500 milliliters per gram) tend to be transported in the dissolved phase, whereas herbicides with high soil sorption coefficients (greater than 1000 milliliters per gram) tend to be transported attached to suspended sediment particles (Goolsby and Battaglin, 1993). The solubility and soil sorption coefficient also affect the *half-life* of the herbicide. The half-life of an herbicide is the time required for the chemical to degrade to one half the previous concentration. Generally, the half life for an herbicide is much greater if the herbicide is in water, rather than contained in soil. Thus, herbicides can be stored in surface reservoirs and in ground water for long periods of time before they can be degraded.

Nitrate is highly soluble and mobile in streams and ground water (Goolsby et al., 1993). Nitrate is usually taken up by aquatic plant in the water, but in streams with high suspended sediment loading and little light penetration, plant life is limited. In these cases, the nitrate in the stream may be transported for great distances. Nitrates may then infiltrate into the ground water supply, where they are stored in the aquifer for an extended period of time (Goolsby et al., 1993).

E. SEASONAL VARIATIONS:

The most important influence on the ground water levels in the Missouri River Flood Plain is the water level in the river. During periods of sustained high river stages, which normally occur during spring, summer, and early autumn, seepage of river water into the aquifers near the river keep ground water levels high. As river levels fall, usually in late fall and winter, ground water flows tend to reverse, with aquifers contributing baseflow to the river, and the river acts as a drain carrying away the seepage. Although this river-ground water relationship may be approximated by averaging water levels over the period of years, the short-term changes caused by flood flow and low flow can cause significant variation in the ground water flow patterns throughout the year (Grannamann and Sharp, 1979).

Geochemistry of water can also be affected by seasonal trends. During dry period of the year, water levels in the ground usually decrease, and ground and surface waters become relatively stable. During this dry period, ground water levels can drop and expose minerals to larger amounts of oxygen, which causes higher-than-normal amounts of mineral oxidation. Then following the first rain after a period of dry weather, two competing processes begin. The new precipitation acts to dilute the existing water, resulting in lower contaminant concentrations. However, the precipitation also creates a flushing action, by which the adsorbed contaminants are washed into the aquifer water. If the dilution is the predominant factor, contaminant concentrations will decrease. If the flushing action dominates, then an increase in impurity concentration can be expected (Rose et al., 1991).

F. THE 1993 FLOOD AND AGRICULTURAL RUNOFF:

Several regional studies of pesticides and nitrates in surface waters of the Mississippi River Basin have been done since 1989. These studies indicate that occurrence and transport of herbicides are related to the season, with concentrations being the highest in a period of about three months after seasonal application. A 1989 study of 147 streams that drain areas between 200 to 100,000 square kilometers showed that some streams carrying storm runoff after planting had herbicide concentrations that were over 1000 times greater than levels before planting (Thurman et al., 1991). Another study of nine streams in the Mississippi River Basin during 1990 showed that in the three months following application of herbicides, elevated herbicide concentrations persisted in storm runoff (Goolsby and Battaglin, 1993). The herbicide concentration in the stream water would peak during periods of storm runoff, as overland flow ceased and streamflow decreased, herbicide concentrations decreased and commonly approached preplanting levels. Herbicide concentrations reached the highest peak during runoff from the first storm after application. The peak herbicide concentrations in the streams tended to decrease with runoff from each subsequent storm, until peak concentrations approached preapplication levels about three months later (Goolsby and Battaglin, 1993).

The seasonal pattern in herbicide concentrations in the Mississippi and Missouri Rivers is similar to that of the smaller tributaries that were described in the previous paragraph. According to a study done in 1991, the Mississippi River was found to have highest

concentrations of herbicides from early May to early July. However, low concentrations of many herbicides were found throughout the year (Goolsby et al., 1991). The year-round occurrence of herbicides in the Mississippi River indicates that they are stored in surface water reservoirs and in aquifers (Goolsby et al., 1993). The herbicides are slowly discharged from storage into streams in quantities large enough to produce detectable concentrations year round in the Mississippi River (Goolsby et al., 1993).

Studies indicate that nitrate concentrations in streams of the Midwestern States also have a seasonal pattern. However, this pattern is distinctly different from that of herbicides. Unlike herbicides, which are transported primarily by overland flow, nitrate appears to be transported by overland and subsurface flows (Goolsby and Battaglin, 1993). Nitrate concentrations are higher during late fall, winter, and spring, and are lower during summer (Goolsby et al., 1993). The lower concentrations in summer are attributed, in part, to assimilation of nitrate by aquatic and terrestrial plants during the growing season, decreased streamflow and ground water discharge to streams, and greater evapotranspiration, all of which contribute to less leaching of nitrate from the soil and unsaturated zones to streams (Goolsby and Battaglin, 1993).

The area of this study, the lower portion of the Missouri River Basin, is part of the largest and most intensive agricultural region in the country (Goolsby et al., 1993). In the spring, this agricultural land is planted and treated with agricultural chemicals (pesticides and nitrogen fertilizers). Shortly after planting time in the spring of 1993, the heavy rains that produced the Great Flood of 1993 started. It was initially anticipated that the increased volumes of water associated with the flood would act to dilute the agricultural chemicals and result in lower agricultural chemical concentrations in the stream waters (Goolsby et al., 1993). Instead, the heavy rains and larger than normal runoffs associated with the flood produced agricultural chemical concentrations similar to much lower stream flows. Concentrations of herbicides, such as atrazine, alachlor, cyanazine, and metolachlor, were similar to the maximum concentrations of the lower stream flows during the spring and summer of the previous two years (Goolsby et al., 1993). Thus, as the volume of water in streams increased, the mass of agricultural chemicals carried by the streams increased proportionally. The result was high agricultural chemical concentrations usually associated with low flow conditions.

Because the agricultural chemical concentrations remained similar to the maximum concentrations normally observed during low flow conditions, the total mass of agricultural chemicals carried by the streams during the flood increased dramatically. The total amount of atrazine discharges to the Gulf of Mexico from April 1993 through August 1993 was estimated to be 539,000 kilograms (Goolsby et al., 1993). The atrazine loading for this five month period was 80 percent greater than that of 1991, and 235 percent greater than that of 1992 (Goolsby et al., 1993). The total nitrate load transported to the Gulf of Mexico from April 1993 to August 1993 was 827,000 tons, which was 37 percent greater than the nitrate loading during 1991 and 112 percent greater than the nitrate loading during 1992 for the same five month period (Goolsby et al., 1993).

III. RESEARCH PROCEDURES

The research for this project began with selection of a monitoring well set and examination of existing data from those wells. During the study, the monitoring wells were sampled on a monthly schedule; samples were analyzed for water quality parameters that could be used to detect impacts on the alluvial aquifer of the 1993 flood. The procedures and methodology for these tasks are outlined in this section.

A. DATA COLLECTED BEFORE THE FLOOD:

The monitoring wells selected for this project were installed by the United States Geological Survey in 1991 for a study of the Weldon Spring area. The wells were chosen for this study due to the quality of well construction, location in the Missouri River alluvium, and the existence of data of known quality obtained prior to the flood. The data from sampling rounds made prior to the 1993 flood were taken from the U.S. Geological Survey Open-File Report 93-109 entitled *Water-Quality Data for the Missouri River and Missouri River Alluvium near Weldon Spring, St. Charles County, Missouri--1991-1992*, by Michael J. Kleeschulte. USGS personnel collected four rounds of samples during the months of March through June, 1992. The data available on the monitoring wells included water levels, concentrations of cations and anions, general physical and chemical parameters. Corresponding data for the Missouri River for this time period were also contained in the USGS report.

B. DATA COLLECTED AFTER THE FLOOD:

1. Well Sampling and Field Analysis. The sampling of the monitoring wells after the Great Flood of 1993 was performed by University of Missouri-Rolla personnel. Ten sample rounds were conducted from June, 1994, through April, 1995. During the sampling rounds for the months of June to October 1994, the monitoring well were purged using a gasoline-powered non-submersible pump. In November 1994, due to pump failure, the monitoring wells were purged by using a hand bailer. A hand bailer was used to collect all samples during the months of June through November 1994. For the remaining sampling rounds, a Grundfos Redi Flo2 stainless steel submersible centrifugal pump was used to purge the wells and to collect the samples. When a pump was used for sample collection, the pumping rate was maintained below 500 milliliters per minute to avoid loss of volatile compounds.

The water quality samples were collected using the following procedures: First, a clean, disposable plastic tarp was spread on the ground around the well riser pipe to maintain cleanliness. Then, the water surface level was measured from the top of well casing. Next the well was purged a minimum of three well volumes. Throughout the purging of the well, conductivity, temperature, and pH were monitored by the use of a portable Hach Conductivity/TDS meter with built in temperature probe, and a portable Hach One pH Meter, respectively. The conductivity meter was calibrated with potassium chloride standard prior to each sampling round and the pH meter was calibrated to pH of 7.0 immediately prior to each sampling event. Each well was purged until conductivity, temperature, and pH measurements

stabilized. Upon stabilization, conductivity, temperature, and pH measurements were recorded and the sample was taken. The procedure for taking the sample included rinsing the sample bottle twice, by filling the sample bottle with water from the monitoring well and then discarding the water, and then filling the sample bottle to the top with water from the monitoring well. The sample bottle was then properly capped, labeled, and stored in a cooler with blue ice for transport to the laboratory. Throughout the ten months of sampling, a field log was kept documenting the following: weather conditions, soil conditions, vegetation in the area, general notes on visual inspection of water and any notable odor, water level, conductance, pH, temperature, and total volume of water purged from the wells.

2. Total Organic Carbon Analysis. Total organic carbon (TOC) data were obtained in accordance with Standard Method 5310C, Persulfate-Ultra Violet Method using a DohrMann DC-180 TOC Analyzer. The instrument was calibrated prior to each sampling event using a 100 milligram per liter TOC standard of potassium acid phthalate.

3. Alkalinity. Alkalinity data were obtained in accordance with Standard Method 2320B, titration method. The sample was titrated to a color-change endpoint that indicated a pH of 4.5.

4. Anion Analysis. Anion data were obtained by using a Hach 2000 Spectrophotometer and the following method for each anion listed below;

- * Nitrate: Cadmium Reduction Method,
- * Sulfate: Standard Method 4500-SO₄-E,
- * Chloride: Mercuric Thiocyanate Method,
- * Fluoride: Standard Method 4500-F-D, using SPADNS reagent.

5. Metals Analysis. Metals data for calcium, magnesium, sodium, potassium, lead, and part of the chromium were obtained through the use of a Perkin-Elmer 2380 Atomic Absorption Spectrophotometer. Standards were run for each metal to calibrate the instrument prior to running the test. Then the calibration of the instrument was checked between each round of samples tested and recalibration was done when necessary. Trace metals data including arsenic, barium, chromium, iron, manganese, and selenium were obtained in accordance with Standard Method 3120B, through the use of a Perkin-Elmer 5500 Inductively-Coupled Plasma unit. Standards for each metal were run prior to and during each analytical run.

6. Coliform Analysis. Coliform data were obtained in accordance with Standard Method 922B, Standard Total Coliform Membrane Filter Procedure, using M-Endo medium. Fresh M-Endo broth was prepared within 24 hours prior to the filtration series for each sample run. All plates were incubated at 35 degrees Celsius +/- 1 degree Celsius for 22-24 hours before the plate count was taken.

7. Pesticide Analysis. Pesticide data were obtained in accordance with Standard Method 6630B, Liquid Extraction Gas Chromatographic Method. Samples were extracted by the Soxhlet extraction method prior to analysis. Pesticide-grade hexane was used as the extraction solvent. The instrument used was a Perkin Elmer 8410 Gas Chromatograph, equipped with a DB-5, 30 meter column and an electron capture detector. Standards were run to calibrate the instrument prior to and during each analytical run.

8. Quality Control. To maintain quality assurance, field blank samples were taken during some of the sampling rounds. Duplicates were also taken during some rounds; these samples were analyzed "blind" with the other monitoring well samples. The blank samples were subjected to all the same conditions as the monitoring well samples, except they were not processed through the sampling pump.

C. MISSOURI RIVER DATA:

Data on the Missouri River water quality were obtained from the City of St. Louis Department of Public Utilities, Water Division of Supply & Purifying Section. The river samples were taken at the Howard Bend Water Treatment Plant, located approximately thirteen miles downstream of the monitoring wells. Data on the Missouri River water elevations were obtained from a river gaging station located at Hermann, Missouri, approximately forty-eight miles upstream from Darst Bottoms. Figure 4 shows the locations of the Howard Bend Water Treatment Plant and the Hermann, Missouri, river gaging station with respect to the Darst Bottoms study area.

D. DATA ANALYSIS:

To compare the data taken before the Great Flood of 1993 with the data taken after the Great Flood of 1993, the statistical method called a "standard boxplot" was used. An example of a standard boxplot is shown in Figure 5. The boxplot is constructed by using the value of the 25th percentile of the data set for the lower end of the box and value of the 75th percentile of the data set for the upper end of the box. The median value for the data set is plotted as a line between the 25th and 75th percentiles that divides the box into two parts. Lines, sometimes called whiskers, are drawn from the ends of the box to extend out away from the box to the last data observation within a value of 1.5 times the height of the box or the interquartile range. Data observations between 1.5 and 3.0 times the interquartile range are called outside values and are plotted as a single asterisk. Outside values occur fewer than once in 100 times for data from a normal distribution. (Helsel and Hirsch, 1992) Data observations farther than 3.0 times the interquartile range beyond the box are called far-out values and are plotted as a small circle. These far-out values occur fewer than once in 300,000 times for data from a normal distribution (Helsel and Hirsch, 1992).

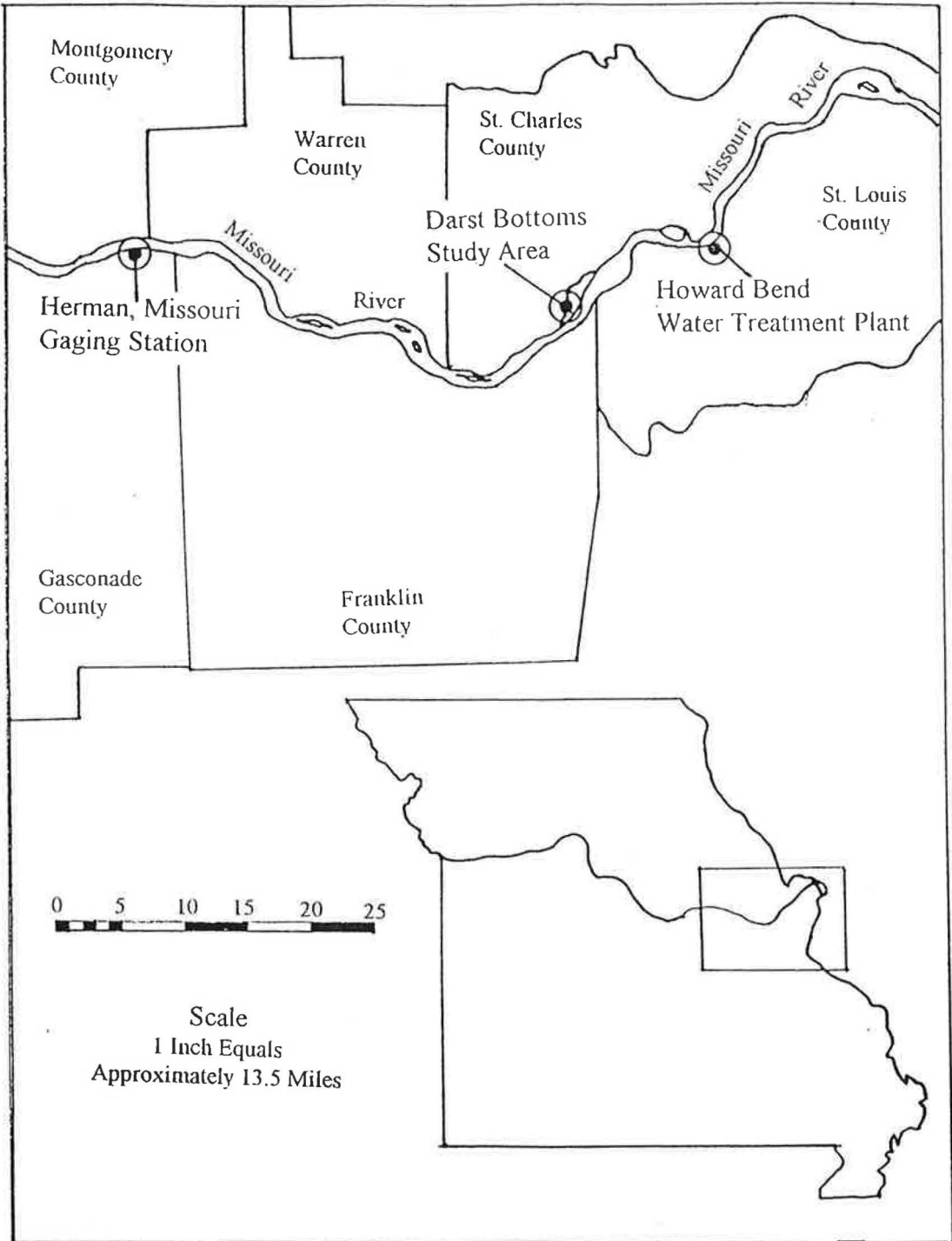


Figure 4. Missouri River Study Area

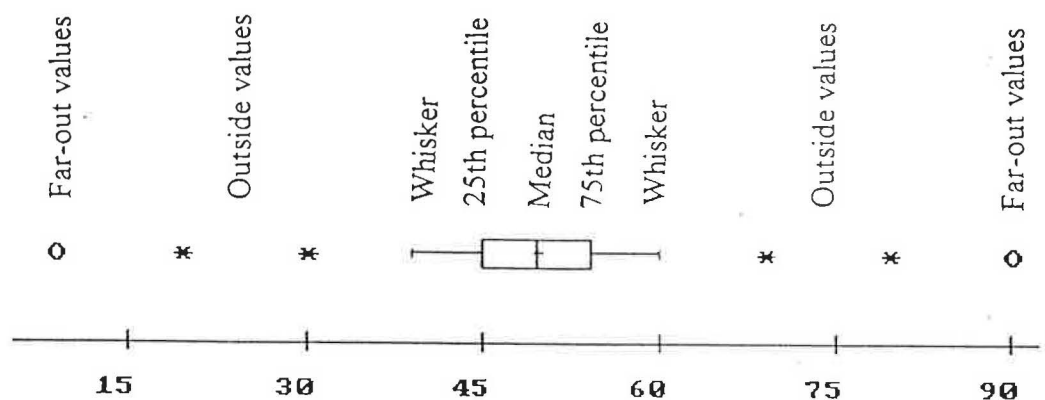


Figure 5. ^{*} Example of boxplot

Boxplots were constructed for the water elevation data and the following water quality parameters: alkalinity, fluoride, sulfate, chloride, barium, calcium, chromium, iron, magnesium, manganese, sodium, potassium, and lead. Boxplots were not constructed for total organic carbon, due to suspected differences in methods of analysis and for nitrate, arsenic and selenium due to large percent of non-detectable levels in the data. Where data sets had a small number of non-detectable levels, the simple substitution method, as described in *Statistical Methods in Water Resources*, (Helsel and Hirsch, 1992) was used. In simple substitution, one-half the value of the detection limit is substituted for non-detectable levels in the data sets.

To look for possible trends over time, and trends between Missouri River quality and the quality of the ground water of the Darst Bottoms area, data from the river and the monitoring wells were plotted as scatterplots. The data for the shallow monitoring wells and the river data were plotted versus time on one graph, and the data for the deep monitoring wells and the river data were plotted on another one graph. The graphs were constructed with the X and Y axis to the same scale for both the monitoring well data and the river data. Graphs comparing monitoring well data and river data were constructed for the following parameters: water elevation, alkalinity, fluoride, sulfate, chloride, calcium, iron, magnesium, sodium, and potassium.

E. DATA QUALITY:

The analytical results for the following parameters are of acceptable quality:

- ◆ water level, pH, temperature, and conductivity
- ◆ anions
- ◆ pesticides
- ◆ coliforms
- ◆ total organic carbon (TOC)
- ◆ sodium, potassium, manganese, and iron

However, the results for some of the metals are of lesser quality. Specifically, the results for lead and chromium concentrations should be considered only semi-quantitative, because of variability in the instrument readings between replicates. Results for calcium and magnesium may be in error; calculations of cation-anion balances (Appendix F) indicated that the milliequivalents of cations in the after-flood samples exceeded those of anions, whereas the opposite result had been seen in prior work by USGS, and in analytical reports from the Howard Bend Water Treatment Plant. Dilution error is the most likely explanation for inaccuracies in calcium, magnesium, sodium and potassium. The instrument was performing well for these analyses, and results for standards and blanks were acceptable. Analytical results for standards and blanks are judged to be reliable.

IV. RESULTS AND DISCUSSION

Examination of the graphical presentation of data taken before and after the flood reveal a great deal of information about potential flood impacts. The boxplots shown in Figures 6 through 19 show that the central values of many parameters vary between data taken before and after the flood. Likewise, the symmetry and skewness of some of the boxplots indicate a different distribution between the "before" and "after" data sets. The scatterplots in Figures 20-39 show that certain parameters appear to have been decreasing or increasing after the flood. A parameter-by-parameter analysis of the graphical data follows in this section.

A. WATER ELEVATION:

Water elevation differs between the sampling events before and after the flood. The central values after the flood are only slightly higher, but the boxplots shown in Figure 6 indicate that the after-flood elevations were skewed toward higher elevations. An examination of the water elevation scatterplot graphs (Figures 20 and 21) of water elevation after the flood indicates a clear downward trend in elevations during the period of study. It appears that the flood did increase water elevations in the alluvial aquifer, and that the effects were still quantifiable over a year after the flood.

B. ALKALINITY:

Alkalinity values were lower after the flood than before. The boxplots shown in Figure 7 show that the central values were lower in all cases, and the number of outliers was higher after the flood. Scatterplots shown in Figures 22 and 23 show a slightly increasing trend of alkalinity concentrations over time. This would indicate that alkalinity decreased after the flood, and was on an increase during the period of this study. As the alkalinity of the river is lower than in the alluvium, this would appear to support the premise that the river provided accelerated recharge to the aquifer during the flood.

C. FLUORIDE:

There is no predictable difference in fluoride data before and after the flood (Figure 8), although the number of outliers is higher after the flood. Scatterplots of data after the flood, Figures 24 and 25, show that fluoride concentrations increased during the early sampling rounds, then dropped and began a slow increase. According to Hem (1992), fluoride concentrations in natural waters are usually below 1.0 mg/l, so even the highest of the outliers (1.2 mg/l) is not an unusual concentration. Fluoride, as CaF₂, is commonly present in sedimentary rocks. Calcium fluoride is relatively insoluble; changes during the course of the study could be due to changes in the aquifer that impacted solubility of the mineral.

D. SULFATE:

The boxplots of sulfate data (Figure 9) show a small increase in central values after the flood as compared to data obtained before the flood. Examination of the scatterplots in Figures 26 and 27 show a slight increasing trend of sulfates over time during the course of the study. The scatterplots also illustrate that sulfate levels in the river are higher than those typically found in the alluvial aquifer. The chemistry of the sulfur cycle, and of sulfates in rivers and aquifers, is complex, (Hem, 1992), and is related to pH and oxygen levels. A strong H₂S odor was noted in most of the samples from Shallow Well 1 and many of the samples from Deep Well 1; chemical and biological activity around and within the wells could have resulted in increased levels of sulfate as the hydrogen sulfide was oxidized.

The flood could have caused an increase in sulfates.

E. CHLORIDES:

The boxplots shown in Figure 10 clearly indicate that chloride concentrations were lower after the flood than before. Figures 28 and 29 show that the chloride concentrations varied over time, but in no clear pattern. Chloride concentrations are also shown to be lower in the wells than in the river. This pattern seems anomalous; however, the chloride concentrations in the river during high flowrates are much lower than average (Cl⁻ concentration of 11.9 mg/l in July, 1993, vs the 1994 average of). Hence, the lower chloride concentrations seen after the flood could be a result of floodwaters recharging the shallow aquifer.

F. BARIUM:

Examination of the boxplot data shown in Figure 11 shows that the central values for barium concentrations in most wells were higher after the flood than before. However, Well 1 Deep differs from this trend. Barium analyses were not performed on samples from the latter sampling rounds, so trends over time cannot be examined. Barium concentrations appeared higher after the flood, but the data set is very limited.

G. CALCIUM:

The boxplots shown in Figure 12 indicate a large increase in calcium concentrations after the flood. Figures 30 and 31 show some variation in concentration over time, but there does not appear to be a clear upward or downward trend. Calcium concentrations could be higher after the flood, if significant dissolution of calcium carbonates occurred during the flood.

Calcium geochemistry is complex, depending upon availability in minerals, solution- and gas-phase equilibria and presence of sulfates (Hem, 1992). Calcium is abundant in the river water, ground water, and probably in the minerals of the alluvium. However, low pH and high carbon dioxide values of the aquifer waters would be required for concentrations to rise so significantly. Low pH values were not seen consistently during the course of this study; the

initial pH values during the study were much lower than subsequent values, however. Alkalinity concentrations seen during the study would correlate with higher carbon dioxide concentrations, as well. It is also possible that pH of the shallow aquifer was lower during and immediately after the flood, but this cannot be verified as no samples exist from this time period.

The possibility of analytical error makes conclusions on calcium concentration patterns very tenuous.

H. CHROMIUM:

Chromium data from samples after the flood clearly vary from samples taken before the flood. The boxplots in Figure 13 indicate that chromium concentration was below detection limit for all samples taken before the flood, and varied from non-detectable to over 250 micrograms/l after the flood. Chromium data on the river are not available.

Hem (1992) reports that the average chromium concentration of natural water is less than 10 micrograms per liter. Ground water at locations downgradient of industrial waste sites can have higher concentrations of chromium. No such sites are known to exist upgradient of Darst Bottoms. It is impossible to make definite conclusions about chromium, considering the analytical problems. If chromium were present in some of the samples, the probable explanation is contamination of laboratory glassware with chromium cleaning solutions.

I. IRON:

Iron appears to have decreased in concentration after the flood. With the exception of Well 3 Shallow, which contained very low concentrations of iron prior to the flood, the central values for iron shown on the boxplots in Figure 14 are lower after the flood than prior to it. Concentrations of iron in the river are consistently lower than in the alluvial aquifer; recharge by floodwaters could be a significant factor in the decrease seen in iron concentration after the flood. However, the geochemistry of iron is complex, being related to pH, concentration of dissolved oxygen, and presence of other chemical constituents. The iron concentrations seen in the monitoring wells were highly variable with time, indicating that complex phenomena were probably taking place.

J. MAGNESIUM:

In a manner similar to calcium, magnesium concentrations appear to have increased after the flood. The boxplots in Figure 15 show that the central values for magnesium concentration were notably higher after the flood than before. Several high outliers were also seen. Figures 34 and 35 show variations in magnesium over time; trends are similar for all wells. Magnesium in the river is typically lower than magnesium in the shallow alluvial aquifer, and concentrations of magnesium in the river during the flood were lower than normal. It is, therefore, unlikely that recharge by floodwater is responsible for the increases seen in magnesium. Geochemical changes which resulted in the higher magnesium concentrations may be a result of the flood, but

the quality of the analytical data makes conclusions impossible.

K. MANGANESE:

Concentrations of manganese appear to be lower after the flood than before. The boxplots shown in Figure 16 indicate that the central values for manganese were lower after the flood for wells at sites 1 and 3, but not at site 2. Manganese concentrations of the river are not available. Manganese concentrations of natural waters are reported to generally be below 1.0 mg/l (Hem, 1992); all concentrations seen during this study were below that value. Iron and manganese act similarly in ground water, and high concentrations of one often (but not always) accompany high concentrations of the other. It is possible that the lower manganese concentrations seen after the flood are a result of floodwater recharging the shallow aquifer.

L. SODIUM:

Sodium. Sodium concentrations appear to be generally lower after the flood than before. The boxplots shown in Figure 17 indicate lower central values, with the presence of some outliers. Sodium data for the wells and for the river vs time, shown in Figures 36 and 37, indicate fairly consistent concentrations of sodium over time. Concentrations of sodium found in the aquifer are lower than those found in the river, although sodium concentrations in the river were much lower than normal during the flood. Sodium concentrations in the wells after the flood were lower than sodium concentrations in the river samples taken during the flood. Sodium is highly soluble in groundwater, and no mechanism is known that could explain lower concentrations in the wells than in the recharge water. Hence, a more likely explanation is direct recharge by rainfall.

M. POTASSIUM:

Potassium concentrations appear to have increased after the flood. The boxplots shown in Figure 18 indicate higher central values, and generally longer "whiskers" and outliers in the direction of higher concentration. As seen in Figure 38 and 39, potassium concentrations did vary over time in the shallow wells, but was relatively constant in the deep wells. Potassium concentrations in the river stayed relatively constant during the flood, unlike concentrations of most chemical constituents. Potassium is present in most commercial fertilizers, so the runoff from the flood probably carried large amounts of potassium into the river. This effect has been noted in the past (Hem, 1992), and could have resulted in increased concentration of potassium in the recharge waters.

N. LEAD:

Concentrations of lead in the alluvial aquifer prior to the flood were below detection limits. After the flood, lead was detected in several samples from the monitoring wells. As shown in Figure 19, central values for lead were higher in all wells after the flood. Lead was usually higher in the shallow wells than in the deeper wells. Lead data are not available for the river water. Previous research (Hem, 1992) has shown that lead is fairly abundant in natural systems, but its low solubility make concentrations of dissolved lead generally low.

Airborne lead readily falls and washes out of the atmosphere to deposit on soils. During rain events, this lead can be mobilized. Lead has been shown to be high in runoff during storms (Hem, 1992). It is possible the higher lead levels found after the flood, especially in the shallow wells, are a result of the flood. Analytical problems also explain at least part of the findings.

WL	Depth below land surface (water level), in feet
WE	Water surface elevation, in feet MSL
Cond	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
pH	In standard units
Temp	Water temperature, in degrees Celsius
TOC	Total organic carbon, in milligrams per liter
Alk	Alkalinity as calcium carbonate, in milligrams per liter
F	Dissolved fluoride, in milligrams per liter
N	Dissolved nitrite plus nitrate as nitrogen, in milligrams per liter
SO4	Dissolved sulfate, in milligrams per liter
Cl	Dissolved chloride, in milligrams per liter
As	Dissolved arsenic, in micrograms per liter
Ba	Dissolved barium, in micrograms per liter
Ca	Dissolved calcium, in milligrams per liter
Cr	Dissolved chromium, in micrograms per liter
Fe	Total dissolved iron, in milligrams per liter
Mg	Dissolved magnesium, in milligrams per liter
Mn	Dissolved manganese, in micrograms per liter
Na	Dissolved sodium, in milligrams per liter
K	Dissolved potassium, in milligrams per liter
Pb	Dissolved lead, in micrograms per liter
Se	Dissolved selenium, in micrograms per liter
ND	Measurement not detectable
NA	Data not available

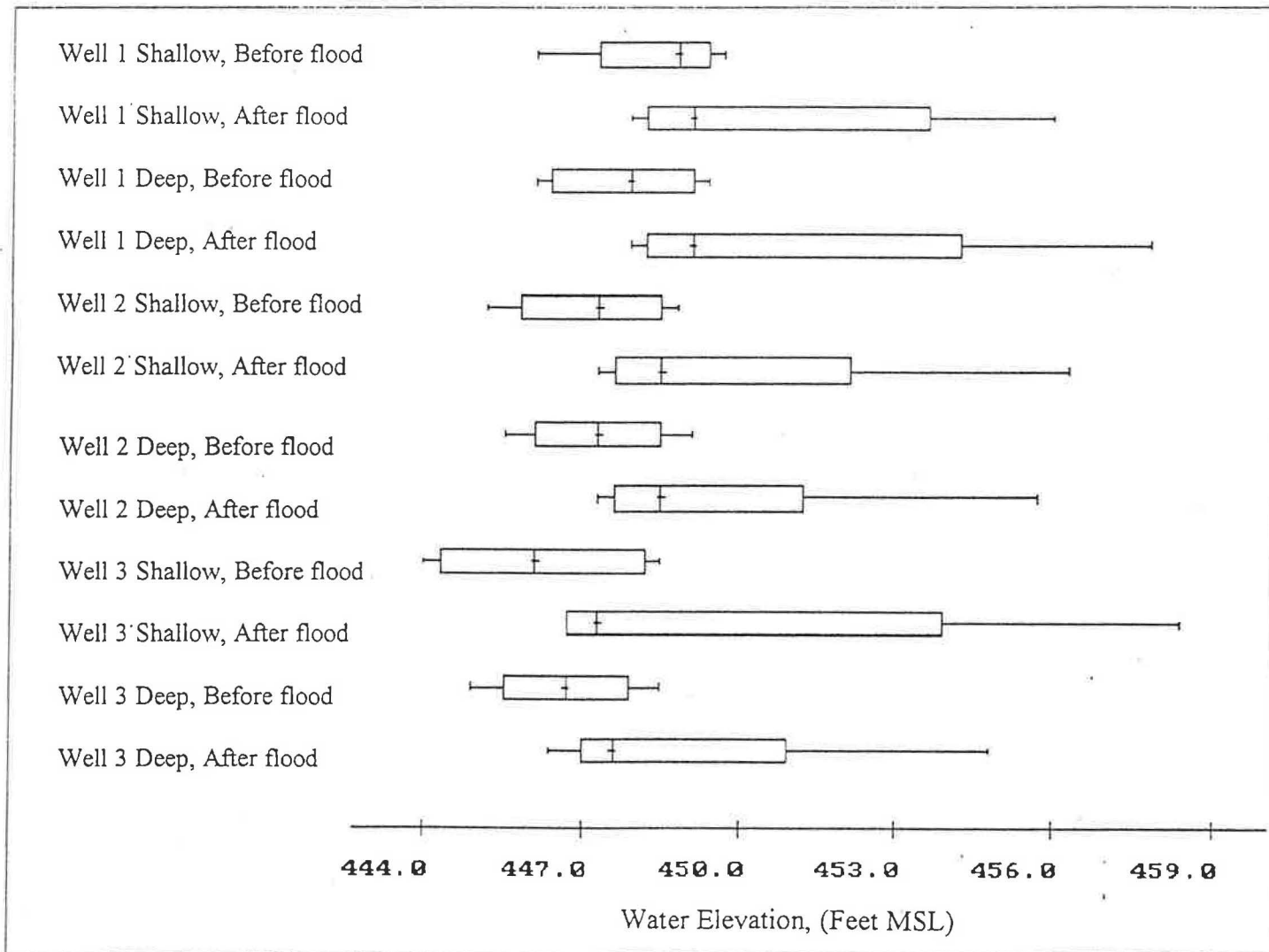


Figure 6. Boxplots of water elevation data

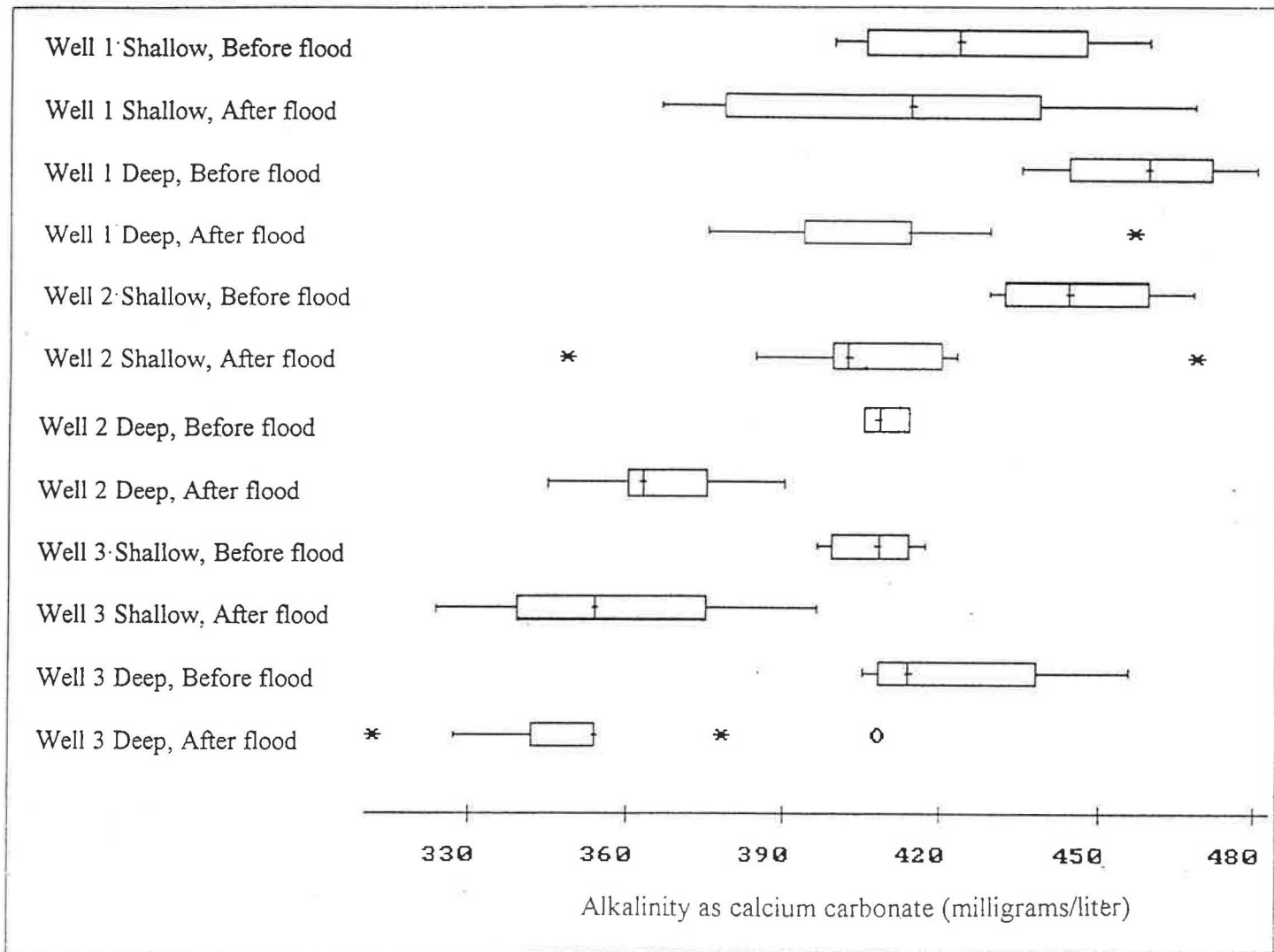


Figure 7. Boxplots of alkalinity data

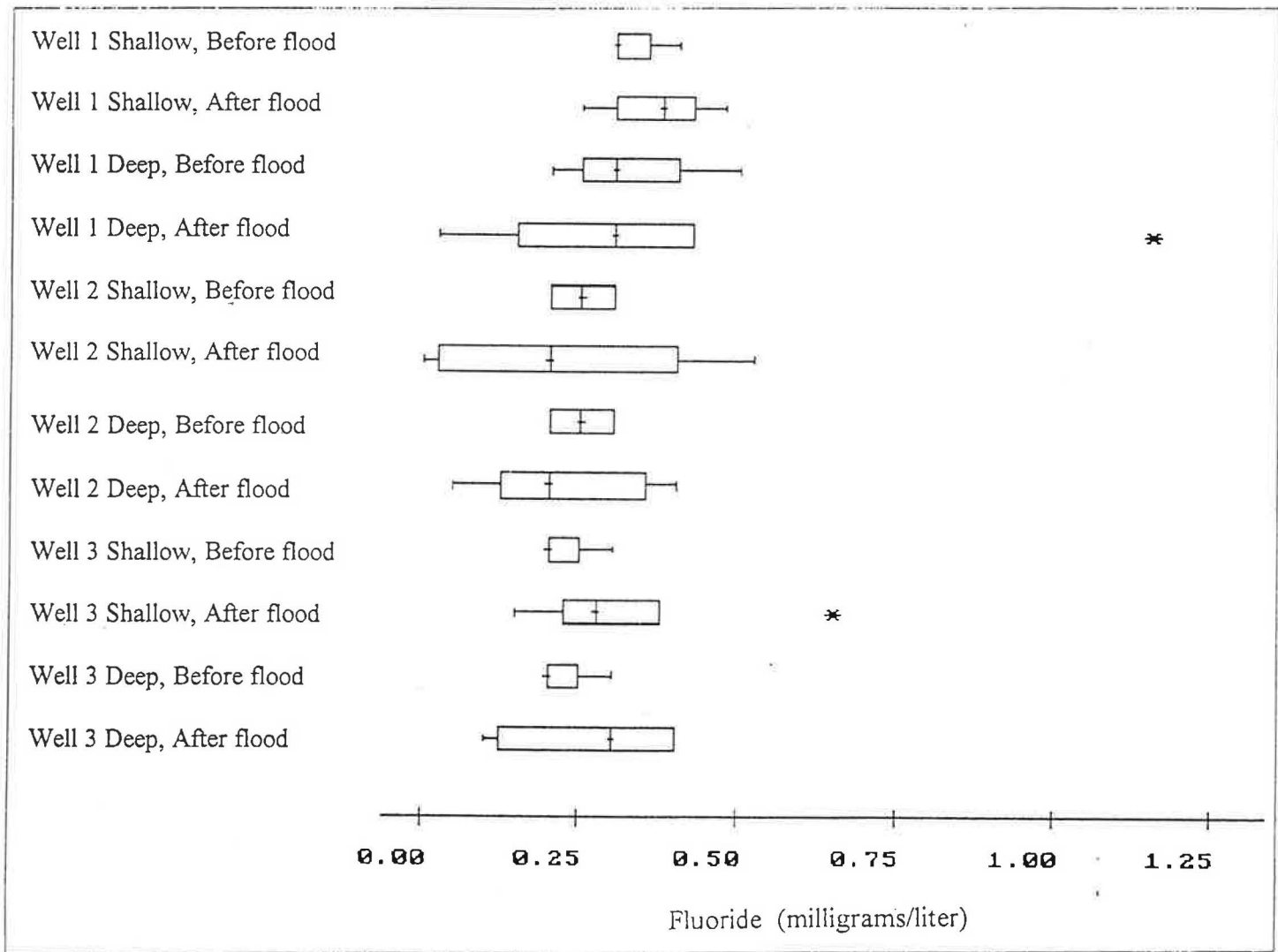


Figure 8. Boxplots of fluoride data

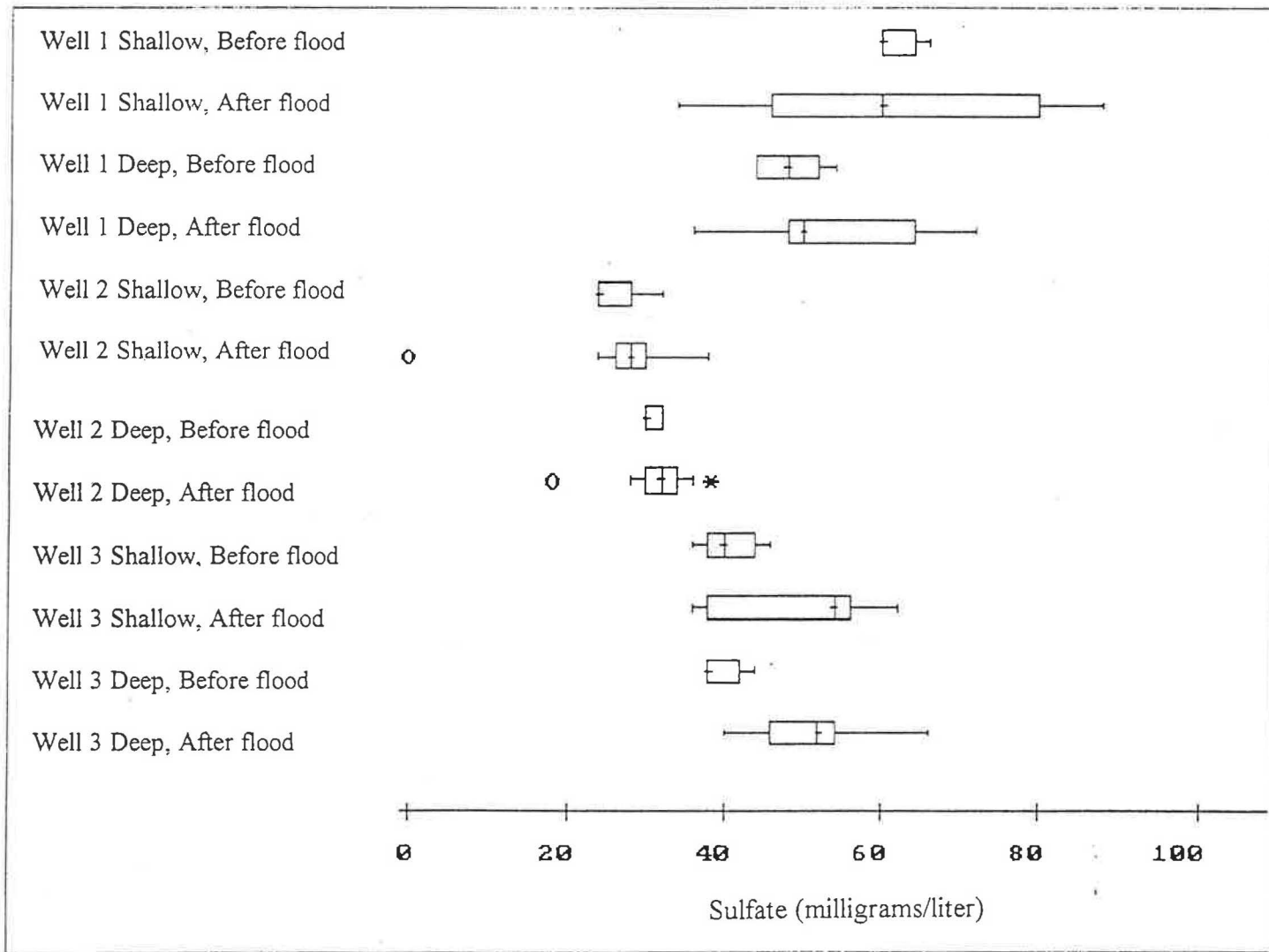


Figure 9. Boxplots of sulfate data

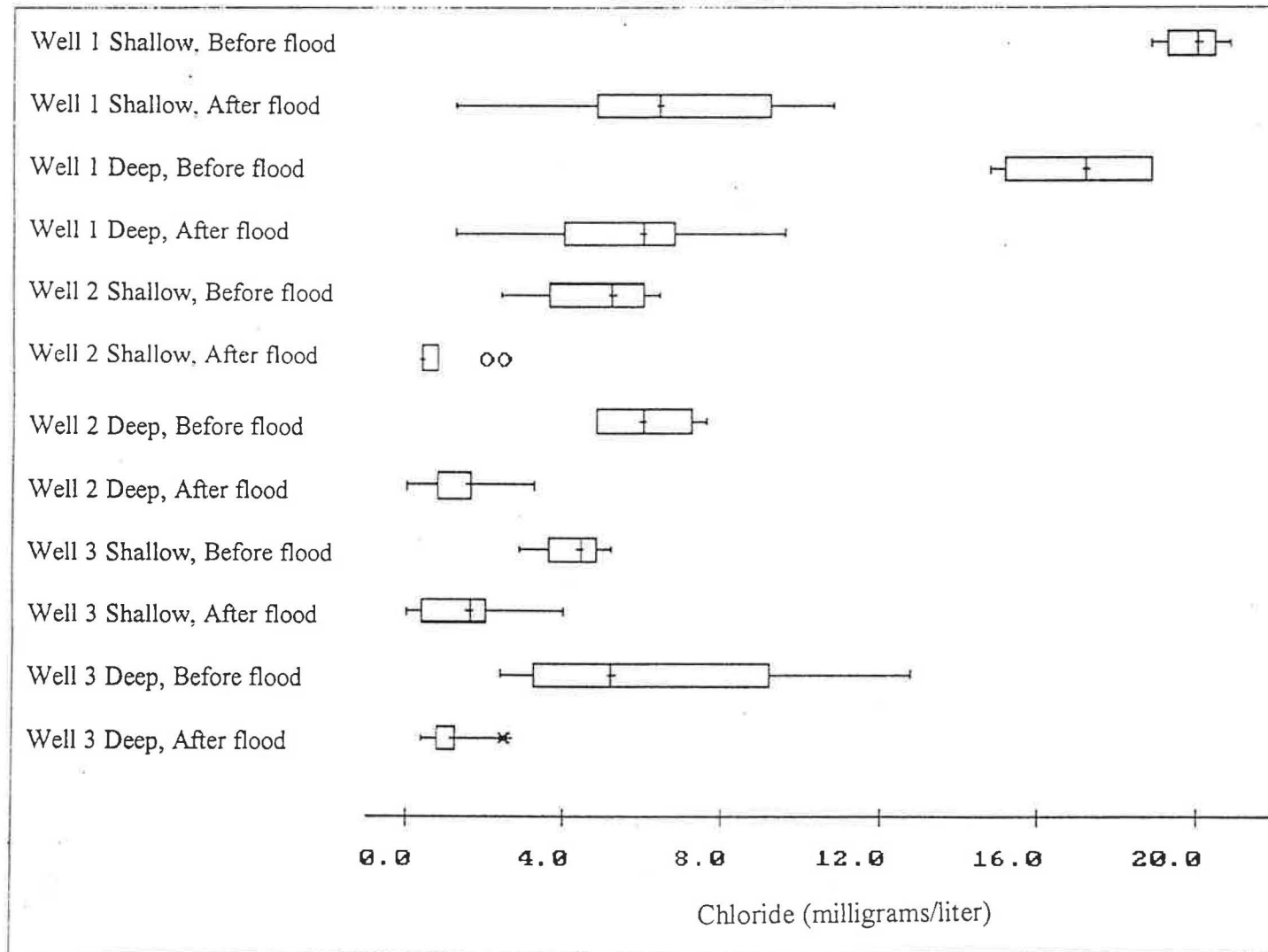


Figure 10. Boxplots of chloride data

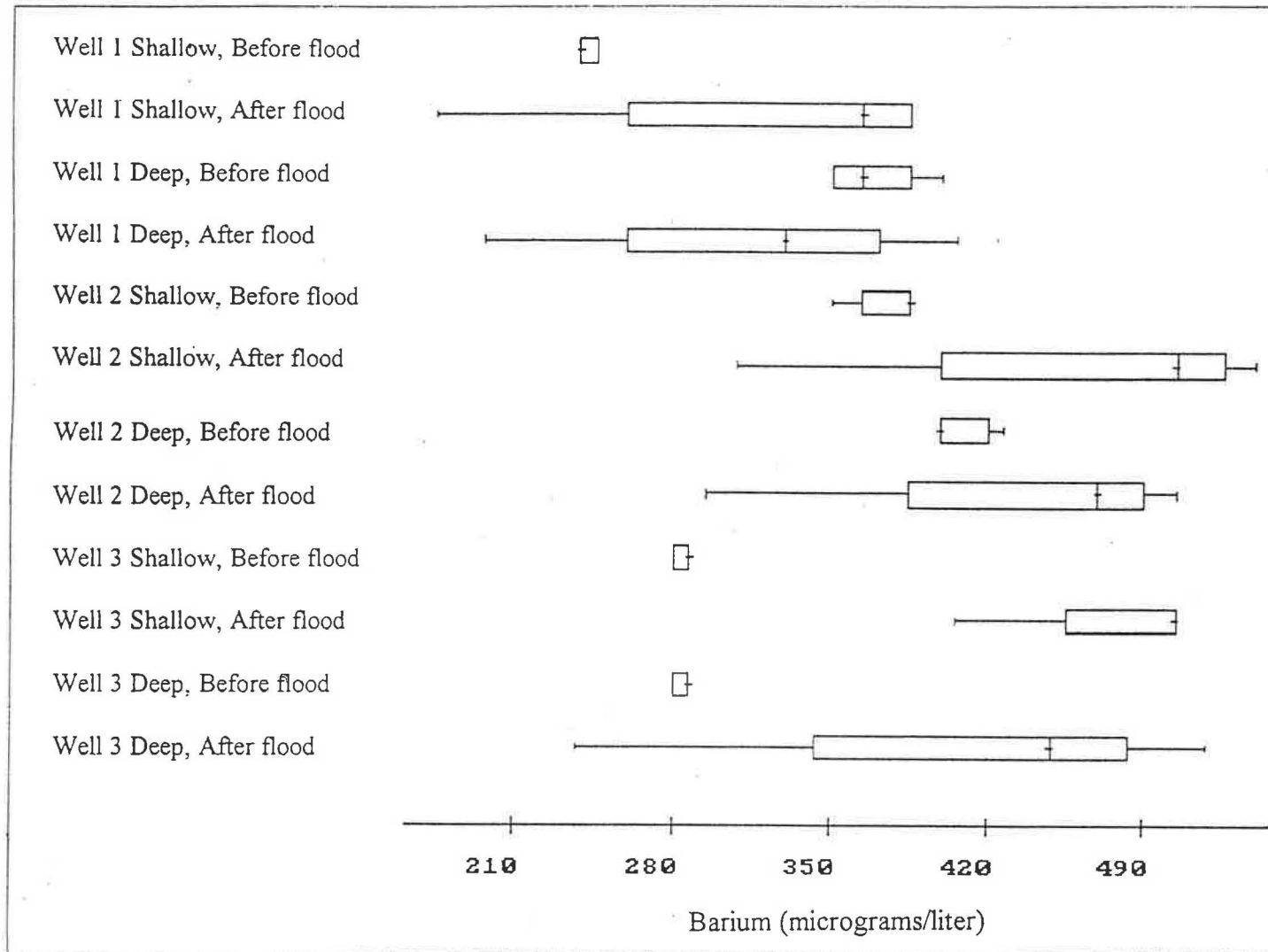


Figure 11. Boxplots of barium data

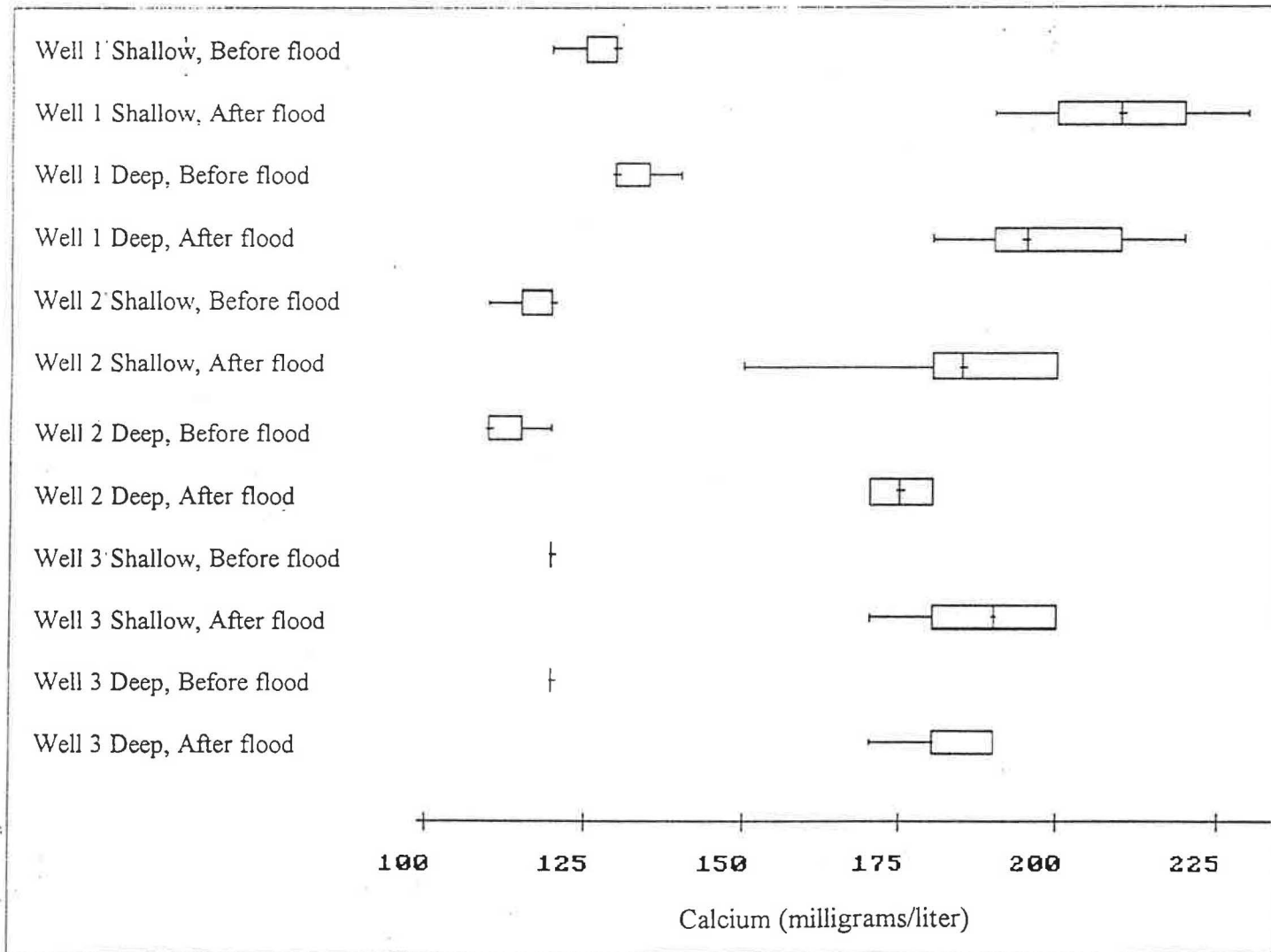


Figure 12. Boxplots of calcium data

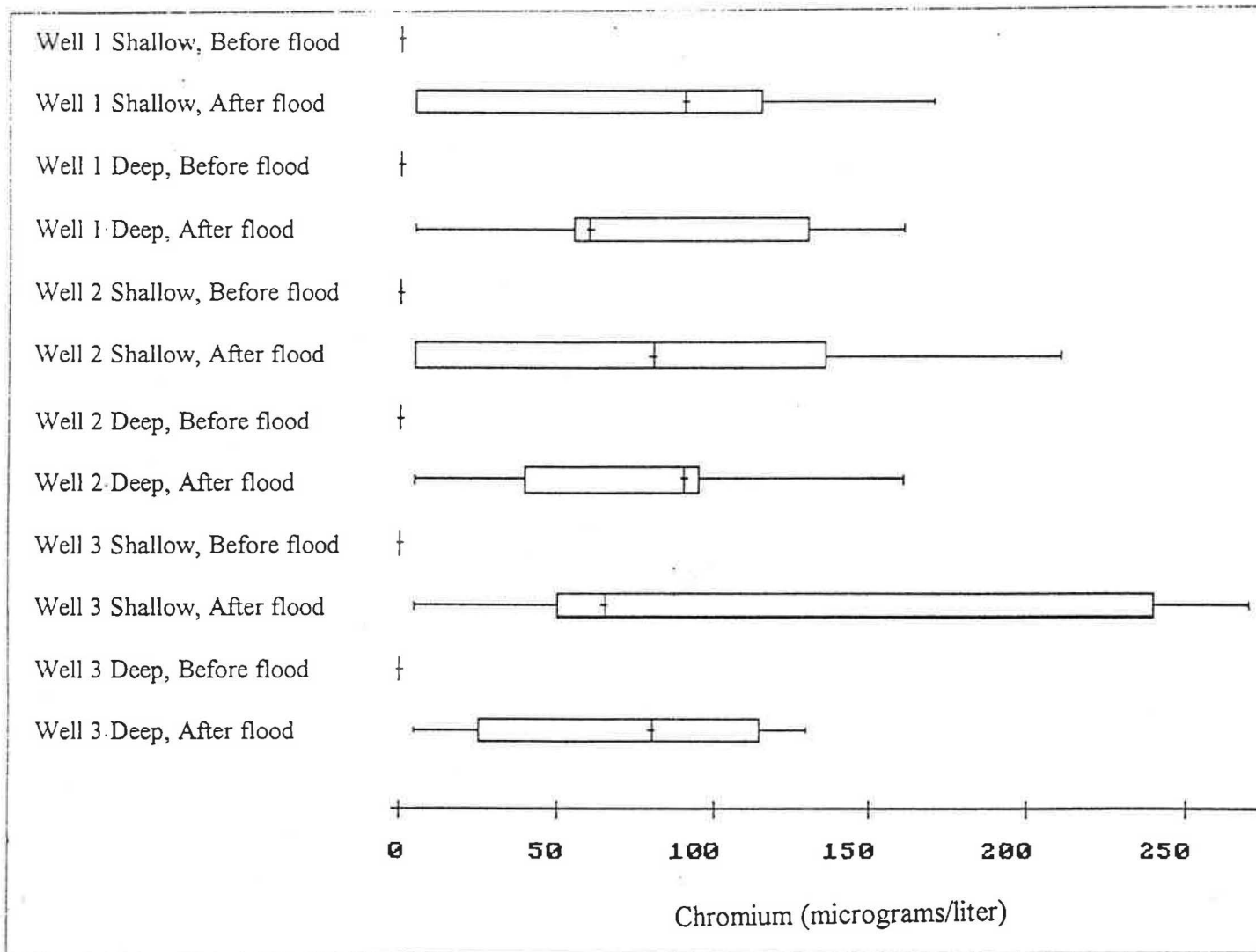


Figure 13. Boxplots of chromium data

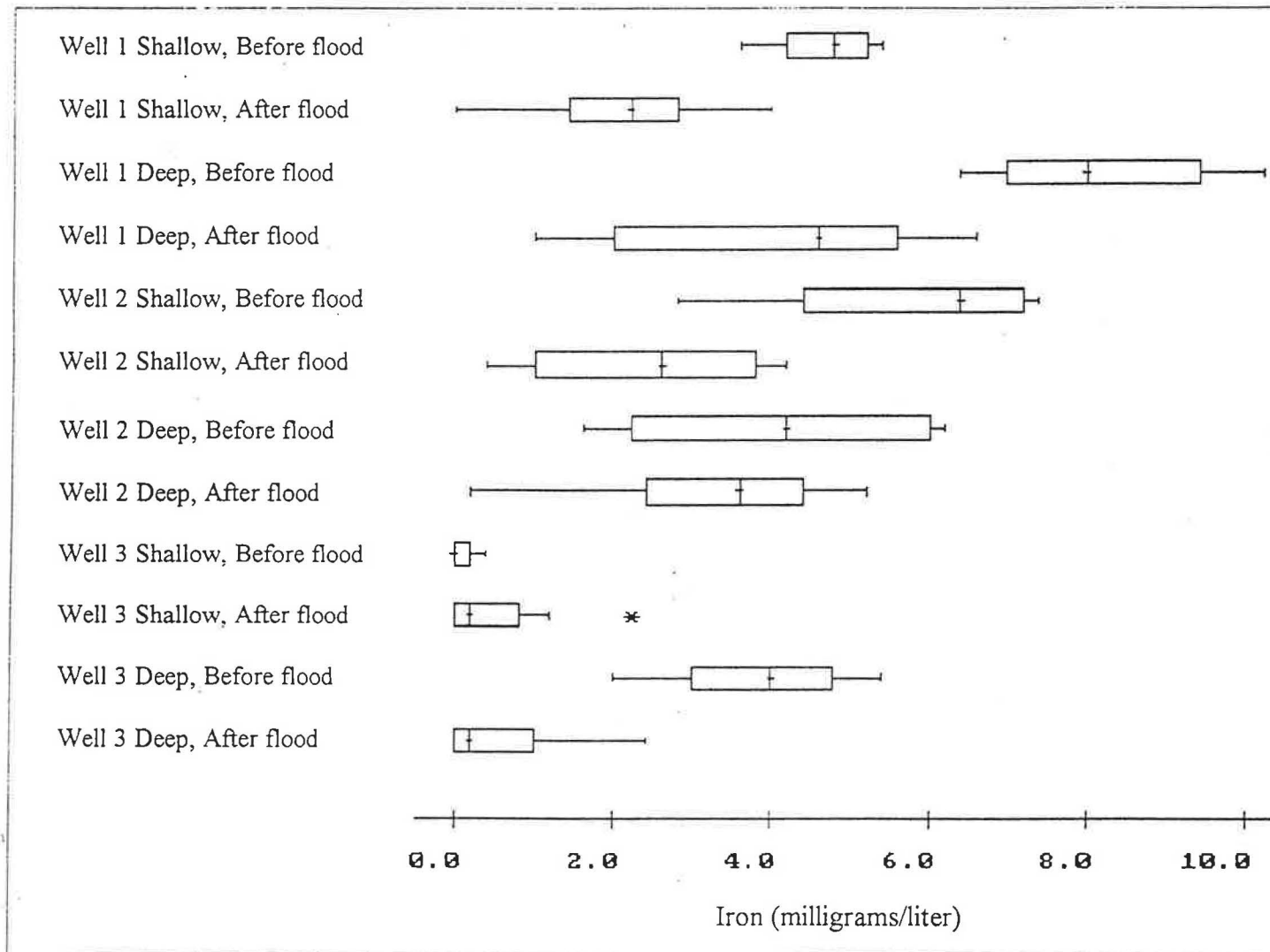


Figure 14. Boxplots of iron data

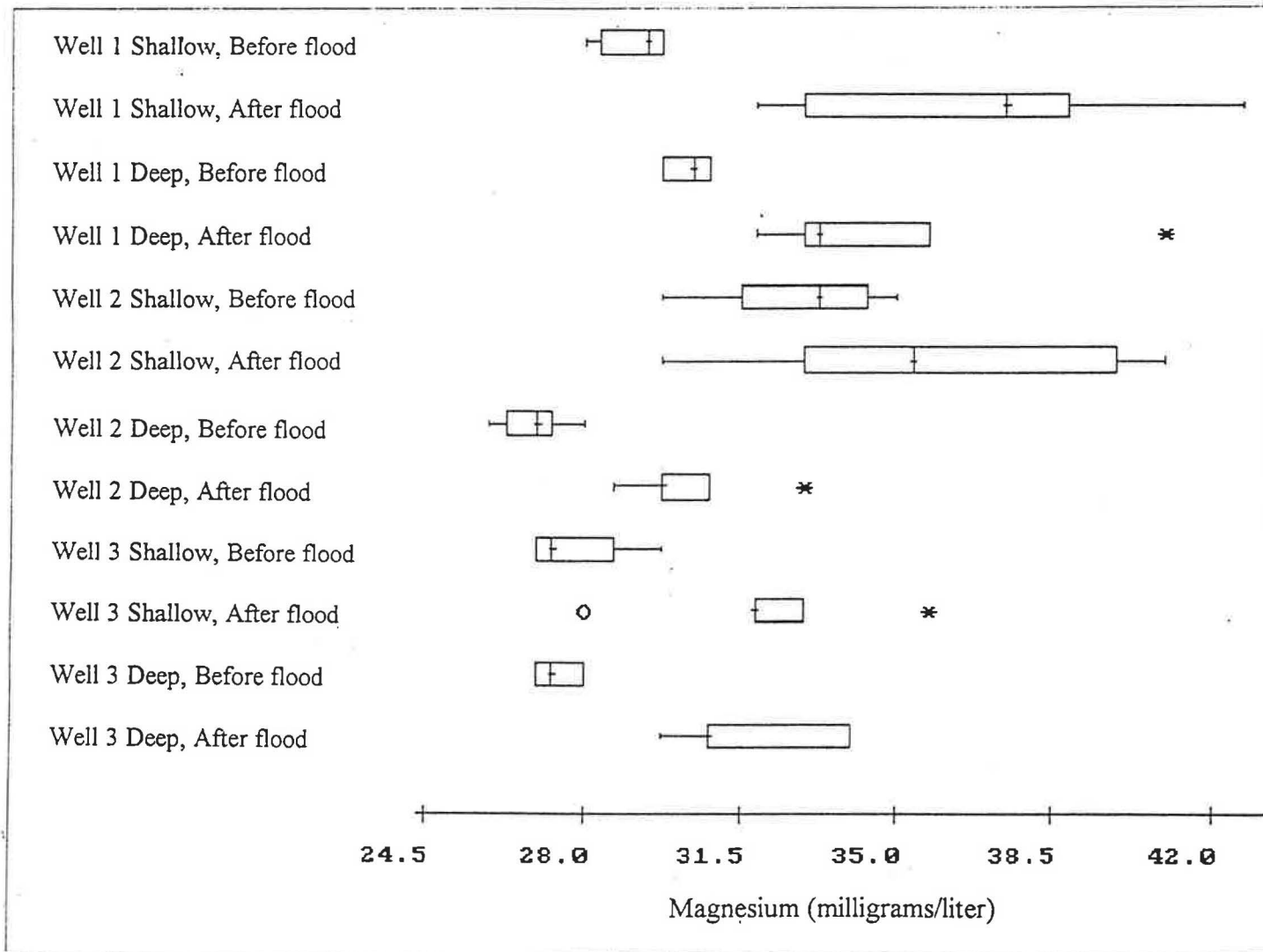


Figure 15. Boxplots of magnesium data

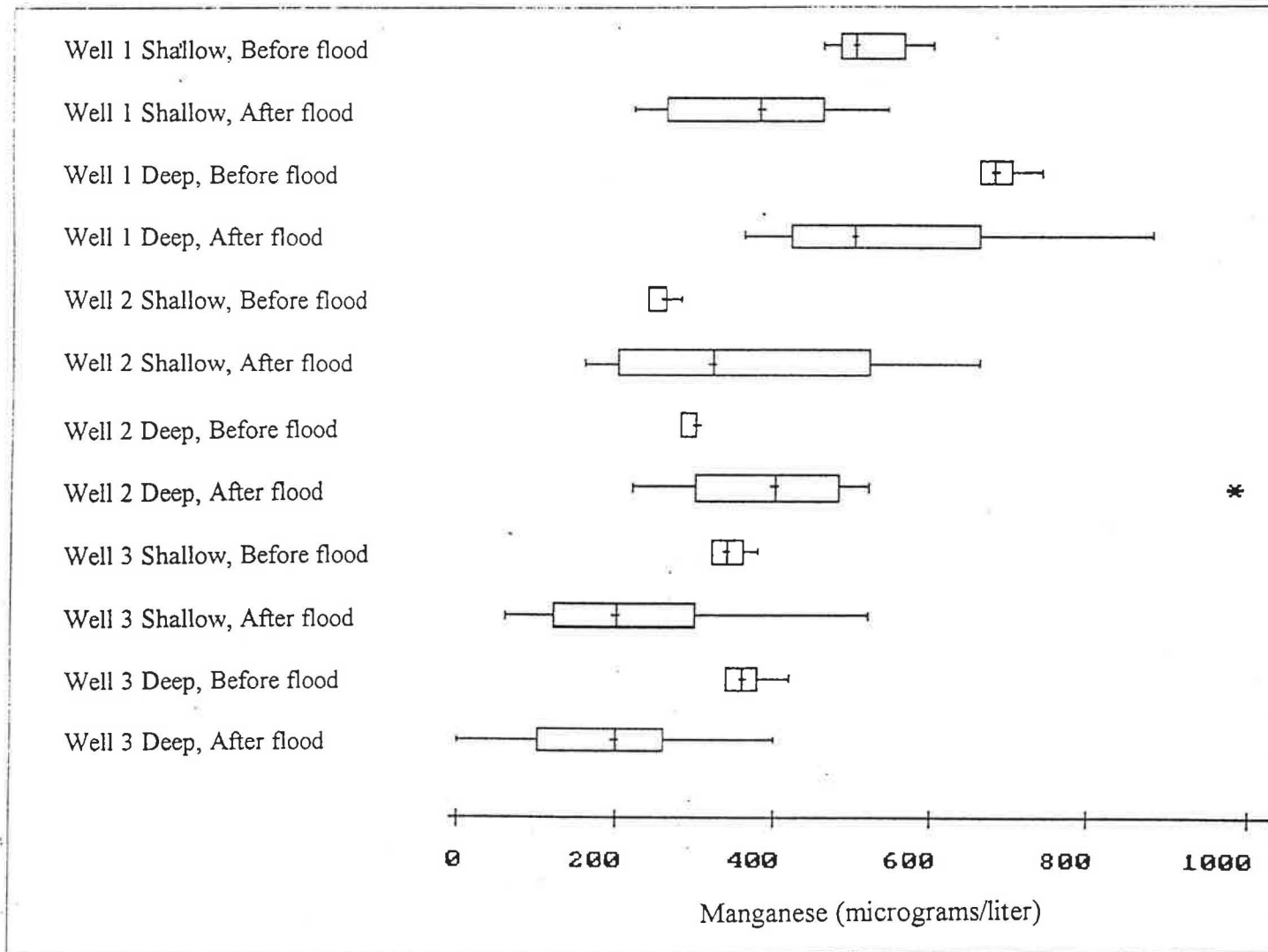


Figure 16. Boxplots of manganese data

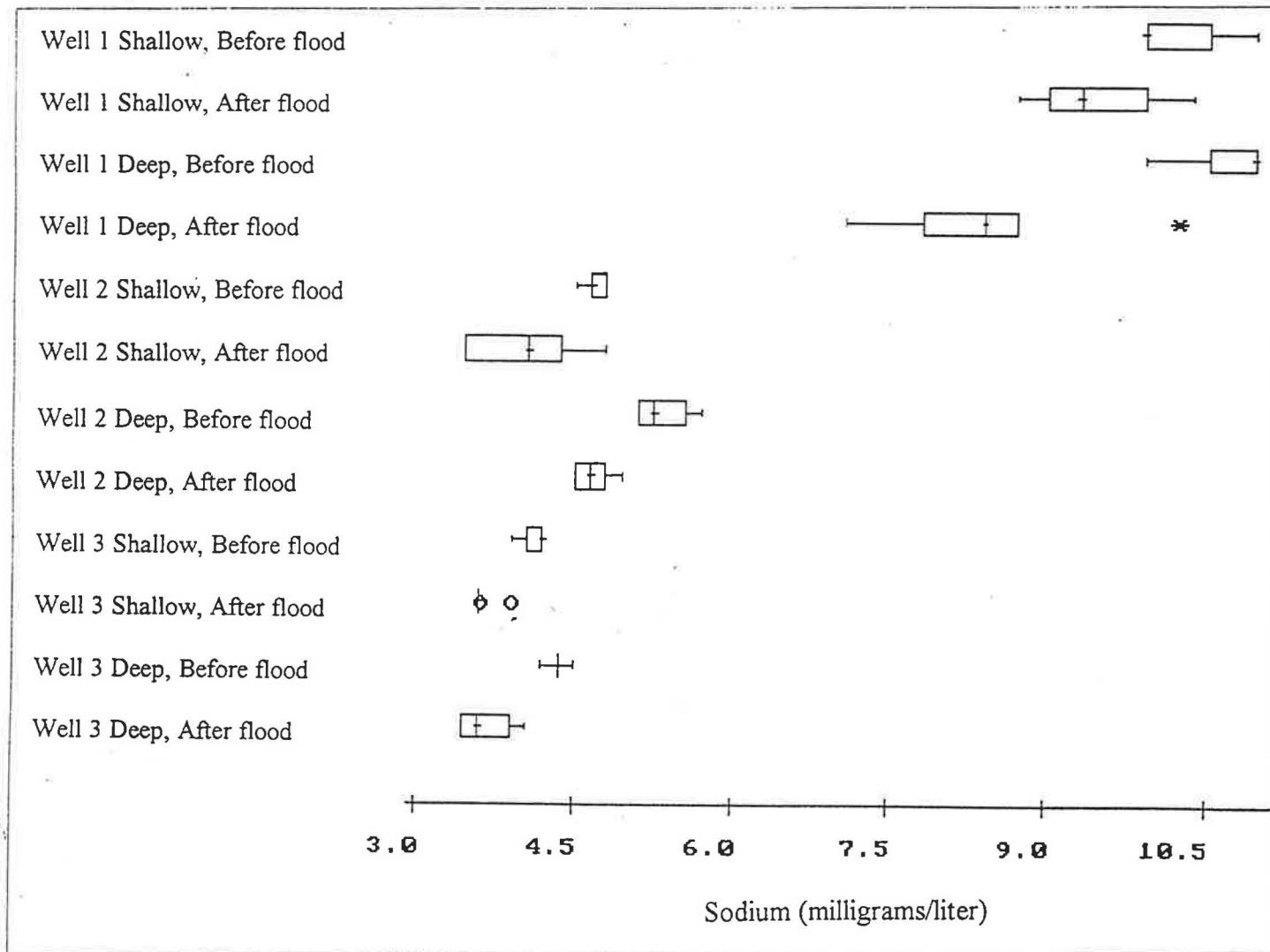


Figure 17. Boxplots of sodium data

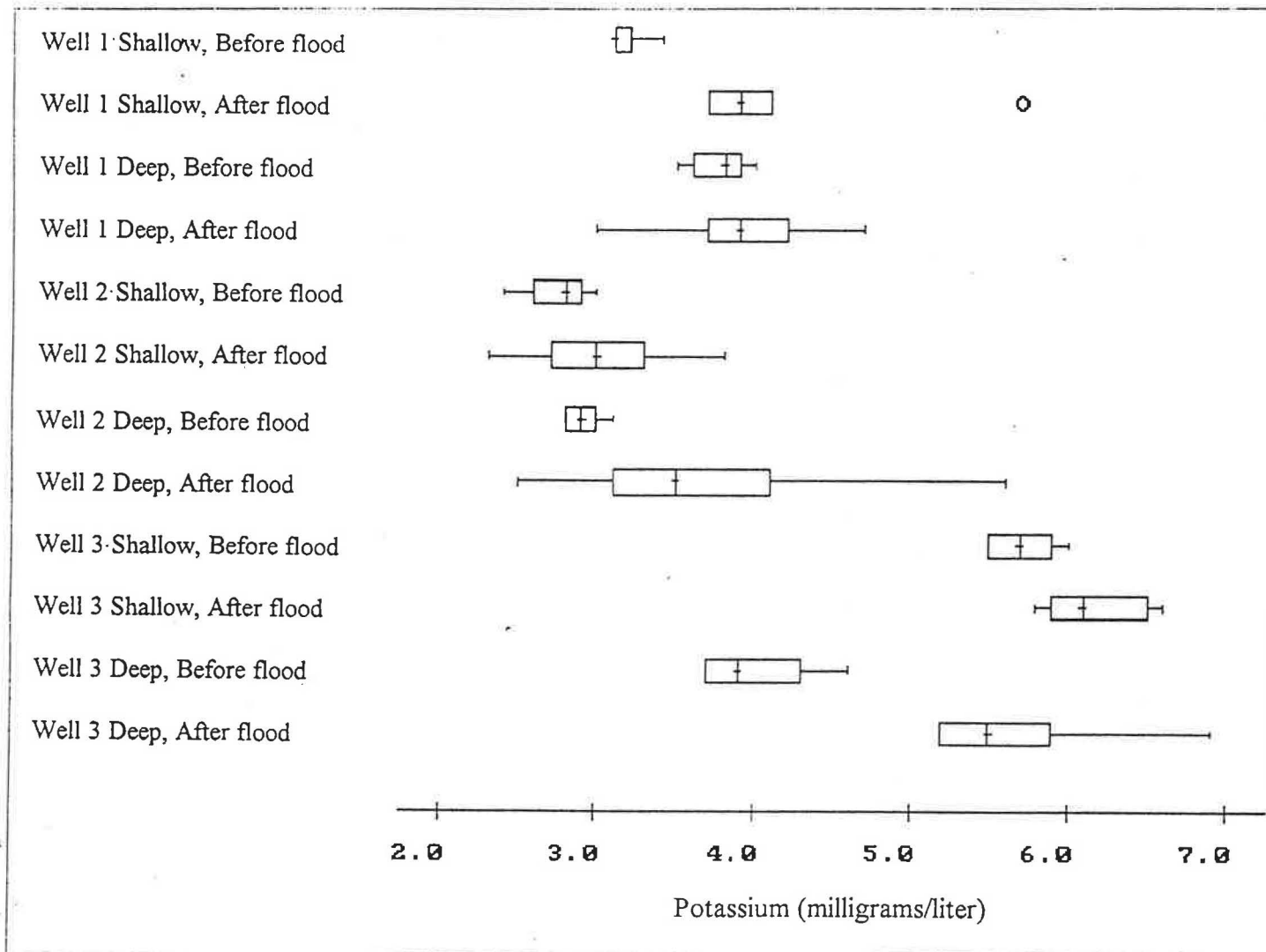


Figure 18. Boxplots of potassium data

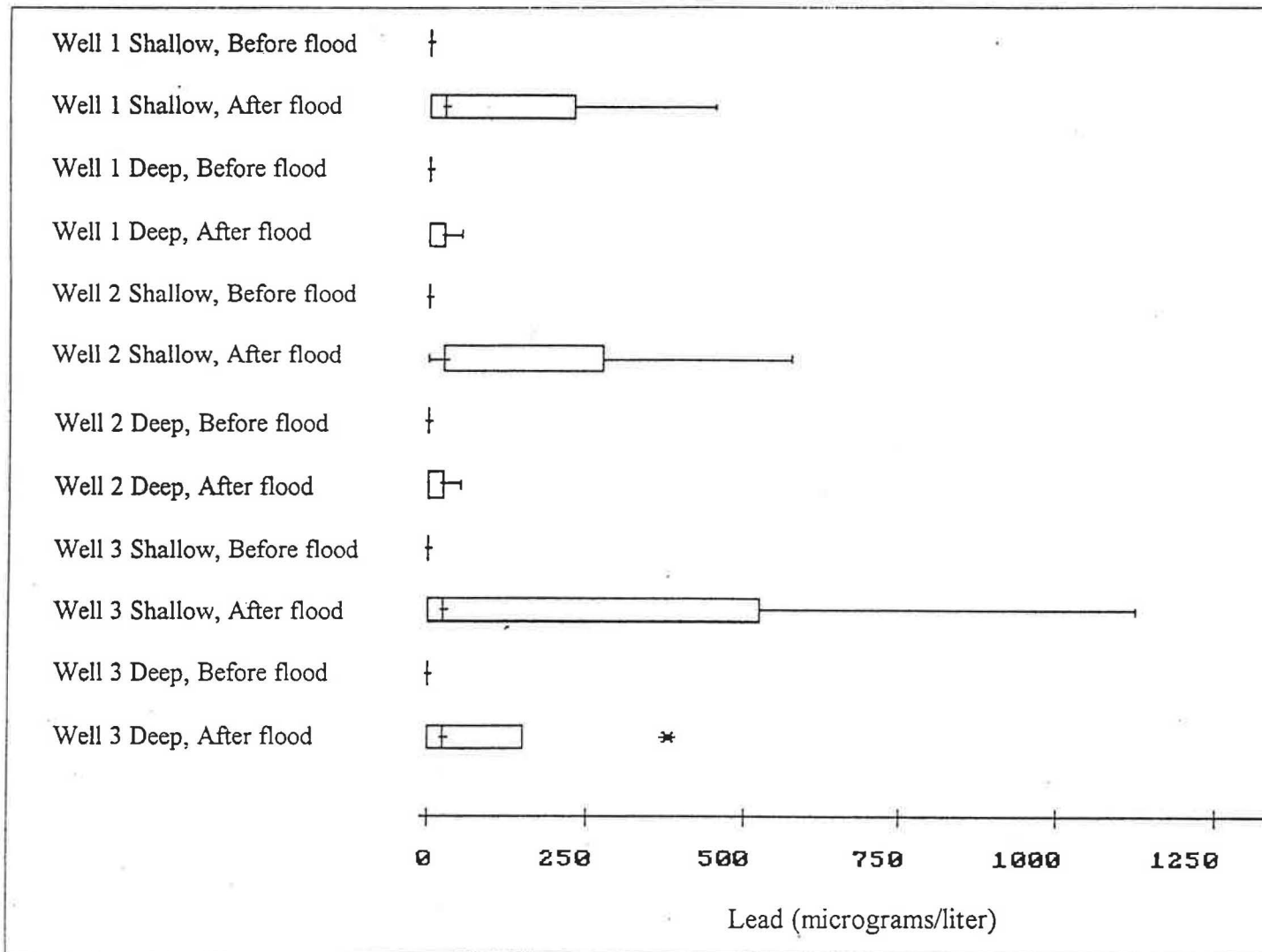


Figure 19. Boxplots of lead data

Table V. Summary of median values of boxplots.

	WE	Alk	F	SO4	Cl	Ba	Ca
Well 1 Shallow							
Before flood	448.87	426	0.30	62	20.0	240	130
After flood	449.36	416	0.39	60	6.5	365	210
Well 1 Deep							
Before flood	448.05	460	0.30	49	17.5	365	130
After flood	449.36	416	0.30	51	6.0	330	195
Well 2 Shallow							
Before flood	447.48	444	0.25	25	5.4	385	120
After flood	448.59	402	0.21	29	0.7	505	185
Well 2 Deep							
Before flood	447.54	410	0.25	31	6.1	405	110
After flood	448.67	364	0.20	32	1.6	475	175
Well 3 Shallow							
Before flood	446.37	410	0.20	41	4.7	290	120
After flood	447.52	356	0.28	54	1.8	510	190
Well 3 Deep							
Before flood	446.96	417	0.20	40	5.3	290	120
After flood	447.73	354	0.31	52	1.2	450	180

Table V. Summary of median values of boxplots. (Continued)

	Cr	Fe	Mg	Mn	Na	K	Pb
Well 1 Shallow							
Before flood	<1	4.90	30	505	10.0	3.1	<1
After flood	90	2.37	38	380	9.3	3.9	35
Well 1 Deep							
Before flood	<1	8.05	31	680	11.0	3.9	<1
After flood	60	4.69	34	505	8.5	4.0	25
Well 2 Shallow							
Before flood	<1	6.55	34	260	4.8	2.9	<1
After flood	80	2.63	36	330	4.1	3.1	45
Well 2 Deep							
Before flood	<1	4.25	27	300	5.3	3.0	<1
After flood	90	3.67	30	405	4.8	3.6	25
Well 3 Shallow							
Before flood	<1	0.03	28	350	4.3	5.8	<1
After flood	65	0.32	32	200	3.7	6.1	40
Well 3 Deep							
Before flood	<1	4.18	28	365	4.4	3.9	<1
After flood	80	0.33	31	205	3.7	5.5	35

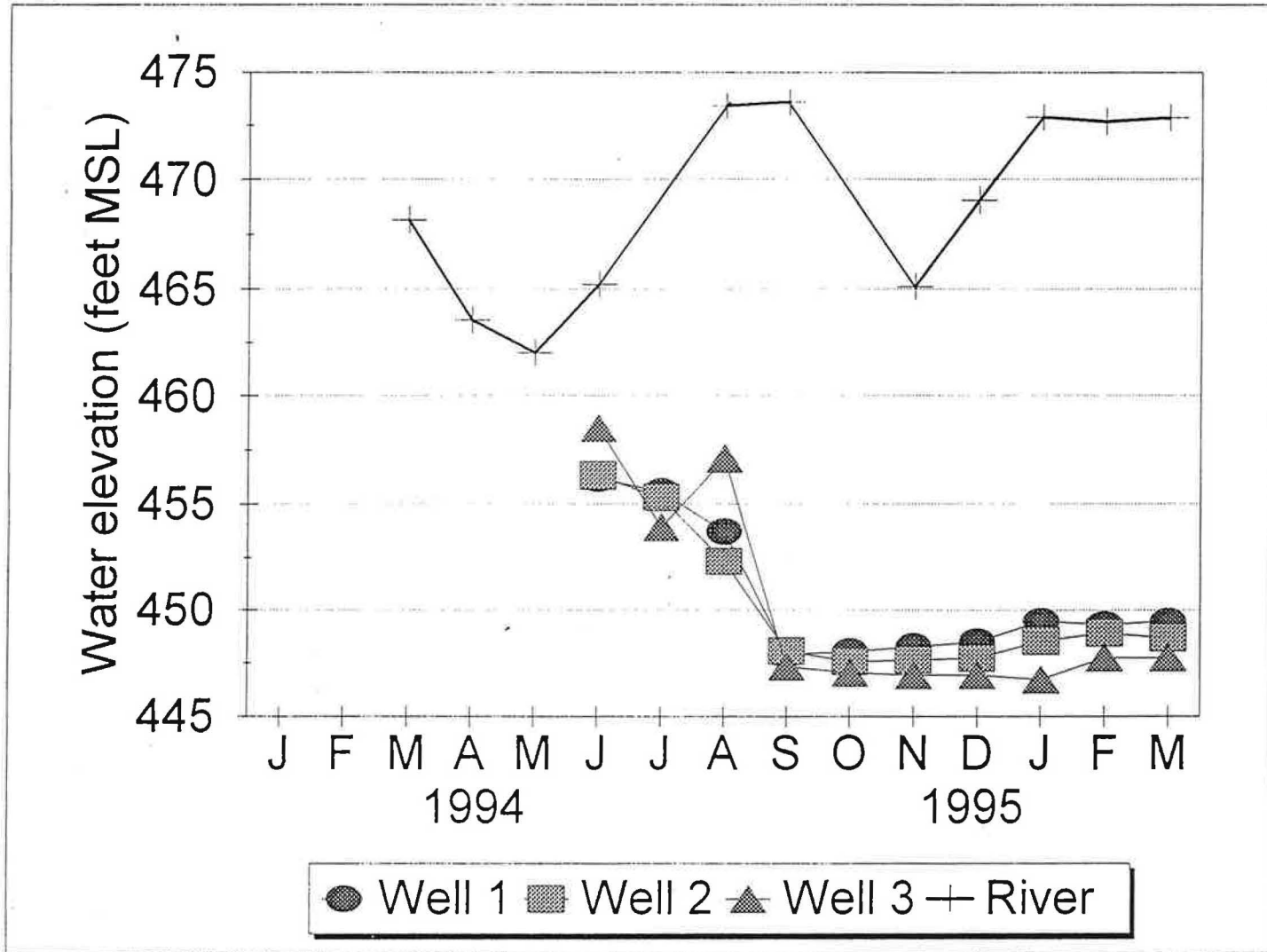


Figure 20. Water elevation data of shallow wells and river versus time

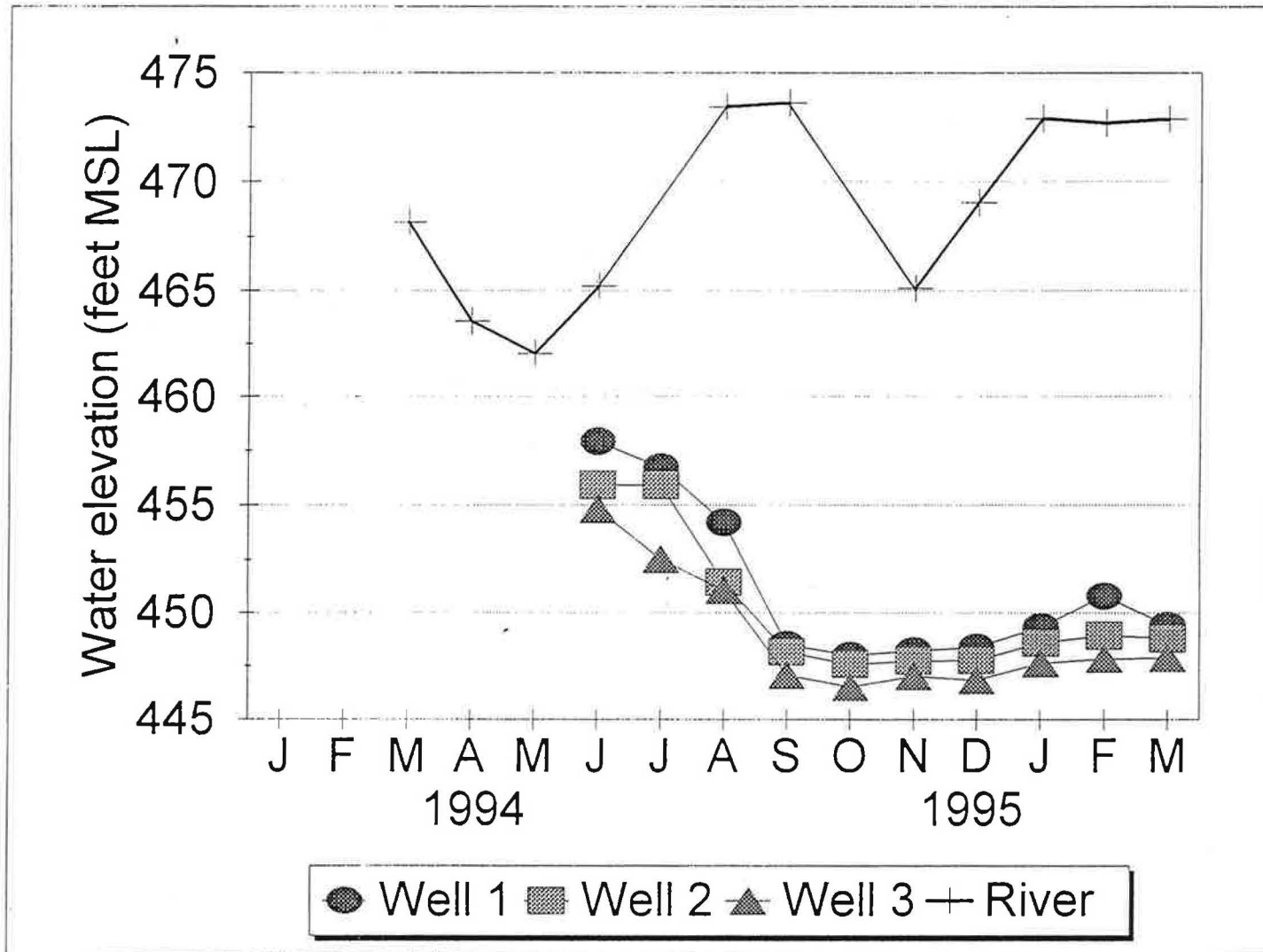


Figure 21. Water elevation data of deep wells and river versus time

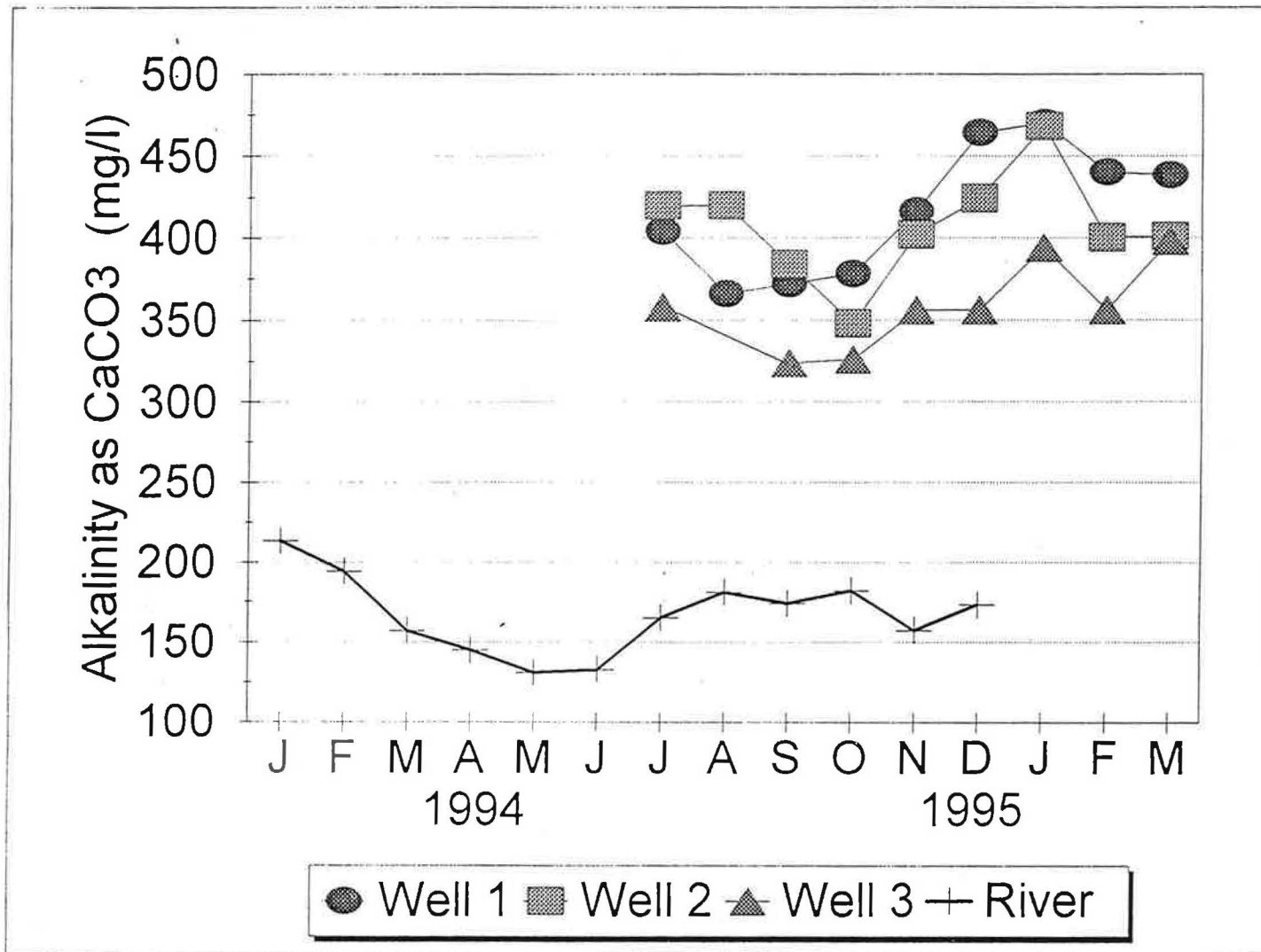


Figure 22. Alkalinity data of shallow wells and river versus time

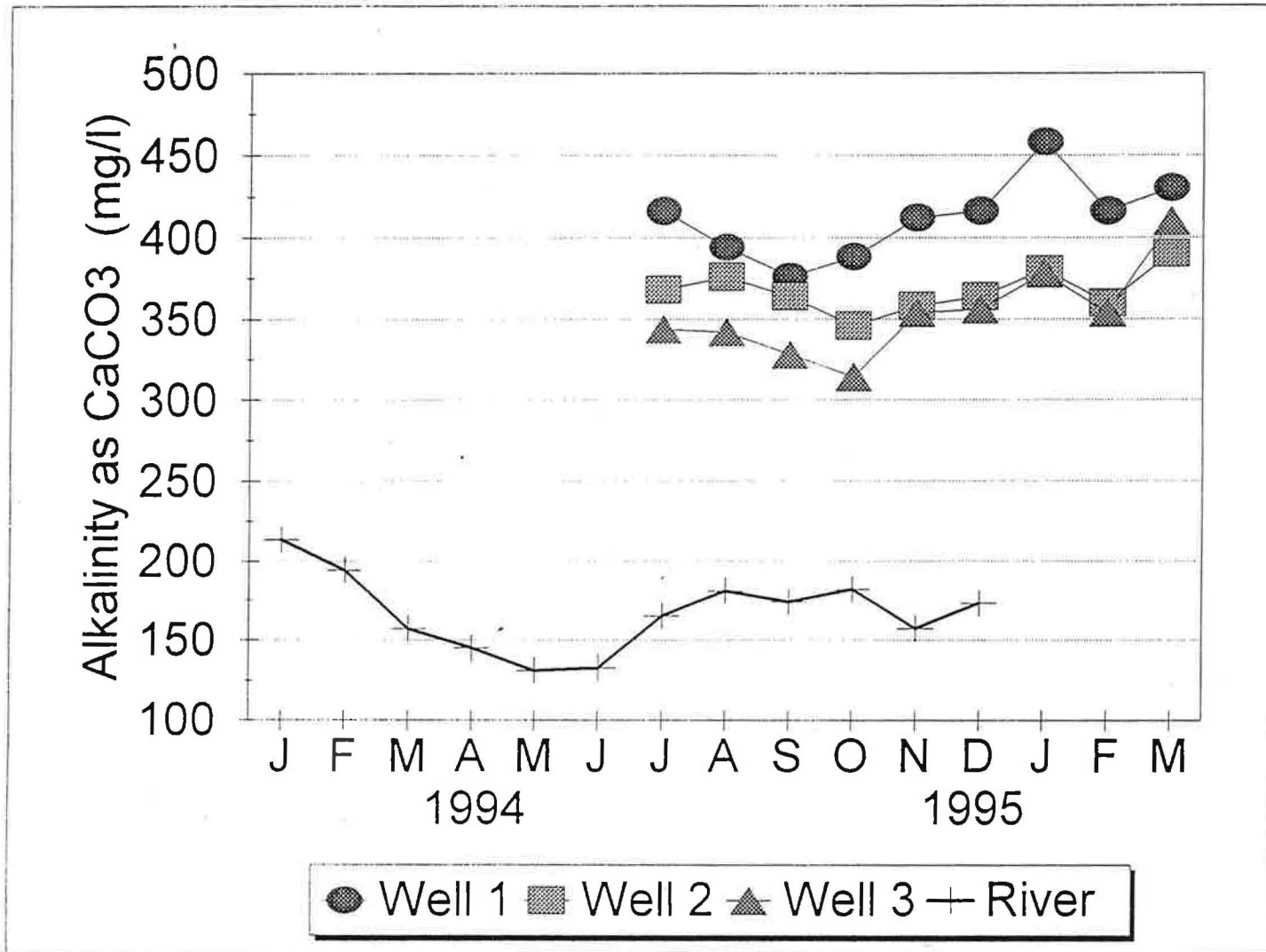


Figure 23. Alkalinity data of deep wells and river versus time

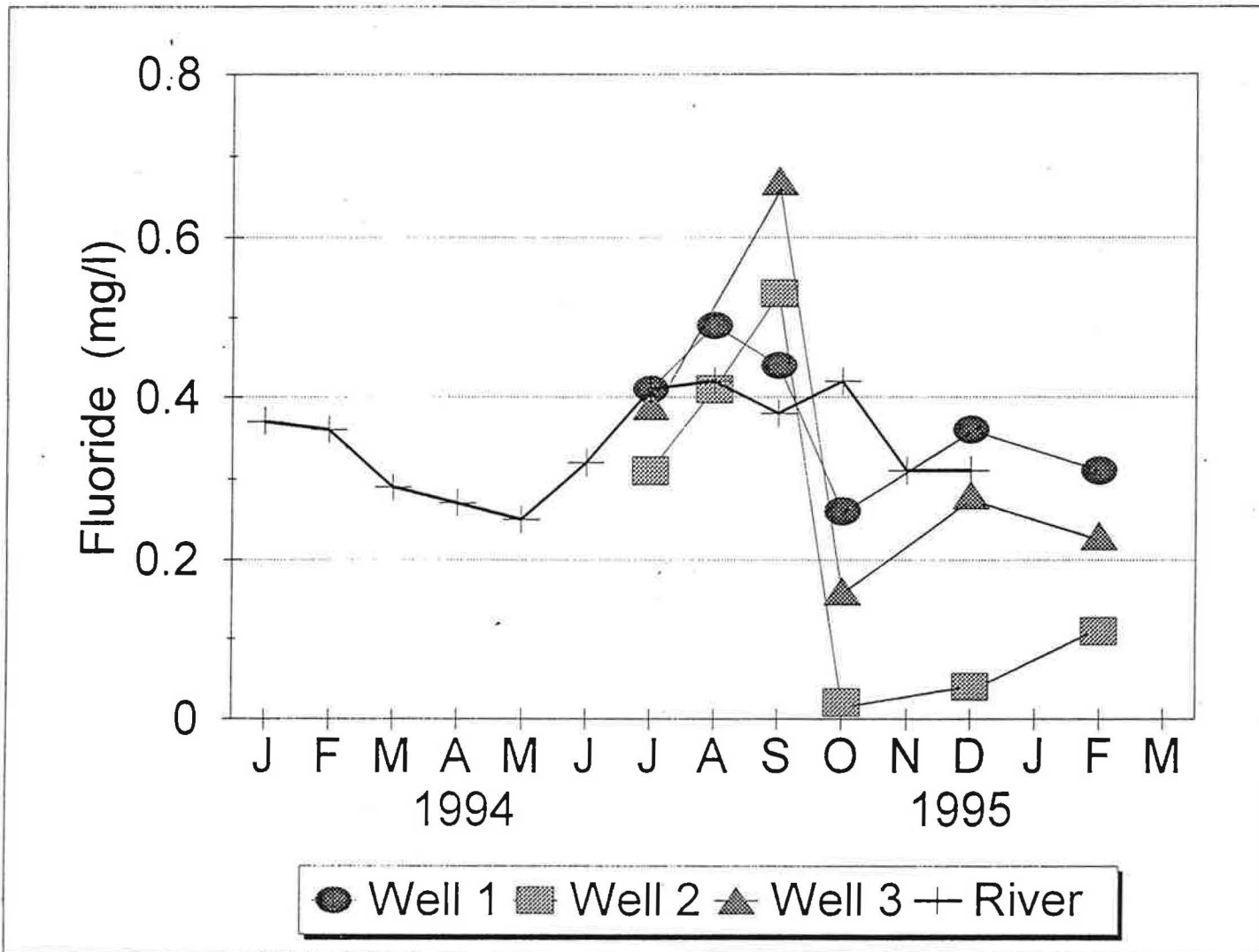


Figure 24. Fluoride data of shallow wells and river versus time

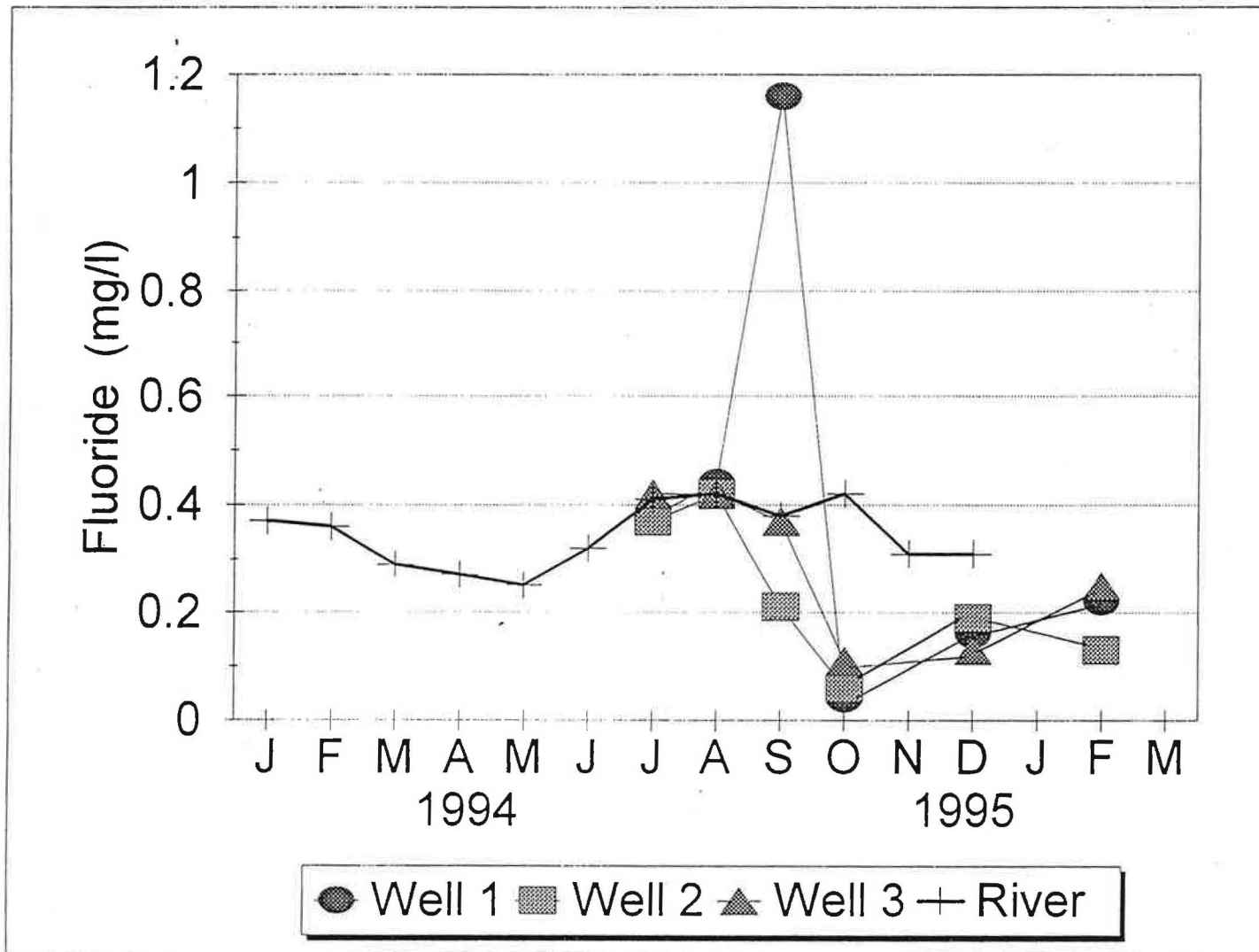


Figure 25. Fluoride data of deep wells and river versus time

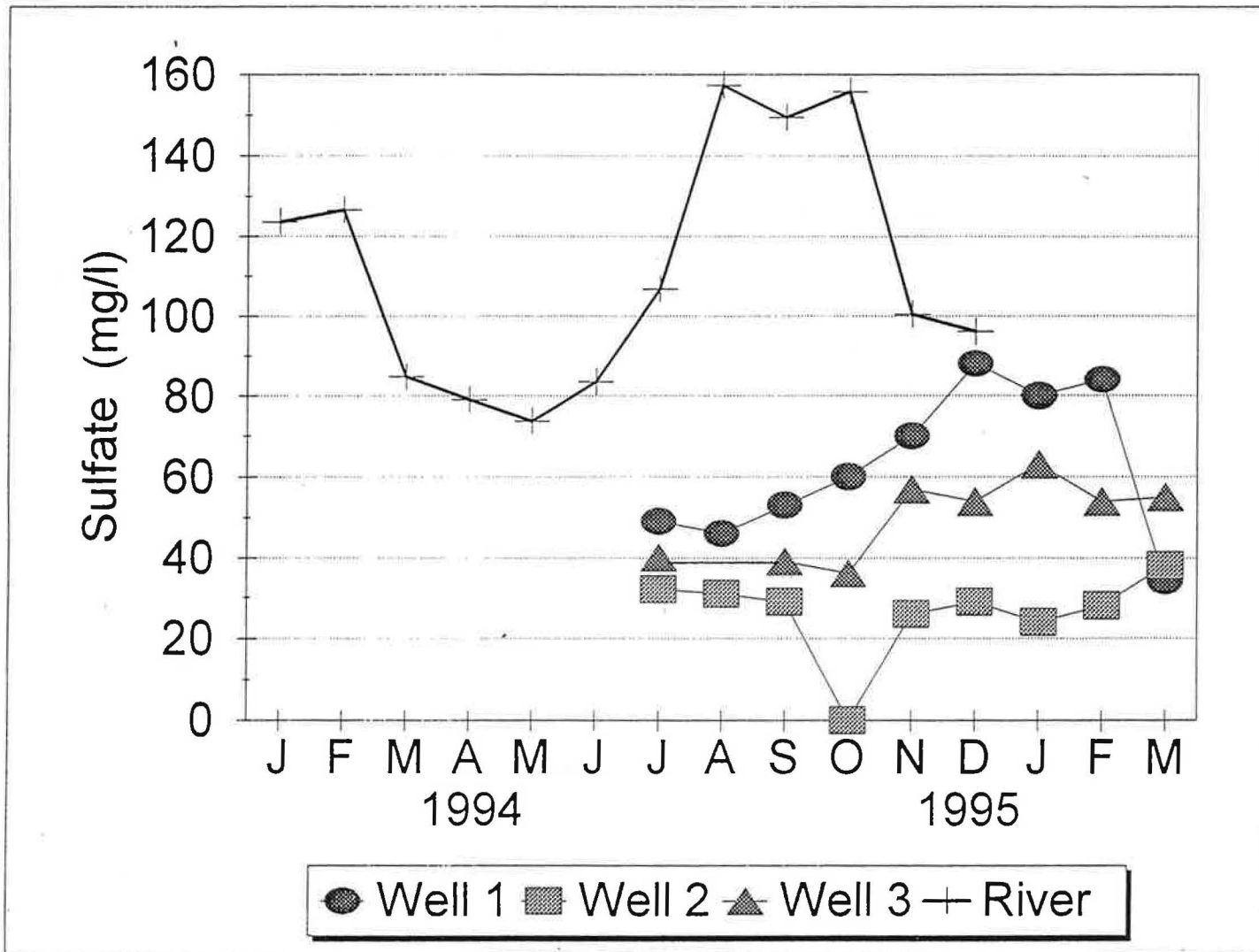


Figure 26. Sulfate data of shallow wells and river versus time

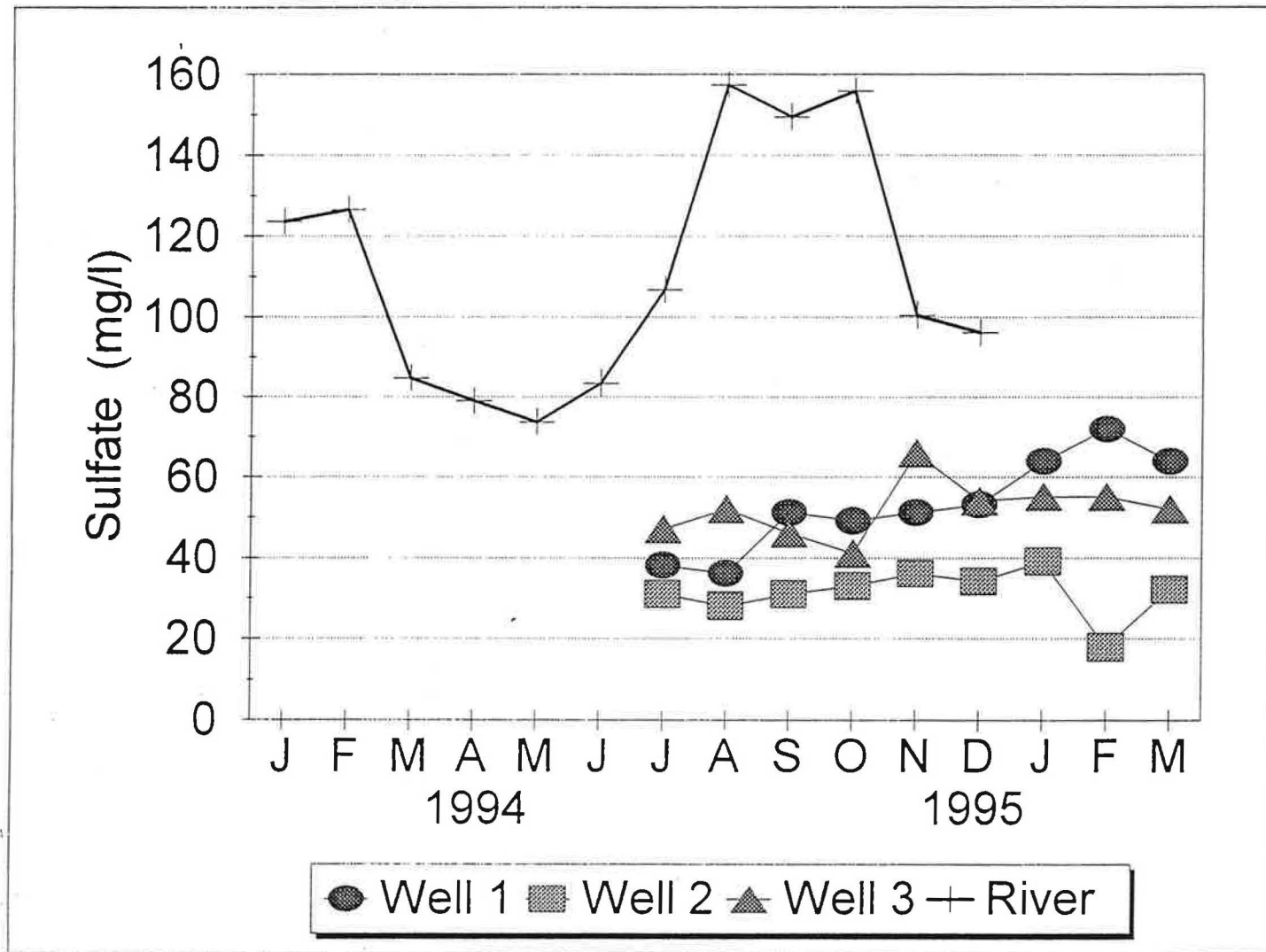


Figure 27. Sulfate data of deep wells and river versus time

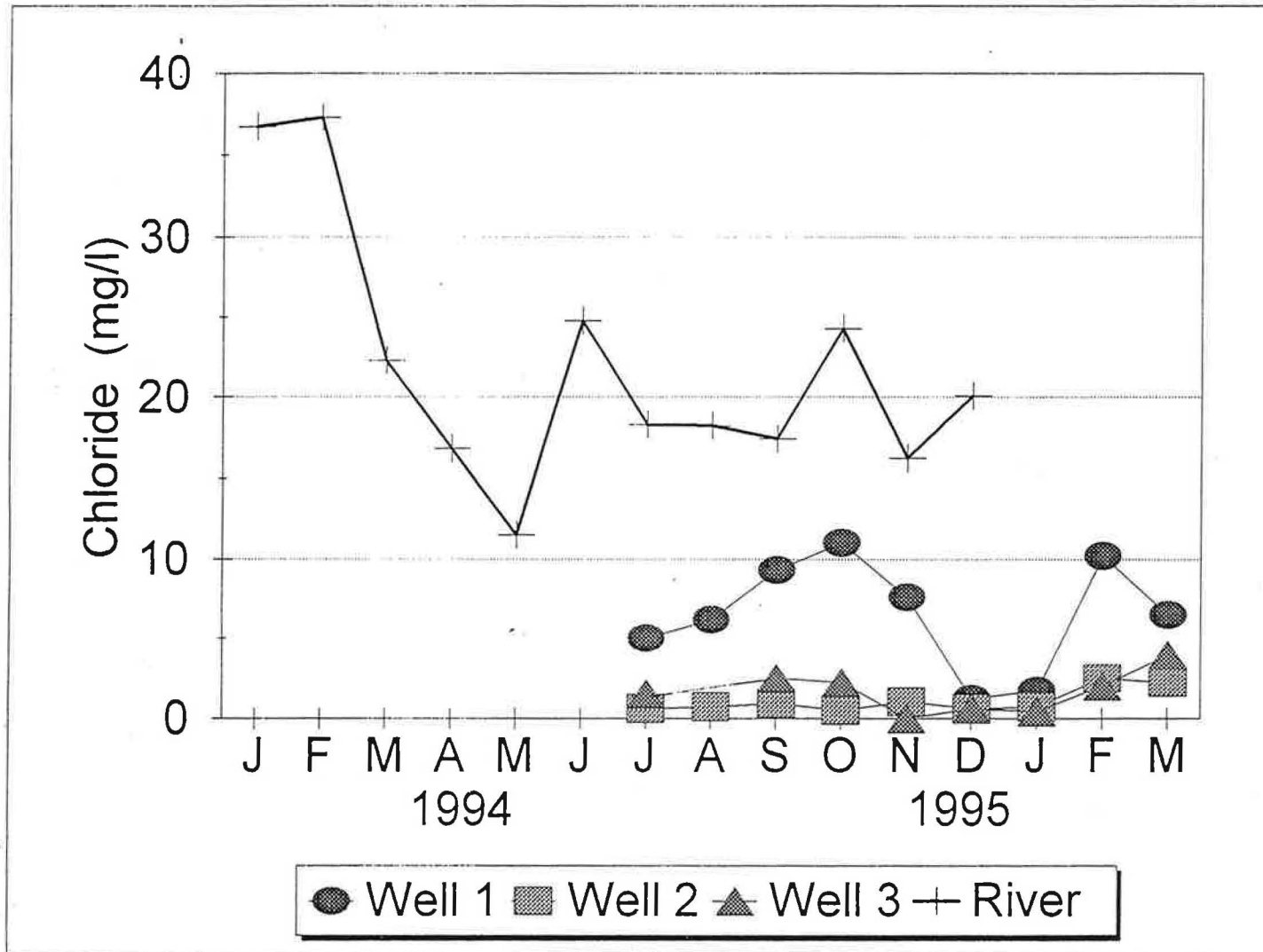


Figure 28. Chloride data of shallow wells and river versus time

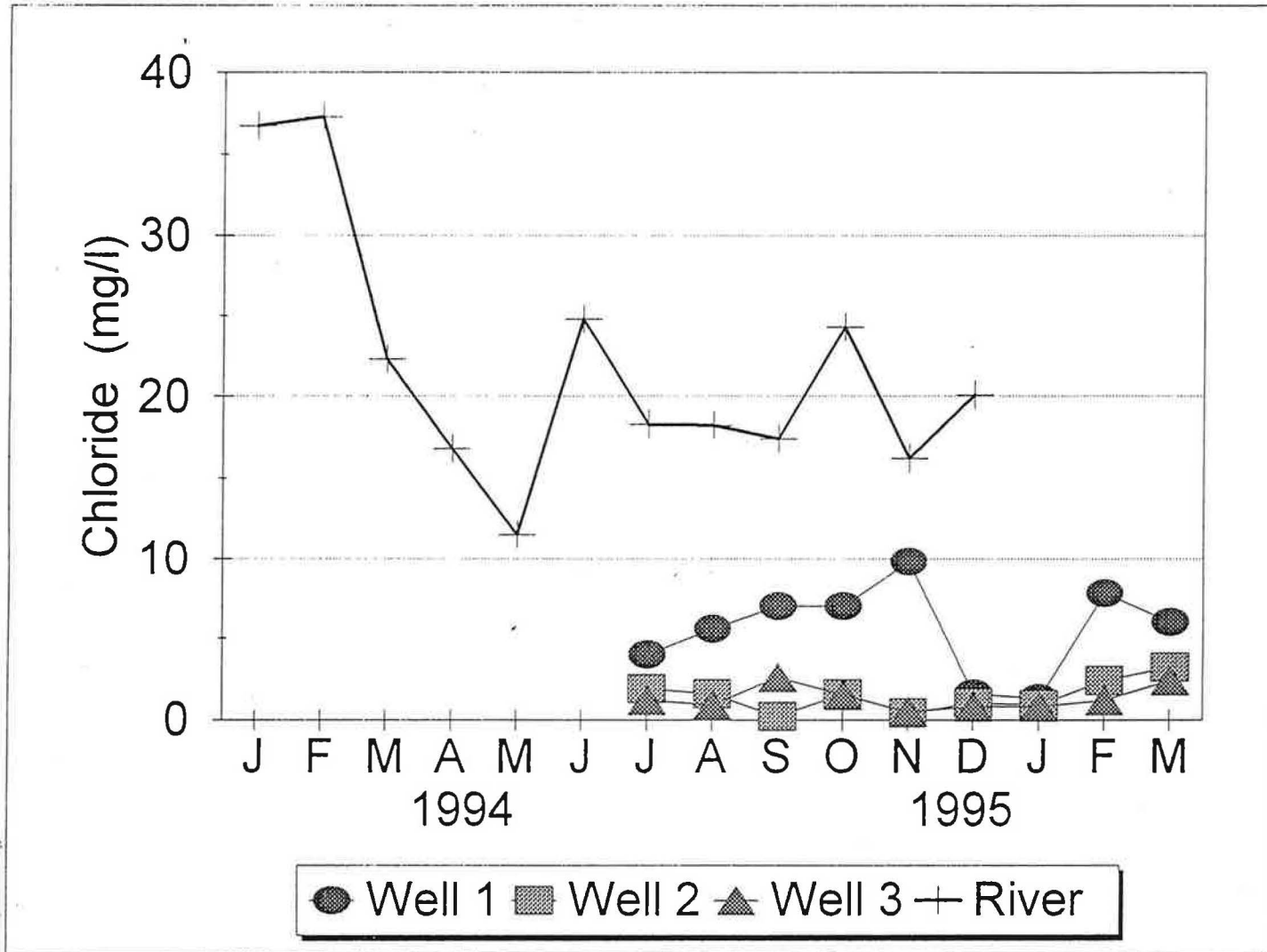


Figure 29. Chloride data of deep wells and river versus time

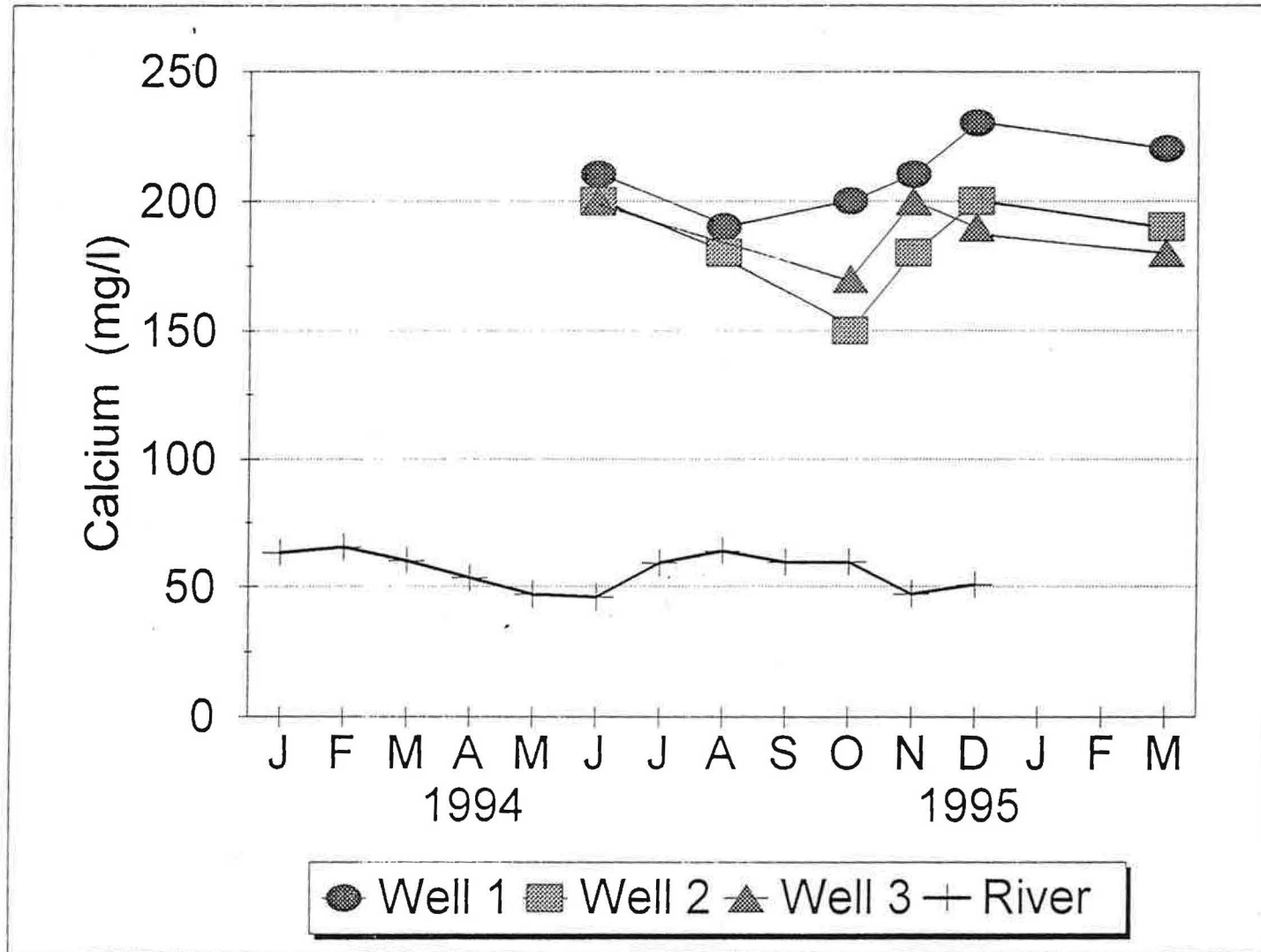


Figure 30. Calcium data of shallow wells and river versus time

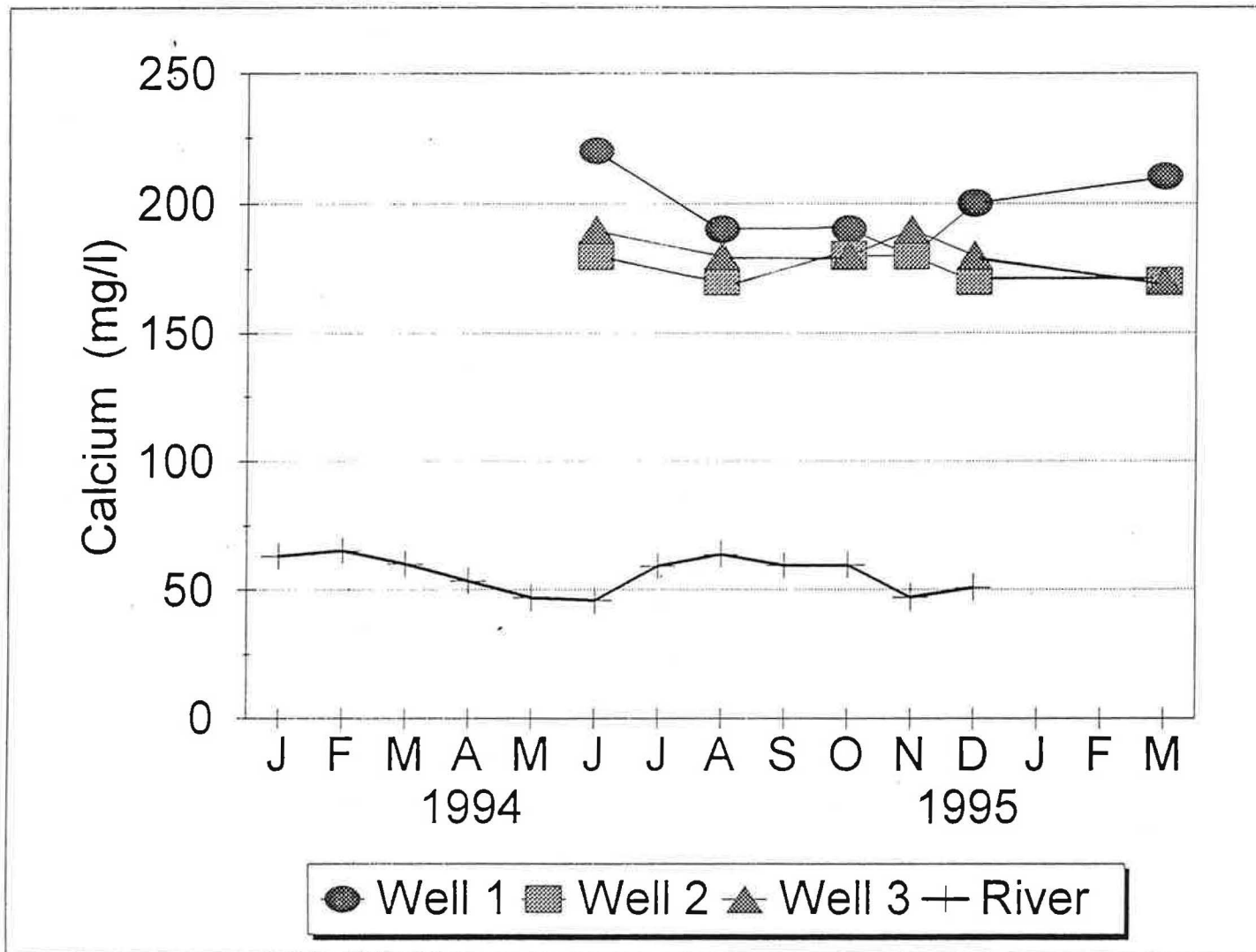


Figure 31. Calcium data of deep wells and river versus time

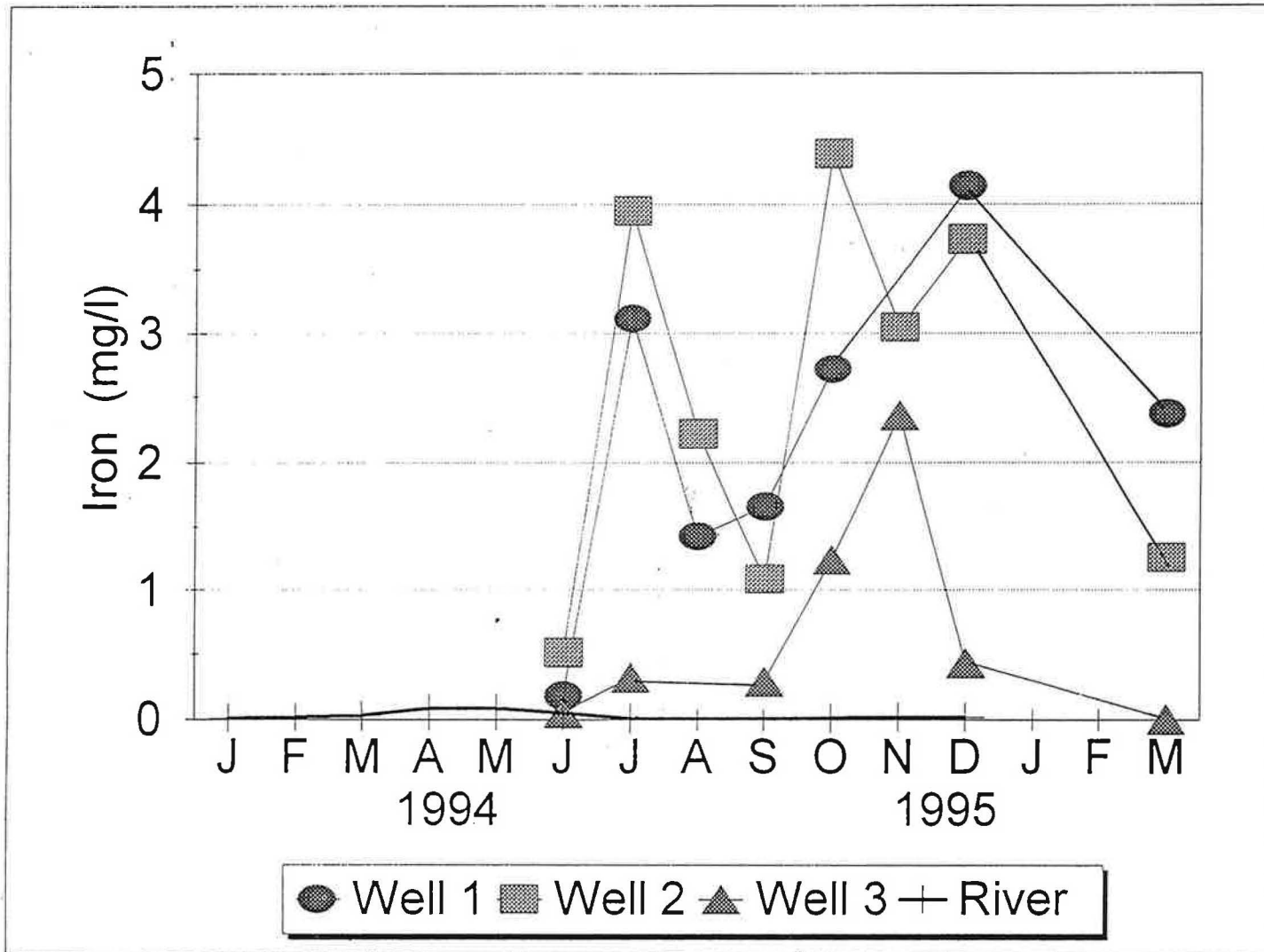


Figure 32. Iron data of shallow wells and river versus time

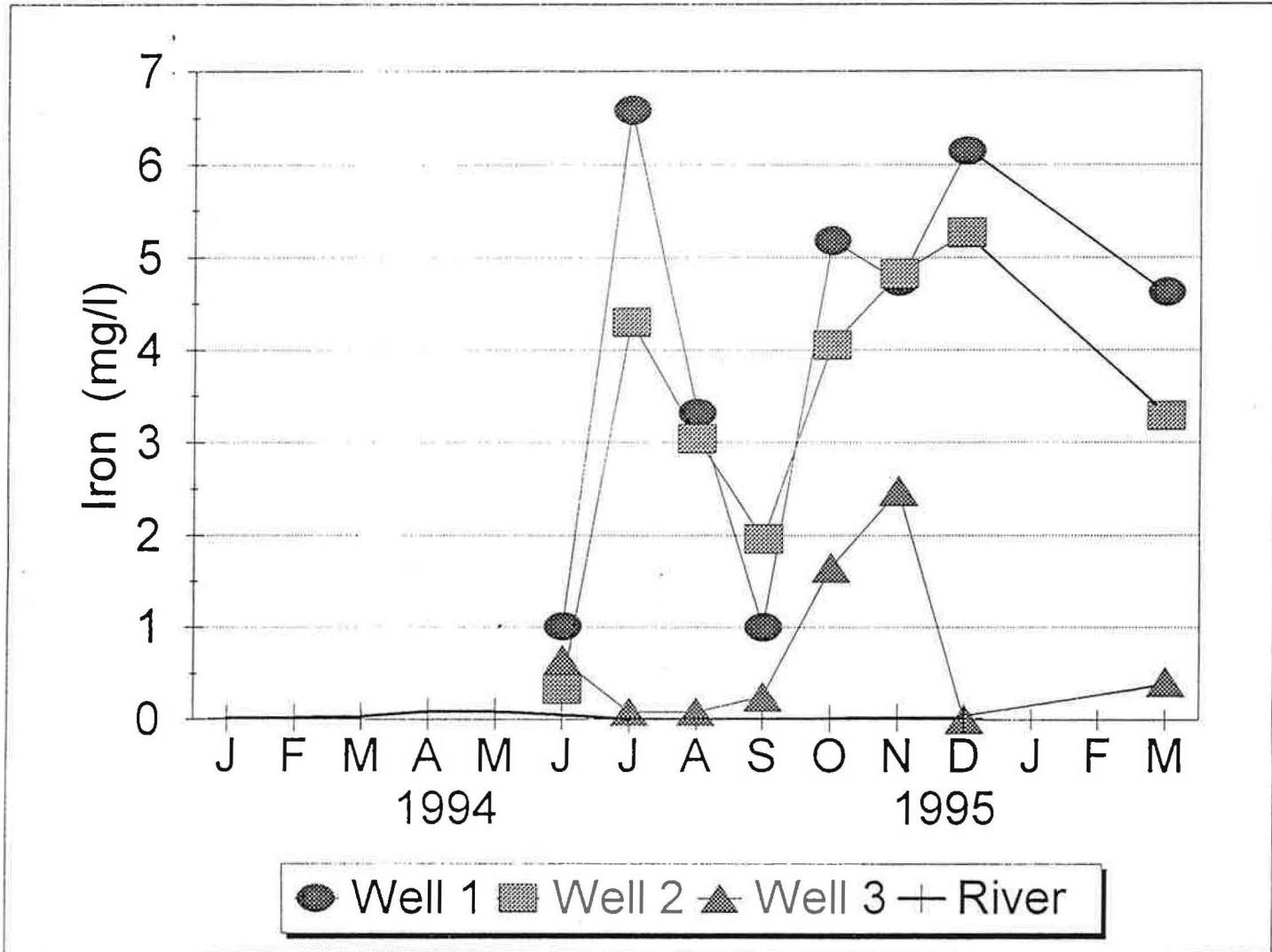


Figure 33. Iron data of deep wells and river versus time

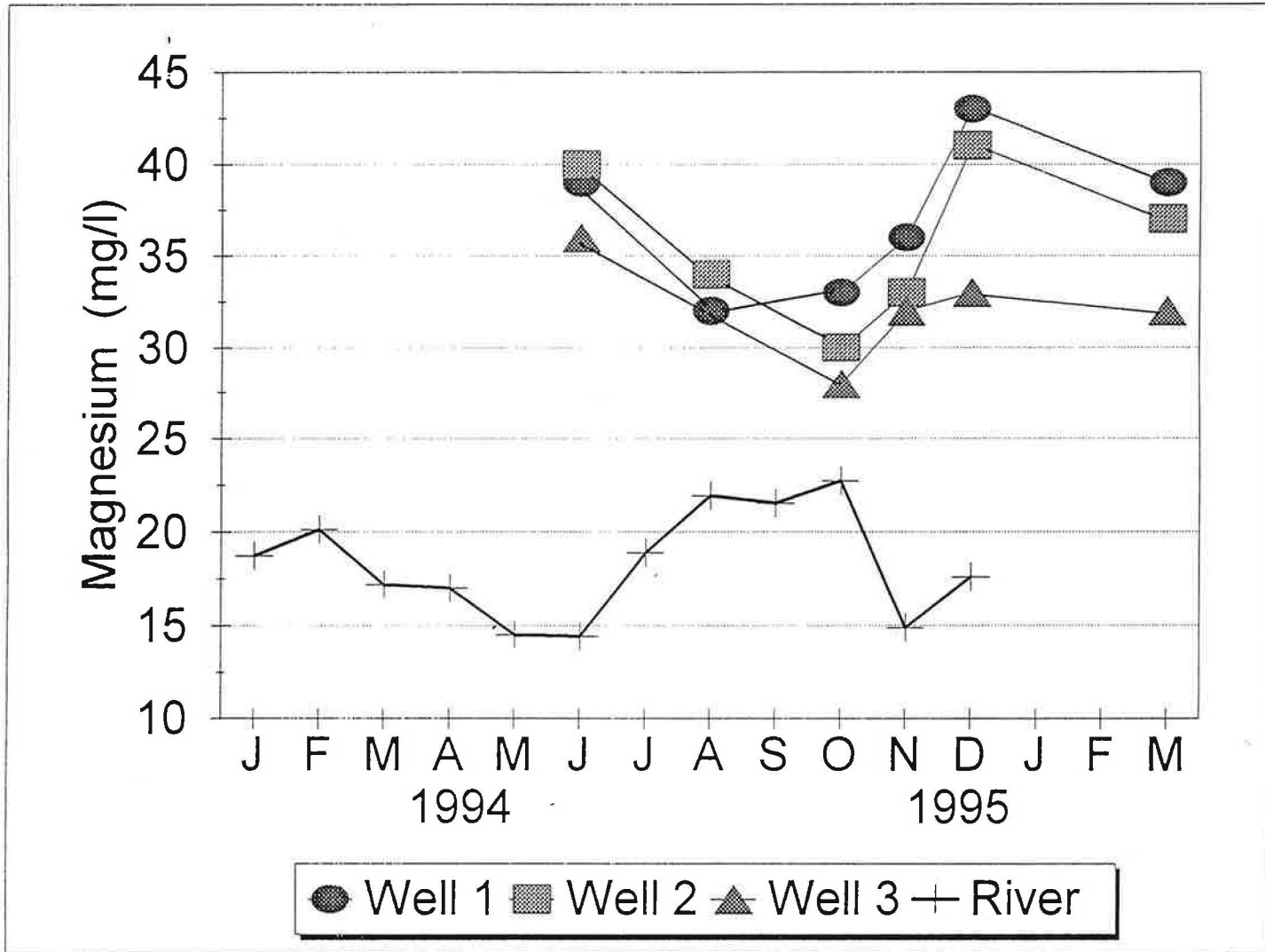


Figure 34. Magnesium data of shallow wells and river versus time

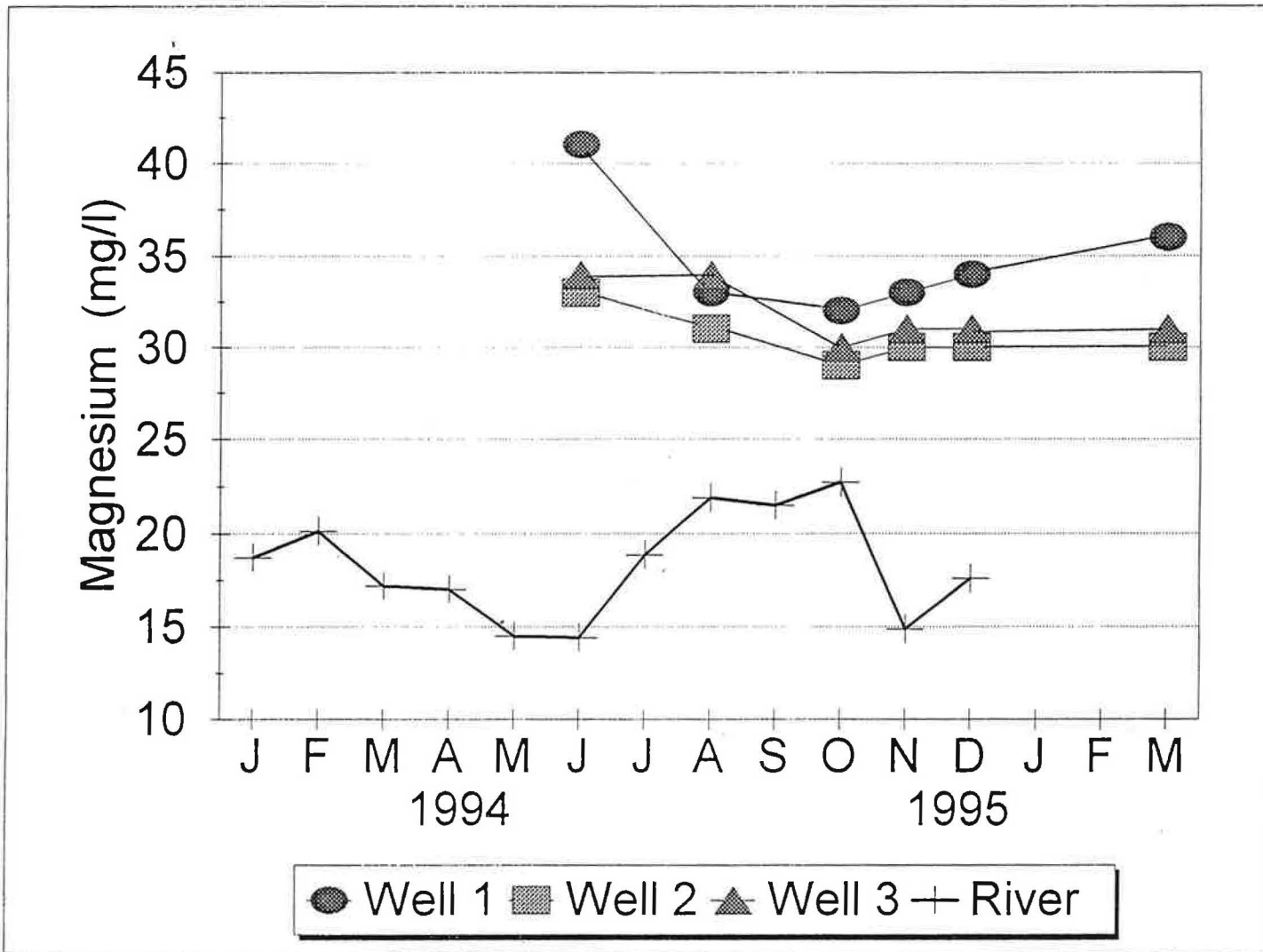


Figure 35. Magnesium data of deep wells and river versus time

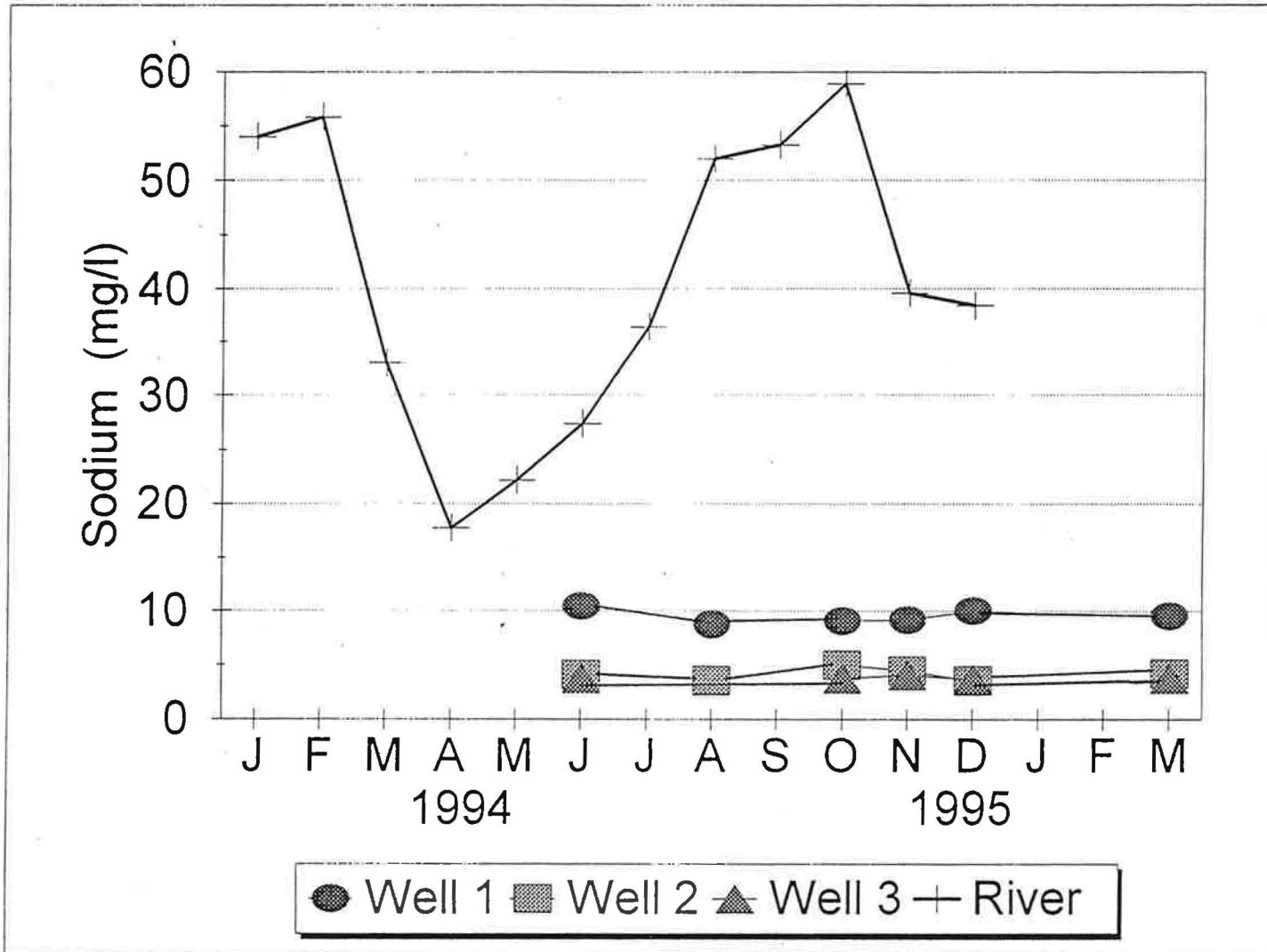


Figure 36. Sodium data of shallow wells and river versus time

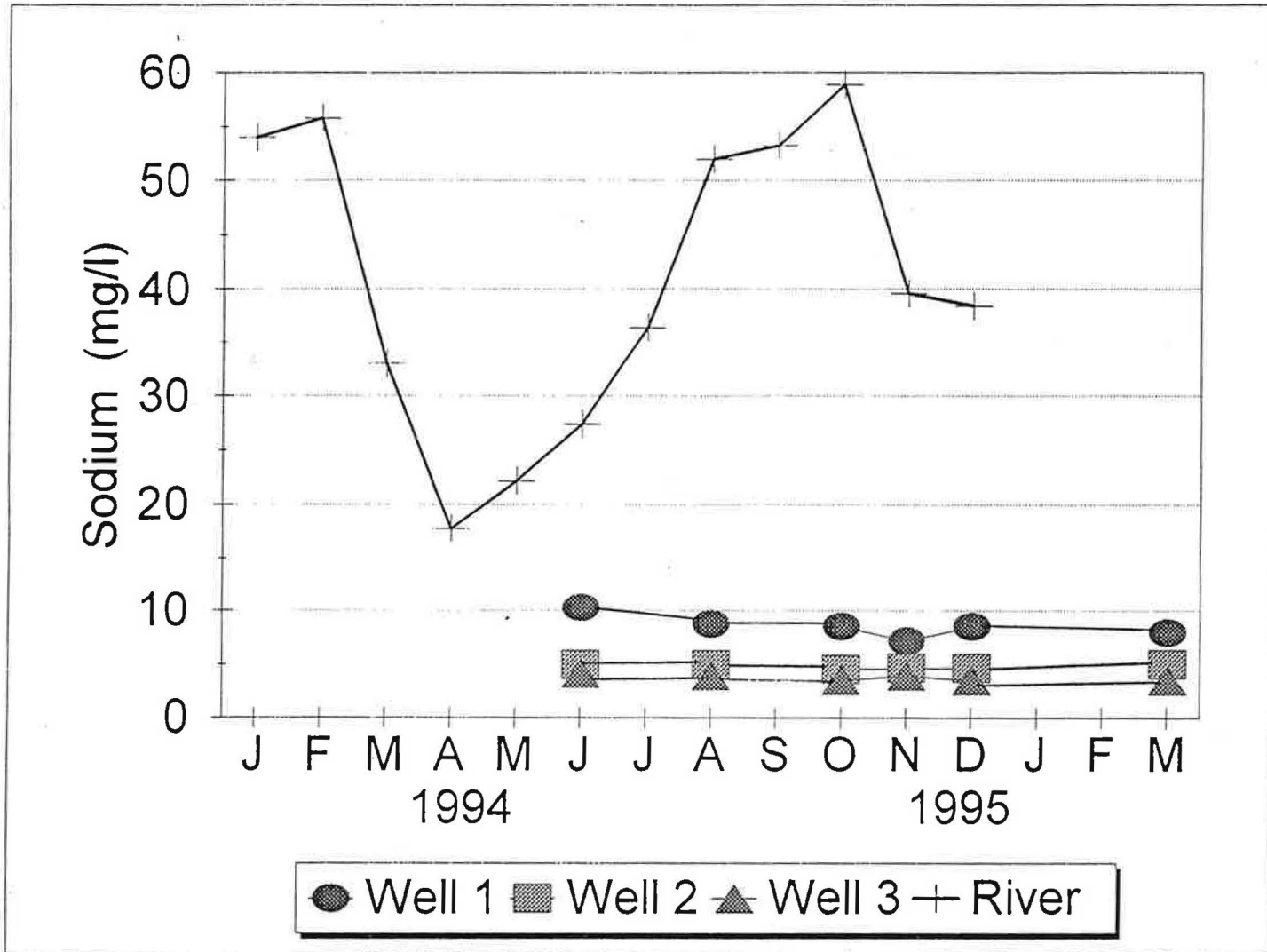


Figure 37. Sodium data of deep wells and river versus time

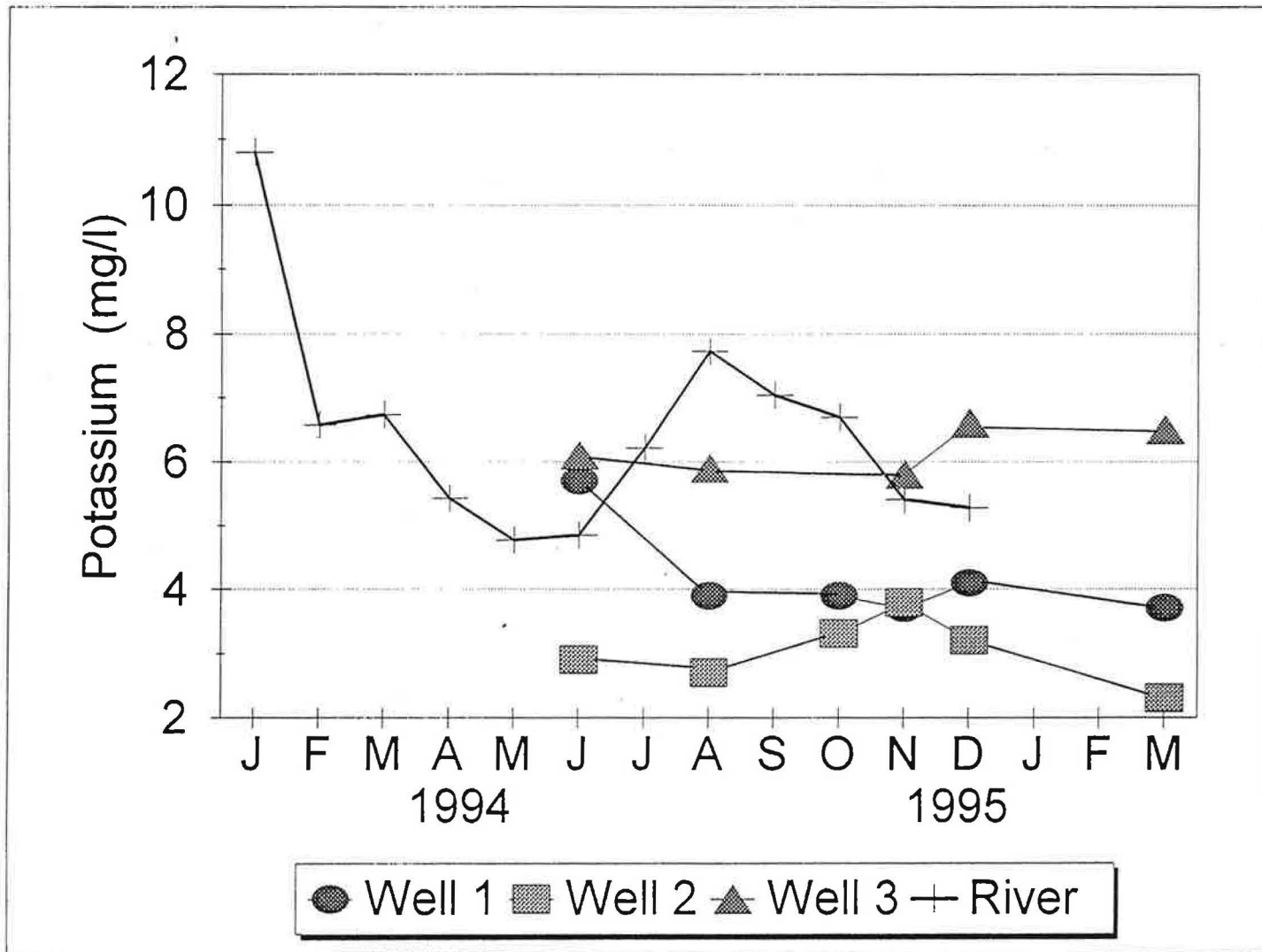


Figure 38. Potassium data of shallow wells and river versus time

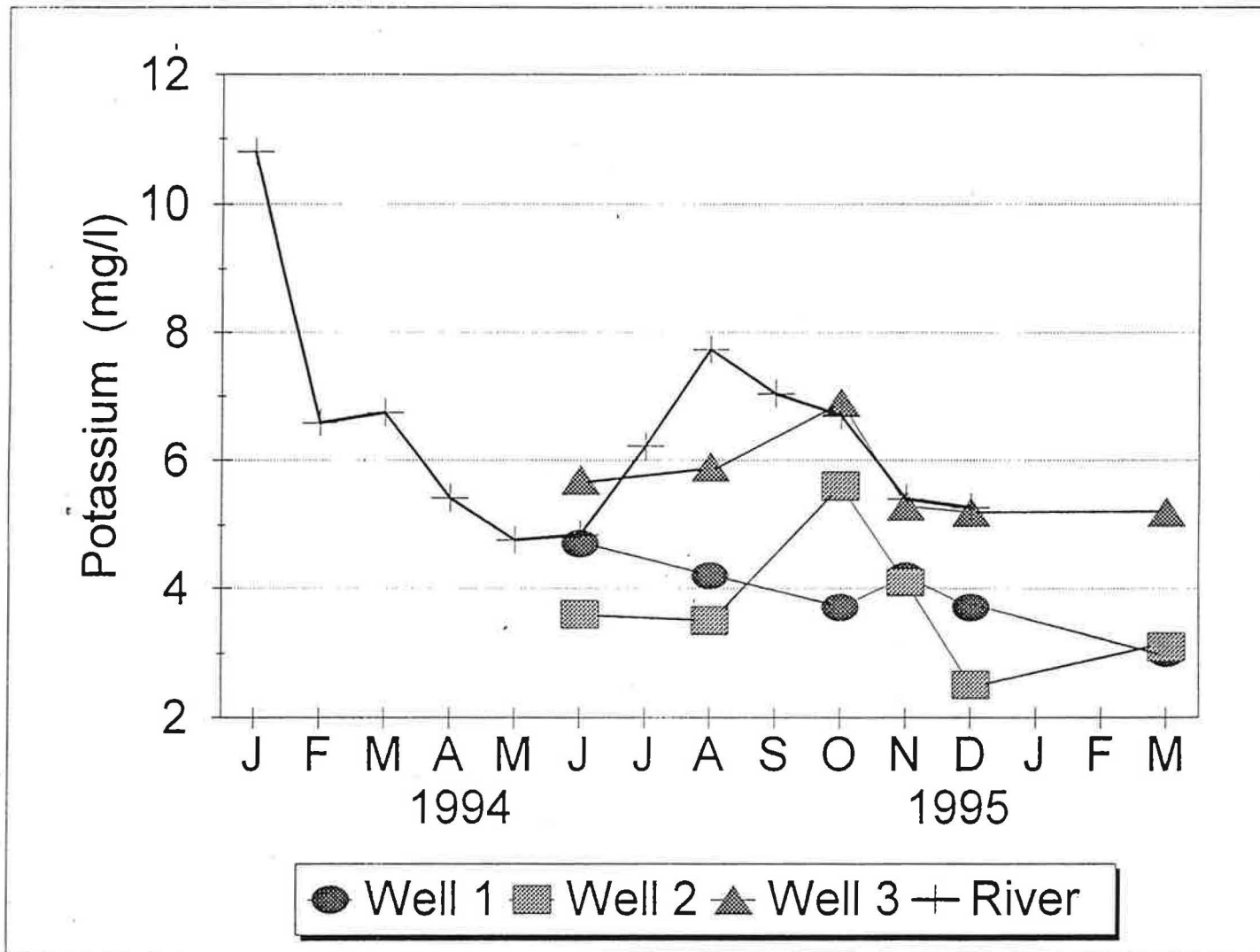


Figure 39. Potassium data of deep wells and river versus time

V. CONCLUSIONS

Ground water elevation appears to have been significantly impacted by the flood. Ground water table elevations were very high at the beginning of this study and fell significantly for four months. During the last six months of the study, the water elevations remained relatively stable, but were elevated about one to two feet above the levels found in 1992.

Data for many of the ground water monitoring parameters appear to indicate a change due to the flood. Concentrations of alkalinity, chloride, sodium, iron, and manganese were lower after the flood, and indicated a slow rise during the period of study. It is likely that these parameters were affected by the influx of flood waters, either through direct recharge over the wells, or recharge of the alluvial aquifer by high river elevations.

Data on coliforms and pesticides indicated that dangerous levels of contaminants were not entering the wells. Direct entry of surface water through the well bores *did not* appear to occur during or after the flood. From a public health perspective, the flood did not appear to compromise the wells.

From the graphs of the alkalinity, iron, and magnesium, it was found that the well sites closest to the river had water quality levels most similar to the river water quality. This suggests that the river water does act to recharge the aquifers in the area, and that the effect of the river is greatest in the wells closest to river. Impacts of the river lessen as the distance from the river to the wells increases.

The graphs of the water elevation data for the monitoring wells suggest that, under normal river stage conditions, ground water flows toward the river. This would suggest that the river would not have much effect on the ground water quality at normal river stages. However, at high river stages, ground water flow reverses, and the river could contribute greatly to the ground water quality.

Due to the very limited time span of the data taken before the flood, it is difficult to assess seasonal variations on ground water parameters. Some of the variation seen in the data between sampling periods could have been caused by natural seasonal variation of the aquifer. The original intent of the researchers in this project was to continue to monitor the Darst Bottoms wells through another year. However, the area was inundated again in May, 1995, and the monitoring wells are still (July, 1995) under water. It is highly recommended that, once the area dries sufficiently to allow access to the monitoring wells, monitoring be resumed for at least one more year.

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APPENDIX A.

Water quality data for wells in the Darst Bottoms study area

before the flood.

Water quality data for wells in the Darst Bottoms study area before the flood.
(Kleeschulte, 1993)

Well	Date	WL	WE	Cond	pH	Temp	TOC	Alk
Well 1 Shallow	3-03-92	17.08	446.12	849	6.4	14.0	2.0	399
	4-09-92	16.26	446.94	755	6.8	13.5	NA	416
	5-15-92	14.09	449.11	720	6.7	14.0	1.7	459
	6-10-92	14.56	448.64	785	7.0	13.5	1.5	435
Well 1 Deep	3-03-92	17.80	446.10	910	6.8	14.0	2.0	456
	4-09-92	16.64	447.26	772	6.9	14.5	NA	435
	5-15-92	14.38	449.52	757	6.5	14.0	1.8	480
	6-10-92	15.05	448.85	805	7.0	14.0	1.5	463
Well 2 Shallow	3-03-92	20.37	445.43	828	6.9	14.5	1.8	468
	4-09-92	19.14	446.66	711	6.6	14.5	NA	450
	5-15-92	16.76	449.04	655	7.1	14.0	1.5	429
	6-10-92	17.50	448.30	675	7.1	14.5	1.1	438
Well 2 Deep	3-03-92	20.39	445.51	741	6.7	15.0	1.8	406
	4-09-92	19.17	446.73	677	6.9	14.0	NA	414
	5-15-92	16.73	449.17	696	7.0	13.5	1.5	416
	6-10-92	17.54	448.36	636	7.0	14.5	1.3	405
Well 3 Shallow	3-03-92	22.64	444.86	785	6.8	15.5	1.3	418
	4-09-92	23.29	444.21	705	6.9	14.5	1.5	396
	5-15-92	18.77	448.73	657	7.2	14.5	1.3	414
	6-10-92	19.81	447.69	659	6.8	15.0	1.0	405
Well 3 Deep	3-03-92	22.83	444.97	770	6.8	15.5	1.5	419
	4-09-92	21.40	446.40	692	6.8	14.0	NA	406
	5-15-92	19.13	448.67	675	6.9	14.5	1.4	414
	6-10-92	20.29	447.51	654	6.9	15.0	1.0	458
Blank	5-26-92	NA	NA	NA	NA	NA	NA	NA
	6-10-92	NA	NA	NA	NA	NA	NA	NA

Water quality data for wells in the Darst Bottoms study area before the flood.
(Continued)

Well	Date	F	N	SO4	Cl	As	Ba	Ca
Well 1 Shallow	3-03-92	0.3	<.05	67	21	NA	240	120
	4-09-92	0.4	<.05	61	19	3	250	130
	5-15-92	0.3	<.05	60	20	3	240	130
	6-10-92	0.3	<.05	62	20	3	240	130
Well 1 Deep	3-03-92	0.5	<.05	45	15	9	400	130
	4-09-92	0.3	<.05	54	16	7	360	130
	5-15-92	0.3	<.05	46	19	6	370	140
	6-10-92	0.2	<.05	52	19	6	350	130
Well 2 Shallow	3-03-92	0.2	<.05	33	6.6	NA	390	120
	4-09-92	0.3	<.05	25	5.9	8	390	120
	5-15-92	0.3	<.05	25	4.8	7	350	110
	6-10-92	0.2	<.05	25	2.7	7	380	120
Well 2 Deep	3-03-92	0.2	<.05	33	5.3	NA	400	110
	4-09-92	0.3	<.05	31	7.9	6	430	120
	5-15-92	0.2	<.05	30	6.8	6	400	110
	6-10-92	0.3	<.05	30	4.8	6	410	110
Well 3 Shallow	3-03-92	0.2	<.05	47	5.3	1	290	120
	4-09-92	0.3	<.05	41	4.8	3	290	120
	5-15-92	0.2	<.05	40	4.5	1	290	120
	6-10-92	0.2	<.05	37	2.8	NA	280	120
Well 3 Deep	3-03-92	0.2	<.05	44	6	5	480	120
	4-09-92	0.3	<.05	39	13	4	550	120
	5-15-92	0.2	<.05	39	4.5	3	560	120
	6-10-92	0.2	<.05	40	2.5	NA	510	120
Blank	5-26-92	<0.1	<.05	0.1	<.10	<1	<2	0.19
	6-10-92	<0.1	<.05	<.1	<.10	<1	<2	0.24

Water quality data for wells in the Darst Bottoms study area before the flood.
(Continued)

Well	Date	Cr	Fe	Mg	Mn	Na	K	Pb	Se
Well 1 Shallow	3-03-92	<1	5.50	28	610	10.0	3.1	<1	<1
	4-09-92	<1	5.10	30	520	11.0	3.1	<1	<1
	5-15-92	<1	4.70	29	490	10.0	3.4	<1	<1
	6-10-92	1	3.70	30	470	10.0	3.1	<1	<1
Well 1 Deep	3-03-92	<1	7.50	31	660	11.0	3.9	<1	<1
	4-09-92	<1	8.60	30	690	11.0	3.8	<1	<1
	5-15-92	<1	6.50	31	740	11.0	4.0	<1	<1
	6-10-92	<1	10.30	30	670	10.0	3.5	<1	<1
Well 2 Shallow	3-03-92	<1	7.55	35	290	4.7	2.8	<1	<1
	4-09-92	<1	7.15	33	260	4.8	3.0	<1	<1
	5-15-92	<1	2.92	30	240	4.8	2.4	<1	<1
	6-10-92	<1	5.95	34	260	4.6	2.9	<1	<1
Well 2 Deep	3-03-92	<1	6.30	27	300	5.2	2.8	<1	<1
	4-09-92	<1	5.70	28	300	5.7	3.1	<1	<1
	5-15-92	<1	1.72	26	300	5.4	3.0	<1	<1
	6-10-92	<1	2.80	27	290	5.1	2.9	<1	<1
Well 3 Shallow	3-03-92	<1	<0.1	30	330	4.3	5.9	<1	<1
	4-09-92	<1	0.04	28	330	4.2	6.0	<1	<1
	5-15-92	<1	0.45	27	380	4.3	5.5	<1	<1
	6-10-92	<1	0.02	27	370	4.0	5.6	<1	<1
Well 3 Deep	3-03-92	<1	4.00	28	370	4.4	4.6	<1	<1
	4-09-92	<1	5.50	27	360	4.5	4.0	<1	<1
	5-15-92	<1	4.36	27	340	4.4	3.7	<1	<1
	6-10-92	<1	2.07	28	420	4.3	3.8	<1	<1
Blank	5-26-92	<1	NA	0.02	<1	<.20	<.10	<1	<1
	6-10-92	<1	NA	0.02	1	<.20	<.10	<1	<1

APPENDIX B.

Water quality data for wells in the Darst Bottoms study area

after the flood:

Water quality data for wells in the Darst Bottoms study area after the flood.

Well	Date	WL	WE	Cond	pH	Temp	TOC	Alk
Well 1 Shallow	6-26-94	7.00	456.20	950	6.40	14.40	NA	NA
	7-22-94	7.65	455.55	820	7.12	14.90	16.24	404
	8-08-94	9.50	453.70	810	7.08	15.60	24.44	366
	9-30-94	15.30	447.90	850	6.86	16.70	4.96	372
	10-16-94	15.17	448.03	890	6.85	15.00	38.05	378
	11-19-94	14.96	448.24	900	7.12	12.60	31.93	416
	12-30-94	14.73	448.47	1050	6.95	10.70	43.00	464
	1-30-95	13.75	449.45	960	7.00	13.40	47.20	470
	3-1-95	13.92	449.28	NA	NA	NA	59.60	440
4-2-95	13.75	449.45	980	6.92	13.80	15.00	438	
Well 1 Deep	6-26-94	6.00	457.90	870	6.50	14.50	NA	NA
	7-22-94	7.20	456.70	840	7.13	15.20	9.92	416
	8-08-94	9.70	454.20	860	7.00	15.20	19.67	394
	9-30-94	15.40	448.50	840	6.84	16.50	4.06	376
	10-16-94	15.92	447.98	860	6.87	15.10	42.51	388
	11-19-94	15.70	448.20	860	7.20	12.90	34.13	412
	12-30-94	15.54	448.36	910	7.07	12.70	34.00	416
	1-30-95	14.58	449.32	930	7.04	12.90	54.10	458
	3-1-95	13.13	450.77	NA	NA	NA	37.60	416
4-2-95	14.50	449.40	950	6.97	14.10	42.00	430	
Well 2 Shallow	6-26-94	9.50	456.30	880	6.60	14.80	NA	NA
	7-22-94	10.50	455.30	850	7.22	15.30	17.63	420
	8-08-94	13.50	452.30	830	6.99	16.40	23.11	420
	9-30-94	17.75	448.05	790	6.94	17.70	7.83	384
	10-16-94	18.25	447.55	810	6.94	15.50	27.06	348
	11-19-94	18.17	447.63	770	7.30	13.10	29.70	402
	12-30-94	18.10	447.70	890	7.21	13.10	28.00	424
	1-30-95	17.29	448.51	810	7.17	11.50	39.60	468
	3-1-95	16.92	448.88	NA	NA	NA	37.70	400
4-2-95	17.13	448.67	850	7.60	13.80	32.00	401	
Well 2 Deep	6-26-94	10.00	455.90	740	6.50	14.70	NA	NA
	7-22-94	10.00	455.90	740	7.22	15.70	28.32	368
	8-08-94	14.50	451.40	740	7.27	16.40	23.41	376
	9-30-94	17.75	448.15	NA	7.01	17.10	14.42	364
	10-16-94	18.33	447.57	760	6.99	15.40	29.57	346
	11-19-94	18.17	447.73	760	7.32	13.10	23.65	358
	12-30-94	18.13	447.77	760	7.19	13.40	26.00	364
	1-30-95	17.33	448.57	770	7.20	11.40	24.70	380
	3-1-95	17.00	448.90	NA	NA	NA	23.40	360
4-2-95	17.13	448.77	770	7.08	13.80	20.00	390	

Water quality data for wells in the Darst Bottoms study area after the flood.(Continued)

Well	Date	WL	WE	Cond	pH	Temp	TOC	Alk
Well 3 Shallow	6-26-94	9.00	458.50	NA	NA	NA	NA	NA
	7-22-94	13.60	453.90	760	7.04	14.70	25.97	358
	8-08-94	10.40	457.10	NA	NA	NA	NA	NA
	9-30-94	20.20	447.30	NA	6.83	16.00	24.98	324
	10-16-94	20.50	447.00	760	6.84	NA	18.83	326
	11-19-94	20.60	446.90	800	7.48	13.10	29.71	356
	12-30-94	20.60	446.90	780	7.09	13.50	27.00	356
	1-30-95	20.80	446.70	820	7.14	11.40	32.40	394
	3-1-95	19.75	447.75	NA	NA	NA	19.50	356
	4-2-95	19.75	447.75	780	7.02	14.10	24.00	398
Well 3 Deep	6-26-94	13.00	454.80	NA	NA	NA	NA	NA
	7-22-94	15.30	452.50	770	7.05	15.30	29.87	344
	8-08-94	16.75	451.05	800	6.89	16.80	27.96	342
	9-30-94	20.75	447.05	NA	6.85	18.40	26.58	328
	10-16-94	21.30	446.50	770	9.82	16.00	17.90	314
	11-19-94	20.80	447.00	790	7.33	12.80	24.98	354
	12-30-94	20.96	446.84	760	7.10	12.00	28.00	356
	1-30-95	20.17	447.63	780	7.13	12.80	27.50	378
	3-1-95	19.98	447.82	NA	NA	NA	23.20	354
	4-2-95	19.92	447.88	750	6.99	13.90	21.00	410
Blank	6-26-94	NA	NA	NA	NA	NA	NA	NA
	7-22-94	NA	NA	NA	NA	NA	0.20	9
	8-08-94	NA	NA	NA	NA	NA	NA	NA
	9-30-94	NA	NA	NA	NA	NA	NA	NA
	10-16-94	NA	NA	NA	NA	NA	0.54	ND
	11-19-94	NA	NA	NA	NA	NA	NA	NA
	12-30-94	NA	NA	NA	NA	NA	0.90	ND
	1-30-95	NA	NA	NA	NA	NA	0.40	8
	3-1-95	NA	NA	NA	NA	NA	NA	NA
4-2-95	NA	NA	NA	NA	NA	NA	NA	

Water quality data for wells in the Darst Bottoms study area after the flood.(Continued)

Well	Date	F	N	SO4	Cl	As	Ba	Ca
Well 1 Shallow	6-26-94	NA	NA	NA	NA	<10	340	210
	7-22-94	0.41	<.1	49	5.0	<10	390	NA
	8-08-94	0.49	<.1	46	6.2	<10	180	190
	9-30-94	0.44	0.2	53	9.3	<10	390	NA
	10-16-94	0.26	<.1	60	11.0	NA	NA	200
	11-19-94	NA	<.1	70	7.6	NA	NA	210
	12-30-94	0.36	<.1	88	1.2	NA	NA	230
	1-30-95	NA	<.1	80	1.7	NA	NA	NA
	3-1-95	0.31	<.1	84	10.2	NA	NA	NA
	4-2-95	NA	<.1	34	6.5	NA	NA	220
Well 1 Deep	6-26-94	NA	NA	NA	NA	<10	410	220
	7-22-94	0.38	<.1	38	4.0	<10	340	NA
	8-08-94	0.44	<.1	36	5.6	<10	200	190
	9-30-94	1.16	0.2	51	7.0	<10	320	NA
	10-16-94	0.04	<.1	49	7.0	NA	NA	190
	11-19-94	NA	<.1	51	9.8	NA	NA	180
	12-30-94	0.16	<.1	53	1.6	NA	NA	200
	1-30-95	NA	<.1	64	1.3	NA	NA	NA
	3-1-95	0.22	<.1	72	7.8	NA	NA	NA
	4-2-95	NA	<.1	64	6.0	NA	NA	210
Well 2 Shallow	6-26-94	NA	NA	NA	NA	<10	490	200
	7-22-94	0.31	<.1	32	0.6	<10	540	NA
	8-08-94	0.41	<.1	31	0.7	<10	310	180
	9-30-94	0.53	<.1	29	0.9	<10	520	NA
	10-16-94	0.02	<.1	0	0.5	NA	NA	150
	11-19-94	NA	<.1	26	1.0	NA	NA	180
	12-30-94	0.04	<.1	29	0.6	NA	NA	200
	1-30-95	NA	<.1	24	0.7	NA	NA	NA
	3-1-95	0.11	0.7	28	2.5	NA	NA	NA
	4-2-95	NA	<.1	38	2.2	NA	NA	190
Well 2 Deep	6-26-94	NA	NA	NA	NA	<10	470	180
	7-22-94	0.37	<.1	31	1.9	<10	510	NA
	8-08-94	0.42	<.1	28	1.6	<10	300	170
	9-30-94	0.21	<.1	31	0.2	<10	480	NA
	10-16-94	0.06	<.1	33	1.6	NA	NA	180
	11-19-94	NA	<.1	36	0.4	NA	NA	180
	12-30-94	0.19	<.1	34	1.0	NA	NA	170
	1-30-95	NA	<.1	39	0.9	NA	NA	NA
	3-1-95	0.13	<.1	18	2.4	NA	NA	NA
	4-2-95	NA	<.1	32	3.2	NA	NA	170

Water quality data for wells in the Darst Bottoms study area after the flood.(Continued)

Well	Date	F	N	SO4	Cl	As	Ba	Ca
Well 3 Shallow	6-26-94	NA	NA	NA	NA	<10	410	200
	7-22-94	0.39	3.9	40	1.5	310	510	NA
	8-08-94	NA	NA	NA	NA	NA	NA	NA
	9-30-94	0.67	6.4	39	2.5	<10	510	NA
	10-16-94	0.16	5.3	36	2.2	NA	NA	170
	11-19-94	NA	1.2	57	0.0	NA	NA	200
	12-30-94	0.28	0.8	54	0.6	NA	NA	190
	1-30-95	NA	0.6	63	0.4	NA	NA	NA
	3-1-95	0.23	1.1	54	2.0	NA	NA	NA
4-2-95	NA	1.4	55	4.0	NA	NA	180	
Well 3 Deep	6-26-94	NA	NA	NA	NA	<10	520	190
	7-22-94	0.42	7.3	47	1.2	<10	450	NA
	8-08-94	0.42	8.6	52	0.9	<10	240	180
	9-30-94	0.37	8.3	46	2.6	<10	450	NA
	10-16-94	0.11	6	41	1.5	NA	NA	180
	11-19-94	NA	0.4	66	0.5	NA	NA	190
	12-30-94	0.13	0.9	54	0.8	NA	NA	180
	1-30-95	NA	0.5	55	0.8	NA	NA	NA
	3-1-95	0.25	0.5	55	1.2	NA	NA	NA
4-2-95	NA	0.3	52	2.4	NA	NA	170	
Blank	6-26-94	NA	NA	NA	NA	NA	NA	NA
	7-22-94	0.08	ND	ND	0.5	<10	130	NA
	8-08-94	NA	ND	ND	NA	NA	NA	NA
	9-30-94	0.04	0.9	NA	NA	NA	NA	NA
	10-16-94	ND	0.7	ND	0.5	NA	NA	10
	11-19-94	NA	NA	NA	NA	NA	NA	NA
	12-30-94	ND	0.4	ND	0.3	NA	NA	30
	1-30-95	NA	0.5	ND	0.2	NA	NA	NA
	3-1-95	NA	NA	NA	NA	NA	NA	NA
4-2-95	NA	NA	NA	NA	NA	NA	NA	

Water quality data for wells in the Darst Bottoms study area after the flood.(Continued)

Well	Date	Cr	Fe	Mg	Mn	Na	K	Pb	Se
Well 1 Shallow	6-26-94	<10	0.18	39	220	10.4	5.7	<10	<10
	7-22-94	170	3.12	NA	550	NA	NA	450	NA
	8-08-94	<10	1.43	32	290	8.7	3.9	<10	<10
	9-30-94	140	1.66	NA	430	NA	NA	360	NA
	10-16-94	90	2.72	33	490	9.0	3.9	130	NA
	11-19-94	NA	NA	36	NA	9.1	3.7	30	NA
	12-30-94	90	4.14	43	260	10.0	4.1	40	40
	1-30-95	NA	NA	NA	NA	NA	NA	NA	NA
	3-1-95	NA	NA	NA	NA	NA	NA	NA	NA
	4-2-95	<10	2.37	39	380	9.5	3.7	20	<10
Well 1 Deep	6-26-94	60	1.01	41	490	10.2	4.7	30	<10
	7-22-94	50	6.59	NA	780	NA	NA	<10	<10
	8-08-94	<10	3.32	33	410	8.7	4.2	10	<10
	9-30-94	60	1.00	NA	540	NA	NA	<10	<10
	10-16-94	160	5.18	32	460	8.5	3.7	50	NA
	11-19-94	NA	4.74	33	890	7.1	4.2	40	NA
	12-30-94	140	6.15	34	360	8.5	3.7	30	NA
	1-30-95	NA	NA	NA	NA	NA	NA	NA	NA
	3-1-95	NA	NA	NA	NA	NA	NA	NA	NA
	4-2-95	120	4.63	36	520	7.9	3.0	20	NA
Well 2 Shallow	6-26-94	<10	0.51	40	160	4.0	2.9	10	<10
	7-22-94	210	3.95	NA	480	NA	NA	580	NA
	8-08-94	<10	2.22	34	240	3.5	2.7	50	<10
	9-30-94	160	1.09	NA	420	NA	NA	540	NA
	10-16-94	110	4.38	30	670	4.9	3.3	50	NA
	11-19-94	NA	3.05	33	580	4.4	3.8	40	NA
	12-30-94	10	3.73	41	160	3.5	3.2	40	NA
	1-30-95	NA	NA	NA	NA	NA	NA	NA	NA
	3-1-95	NA	NA	NA	NA	NA	NA	NA	NA
	4-2-95	80	1.26	37	240	4.1	2.3	30	NA
Well 2 Deep	6-26-94	<10	0.33	33	220	4.9	3.6	<10	<10
	7-22-94	100	4.30	NA	440	NA	NA	10	<10
	8-08-94	<10	3.04	31	250	4.9	3.5	70	<10
	9-30-94	90	1.96	NA	370	NA	NA	50	20
	10-16-94	160	4.05	29	470	4.5	5.6	40	NA
	11-19-94	NA	4.83	30	990	4.6	4.1	30	NA
	12-30-94	80	5.27	30	520	4.6	2.5	20	NA
	1-30-95	NA	NA	NA	NA	NA	NA	NA	NA
	3-1-95	NA	NA	NA	NA	NA	NA	NA	NA
	4-2-95	90	3.29	30	360	5.0	3.1	20	NA

APPENDIX C.

Coliform data for the wells in the Darst Bottoms study area
after the flood.

Coliform data for wells in the Darst Bottoms study area after the flood

Well	Date	Coliform/100 ml	Well	Date	Coliform/100 ML
Well 1 Shallow	6-26-94	<1	Well 3 Shallow	6-26-94	ND
	7-22-94	ND		7-22-94	ND
	8-08-94	10		8-08-94	NA
	9-30-94	ND		9-30-94	ND
	10-16-94	ND		10-16-94	50
	11-19-94	ND		11-19-94	ND
	12-30-94	ND		12-30-94	ND
	1-30-95	ND		1-30-95	ND
	3-1-95	ND		3-1-95	ND
4-2-95	ND	4-2-95	ND		
Well 1 Deep	6-26-94	<1	Well 3 Deep	6-26-94	ND
	7-22-94	70		7-22-94	10
	8-08-94	ND		8-08-94	10
	9-30-94	ND		9-30-94	ND
	10-16-94	ND		10-16-94	20
	11-19-94	ND		11-19-94	ND
	12-30-94	ND		12-30-94	ND
	1-30-95	ND		1-30-95	ND
	3-1-95	ND		3-1-95	ND
4-2-95	ND	4-2-95	ND		
Well 2 Shallow	6-26-94	ND	Blank	6-26-94	NA
	7-22-94	ND		7-22-94	ND
	8-08-94	ND		8-08-94	ND
	9-30-94	<1		9-30-94	NA
	10-16-94	ND		10-16-94	ND
	11-19-94	ND		11-19-94	NA
	12-30-94	ND		12-30-94	NA
	1-30-95	ND		1-30-95	ND
	3-1-95	ND		3-1-95	NA
4-2-95	ND	4-2-95	NA		
Well 2 Deep	6-26-94	ND			
	7-22-94	<1			
	8-08-94	30			
	9-30-94	ND			
	10-16-94	ND			
	11-19-94	ND			
	12-30-94	ND			
	1-30-95	ND			
	3-1-95	ND			
4-2-95	ND				

APPENDIX D.

Pesticide data for the wells in the Darst Bottoms study area
after the flood.

Pesticide data for wells in the Darst Bottoms study area after the flood.

Concentrations in micrograms per liter

Well	Date	Atrazine	Chlordane	DDE	DDT	Silvex
Well 1 Shallow	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA
Well 1 Deep	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA
Well 2 Shallow	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA
Well 2 Deep	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA
Well 3 Shallow	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA
Well 3 Deep	6-26-94	NA	NA	NA	NA	NA
	7-22-94	ND	ND	ND	ND	ND
	8-08-94	ND	ND	ND	ND	ND
	9-30-94	ND	ND	ND	ND	ND
	10-16-94	NA	NA	NA	NA	NA

APPENDIX E.

River data.

Hermann, Missouri River Gaging Station

Date	WE
1994	
Jan	NA
Feb	NA
Mar	468.16
Apr	463.56
May	462.03
Jun	465.22
Jul	NA
Aug	473.41
Sep	473.59
Oct	NA
Nov	465.1
Dec	469.05
1995	
Jan	472.88
Feb	472.67
Mar	472.86

CITY OF ST. LOUIS
DEPARTMENT OF PUBLIC UTILITIES
WATER DIVISION
SUPPLY & PURIFYING SECTION
MINERAL ANALYSIS OF RIVER WATER FROM THE HOWARD BEND PLANT*
(Results expressed in parts per million**)
FOR CALENDAR YEAR 1994

DESCRIPTION	METHOD DETECTION LEVEL	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR AVG
Silicon, Si	1.00	7.47	6.57	5.48	4.08	3.58	3.18	5.58	5.53					5.1
Iron, Fe	0.001	0.009	0.017	0.030	0.085	0.086	0.047	0.007						0.04
Aluminum, Al	0.001	0.005	0.057	0.036	0.019	0.088	0.043	0.012						0.03
Calcium, Ca		63.2	65.4	60.1	53.3	46.9	45.9	59.3	63.8					57.
Magnesium, Mg		18.7	20.1	17.2	17.0	14.5	14.4	18.9	21.9					17.
Sodium, Na	0.150	54.0	55.8	33.0	17.7	22.2	27.4	36.4	52.0					37.
Potassium, K	0.100	10.80	6.58	6.74	5.42	4.77	4.84	6.22	7.73					6.6
Carbonate, CO ₃		0	0	0	2	0	0	0	0					
Bicarbonate, HCO ₃		260	236.7	192	177	160	162	201.3	221					20
Sulfate, SO ₄		123.5	126.5	84.7	79.1	73.8	83.5	106.9	157.4					104.
Chloride, Cl		36.7	37.3	22.3	16.8	11.5	24.8	18.3	18.2					23.
Nitrate, N		1.76	1.67	2.08	1.01	1.55	1.35	1.86	0.85					1.5
Turbidity (NTU)		25	117	239	142	119	192	233	31					137.2
pH		8.14	8.13	8.06	8.11	8.01	8.13	8.22	8.34					8.1
Residual Chlorine		---	---	---	---	---	---	---	---					---
Total Alkalinity, CaCO ₃		213	194	157	145	131	133	165	181					16
Non Carb. Hardness, CaCO ₃		74	70	59	53	45	50	65	78					6
Total Hardness, CaCO ₃		286	264	216	198	177	183	230	261					22
Dissolved Solids		466	468	360	301	268	296	374	454					37
Fluoride, F ⁻		0.37	0.36	0.29	0.27	0.25	0.32	0.41	0.42					0.3
Phosphate, PO ₄	0.01	0.22	0.20	0.28	0.17	0.22	0.24	0.66	0.47					0.3

* MISSOURI RIVER

** EXCEPT TURBIDITY AND pH

CITY OF ST. LOUIS
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MINERAL ANALYSIS OF RIVER WATER FROM THE HOWARD BEND PLANT*
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FOR CALENDAR YEAR 1993

DESCRIPTION	METHOD DETECTION LEVEL	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR AVG
Silicon, Si	1.00	4.25	5.54	4.66	4.69	4.53	5.40	6.33	5.68	5.36	4.92	5.10	6.06	5.21
Iron, Fe	0.001	0.102	0.135	0.165	0.119	0.005	0.032	0.078	0.042	0.092	0.048	0.052	0.043	0.076
Aluminum, Al	0.001	0.153	0.157	0.128	0.056	0.034	0.033	0.073	0.072	0.070	0.042	0.042	0.029	0.074
Calcium, Ca		45.6	52.8	44.8	45.8	58.4	55.1	34.1	42.7	43.6	46.9	44.8	64.6	48.3
Magnesium, Mg		16.0	14.6	13.8	13.5	14.1	14.4	10.2	10.7	12.4	12.7	13.4	18.5	13.7
Sodium, Na	0.150	21.9	27.8	23.9	20.4	20.4	22.0	11.9	16.1	19.3	28.4	30.6	41.8	23.7
Potassium, K	0.100	5.66	6.31	7.34	6.10	5.91	5.58	5.65	6.42	6.00	5.81	5.69	5.95	6.04
Carbonate, CO ₃		0	0	0	0	0	0	1	0	0	0	0	0	0
Bicarbonate, HCO ₃		170	187	166	170	188	183	129	166	156	183	183	223	175
Sulfate, SO ₄		58.5	66.2	57.4	56.1	67.4	69.8	32.8	45.7	52.0	64.1	76.5	91.9	61.5
Chloride, Cl		17.5	20.9	20.4	16.6	14.3	16.1	7.9	12.1	14.6	16.6	18.9	24.1	16.7
Nitrate, N		1.19	1.31	1.38	1.68	1.84	2.30	1.35	1.23	1.21	1.25	1.32	1.62	1.47
Turbidity (NTU)		100	132	427	627	474	509	427	222	253	115	67	42	282.92
pH		7.71	7.81	8.01	7.98	7.98	8.02	7.95	7.94	8.09	8.15	8.14	8.17	8.00
Residual Chlorine		---	---	---	---	---	---	---	---	---	---	---	---	---
Total Alkalinity, CaCO ₃		139	153	136	139	154	150	108	136	128	150	150	180	144
Non Carb. Hardness, CaCO ₃		44	48	39	44	51	54	31	35	36	39	48	59	44
Total Hardness, CaCO ₃		179	201	174	184	204	204	138	171	165	185	197	239	187
Dissolved Solids		269	303	268	275	458	306	190	530	256	281	306	378	318
Fluoride, F		0.25	0.28	0.25	0.27	0.31	0.30	0.34	0.27	0.27	0.26	0.28	0.30	0.28
Phosphate, PO ₄	0.01	0.24	0.30	0.30	0.23	0.31	0.36	0.22	0.26	0.31	0.30	0.17	0.22	0.27

* MISSOURI RIVER

** EXCEPT TURBIDITY AND pH

CITY OF ST. LOUIS
DEPARTMENT OF PUBLIC UTILITIES
WATER DIVISION
SUPPLY & PURIFYING SECTION
MINERAL ANALYSIS OF RIVER WATER FROM THE HOWARD BEND PLANT*
(Results expressed in parts per million**)
FOR CALENDAR YEAR 1995

DESCRIPTION	METHOD DETECTION LEVEL	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR AVG
Silicon, Si	1.00	4.33	4.33	5.23	5.23									4.78
Iron, Fe	0.001	0.038	0.125	0.024	0.022									0.052
Aluminum, Al	0.001	0.050	0.190	0.033	<0.035									0.068
Calcium, Ca		48.7	53.8	55.8	54.9									53.3
Magnesium, Mg		17.0	17.8	17.6	18.6									17.8
Sodium, Na	0.150	37.7	36.9	35.3	30.3									35.1
Potassium, K	0.100	5.30	5.54	5.61	5.49									5.49
Carbonate, CO ₃		0	0	0	0									0
Bicarbonate, HCO ₃		203	196	200	196									199
Sulfate, SO ₄		88.1	100.4	89.9	95.1									93.4
Chloride, Cl		22.2	28.1	21.3	17.0									22.2
Nitrate, N		1.11	1.22	1.54	1.87									1.44
Turbidity (NTU)		56	52	110	247									116.25
pH		8.24	8.21	8.28	8.18									8.23
Residual Chlorine		---	---	---	---									---
Total Alkalinity, CaCO ₃		166	161	164	161									163
Non Carb. Hardness, CaCO ₃		51	46	51	57									51
Total Hardness, CaCO ₃		217	206	222	218									216
Dissolved Solids		353	351	355	344									351
Fluoride, F		0.28	0.28	0.31	0.31									0.30
Phosphate, PO ₄	0.01	0.22	0.24	0.29	0.26									0.25

* MISSOURI RIVER

** EXCEPT TURBIDITY AND pH

APPENDIX F
Cation-Anion Balance Calculations

Well 1 Shallow

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	210	10.48	NA	0.00	190	9.48	NA	0.00	200	9.98
MAGNESIUM	39	3.21	NA	0.00	32	2.63	NA	0.00	33	2.72
SODIUM	10.4	0.45	NA	0.00	8.7	0.38	NA	0.00	9	0.39
POTASSIUM	5.7	0.15	NA	0.00	3.9	0.10	NA	0.00	3.9	0.10
IRON	0.18	0.01	3.12	0.11	1.43	0.05	0.44	0.02	2.72	0.10
TOTAL meq.		14.29		0.11		12.64		0.02		13.28
ANIONS										
CARBONATE	NA	0.00	404	8.08	366	7.32	372	7.44	378	7.56
SULFATE	NA	0.00	49	1.02	46	0.96	53	1.10	60	1.25
CHLORIDE	NA	0.00	5	0.14	6.2	0.17	9.3	0.26	11	0.31
TOTAL meq.		0.00		9.24		8.45		8.81		9.12
SUM (CATION-ANION)		NA		NA		4.19		NA		4.16

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	210	10.48	230	11.48	NA	0.00	NA	0.00	220	10.98
MAGNESIUM	36	2.96	43	3.54	NA	0.00	NA	0.00	39	3.21
SODIUM	9.1	0.40	10	0.43	NA	0.00	NA	0.00	9.5	0.41
POTASSIUM	3.7	0.09	4.1	0.10	NA	0.00	NA	0.00	3.7	0.09
IRON	NA	0.00	4.14	0.15	NA	0.00	NA	0.00	2.37	0.08
TOTAL meq.		13.93		15.70		0.00		0.00		14.78
ANIONS										
CARBONATE	416	8.32	464	9.28	470	9.40	440	8.80	438	8.76
SULFATE	70	1.46	88	1.83	80	1.67	84	1.75	34	0.71
CHLORIDE	7.6	0.21	1.2	0.03	1.7	0.05	10.2	0.29	6.5	0.18
TOTAL meq.		9.99		11.15		11.11		10.84		9.65
SUM (CATION-ANION)		3.94		4.56		NA		NA		5.13

Well 1 Deep

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	220	10.98	NA	0.00	190	9.48	NA	0.00	190	9.48
MAGNESIUM	41	3.37	NA	0.00	33	2.72	NA	0.00	32	2.63
SODIUM	10.2	0.44	NA	0.00	8.7	0.38	NA	0.00	8.5	0.37
POTASSIUM	4.7	0.12	NA	0.00	4.2	0.11	NA	0.00	3.7	0.09
IRON	1.01	0.04	6.59	0.24	3.32	0.12	1	0.04	5.18	0.19
TOTAL meq.		14.95		0.24		12.80		0.04		12.76
ANIONS										
CARBONATE	NA	0.00	416	8.32	394	7.88	376	7.52	388	7.76
SULFATE	NA	0.00	38	0.79	36	0.75	51	1.06	49	1.02
CHLORIDE	NA	0.00	4	0.11	5.6	0.16	7	0.20	7	0.20
TOTAL meq.		0.00		9.22		8.79		8.78		8.98
SUM (CATION-ANION)		NA		NA		4.01		NA		3.79

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	180	8.98	200	9.98	NA	0.00	NA	0.00	210	10.48
MAGNESIUM	33	2.72	34	2.80	NA	0.00	NA	0.00	36	2.96
SODIUM	7.1	0.31	8.5	0.37	NA	0.00	NA	0.00	7.9	0.34
POTASSIUM	4.2	0.11	3.7	0.09	NA	0.00	NA	0.00	3	0.08
IRON	4.74	0.17	6.15	0.22	NA	0.00	NA	0.00	4.63	0.17
TOTAL meq.		12.28		13.46		0.00		0.00		14.03
ANIONS										
CARBONATE	412	8.24	416	8.32	458	9.16	416	8.32	430	8.60
SULFATE	51	1.06	53	1.10	64	1.33	72	1.50	64	1.33
CHLORIDE	9.8	0.28	1.6	0.05	1.3	0.04	7.8	0.22	6	0.17
TOTAL meq.		9.58		9.47		10.53		10.04		10.10
SUM (CATION-ANION)		2.71		3.99		NA		NA		3.93

Well 2 Shallow

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	200	9.98	NA	0.00	180	8.98	NA	0.00	150	7.49
MAGNESIUM	40	3.29	NA	0.00	34	2.80	NA	0.00	30	2.47
SODIUM	4	0.17	NA	0.00	3.5	0.15	NA	0.00	4.9	0.21
POTASSIUM	2.9	0.07	NA	0.00	2.7	0.07	NA	0.00	3.3	0.08
IRON	0.51	0.02	3.95	0.14	2.22	0.08	1.09	0.04	4.38	0.16
TOTAL meq.		13.54		0.14		12.08		0.04		10.41
ANIONS										
CARBONATE	NA	0.00	420	8.40	420	8.40	384	7.68	348	6.96
SULFATE	NA	0.00	32	0.67	31	0.65	29	0.60	0	0.00
CHLORIDE	NA	0.00	0.6	0.02	0.7	0.02	0.9	0.03	0.5	0.01
TOTAL meq.		0.00		9.08		9.07		8.31		6.97
SUM (CATION-ANION)		NA		NA		3.02		NA		3.43

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	180	8.98	200	9.98	NA	0.00	NA	0.00	190	9.48
MAGNESIUM	33	2.72	41	3.37	NA	0.00	NA	0.00	37	3.04
SODIUM	4.4	0.19	3.5	0.15	NA	0.00	NA	0.00	4.1	0.18
POTASSIUM	3.8	0.10	3.2	0.08	NA	0.00	NA	0.00	2.3	0.06
IRON	3.05	0.11	3.73	0.13	NA	0.00	NA	0.00	1.26	0.05
TOTAL meq.		12.10		13.72		0.00		0.00		12.81
ANIONS										
CARBONATE	402	8.04	424	8.48	468	9.36	400	8.00	401	8.02
SULFATE	26	0.54	29	0.60	24	0.50	28	0.58	38	0.79
CHLORIDE	1	0.03	0.6	0.02	0.7	0.02	2.5	0.07	2.2	0.06
TOTAL meq.		8.61		9.10		9.88		8.65		8.87
SUM (CATION-ANION)		3.49		4.62		NA		NA		3.93

Well 2 Deep

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	180	8.98	NA	0.00	170	8.48	NA	0.00	180	8.98
MAGNESIUM	33	2.72	NA	0.00	31	2.55	NA	0.00	29	2.39
SODIUM	4.9	0.21	NA	0.00	4.9	0.21	NA	0.00	4.5	0.20
POTASSIUM	3.6	0.09	NA	0.00	3.5	0.09	NA	0.00	5.6	0.14
IRON	0.33	0.01	4.3	0.15	3.04	0.11	1.96	0.07	4.05	0.15
TOTAL meq.		12.01		0.15		11.45		0.07		11.85
ANIONS										
CARBONATE	NA	0.00	368	7.36	376	7.52	364	7.28	346	6.92
SULFATE	NA	0.00	31	0.65	28	0.58	31	0.65	33	0.69
CHLORIDE	NA	0.00	1.9	0.05	1.6	0.05	0.2	0.01	1.6	0.05
TOTAL meq.		0.00		8.06		8.15		7.93		7.65

SUM (CATION-ANION) NA NA 3.30 NA 4.20

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	180	8.98	170	8.48	NA	0.00	NA	0.00	170	8.48
MAGNESIUM	30	2.47	30	2.47	NA	0.00	NA	0.00	30	2.47
SODIUM	4.6	0.20	4.6	0.20	NA	0.00	NA	0.00	5	0.22
POTASSIUM	4.1	0.10	2.5	0.06	NA	0.00	NA	0.00	3.1	0.08
IRON	4.83	0.17	5.27	0.19	NA	0.00	NA	0.00	3.29	0.12
TOTAL meq.		11.93		11.40		0.00		0.00		11.37
ANIONS										
CARBONATE	358	7.16	364	7.28	380	7.60	360	7.20	390	7.80
SULFATE	36	0.75	34	0.71	39	0.81	18	0.37	32	0.67
CHLORIDE	0.4	0.01	1	0.03	0.9	0.03	2.4	0.07	3.2	0.09
TOTAL meq.		7.92		8.02		8.44		7.64		8.56

SUM (CATION-ANION) 4.01 3.39 NA NA 2.81

Well 3 Shallow

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	200	9.98	NA	0.00	NA	0.00	NA	0.00	170	8.48
MAGNESIUM	36	2.96	NA	0.00	NA	0.00	NA	0.00	28	2.30
SODIUM	3.7	0.16	NA	0.00	NA	0.00	NA	0.00	3.7	0.16
POTASSIUM	6.1	0.16	NA	0.00	5.9	0.15	NA	0.00	NA	0.00
IRON	0.05	0.00	0.32	0.01	NA	0.00	0.29	0.01	1.24	0.04
TOTAL meq.		13.26		0.01		0.15		0.01		10.99
ANIONS										
CARBONATE	NA	0.00	358	7.16	NA	0.00	324	6.48	326	6.52
SULFATE	NA	0.00	40	0.83	NA	0.00	39	0.81	36	0.75
CHLORIDE	NA	0.00	1.5	0.04	NA	0.00	2.5	0.07	2.2	0.06
TOTAL meq.		0.00		8.04		0.00		7.36		7.33
SUM (CATION-ANION)		NA		NA		NA		NA		3.66

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	200	9.98	190	9.48	NA	0.00	NA	0.00	180	8.98
MAGNESIUM	32	2.63	33	2.72	NA	0.00	NA	0.00	32	2.63
SODIUM	4	0.17	3.6	0.16	NA	0.00	NA	0.00	3.7	0.16
POTASSIUM	5.8	0.15	6.6	0.17	NA	0.00	NA	0.00	6.5	0.17
IRON	2.36	0.08	0.43	0.02	NA	0.00	NA	0.00	0	0.00
TOTAL meq.		13.02		12.54		0.00		0.00		11.94
ANIONS										
CARBONATE	356	7.12	356	7.12	394	7.88	356	7.12	398	7.96
SULFATE	57	1.19	54	1.12	63	1.31	54	1.12	55	1.15
CHLORIDE	0	0.00	0.6	0.02	0.4	0.01	2	0.06	4	0.11
TOTAL meq.		8.31		8.26		9.20		8.30		9.22
SUM (CATION-ANION)		4.71		4.28		NA		NA		2.72

Well 3 Deep

	JUNE 26, 1994		JULY 22, 1994		AUGUST 8, 1994		SEPT. 30, 1994		OCTOBER 16, 1994	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	190	9.48	NA	0.00	180	8.98	NA	0.00	180	8.98
MAGNESIUM	34	2.80	NA	0.00	34	2.80	NA	0.00	30	2.47
SODIUM	4.1	0.18	NA	0.00	3.9	0.17	NA	0.00	3.5	0.15
POTASSIUM	5.7	0.15	NA	0.00	5.9	0.15	NA	0.00	6.9	0.18
IRON	0.65	0.02	0.09	0.00	0.09	0.00	0.25	0.01	1.65	0.06
TOTAL meq.		12.63		0.00		12.10		0.01		11.84
ANIONS										
CARBONATE	NA	0.00	344	6.88	342	6.84	328	6.56	314	6.28
SULFATE	NA	0.00	47	0.98	52	1.08	46	0.96	41	0.85
CHLORIDE	NA	0.00	1.2	0.03	0.9	0.03	2.6	0.07	1.5	0.04
TOTAL meq.		0.00		7.89		7.95		7.59		7.18
SUM (CATION-ANION)		NA		NA		4.16		NA		4.66

	NOVEMBER 19, 1994		DECEMBER 30, 1994		JANUARY 30, 1995		MARCH 1, 1995		APRIL 2, 1995	
	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.	mg/l	meq.
CATIONS										
CALCIUM	190	9.48	180	8.98	NA	0.00	NA	0.00	170	8.48
MAGNESIUM	31	2.55	31	2.55	NA	0.00	NA	0.00	31	2.55
SODIUM	3.9	0.17	3.5	0.15	NA	0.00	NA	0.00	3.5	0.15
POTASSIUM	5.3	0.14	5.2	0.13	NA	0.00	NA	0.00	5.2	0.13
IRON	2.48	0.09	0	0.00	NA	0.00	NA	0.00	0.41	0.01
TOTAL meq.		12.43		11.82		0.00		0.00		11.33
ANIONS										
CARBONATE	354	7.08	356	7.12	378	7.56	354	7.08	410	8.20
SULFATE	66	1.37	54	1.12	55	1.15	55	1.15	52	1.08
CHLORIDE	0.5	0.01	0.8	0.02	0.8	0.02	1.2	0.03	2.4	0.07
TOTAL meq.		8.47		8.27		8.73		8.26		9.35
SUM (CATION-ANION)		3.96		3.55		NA		NA		1.98



UNIVERSITY OF MISSOURI-ROLLA

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August 6, 1995

Dr. Thomas Clevenger, Director
Water Resources Research Center
E1511 Engineering Building East
University of Missouri - Columbia
Columbia, MO 65211

Dear Dr. Clevenger:

We are pleased to submit the final report on our USGS-funded project, "Integrating the Effects of the Great Flood of 1993: Changes in Ground Water Hydrology and Quality in Relation to Changes in Surface Waters." It was a pleasure working with you and others at the Water Resources Research Center, and we hope to be able to work with you again in the future.

Sincerely,

A handwritten signature in blue ink, appearing to read "Dee Ann Sanders".

Dee Ann Sanders, Ph.D., P.E.
Environmental Area

enclosure