THE COMBINED USE OF TRACER TESTS AND GROUND WATER MODELS TO CHARACTERIZE SOLUTE TRANSPORT OF AGRICULTURAL CHEMICALS IN AN ALLUVIAL AQUIFER

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CHAPTER I

INTRODUCTION

General

Interest in the transport and fate of contaminants in a terrestrial subsurface environment is based on the concern for the protection and remediation of both ground and surface water resources and to predict the time of arrival and concentration of contaminants at a receptor such as a monitoring well, a water supply well, or a surface water body. To attain this goal, the processes involved in the transport and transformation of contaminants in both porous and fractured media, and under either saturated or unsaturated conditions must be understood.

A "Tracer" is distinguishable matter or energy in ground water that provides information on the hydraulic and transport capabilities of the ground water system. A tracer can be entirely natural, such as heat carried by hot spring water; accidentally introduced, such as fuel oil from a ruptured storage tank ; or intentionally introduced, such as dyes placed in water flowing within a system.

When the study comes to the point of simulating the effect of natural phenomena, modelling is engaged. Models are simplified representations of an existing physical system. Any ground water investigation that involves more than simply collecting and tabulating data involves modelling.

A model can be a qualitative description of how a process operates in a system, or it can be a mathematical representation of the physical system. This work demonstrates the combined use of a ground water tracer test and ground water numerical model to characterize solute transport of agricultural chemicals in the saturated zones of an Alluvial Aquifer.

Objectives

The general objective of this study is to understand the movement of chemicals in the saturated zone at the Perkins site. The study will help to better understand the difference in velocity between chemicals versus time and distance using pumping test results and to predict the rate of movement in the saturated zone using chemicals.

The specific objectives of this study include:

1) Conduct an additional tracer test at the Perkins site;

2) Compare between velocities of Nitrate, Bromide, Chloride, and Potassium in the saturated zones for the newly conducted tracer test and an old tracer test conducted in 1989; and

3) Calibrate and verify these data in the saturated zone using the MOC Model developed by Konikow and Bredehoft (1978).

Location

The site chosen for this study is the Oklahoma State University Agronomy Research Station at Perkins, Oklahoma. The site is located 9 miles south of Stillwater, near the intersection of State Highways 177 and 33 (Figure 1).

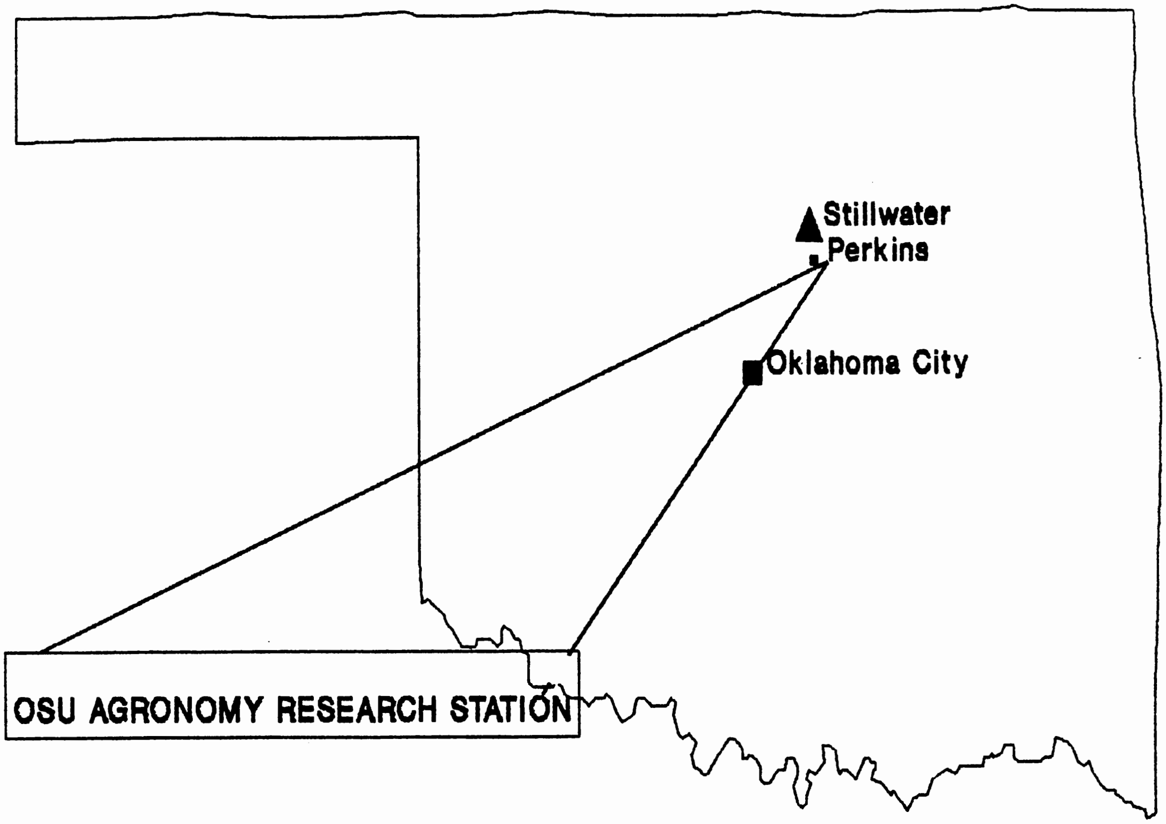


Figure 1. Site Location

Methodology

The methods utilized to accomplish the objectives set in this study were conducted in three phases:

Phase I: Collecting old tracer test data and calculating approximate velocity (time of travel) for different chemicals.

Phase II: Conducting a new tracer test.

Phase III: Applying the MOC, NRC Model to the new and old data and comparing them for different runs to determine ground-water flow and transport characteristics.

CHAPTER II

LITERATURE REVIEW

Groundwater Tracer Overview

In hydrogeology, " TRACER" is a distinguishable matter or energy in ground water that can be used to characterize the ground-water system. Stanley et al (1985) described a tracer test as " A matter or energy carried by ground water which gives information concerning the direction and velocity of the water and potential contaminants which might be transported by water, and if enough information is collected, a tracer test can also help in the determination of hydraulic conductivity (K), porosity (θ), dispersivity and a chemical distribution coefficient".

The first reported ground-water tracing experiment was almost 2000 years ago when Philip the Tetrarch of Trachinotis threw chaff into a crater lake and reported that chaff appeared down gradient in one of the springs at the head water of the Jordan River.

Dyes and salts have been used in Europe since 1869 to find the hydraulic connection in karst areas (Kass, 1964). Among the first dye experiments was an effort made to establish the water origin of typhoid fever in France in 1882. The fluoroscope was invented in France in 1901 by M. Trillat and perfected by M. Marbautin. This instrument greatly increased the precision of fluorescence dye measurements.

At the same time, Theim used sodium chloride (NaCl) to determine the flow velocity of water (Slichter, 1902). Slichter modified Theim's method by obtaining a continuous recording of electrical conductivity in the field. He also used ammonium chloride to determine the time of travel and direction of flow in the first field tracer test in porous media. In the 1950's, radioactive tracers were developed (Fox, 1952). In the last two decades, tracer tests have been improved to be more sensitive by using fluorinated organic acids, such as fluorescence as well as holocarbons and rhodamine WT.

Uses of Tracer Test

The variety of tracer tests is almost infinite, considering the numerous combinations of tracer types, local hydrologic conditions, injection method, sampling method, and geologic setting (EPA, 1991). The tracer test is mainly used to measure one or more hydrogeologic parameter of an aquifer or, to identify the source, velocity and direction of flow of a contaminant. The ground-water tracers can be broadly classified as natural tracers or injected tracers.

Donald, Jeffery and Bradford (1978) studied the use of tracers to confirm ground-water flow in Lake George, New York. In their study, they used rhodamine WT and tritium to determine the direction and velocity of flow of the secondary treated effluent from the Lake George village sewage treatment plant. They concluded that both tracers were satisfactory and useful in determining the velocity of flow in the sand in both the vertical and horizontal directions. They observed that the velocity of horizontal flow in the saturated aquifer was greater than the vertical flow in the unsaturated sand. They also observed that the rhodamine WT has two advantages: it can be detected visually and it has no potential radioactive hazards. Rhodamine B is not suitable as a tracer of ground water due to its high sorption losses. The velocity observed from this tracer study indicates a more rapid flow in the saturated zone than in the unsaturated zone.

Another application of the tracer test was applied by Mark, Ralph and Blakley (1991), for ground-water remediation design. The study explored the role of short-term tracer and other field technology for quantification of aquifer hydraulic conductivity distribution. Various techniques involving multi-level testing and tracer tests involving the monitoring of solute transport were used.

Hydrogeologic Considerations

The first step in determining the physical feasibility of a tracer test is to collect as much hydrologic information as possible about the field area. Several major factors that must be considered in selecting a tracer are lithology, flow regime, direction of flow and travel time.

Fine grained materials such as clay have higher sorption capacity than coarse grained materials; this must be considered when evaluating the potential mobility of a tracer. Whether flow is predominantly through porous media, solution features or fractures will influence the selection of a tracer. For studying tracers using two or more wells, the general direction of ground water must be known.

The equation used to determine the travel time can be applied based on a number of hydrologic principles such as Darcy's Law which states that: For a simple flow system, the volume of water flowing per unit of time , Q, through a cross sectional area, A, is directly proportional to the hydraulic gradient, $\Delta H/\Delta L$, and the hydraulic conductivity K,

$$Q = KA\,\Delta H/\Delta L \tag{1}$$

Also, the general direction of ground-water movement should be known, and it is generally perpendicular to the lines of equal ground potential levels as defined by water levels in wells penetrating the water-bearing zone of interest.

Another equation that can be considered for tracer movement states that:

$$Q = V\ \ A \tag{2}$$

where Q is the volume of water flowing per unit time, A is the cross sectional area, V is the average velocity of the ground water, and can be replaced by the term $L/\ T$

$$Q = \Delta L/\Delta T\ \ A \tag{3}$$

where ΔT is the time taken by the average water particles to move through a distance ΔL.

The travel time can be calculated from equations (1) and (2)

$$T = ne\ (\Delta L)^2 / K\ \Delta H \tag{4}$$

This time is the time required for the water and/or tracer to move from one point to another.

Tracer Characteristics

In order to choose the most suitable substance to conduct a tracer test, a number of physical, chemical and biological characteristics must be considered such as detectability, mobility, and toxicity.

Injected tracers should have no or very low natural background levels. The degree of dilution is a function of the type of injection, distance, dispersion, porosity and hydraulic conductivity. Too much dilution may result in failure to observe the tracer when it reaches a sampling point, because concentration will be below the detection point (EPA, 1991). Conservative tracers used to measure aquifer parameters such as flow direction and velocity should be stable (not subject to transformation), soluble in water, of similar density and viscosity and not subject to adsorption or precipitation (EPA, 1991). Non-toxic tracers should be used; If the tracer is toxic at certain concentration, maximum permissible levels as determined by the federal, state or county agencies must be considered in relation to expected dilution and proximity to drinking-water sources (EPA, 1991).

Types of Tracers

Considering the full range of organic ground-water contaminants, hundreds and possibly thousands of substances have been used as tracers in ground-water (EPA, 1991). The most often used tracers can be grouped into two categories, ions and dyes.

Inorganic ionic compounds such as common salts have been used extensively as ground water tracers. This category undergoes ionization in water, resulting in separation into charged species possessing a positive charge (cations), or a negative charge (anions)(Davis et al, 1985). Ionic tracers have also been used as tools to determine flow path, residence time and to measure aquifer properties. Slichter (1902-1905), used ionic tracers to study ground water in the United States. The advantage of simple ionic tracers is that they do not decompose and therefore are not lost from the system.

Various applications of ionic tracers have been studied and published. Murray et al. (1981), used lithium bromide (LiBr) in carbonate terrain to establish the hydraulic connection between a landfill and a freshwater spring. Tennyson and Settergren (1980) used bromide (Br-) to evaluate the pathways and transit time of recharge through soil at a proposed sewage-effluent irrigation site. Mather and others (1969), used sodium chloride (NaCl) to investigate the influence of mining subsidence on the pattern of ground water flow. Also chloride (Cl-) and calcium (Ca+) were used by Grisak and Pickens (1980a) to study solute transport mechanisms in fractured media. Potassium (K+) was used by Ellis (1980) to determine the migration and the extent of dilution by receiving water located beside a waste-disposal site.

Various organic dyes have been used for surface water and ground-water tracing since the 1800's. Dyes are relatively inexpensive, simple to use and effective. The extensive use of fluorescent dyes for water tracing began around 1960 (Davis et al. 1985).

Fluorescent dyes are preferable to nonfluoroscent varieties in ground-water tracer studies because they are easier to detect (EPA, 1991). Dale (1906) was the first to recommend the use of dyes in ground-water study in the United States by reporting the results of fluorescein et al dyes used in France in 1882. In 1927 Stiles and others conducted early experiments using fluorescein to demonstrate the pollution of wells in a sandy aquifer. Meinzer described in 1932 the use of fluorescein as a ground-water tracer.

Generally, dyes travel slower than water due to adsorption, and they are not as conservative as radioactive tracers or some of the ionic tracers. Adsorption can occur on organic matter, clay, sandstone, limestone, plants and even glass sample bottles (EPA, 1991).

Fluorescein, also is known as uranin; sodium fluorescein, is one of the most widely used green dyes. Feuerstein and Selleck (1963) recommend that fluorescein be restricted to short-term studies of only high quality water. Blue Fluorescein dyes are optical brighteners and have been used increasingly in the past decade. Water that has been contaminated by domestic waste entering septic-tank soil-absorption fields can be used as a natural tracer if it contains a detectable amounts of the brighteners (EPA, 1991). The use of optical brighteners was first described by Glover in 1972 as a tracer in Karst environments.

Tracer Tests in Porous Media

Tracer tests in porous media are used primarily to characterize aquifer parameters such as regional velocity (Leap, 1985), and hydraulic conductivity distributions (Malz et al. 1988).

Ground Water Modelling Overview

In 1984, the American Society for Testing and Materials (ASTM) defined models as " An assembly of concepts in the form of mathematical equations that portrays understanding of a natural phenomenon ". Also, the ASTM has defined computer code as " The assembly of numerical techniques, bookkeeping, and control languages that represent the models from acceptance of input data and instruction to delivery of output", (EPA, 1991).

Ground-water modelling has become a successful tool that can help analyze many ground-water problems. Models are useful and simplified representations of real-world processes for reconnaissance studies preceding field investigation and for predictive studies to estimate future field behavior. Their creation and use requires many judgements based on observation of specific natural processes (Keely, 1989b). In addition, models are useful for studying various types of flow behavior by examining hypothetical aquifer problems (James and Charles, 1980).

Types of Models

Ground-water models can be classified in many different ways including Analytical and Numerical models and Finite Elements and Finite Difference.

Analytical and Numerical Models. A model's governing equation can be solved either analytically (physically) or numerically. Analytical models use exact close form solution of the appropriate differential equation. The solution is continuous in space and time, and it is used to study contaminant flow through aquifer materials to obtain information on contaminant movement (Keely, 1989b). Analytical models provide exact solutions, but employ simplified assumptions in order to produce tractable solutions.

In contrast, numerical models apply approximate solutions for the same equation. (James, and Charles, 1980).

This type of models relies on quantification of relationships between specific parameters and variables to simulate the effects of natural processes. (Weaver and others, 1989). Numerical models are much less burdened by assumptions, and, therefore are inherently capable of addressing more complicated problems, but they require more data and the solutions are approximate. A fundamental requirement of the numerical approach is the construction of a grid system which represents the aquifer being tested. This grid of interconnected nodes, at which process input parameters must be specified, forms the basis for a matrix of equations to be solved. The grid is influenced by the choice of numerical solution techniques.

Finite Elements and Finite Differences. The finite-element method approximates the solution of partial differential equations by using finite-difference equivalent, whereas the finite-difference method approximates differential equations by using an integral approach. In general, finite-difference methods are best suited for relatively simple hydrologic settings; finite-element methods are used where hydrogeology is complex (EPA, 1991).

Hydrogeological Model Parameters

The hydrogeological parameters that can be simulated can be divided to two major groups: flow parameters and solute-transport parameters.

Ground Water Flow Parameters.

Types of Aquifers. Confined aquifers of uniform thickness are easier to simulate because the transmissivity remains constant. The thickness of unconfined aquifers varies with the fluctuations of the water tables. Variable-thickness confined aquifers are complicated to model because the velocity will change with the change of the aquifer thickness.

Matrix Characteristics. Flow in porous media is much easier to model than in rocks with fractures or solution porosity.

Homogeneity and Isotropy. Homogeneous and isotropic aquifers are easier to model because their properties do not change in any direction. Most aquifers show variations in all directions and so they require three-dimensional representations.

Phases. Flow of ground water and contaminated ground water in which the dissolved constituents create a plume with properties not unlike unpolluted aquifer is easier to simulate.

Numbers of Aquifers. A single aquifer is much easier to simulate than multiple aquifers.

Flow Conditions. Steady state flow, where the magnitude and direction of flow velocity are constant with time at any point, is easier to model than transient flow.

Contaminant Transport Parameters

Types of Sources. In modelling, the source can be represented as point, line, area or volume. A point source can represent an injection well or a pipe outflow. If a contaminant is leaching from the bottom of a trench, it will be represented as a line. An area source enters the ground water through a horizontal or vertical plane.

Type of Source release. Release of an instantaneous pulse or slug of contaminant is much easier to simulate. Dispersions: Accurate contaminant modelling requires incorporation of transport by dispersion.

Adsorption. It is much easier to simulate adsorption with partition coefficients.

Degradation. Simulation of degradation is easier when using first-order degradation coefficient. The second-order degradation, which results from variation in parameters, is more difficult to simulate.

Density and Viscosity Effects. Simulation must include density and viscosity effects in order to obtain a good representation of the problem.

Modelling Applications. James and Charles (1980), suggest that a successful model application requires a combination of experience with hydrologic principals, numerical methods, the aquifer to be modelled, and model use.

Pinder and Bredehoft (1968) presented a study on the use of a ground-water flow model to analyze an aquifer system composed of glaciofluvial deposits. The study includes a history match with limited data and a prediction using a finite-difference model. The same problem was simulated later in 1972 by Pinder and Frind using a Galerkin, finite-element model.

This study proved that because of the boundary condition suggested from the pumping-test data, the analytical technique was not adequate. Therefore, the authors decided to use a numerical model and performed necessary developmental work such as analyzing pumping-test data to provide estimation of the transmissivity and storage coefficient. It was found that the final transmissivity value was close to the value calculated using Jacob's method.

More results were provided by Pinder and Frind (1972) mentioning that:

a. "The analysis of the aquifer indicate that a carefully designed model using deformed elements may provide the same accuracy as a finite difference model that use many more nodes ".

b. "The theoretical development of the Galerkin method of approximation is possibly more abstract than the finite-difference method."

c. "Experience has shown that errors in the input of nodal location in the Galerkin model can lead to problems that are difficult to detect. This problem does not arise in the finite-difference model because the entire grid is specified by the spacing between rows and columns."

d. "In the final analysis the primary advantage of the Galerkin approach to digital modeling of aquifer systems is its flexibility in application."

In 1977 Konikow presented a good example of a solute-transport model applied to a chemical pollution problem at the Rocky Mountain Arsenal, Colorado. The study couples a finite-difference solution to the ground-water flow equation with the Method-Of-Characteristics (MOC) solution to the solute-transport equation. The problem began in 1943; when liquid waste by-products from the manufacturing of chemicals for warfare and pesticides were disposed of in unlined ponds. This disposal continued from 1943 to 1956. The waste contained chloride concentrations of several thousands of mg/L. In 1943, several crops were damaged due to irrigation with the contaminated ground water. The purpose of this study was to demonstrate the application of a numerical solute transport model. The model uses a finite-difference grid of blocks of 1000 ft (305 m) on a side. The grid is 25 columns by 38 rows and comprise of 950 nodes, due to boundaries conditions, only 516 nodes were actually used. According to Konikow: "Analysis of the simulated results indicates that the geologic framework of the area markedly restricted the transport and dispersion of dissolved chemicals in the alluvium. Dilution, from irrigation recharge and seepage from unlined canals, was an important factor in reducing the level of chloride concentrations downgradient from the arsenal. Similarly, recharge of uncontaminated water from the unlined ponds since 1956 has helped to dilute and flush the contaminated ground water ".

This example shows the additional complexity typical of solute-transport problems. Konikow concluded that the stringent data requirement for applying the solute-transport model pointed out deficiencies in data existing at the start of the investigation. The conclusion and predictions based on model results, though quantitatively nonunique, provided a great deal of qualitative insight into reclamation alternatives. The relative merits of the various proposed remedial measures would have been extremely difficult to assess without the use of the model.

In 1992, Warner, Abdel-Rahman and Tamayo published a paper concerning the same problem of the Rocky Mountain Arsenal using numerical and geostatistical analysis. In their study, a finite-element model was used (CSU/GWFLOW), where a very detailed mesh was used for the model grid which consists of 13,156 nodes and 25,524 elements. Because of the complexities of the hydrological conditions of the arsenal, this system has proven to be very difficult to manage. In this regard a slurry wall was built by the U.S. Army to cut-off the migration pathway. The system involves arrays of pumping wells and recharge wells. The model was used to calibrate the effectiveness and efficiency of the system. The model has proven to be very effective. It allows better calibration for the system and it increases the model's capability for representing different system configurations to achieve desired conditions, such as reverse gradient along the system.

Another application of ground water modeling involves a study where a two-well tracer test in a relatively porous media was used. The results of the tracer test were used to determine field dispersivity values for a solute transport study. The conclusions of this study includes:

a. For a given well spacing and head differential in the wells, the duration of the test will be related inversely to the hydraulic conductivity and directly to the porosity.

b. Based on the range of the hydrologic data, a single injection test may require from less than one month to more than one year to obtain sufficient information about the system.

c. If the hydraulic conductivity of the aquifer is low, a small well spacing is required in order to conduct the test in a reasonable amount of time.

d. The time required to reach a quasi-steady flow between wells will be short in comparison to the duration of the test.

e. Tests can be designed for a moderate injection rate of less than 1500 m3/day.

Karplus (1976) suggested the evolution of modelling in any discipline follows a general pattern. He represented the evolution of modeling in a graph (Figure 2) which shows the predictive validity of modeling as a function of time. The curve has two break points A and B, in between which the most rapid improvement in model validity occurs. Most ground-water modelling lies somewhere between A and B. Ground-water-flow modeling is located near B, whereas solute-transport modeling lags behind closer to point A.

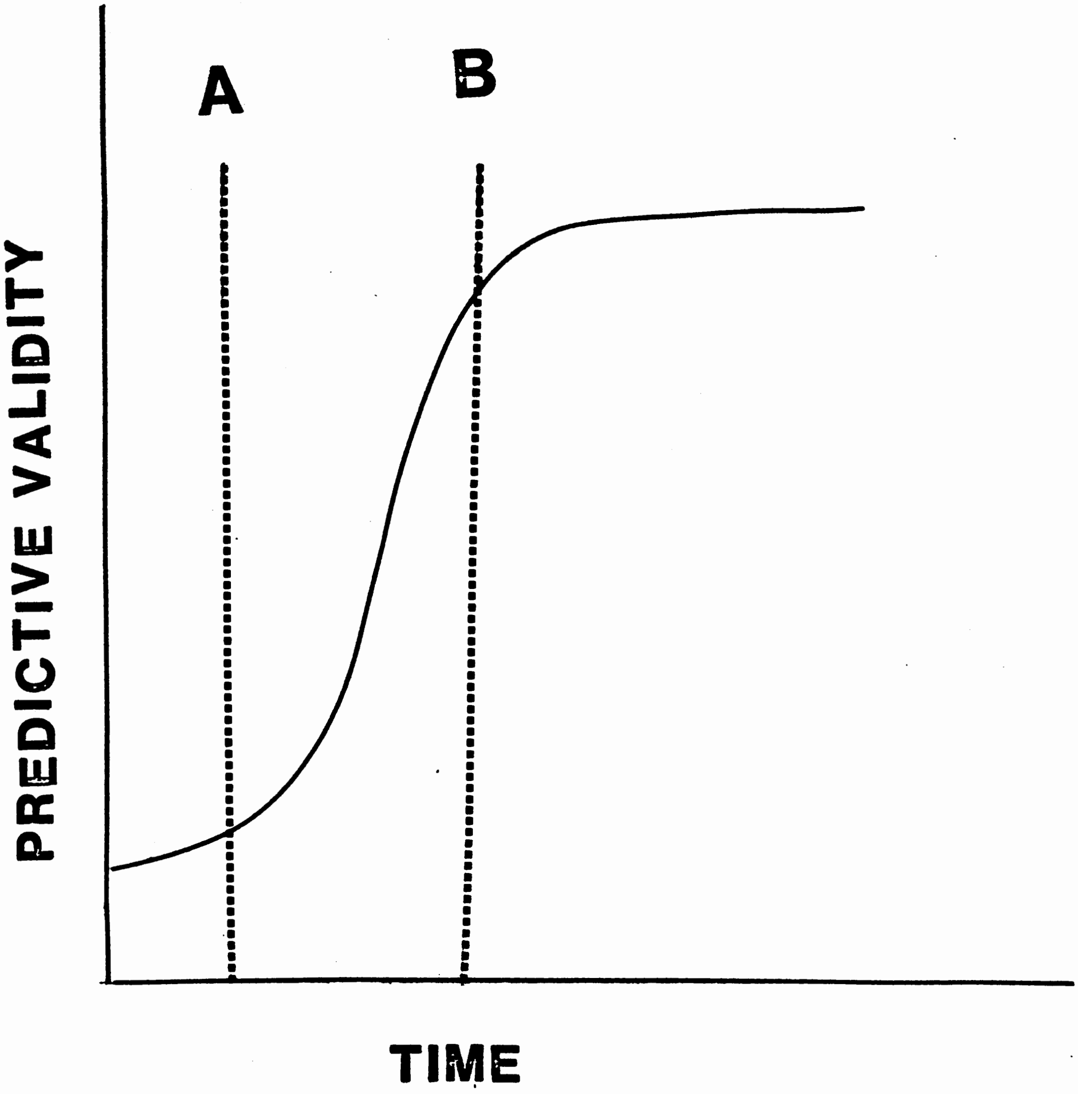


Figure 2. A graph Showing the validity of models versus time After which model activity started. (After Karplus, 1976)

CHAPTER III

HYDROGEOLOGY OF THE ALLUVIUM

Physiography

The study area lies in a transitional zone between the Central Redbed Plain and the Northern Limestone Cuesta Plains (Curtis and Ham, 1957). Most of the surrounding countryside has been used for farming and cattle ranching. The area also lies in the Cimarron River drainage basin of the Arkansas River; the river is 1¼ miles south of the site and flows towards the southeast. The mean temperature of the area is 59° F(28° C) and the average annual rainfall is approximately 35 inches (87 cm) (Shelton, Ross, Garden and Frank, 1985).

Soils

The area is covered by soil on terrace deposits which are cultivated, flat, and not subject to rapid erosion. Two predominant soils in the area are Teller and Konawa soils.

Teller soils are deep, well drained, moderately permeable and gently sloping. The surface layer is reddish brown loam; the subsoil consists of reddish brown loam, yellowish red clay loam and red fine sandy loam (Henley et al. 1987). Konawa soil, occurs on ridgetops and side slopes; it is a deep soil, very gently sloping and well drained. The surface layer consists of brown and reddish brown, fine, sandy loam. The subsoil consists of red sandy clay loam and red fine sandy loam (Henley et al. 1987).

Geology

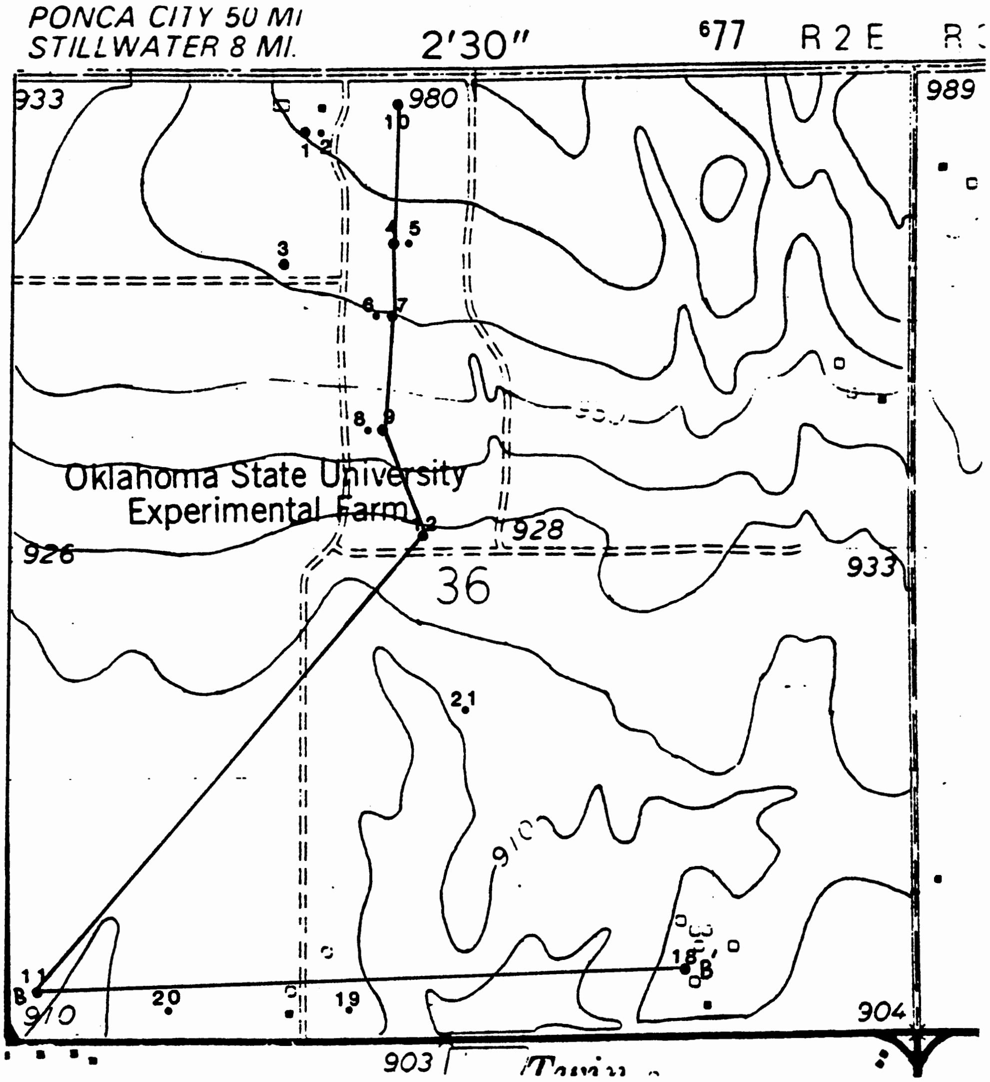
The study area is penetrated by several wells ranging in depth from 21 to 58 ft. Figure 3 shows the locations of these wells. Data obtained from drilling was used to describe the subsurface as follows.

Bedrock Geology

The subsurface geology of the area is dominated by interbedded sandstones, siltstones and shales belonging to the Wellington Formation of Permian age, the lowest unit of the Cimarron Series. The Wellington Formation consists of lenticular sandstones, shales and thin carbonate beds (Shelton, 1985). The upper few feet of the bedrock are penetrated by the drilling. The cores obtained show red-brown to gray shale and orange-brown fine grained sandstones with interbedded limestone. The bedrock has been warped by Post-Permian epeirogenic activities. (Bingham, 1975).

Quaternary System

The surface geology of the area is dominated by alluvial terrace deposits formed by the Cimarron River which act as the principal aquifer in the area. The deposits are referred to as the Perkin's Terrace Aquifer. This aquifer is characterized by unconsolidated terrace deposits of the Quaternary age and consisting of fine to medium grained sand



● Deep Well

• Shallow Well

Figure 3. Location of Groundwater Monitoring Wells at OSU Agronomy Station.

with some thin layers of silt and clay. These terrace deposits are underlain by Permian beds consisting of red shale and sandstone (Blair, 1975). These alluvial sediments, are mappable units in the flood plain and terraces of the Cimarron River and along major creeks (Figure 4).

Cores from drilling show fine grained red, orange and tan silty sand layers separated by yellow, tan and gray silty clay lenses. Two stratigraphic cross sections, Figures 5 and 6 were plotted using the sample-cutting data and gamma ray data (Dwidevi, 1989). A general increase in grain size from fine at the top of the section to coarse at the bottom of the section is observed, which indicates a fluvial sedimentation cycle.

Hydrogeological Characteristics

The wells drilled in the area provide water for rural homes and for municipal use in small communities. The area most favorable for ground-water development lies along the flood plain and terrace deposits of the Cimarron River (Bingham, 1980).

The saturated thickness of the Perkins terrace deposits ranges from 25 to 48 ft (7-15 m). The well yield is about 20 to 60 gpm (106 - 318 m3/day); a well yield of 100 gpm (530 m3/day) is obtained where wells penetrate the gravel lenses at the base of the aquifer. The total annual precipitation is 32 inches (81.3 cm) (Shelton, 1985).

Clustered and single monitoring wells were installed at

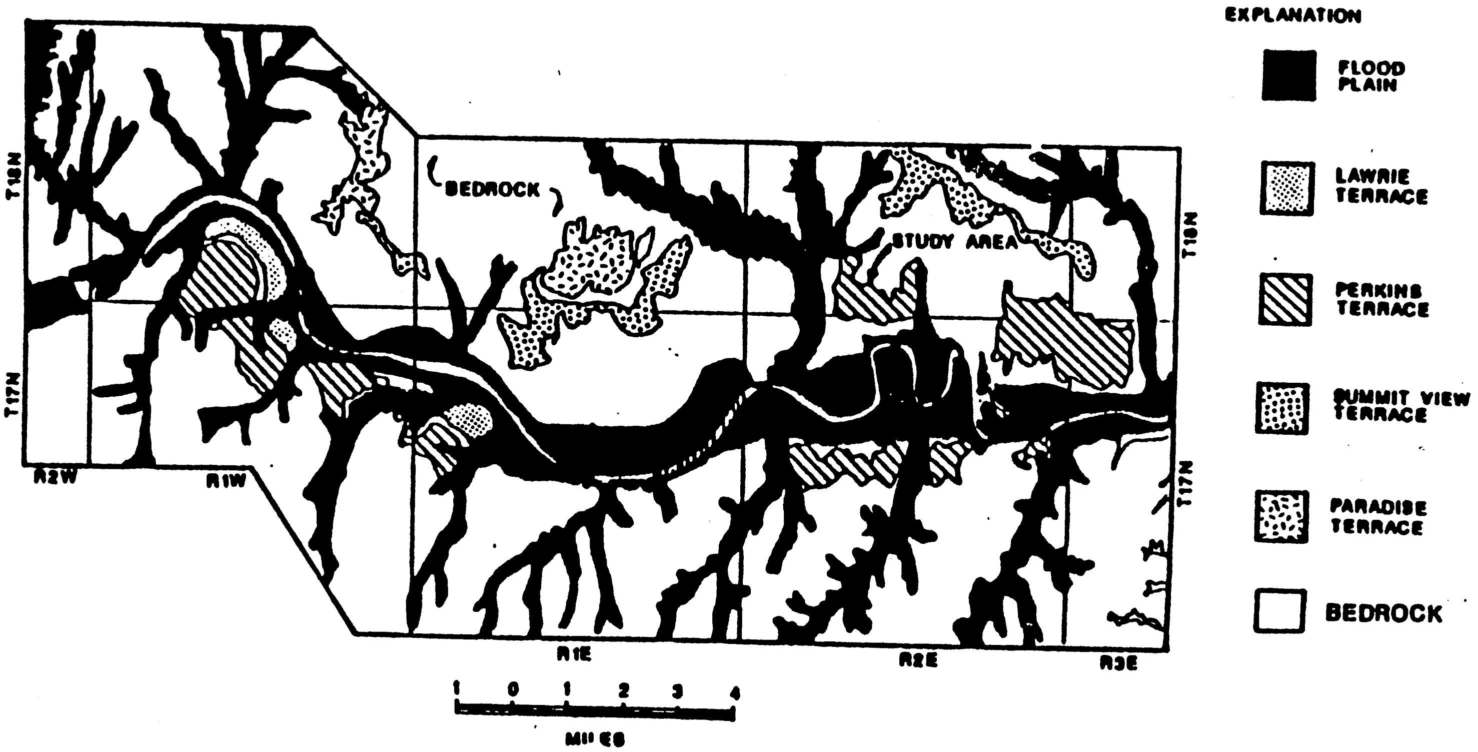


Figure 4. Alluvial Surface Map of the Cimarron Valley from Interstate 35 to Perkins, North-Central Oklahoma (After Blair, 1975)

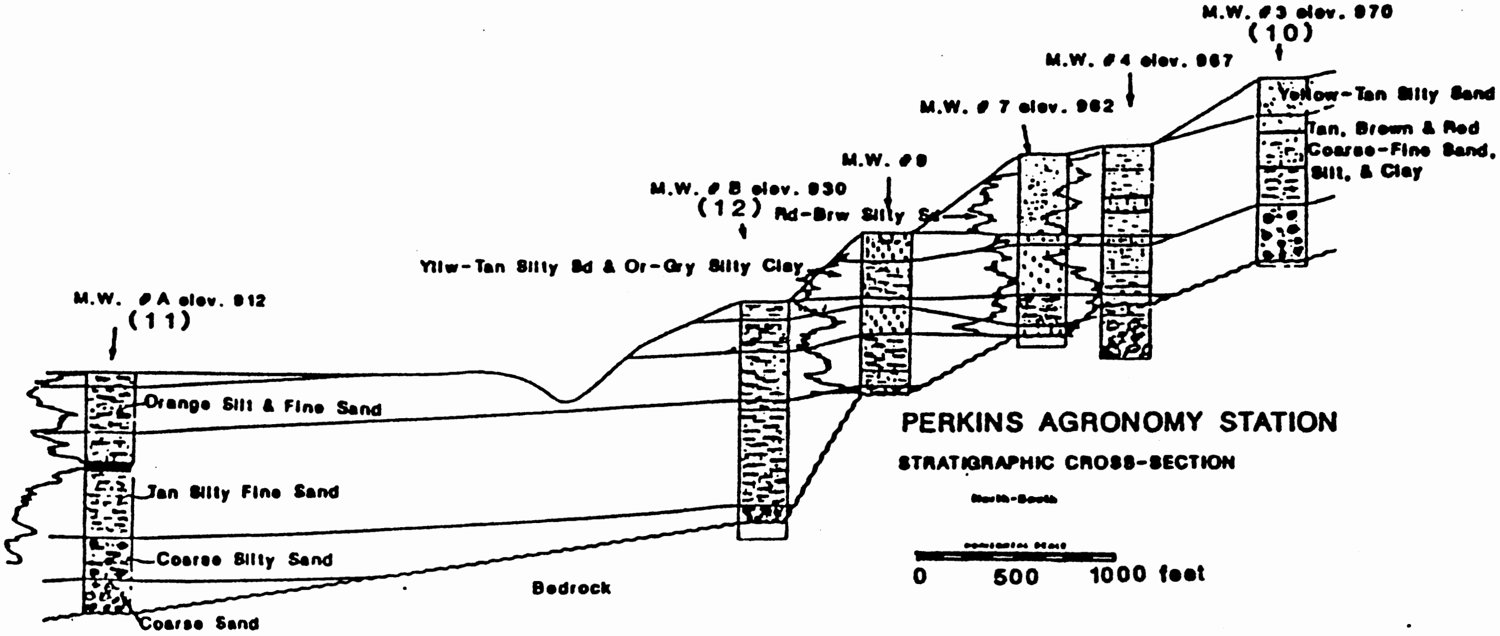


Figure 5. North-South Stratigraphic Cross-Section (After Dwidevi, 1989).

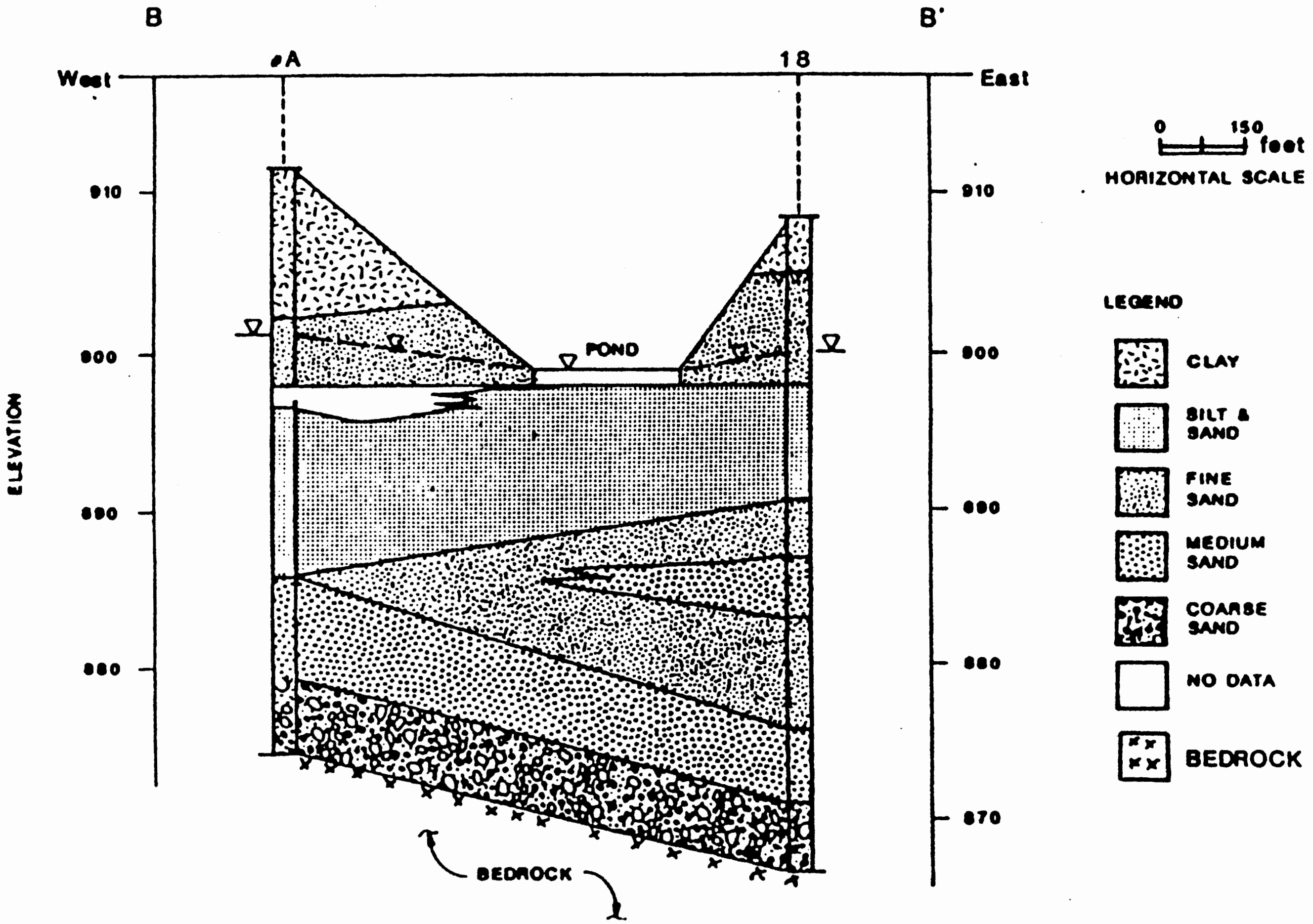


Figure 6. East-West (B-B') Stratigraphic Cross-Section (After Dwidevi,1989).

the site by the ARS and are shown in Figure 3. Water-level fluctuation is created by variations in precipitation, evapotranspiration and by intermittent pumping of water from nearby wells (Bingham, 1980). Ground-water-level measurements and samples were obtained from the monitoring wells during the period between January 1986 and June 1992. A detailed hydrologic study is performed and included in a Chapter IV.

CHAPTER IV

METHOD OF APPROACH

Site Investigation

Geophysical Study

The site was characterized based on data from the drilled wells as well as borehols and surface geophysical investigations. A surface geophysical study was performed in the area using the D.C. Resistivity Method. This method aided in the construction of the bedrock map shown in Figure 7. The potentiometric surface map is also constructed and shown in Figure 8. The saturated thickness range between 10 ft to 48 ft.

Analysis of Aquifer Testing

An important goal in any hydrogeological investigation is the analysis of pumping test data to determine Hydraulic Conductivity (K), Transmissivity (T) and Storativity (S) within the tested area. Several pumping tests were conducted at the site; data was analyzed using the Theis and Cooper-Jacob Methods, Table I includes a summary of results obtained from the pumping test in wells 14(E0), E1, E2 and E3. Figures 9, 10, 11 and 12 represents the pumping test plots for different wells for data collected in 1989.

The calculated Hydraulic Conductivity range from 250 gpd/ft to 650 gpd/ft^2 (10,1875 m/d to 28,525 m/d). The average value for Transmissivity obtained by Cooper-Jacob Method ranges for 20,000 gpd/ft to 25,000 gpd/ft (248 m^2/d to 310 m^2/d). Table I represents a summary of aquifer coefficients obtained from earlier data. These data will be used to identify a lower and upper limits of hydraulic conductivity, ie. 250 gpd/ft^2 and 650 gpd/ft^2 . These values will be used to compute anticipated velocities of tracers used in tracer test study. This study is described in detail in Chapter V (Data Analysis).

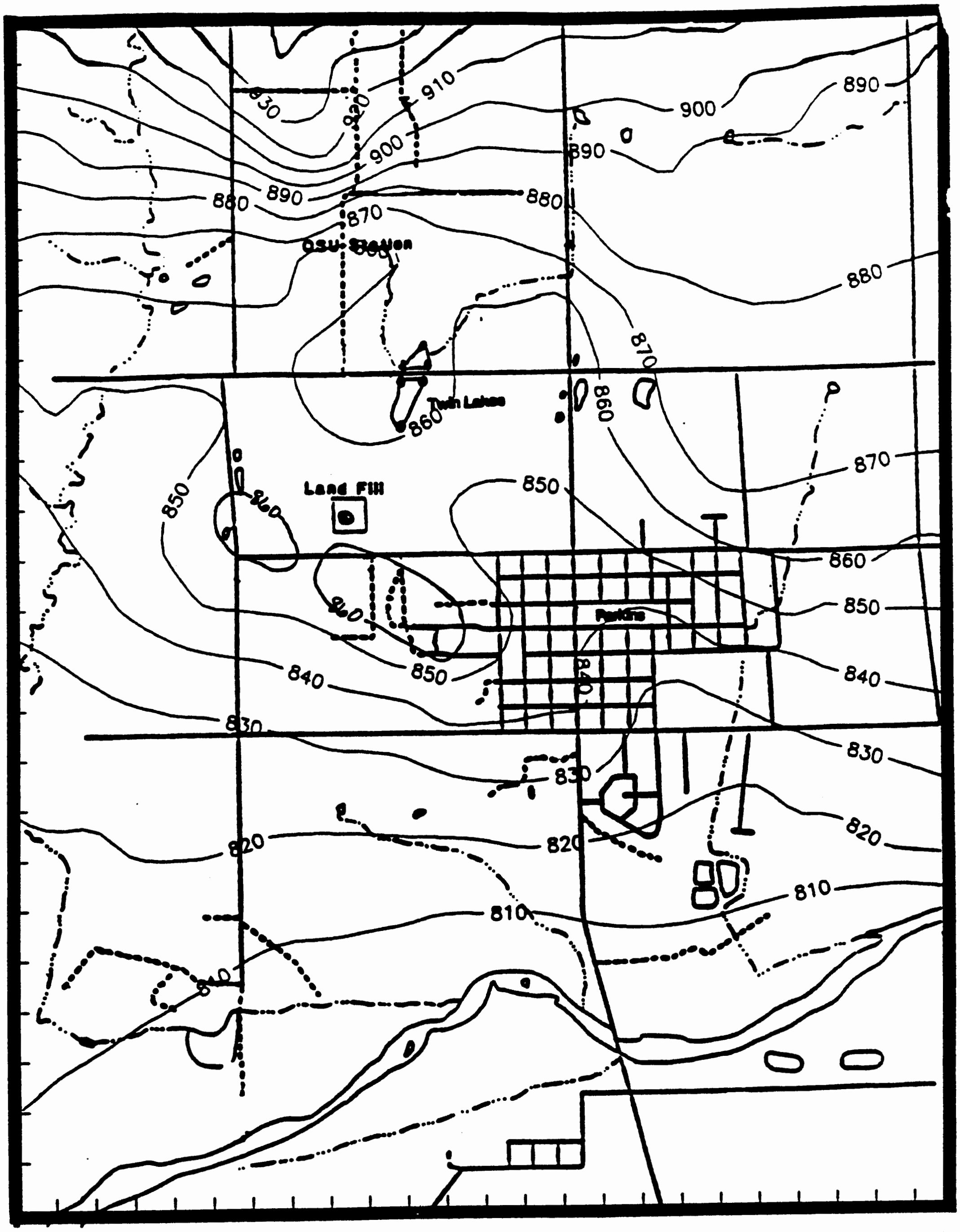


Figure 7. Bedrock elevation map (1992).

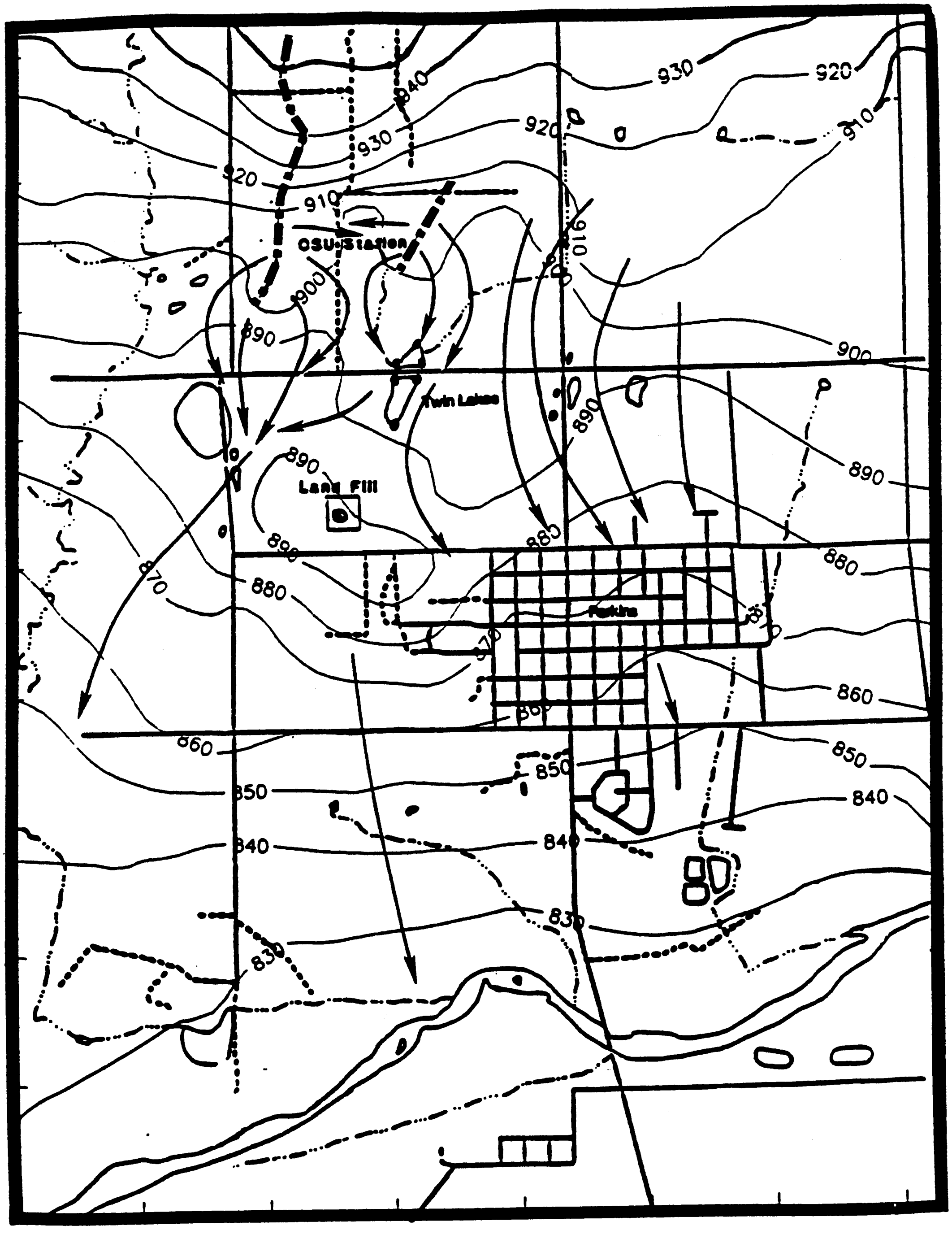


Figure 8. Potentiometric surface map. (1992)

TABLE I

SUMMARY OF AQUIFER COEFFICIENTS

WELL#	MW14(Eo)	MW15	E1	E2	E3
Distance (in feet from MW18)	12.85	7.65	20.4	39.5	80.6
Cooper-Jacob					
T (gpd/ft)	17296	13360	16062	16615	23748
S	0.018	0.11	0.007	0.019	0.002
K (gpd/ft2)	432	334	401	415	593
Theis					
T (gpd/ft)	N/A	1900	8175	21705	29545
S	N/A	0.03	0.06	0.006	N/A
K (gpd/ft2)	N/A	272	204	542	738
Jacob Straight line Method					
T (gpd/ft)	24137	N/A	20114	19200	25000
S	.46	N/A	0.031	0.003	0.3348
K (gpd/ft2)	575	N/A	479	457	595

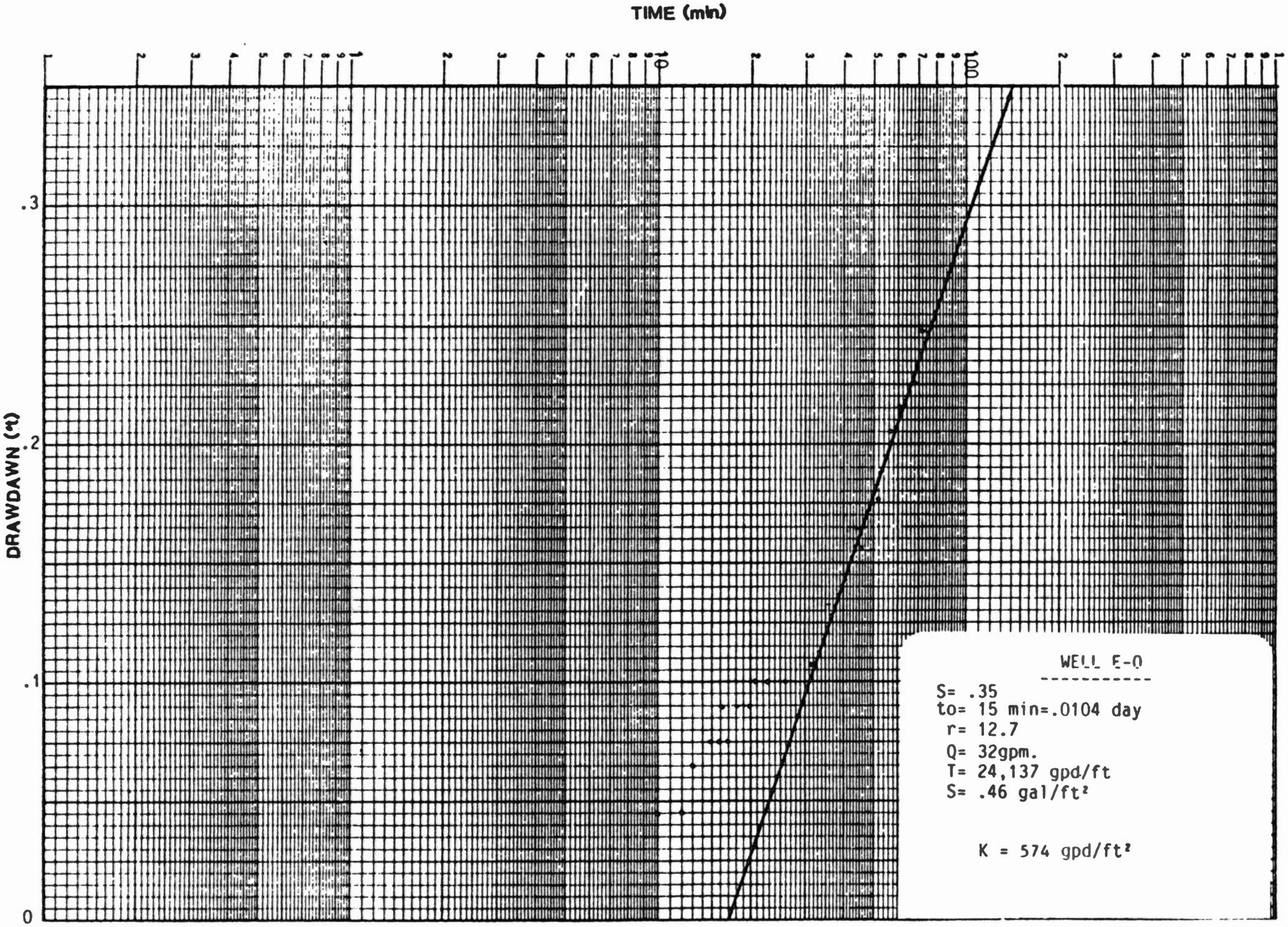
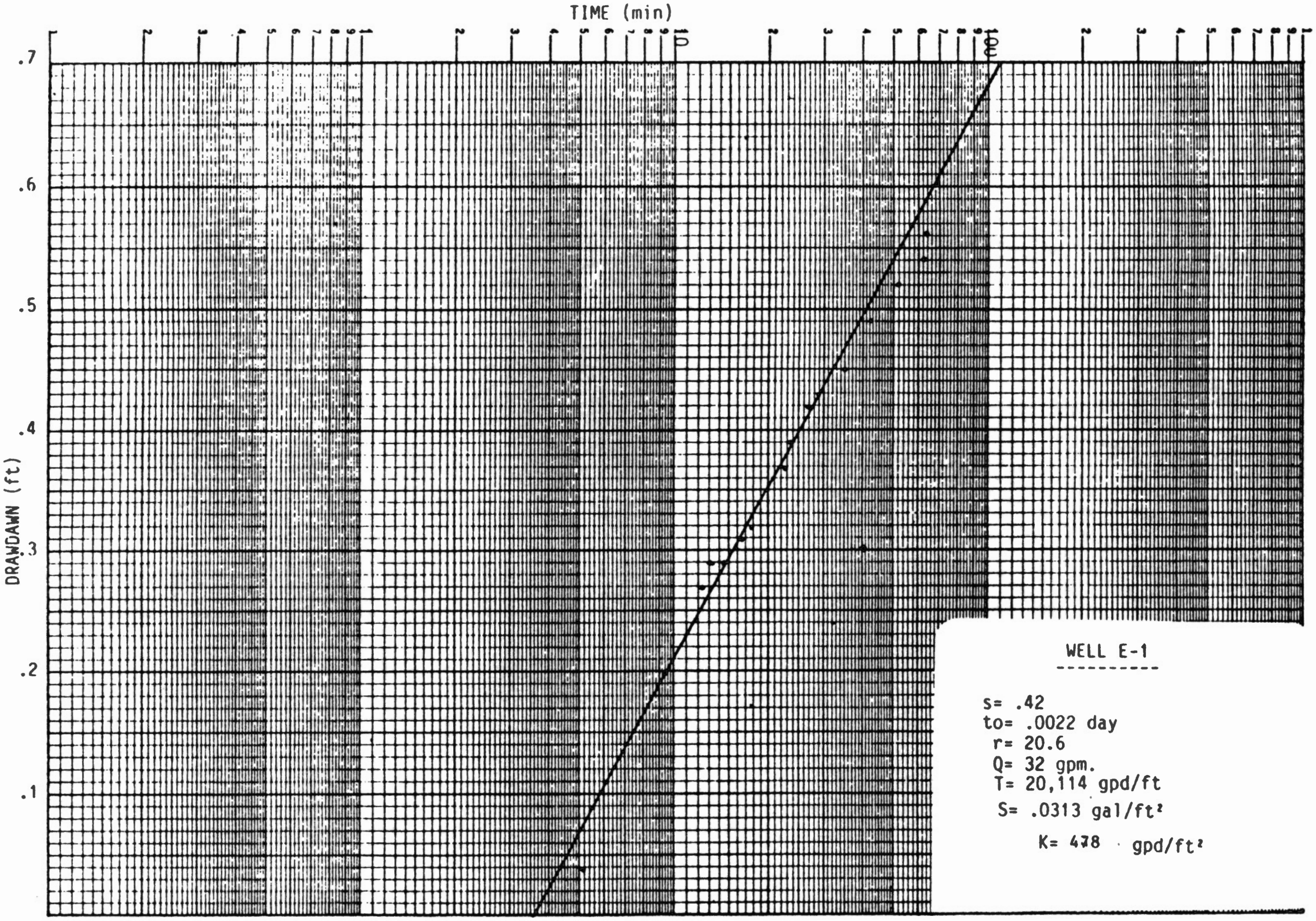


Figure 9. Semi-log Plot of drawdawn versus time for wellEO (MW14).



WELL E-1

s= .42
to= .0022 day
r= 20.6
Q= 32 gpm.
T= 20,114 gpd/ft
S= .0313 gal/ft²
K= 478 gpd/ft²

Figure 10. Semi-log Plot of drawdawn versus time for well E1.

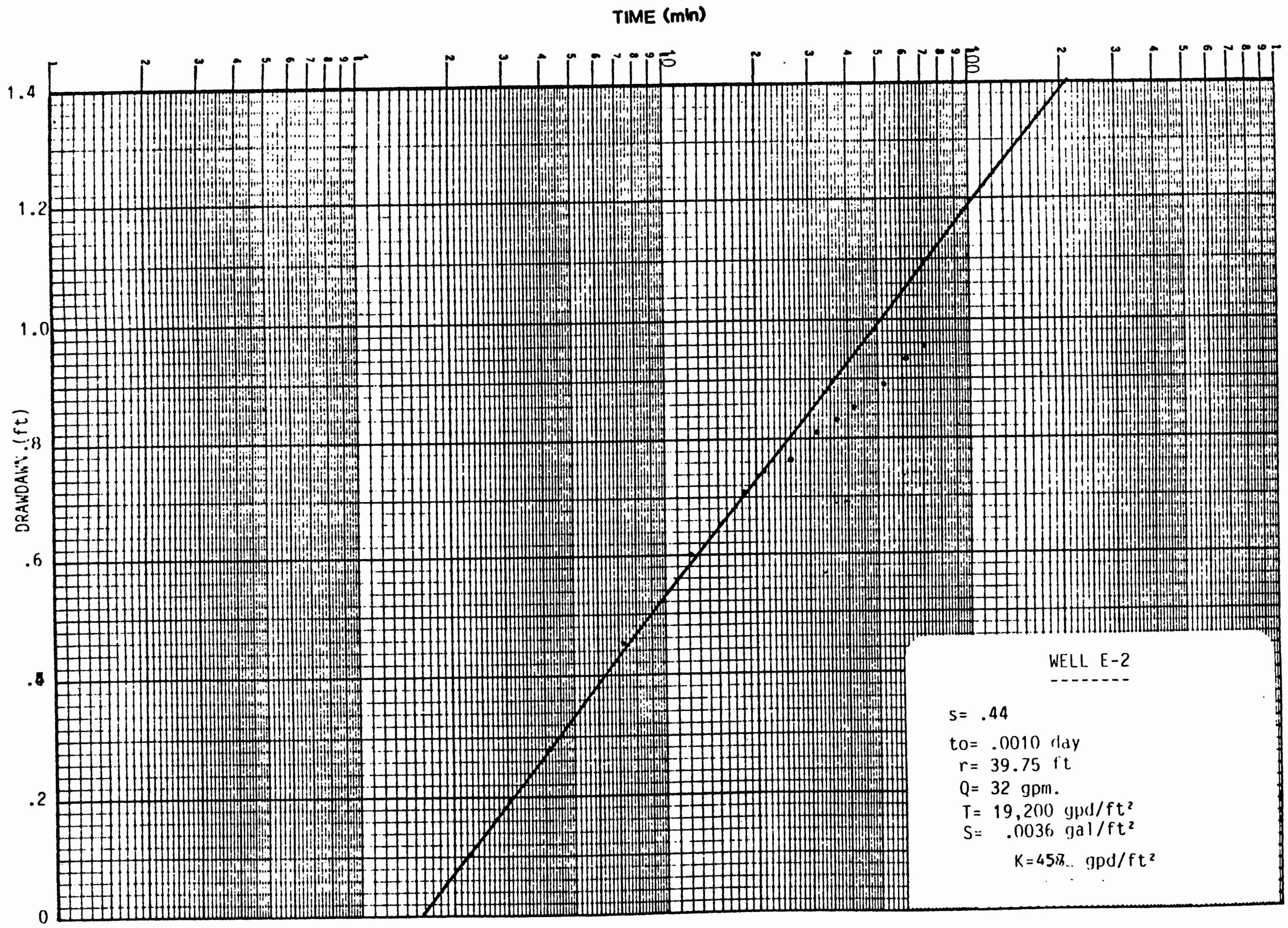
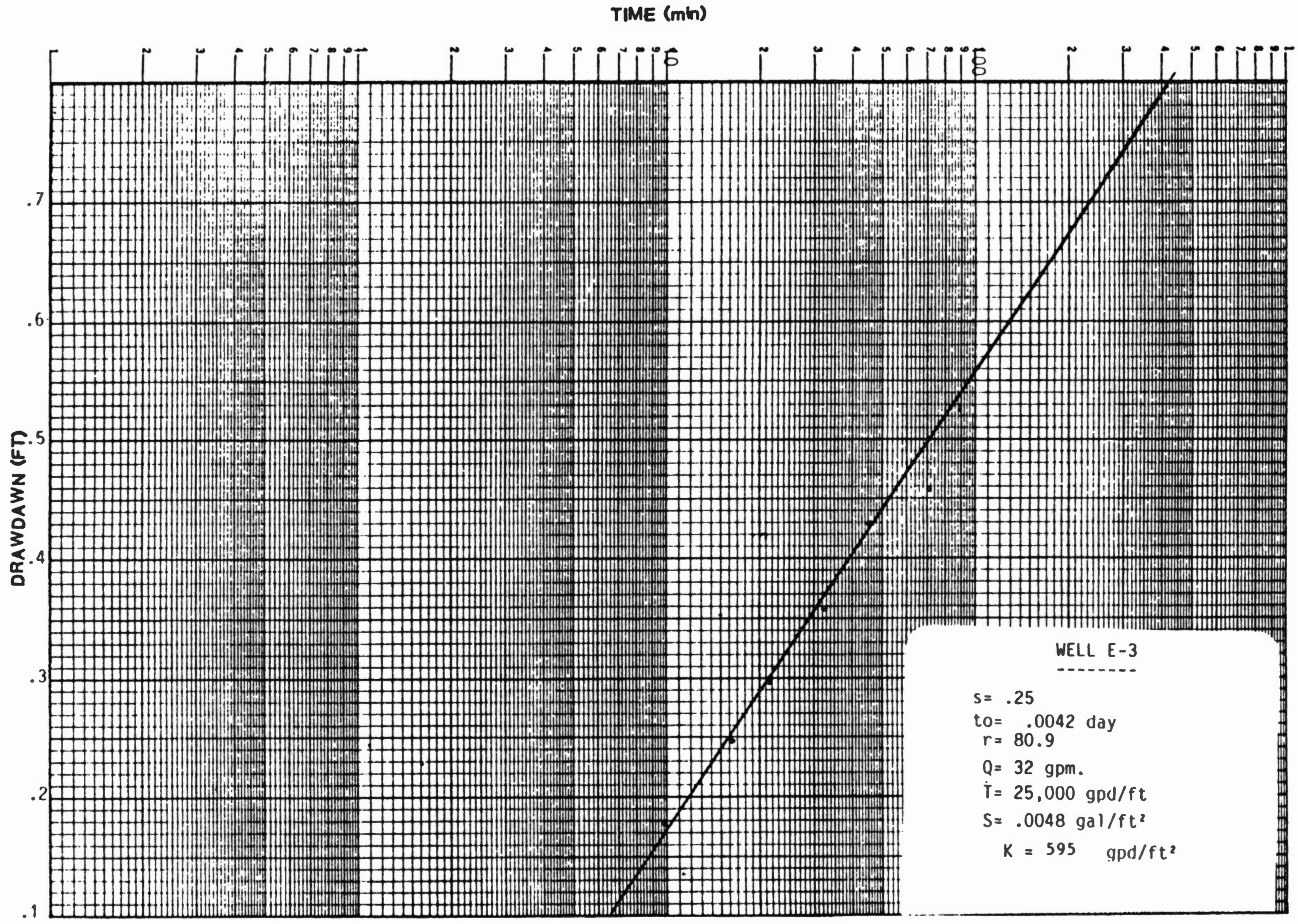


Figure 11 . Semi-log plot of drawdawn versus time for well E2.



WELL E-3

s= .25
to= .0042 day
r= 80.9
Q= 32 gpm.
T= 25,000 gpd/ft
S= .0048 gal/ft²
K = 595 gpd/ft²

Figure 12. Semi-log plot of drawdawn versus time for well E3.

Tracer Test

The main intent of this section is primarily to characterize the movement of chemicals in ground water and to obtain aquifer parameters such as travel time of different chemicals and change of initial concentration versus time and distance. The results of this test will be used to verify the hydraulic conductivity obtained from pumping test, and finally to calibrate field data and model prediction results.

Site and Wells Used in Tracer Test

The site selected to conduct the Tracer test is located near Perkins at the OSU Agronomy Research Station . Two four-inch-diameter wells, MW 14 and MW 18, and three two-inch-diameter wells, MW 15, MW 16 (shallow 21 ft) and MW 17 (deep 35 ft), were installed at the Perkins site and were used for the tracer purpose (Figure 13). Figure 14 is a cross-section of ground-water monitoring wells used in aquifer tracer test.

Monitoring Well 18 was used as a discharge well, pumping at a rate of 30 gpm. Monitoring Well 14 was the injection well.

Monitoring Wells 15, 16 and 17 were used for sampling purposes.

A stratigraphic cross section for tracer-test wells is shown in Figure 15; all wells were logged using gamma-ray log geophysical method. Analysis of the stratigraphic cross-section indicates near-homogeneity of the aquifer; all the identified lithologic units in the subsurface were traceable from one well to another (Dwidevi, 1989).

The distances between wells and the source are listed in table II.

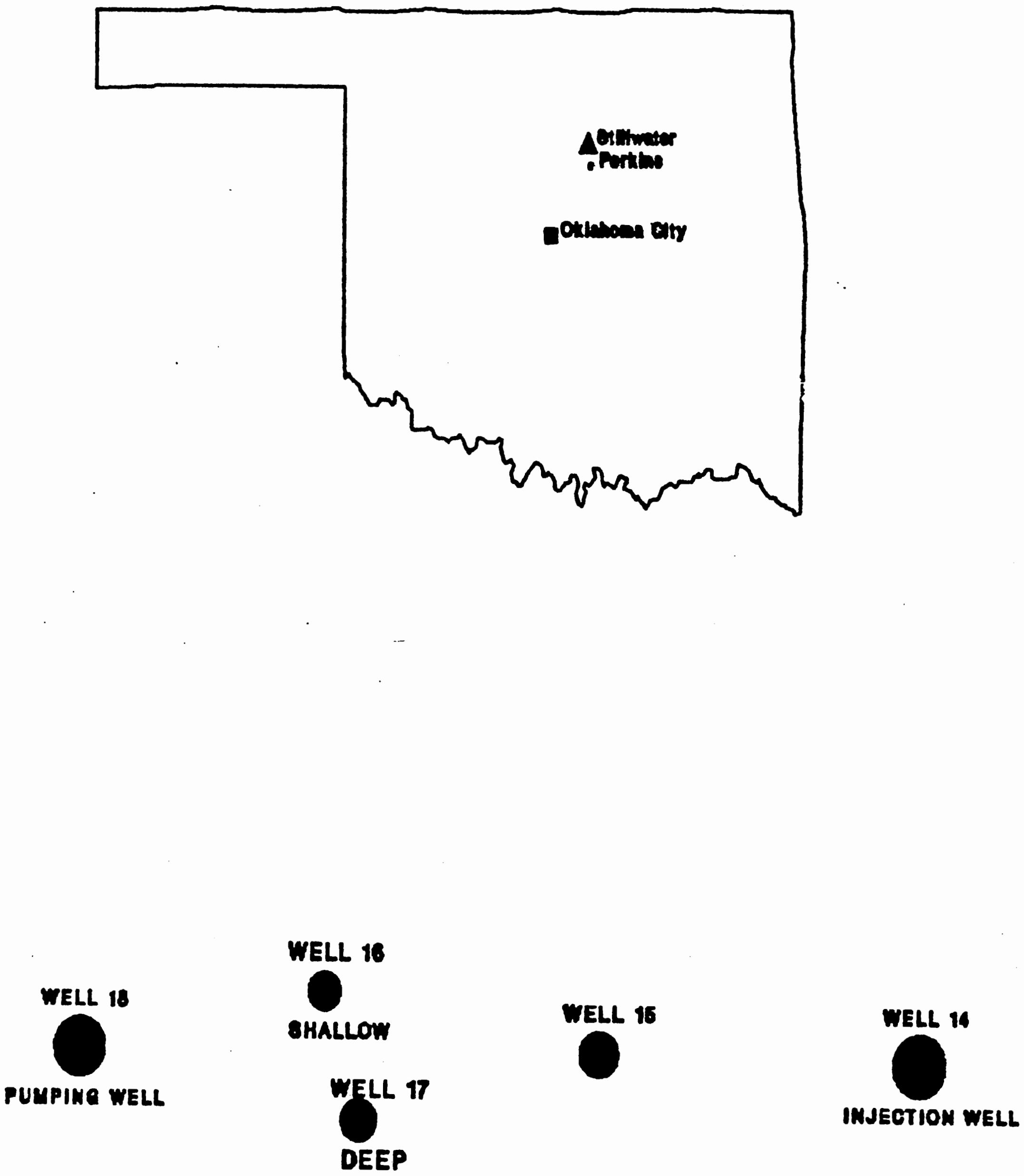


Figure 13. Location of Wells Used in Tracer Test.

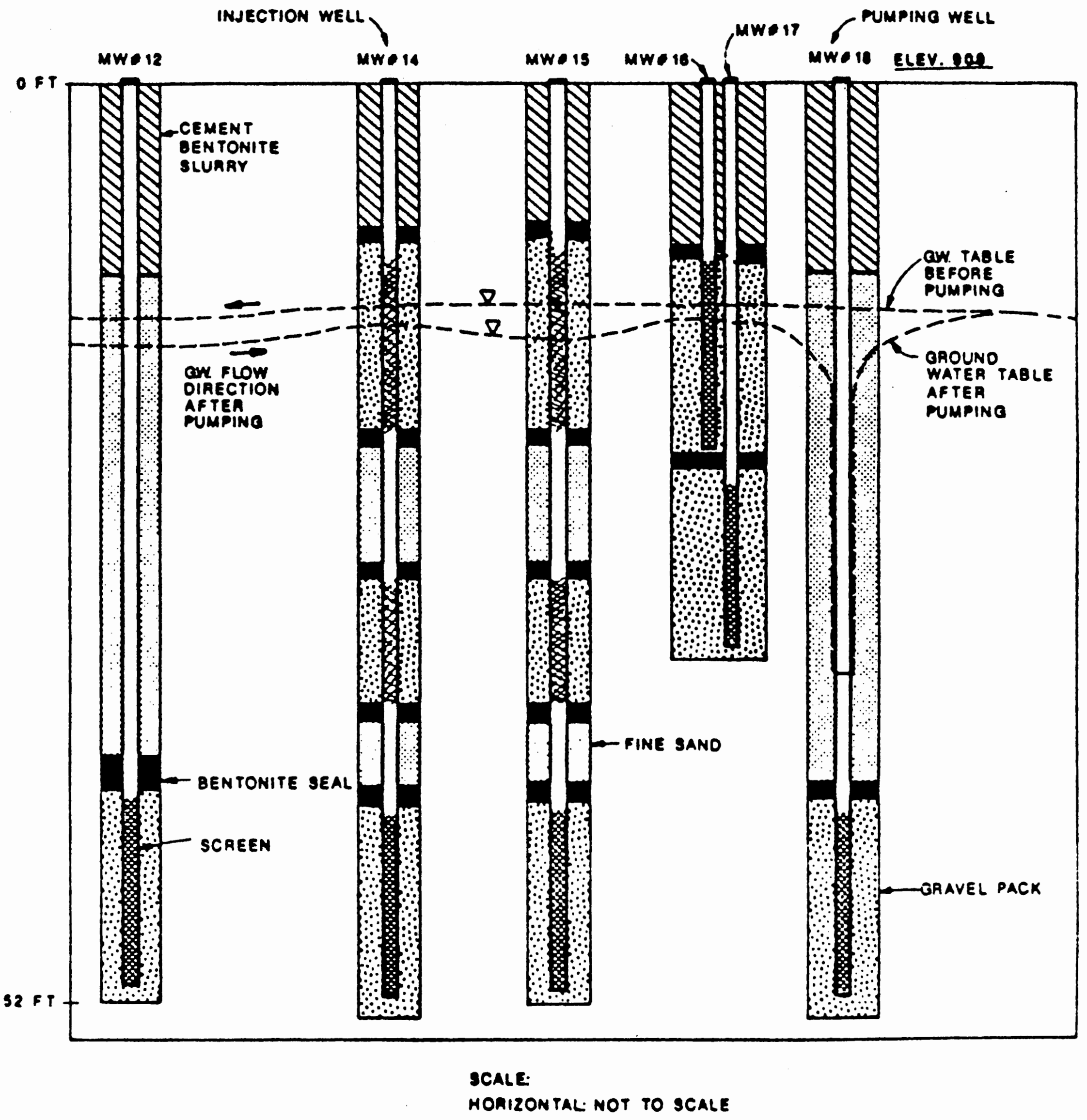


Figure 14. Cross-section of Groundwater Monitoring Wells Used for Aquifer Tracer Testing (After Dwidevi, 1989).

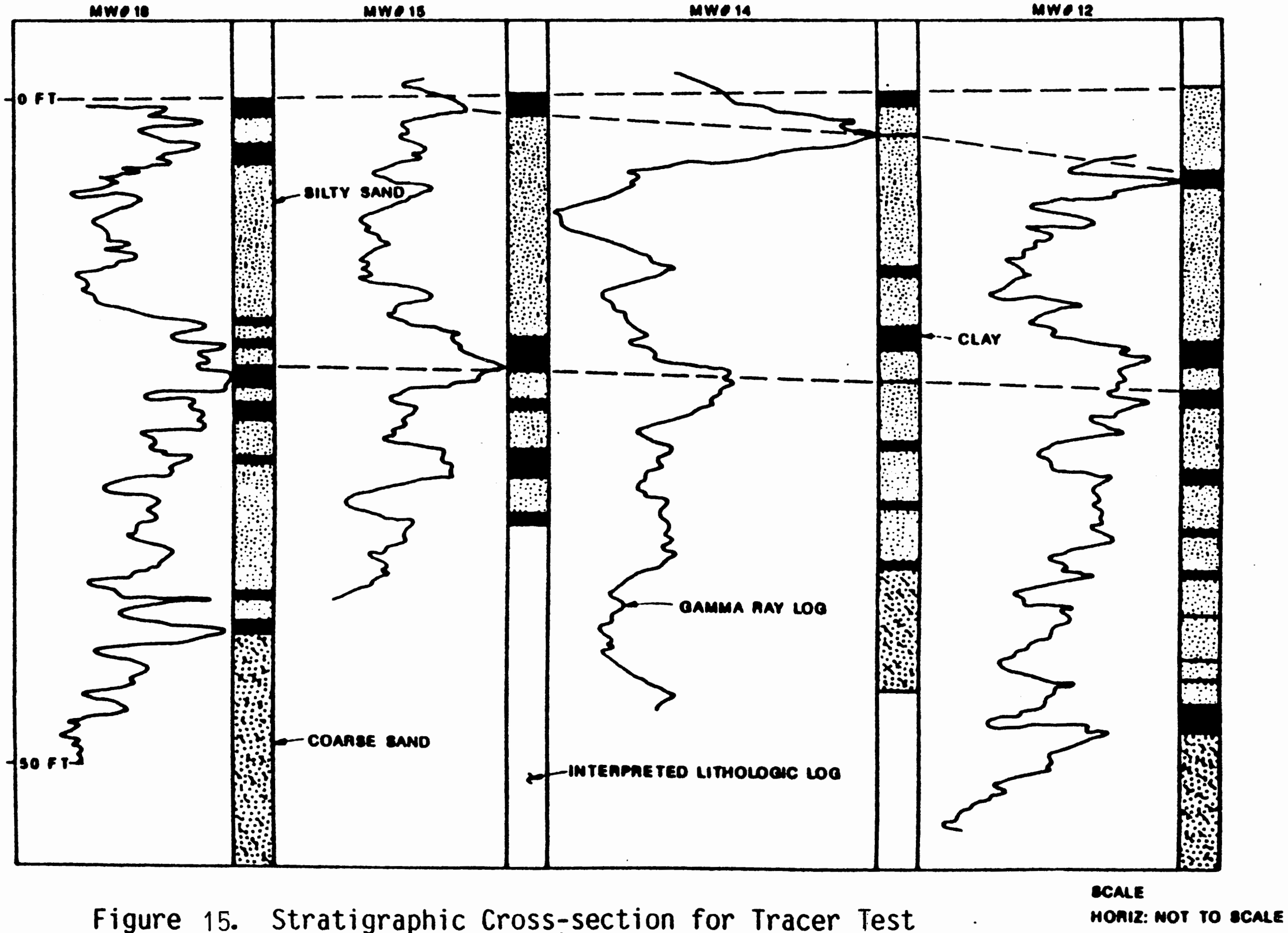


Figure 15. Stratigraphic Cross-section for Tracer Test (After Dwidevi, 1989).

TABLE II

DISTANCES BETWEEN OBSERVATION WELLS AND THE SOURCE

WELL#	Distance From Source(FT)
14	SOURCE
15	4.25
16	9.2
17	8.9
18	12.85

Tracer Selection and Type of Injection

As pointed out in chapter II, several considerations were taken in account in order to select the substances for the test. The following is a brief description of substances used which are chloride, bromide, nitrate, potassium and fluorescein.

The background levels of chloride (Cl) in ground water is moderate to high; the Chloride front proceeds at a high velocity, exihibits little distortion and is considered as a fairly conservative tracer, which indicates that it is weakly adsorbed by soil. A compound of Potassium Chloride was chosen for the test. Low background levels of bromide (Br) occurs in ground water. It is the most commonly used ionic tracer, biologically stable, and appears not to be lost by precipitation, absorption or adsorption and does not require high injected concentration. A compound of Potassium Bromide (KBr) was chosen for the test. Low background values of Nitrate (NO3) occurs in potable groundwater, not absorbed by soil. A compound of Potassium Nitrate was chosen for the test.

It is important to note that Potassium was chosen in all compounds due to its low cost, its being rapid and easy to analyze, and its low background value in potable water. A fluorescent Dye was also used in the test; it is considered as the ideal dye tracer. The advantage of using the fluorescent dye is due to the very high detectability, low cost and low toxicity.

In January 22, 1992 a combination of 5.5 lb (2.5 Kg) of Potassium Chloride (KCl), 2.2 lb (1 Kg) of Potassium Nitrate (KNO3), 2.2 lb (1 Kg) of Potassium Bromide (KBr) and 4.4 lb (2 Kg) of fluorescent dye tablets (Fl) was diluted in 57 gallon (216 litres) of water was injected in Well 14 at a rate of 1gpm (5.3 m3/d).

Sampling Method

The tracer test lasted for two weeks, divided in two different scenarios, each one lasting a week, the first scenario consisting of one week in which two sets of two samples were collected every 12 hours; each well was sampled in two different bottles, one dark in order to prevent sun degradation of fluorescein, and one clear sample for correcting NO3-N, Cl, Br and K samples. The second scenario consisted of one week, only one set of two samples was collected every 24 hours. A total of 180 samples was collected during the two-week tracer test. These samples were collected by bailing samples from each well; well MW 18 was sampled at the outflow tube of the pump, and a special bailer was used to sample MW 14 (Source).

The samples were analyzed at the United States Department of Agriculture, NAWQL, Durant, Oklahoma.

Tracer Modelling Using Konikow Model (MOC-NRC)

A modified two-dimenSional Numerical Model (MOC, NRC) was originally developed and documented by Konikow and Bredehoeft (1978) and modified by Kent et al (1985). This model was used to calibrate and simulate the solute movement in the Perkins Aquifer.

The model was used from the cross-sectional prospective; data, boundary conditions and initial conditions are specified for each node on a two-dimensional matrix shown in Figure 16. The input data was prepared through a preprocessor developed by Kent et al (1985). This numerical model uses a finite-difference scheme to solve both head and solute transport equations.

The model was run using two different simulation procedure of inputing the data in order to obtain the best results when calibrated with the observed data obtained from the field.

First Simulated Procedure

Include only one pumping period for 14 days; the injected materials correspond to the first concentration obtained from the field after 8 hours.

Second Simulated Procedure

Includes four pumping period organized as follow:

-First Pumping Period: Four time step for one day each; includes inflow boundary as an injection well with no concentration.

-Second Pumping Period: Four time step for one day each; pumping wells were added.

-Third Pumping Period: One time step for one day, concentration was added as initial concentration added in the field at a rate of 1 gpm.

-Fourth Pumping Period: 14 time step for one day each, no concentration was add but pumping was maintained at a rate of 30 gpm.

It should be noted that in all three simulated procedures, the system was set such that a constant head of 900 ft was used at the south part of the area in order to maintain the steady-state flow conditions.

Many assumptions were considered in order to use the Konikow model in the given unconfined aquifer. These assumptions are listed below.

- The aquifer is assumed to be homogeneous and therefore isotropic, which reduces the problem to one of steady state solute transport.

- Storage coefficient: 0.4 .
- Effective porosity: 0.2 .
- Aquifer density : 2 g/cm3 .
- Grid used : 20 column * 20 row .
- Characteristic length: 75.0 feet .
- Aquifer thickness : 42 feet .
- Hydraulic conductivity : 450 gpd/ft2, which is the mean arithmetic value obtained from pumping-test data and which conform with the peak obtained from tracer test.
- Sorption : 1 (No Sorption).
- Decay : 0

It is important to note that these assumptions were considered in the two simulated procedures discussed above.

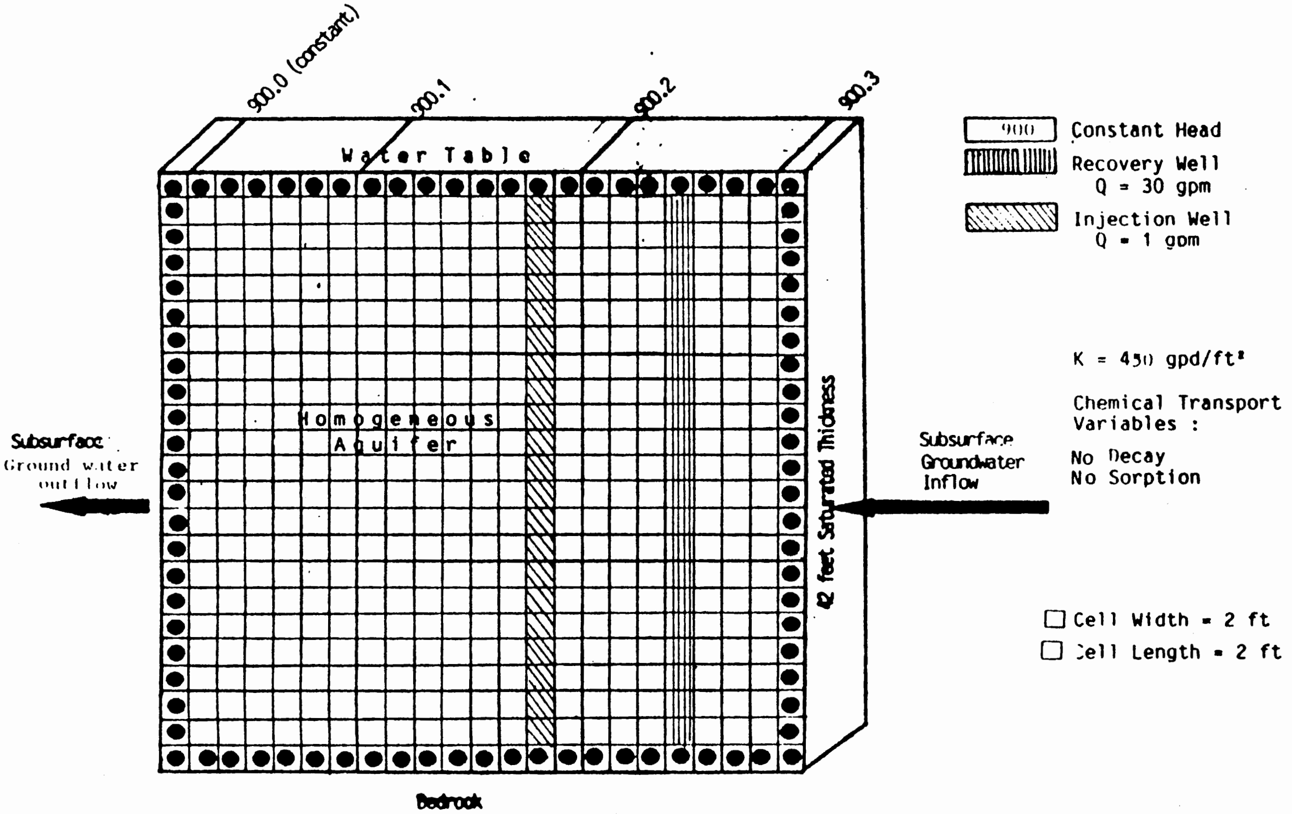


Figure 16. Conceptual Cross-Sectional Grid for MOC,NRC (Konimkow) Model for Tracer Test.

CHAPTER V

DATA ANALYSIS

TRACER AND PUMPING TEST

The Tracer test conducted at the Perkins aquifer was intended mainly to characterize solute movement in the saturated zone. The analysis of samples was conducted at the National Agriculture U.S.Department of Agriculture,Agricultural Research Service Water Quality Laboratory, Durant Oklahoma. The result are presented in Tables III, IV, V, VI and VII for wells 14, 15, 16, 17 and 18 respectively. The data were plotted in Figures 17, 18, 19, 20 and 21 as group plot for each well as a function of time; also the water table elevation is included in the same plot. In addition, a composite hydrograph of all wells are represented in Figure 22.

It appears from all plots that the concentration conforms with the water table elevation and is directly affected by it. This phenomenon appears very clear in some plots included in Appendix A where data are plotted and smoothed using different degrees of polynomials in order to obtain the best fitting curve for the points.

For more details and comparison between some constituents, Fluorescein (Fl) and Nitrate (NO3) were plotted for well 14 and shown in Figure 23, and show the peak at about 100 hours.

Nitrate (NO3) and Bromide (Br) were plotted for well 16, 17 and 18 and are shown in Figures 24, 25 and 26 respectively.

TABLE III

CHEMICAL CONCENTRATION FOR WELL 14 (INJECTION WELL)

SAMPLE	TIME HOURS	FL Mg/L	CL PPM	K PPM	NO3 PPM	BR PPM	DTW FT(MSL)
1	0		9686	5262	2.73	1674	902.85
2	13	420	8448	5092	3.97	1687	902.60
3	24	440	8842	4796	3.95	1648	
4	38	410	7039	4281	6.50	1629	902.70
5	46	370	6139	4021	6.07	1578	
6	62	280	5866	3553	5.71	1398	902.47
7	71	190	5355	2823	7.88	1234	
8	86	245	5116	2489	8.19	1137	902.46
9	95	152	4263	2433	7.45	1076	
10	109	208	4670	2112	6.94	995	902.56
11	119	115	3394	1565	6.07	728	
12	133	120	3552	1533	5.49	734	902.15
13	158	107	3243	1375	4.92	652	902.23
14	181	92	2357	1187	4.48	576	901.85
15	205	68	2252	1070	3.98	518	902.32
16	229	85	2055	1026	3.76	492	902.33
17	253	60	1713	925	3.38	450	902.45
18	278	58	1964	922	3.34	413	902.45
19	300	66	1713	882	3.18	389	902.39

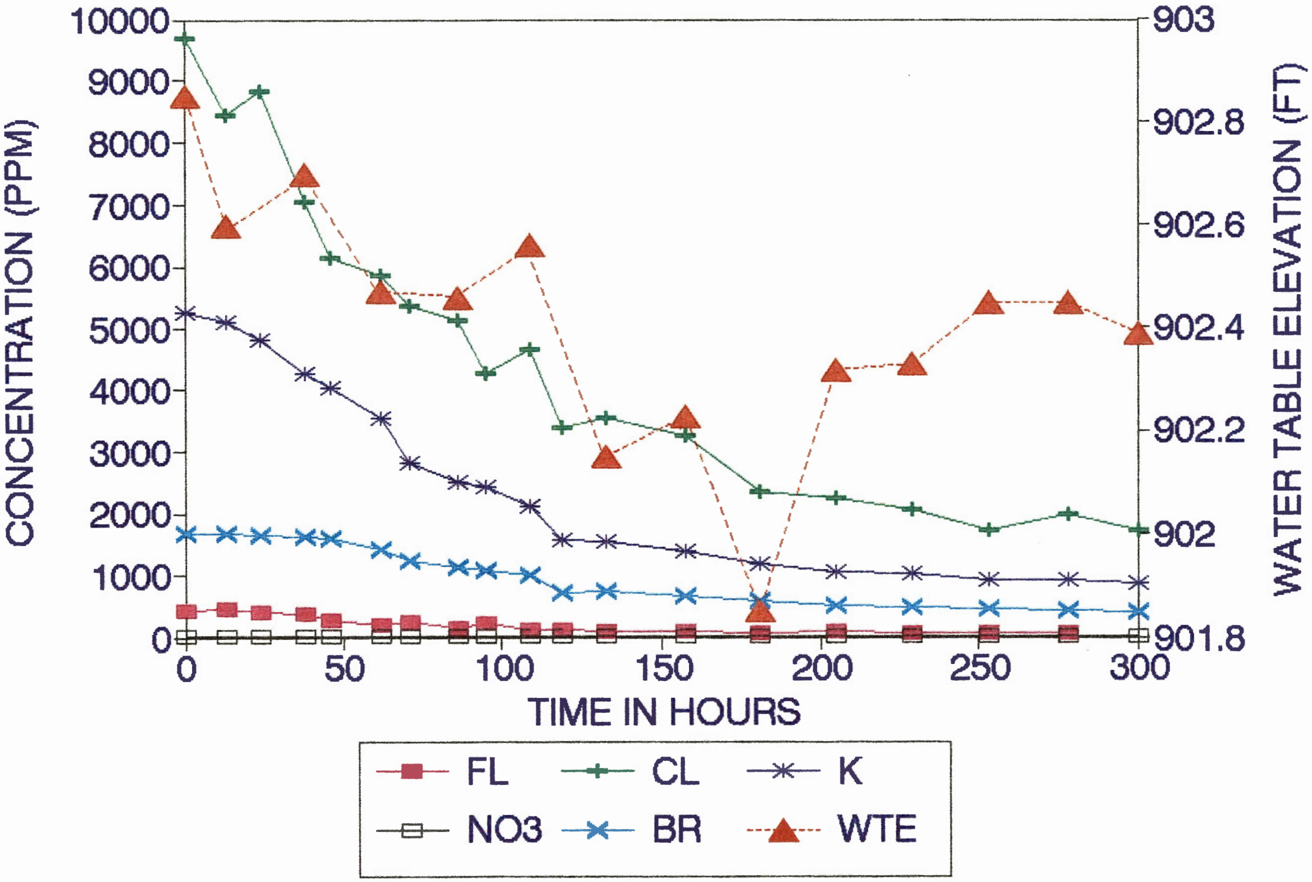


Figure 17 . Chemical Concentration For Well 14 (Injection Well)

TABLE IV

CHEMICAL CONCENTRATION FOR WELL 15

SAMPLE	TIME HOURS	FL Mg/L	CL PPM	K PPM	NO3 PPM	BR PPM	COND umhos/cm	PH	WTE FT(MSL)
1	0		6.10	3.00	0.06	0.70			903.19
2	13	4.50	7.30	2.70	0.07	0.51	871	7.05	903.07
3	24	3.50	7.00	2.50	0.06	0.45			
4	38	2.70	7.00	2.30	0.07	0.42	800	6.83	902.99
5	46	4.30	6.40	2.40	0.06	0.40			
6	62	2.80	6.40	2.30	0.07	0.38	850		902.91
7	71	3.00	6.40	2.20	0.06	0.38			
8	86	3.20	6.10	2.20	0.09	0.36	880	6.50	902.95
9	95	3.50	6.10	2.20	0.07	0.38			
10	109	3.00	5.60	2.20	0.06	0.36			902.85
11	119	2.80	5.30	2.10	0.07	0.51			
12	133	3.10	4.80	1.70	0.06	0.35	900	6.18	902.86
13	158		4.60	2.20	0.06	0.37	870	6.29	902.80
14	181	2.40	5.30	2.40	0.07	0.43	900	6.03	902.84
15	205	2.60	5.10	2.20	0.06	0.39	915	5.98	902.78
16	229	2.60	5.30	2.30	0.06	0.48	850	6.25	902.83
17	253	2.40	4.80	2.00	0.07	0.37	878		902.81
18	278	2.30	4.60	1.90	0.06	0.32	950	6.36	902.83
19	300	2.40	4.20	1.90	0.08	0.30	985	6.53	902.77

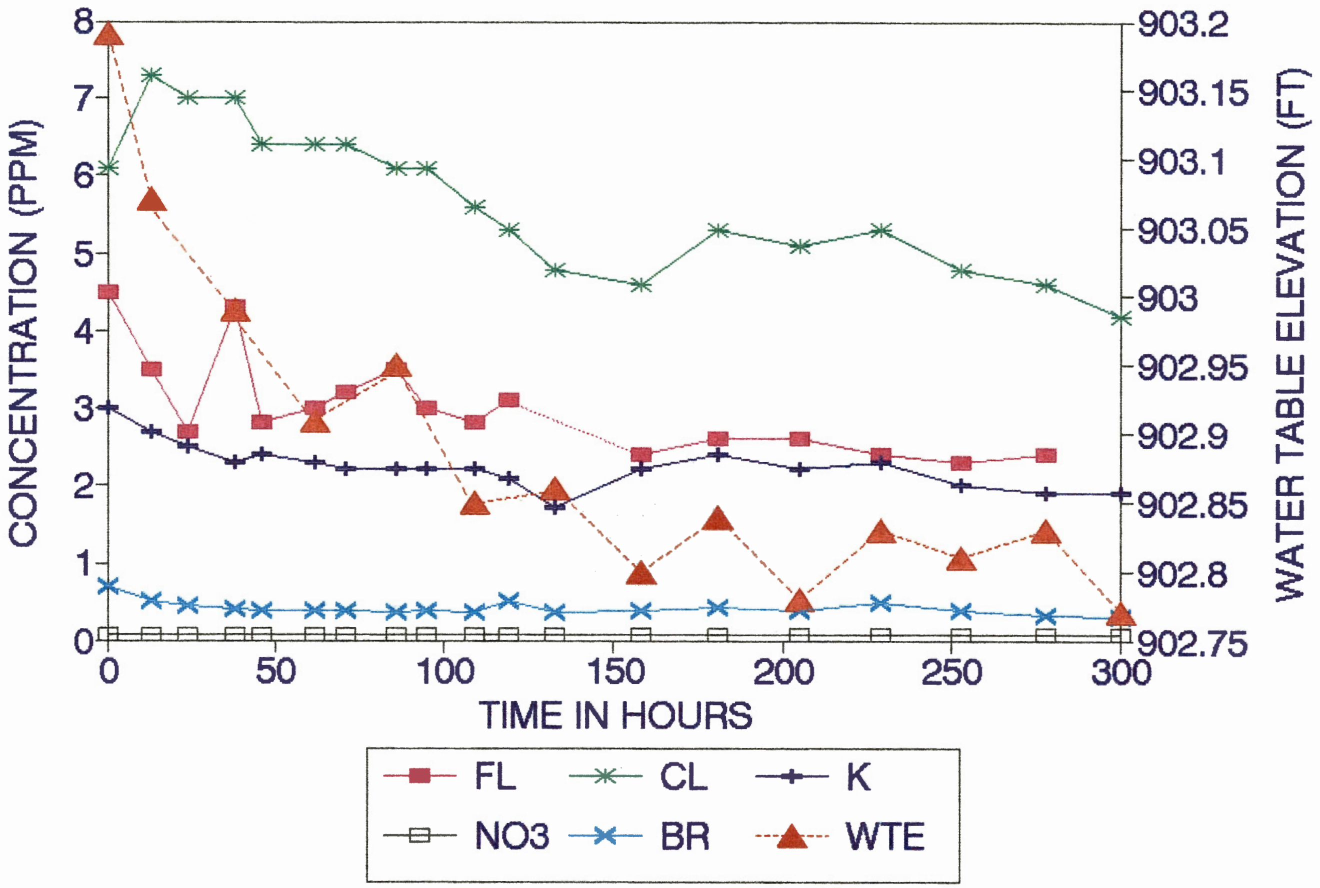


Figure 18 . Chemical Concentration Well 15 .

TABLE V

CHEMICAL CONCENTRATION FOR WELL 16 (SHALLOW WELL)

SAMPLE	TIME HOURS	FL Mg/l	CL PPM	K PPM	NO3 PPM	BR PPM	COND uhmos/cm	PH	WTE FT(MSL)
1	0		2.9	5.4	0.08	2.61			903.65
2	13	13.2	3.5	5.1	0.08	1.77	411	6.21	903.42
3	24	11.8	2.7	4.4	0.1	1.45			
4	38	13.7	2.3	4.4	0.06	1.01	435	5.93	903.39
5	46	13.7	1.9	4.0	0.08	0.83			
6	62	10.7	2.1	4.0	0.06	0.89	385		903.32
7	71	14.2	2.0	4.0	0.06	0.84			
8	86	11.0	1.9	3.9	0.07	0.85	426	5.5	903.36
9	95	6.9	1.9	4.0	0.06	0.78			
10	109	14.8	1.8	4.0	0.06	0.81			903.25
11	119	9.8	2.1	3.9	0.06	0.81			
12	133	5.0	2.0	3.9	0.05	0.87	420	5.44	903.26
13	158	12.9	2.7	4.6	0.07	1.16	445	5.4	903.22
14	181	15.1	2.0	3.9	0.06	0.79	570	5.2	903.90
15	205	3.4	1.8	4.2	0.07	0.8	500	5.2	903.20
16	229	4.7	1.8	3.5	0.06	0.7	530		903.24
17	253	12.6	1.9	4.5	0.06	0.88	437		903.24
18	278	5.0	2.3	4.3	0.07	0.84	480		903.23
19	300	12.9	2.3	4.3	0.07	0.98	480	4.9	903.22

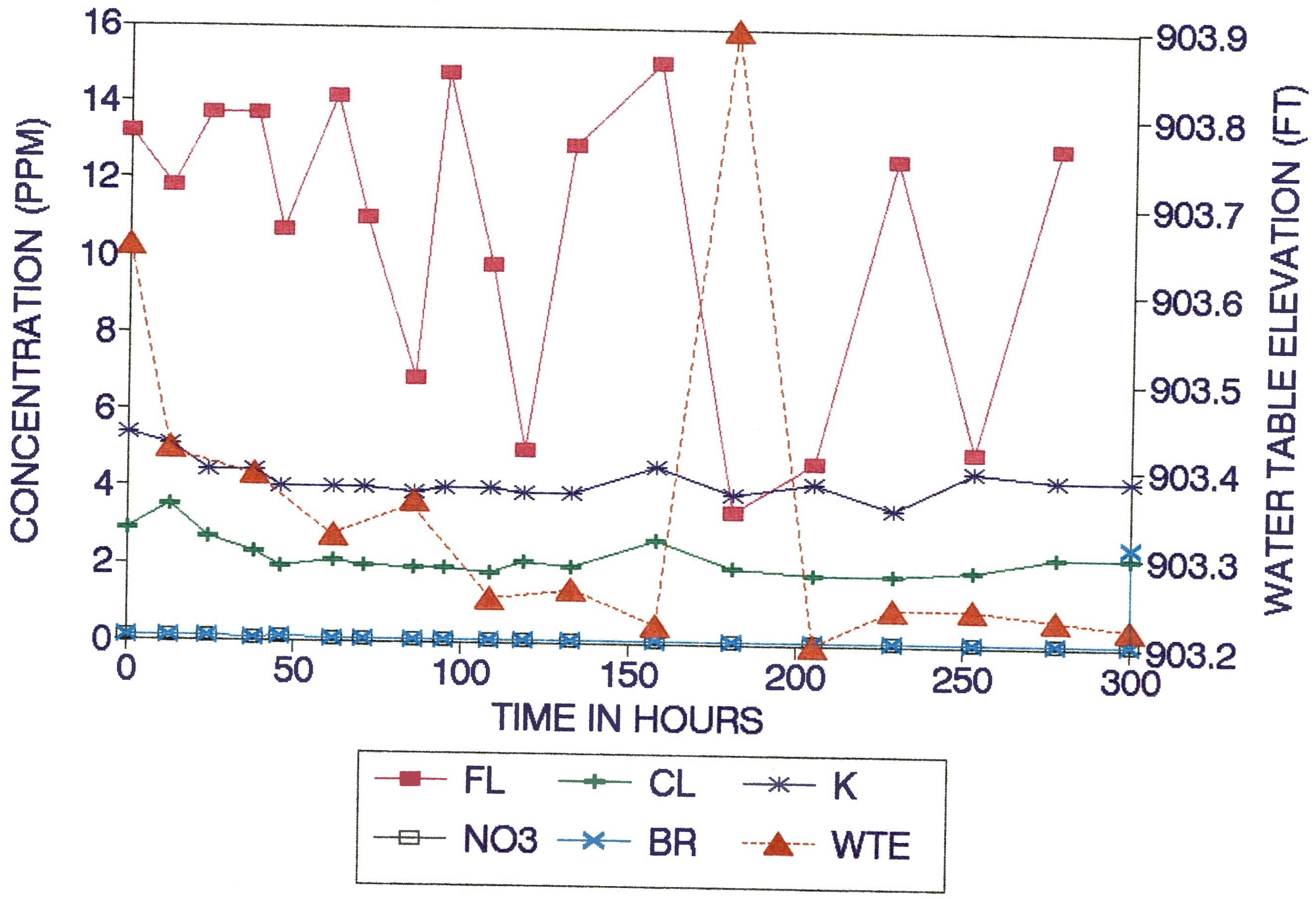


Figure 19 . Chemical Concentrations well 16 (Shallow well)

TABLE VI

CHEMICAL CONCENTRATION FOR WELL 17 (DEEP WELL)

SAMPLE	TIME Hours	FL mg/l	CL PPM	K PPM	NO3 PPM	BR PPM	COND uhmos/cm	PH	WTE FT
1	0		4.6	2.1	0.07	0.47			903.25
2	13	3.60	6.10	3.50	0.07	0.47	923	7.32	903.16
3	24	3.60	6.40	2.30	0.07	0.38			
4	38	3.20	6.40	2.30	0.06	0.34	817	7.00	903.12
5	46	3.50	6.10	2.10	0.06	0.33			
6	62	3.30	6.10	1.80	0.06	0.33	860		903.10
7	71	3.40	6.40	2.10	0.07	0.33			
8	86	3.20	6.10	2.00	0.06	0.33	873	6.64	903.15
9	95	3.40	5.60	2.00	0.07	0.31			
10	109	3.00	5.10	1.90	0.06	0.31	870	6.35	903.05
11	119	3.20	5.10	1.90	0.06	0.31			
12	133	3.20	5.60	2.10	0.10	0.33	930	6.62	902.98
13	158	2.40	5.30	2.00	0.06	0.32	885	6.30	903.01
14	181	2.50	3.90	2.00	0.07	0.32	870	6.00	903.01
15	205	2.60	4.60	2.00	0.08	0.29	910	6.08	902.96
16	229	2.80	4.40	1.90	0.07	0.29	865		903.01
17	253	2.50	4.60	2.00	0.09	0.28	940		903.01
18	278	2.50	4.40	2.00	0.08	0.30	840		903.00
19	300	2.50	4.40	2.40	0.07	0.28	945	6.30	902.95

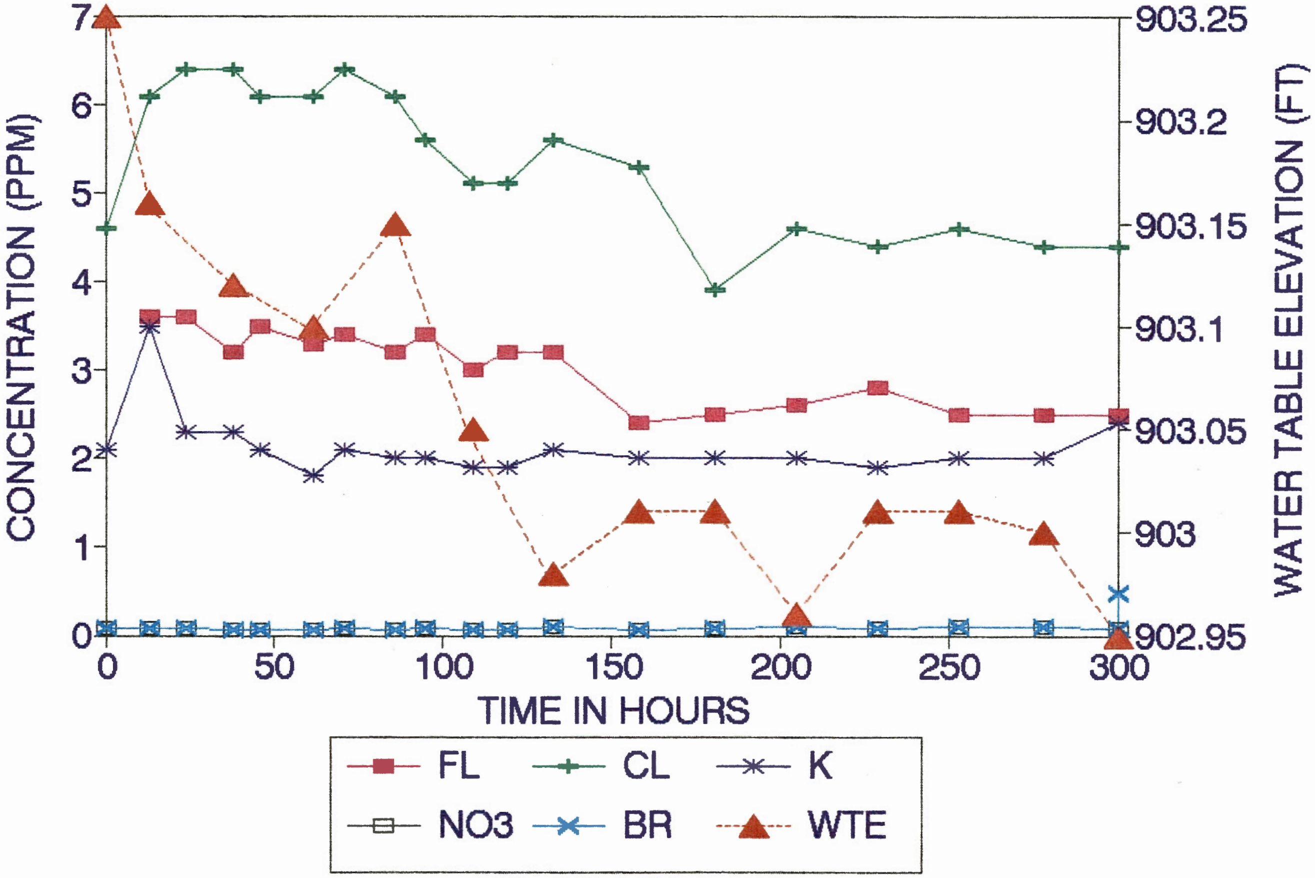


Figure 20 . Chemical Concentrations For Well 17 (Deep Well)

TABLE VII

CHEMICAL CONCENTRATION FOR WELL 18 (PUMPING WELL)

SAMPLE	TIME HOURS	FL Mg/L	CL PPM	K PPM	NO3 PPM	BR PPM	COND umhos/cm	PH	WTE FT(MSL)
1	0		7.0	1.7	0.1	0.58			895.60
2	13		9.2	2.7	0.08	0.56	377	6.62	895.65
3	24	2.3	9.2	1.4	0.07	0.56			
4	38	1.7	9.2	1.9	0.06	0.58	357	5.93	895.03
5	46	1.8	8.8	1.9	0.06	0.56			
6	62	1.9	9.6	1.9	0.06	0.58	361		895.96
7	71	1.8	9.6	2.0	0.07	0.61			
8	86	1.8	10.0	2.3	0.07	0.61	367	5.41	894.6
9	95	1.6	9.6	2.0	0.07	0.59			
10	109	1.8	9.6	2.0	0.07	0.58	375	5.64	894.89
11	119	1.7	7.3	1.7	0.07	0.54			
12	133	1.8	9.6	2.0	0.07	0.59	400	5.43	894.91
13	158	1.7	10.0	2.1	0.07	0.61	420	5.36	894.11
14	181	1.6	10.0	2.0	0.09	0.6	400	5.2	894.14
15	205	1.7	9.6	2.1	0.07	0.41	420	5.43	894.09
16	229		9.6	1.8	0.07	0.42	460		894.11
17	253	1.6	9.6	1.9	0.07	0.47	450		894.01
18	278	1.8	10.0	3.0	0.09	0.47			894.07
19	300	1.8	9.6	2.0	0.1	0.48	454	6.45	893.90

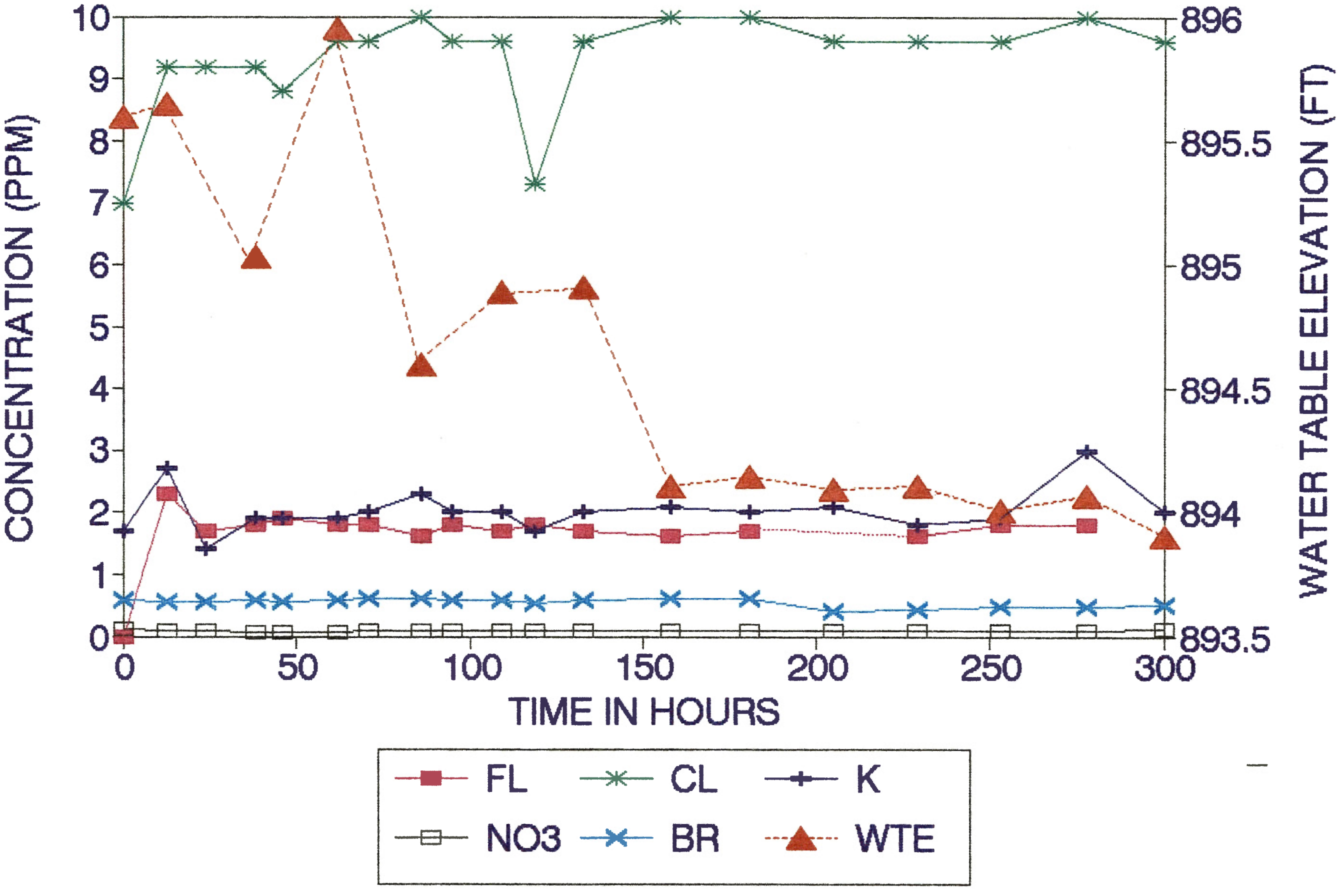


Figure 21 . Chemical Concentration For Well 18 (Pumping Well)

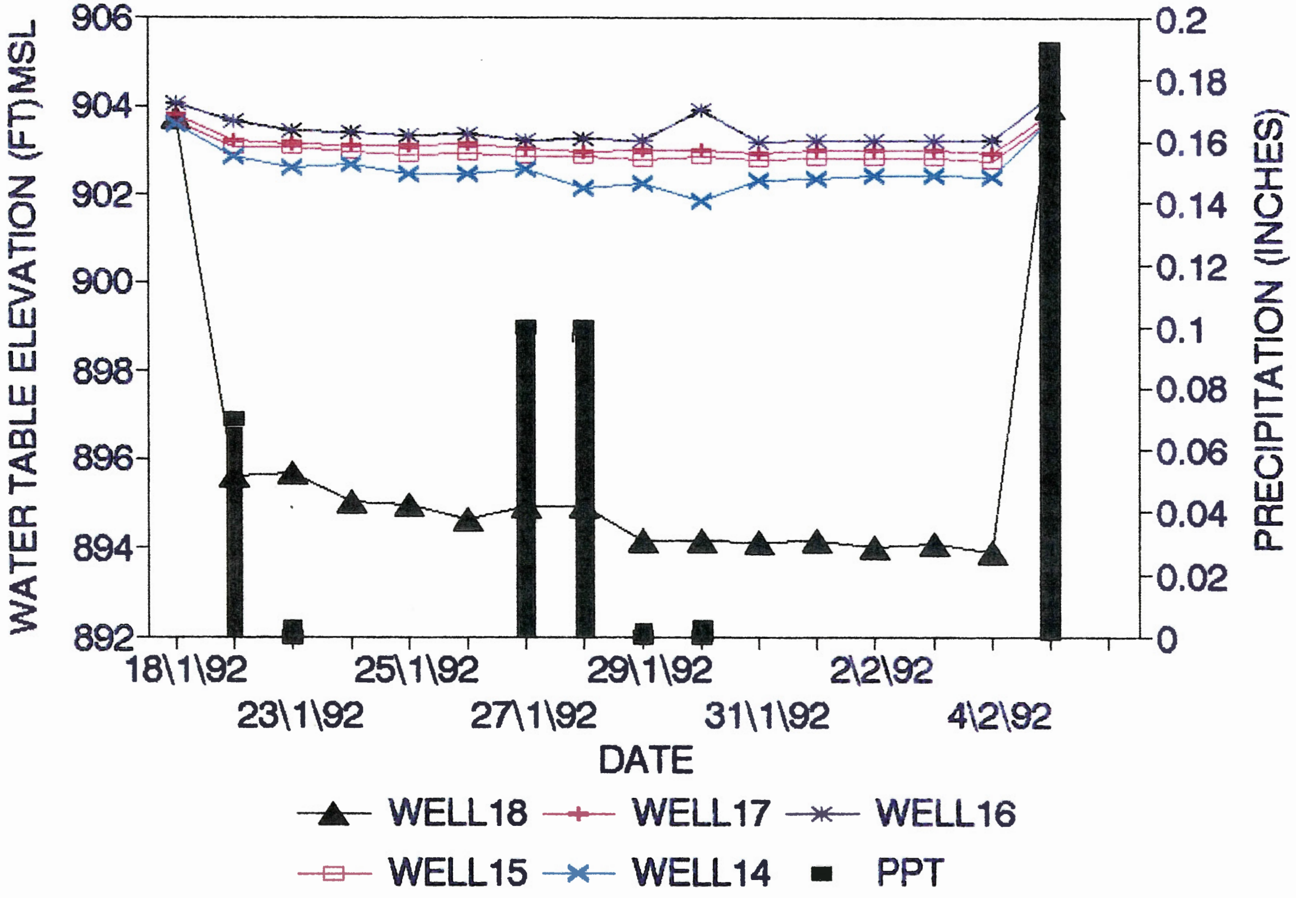


Figure 22. Composite Hydrograph For Wells Used in Tracer test.

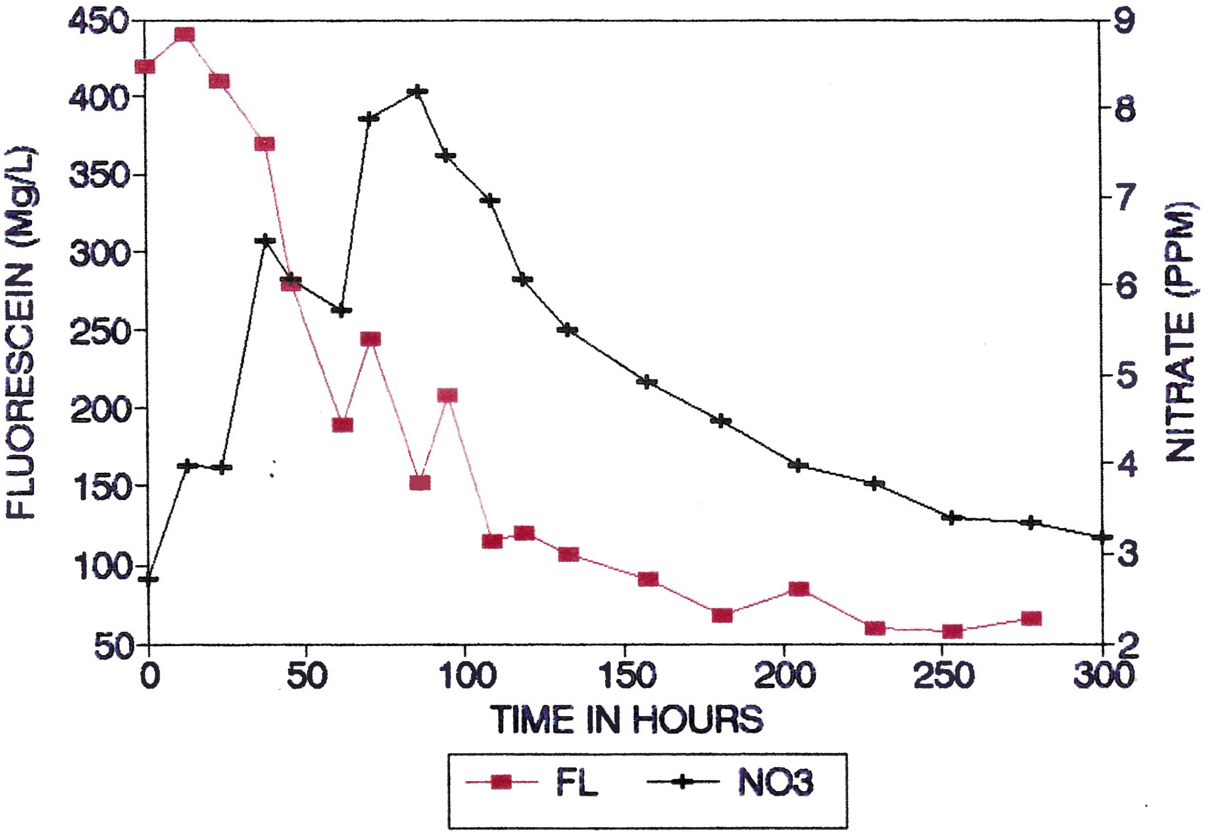


Figure 23. Fluorescein and Nitrate for Well 14 (Injection Well).

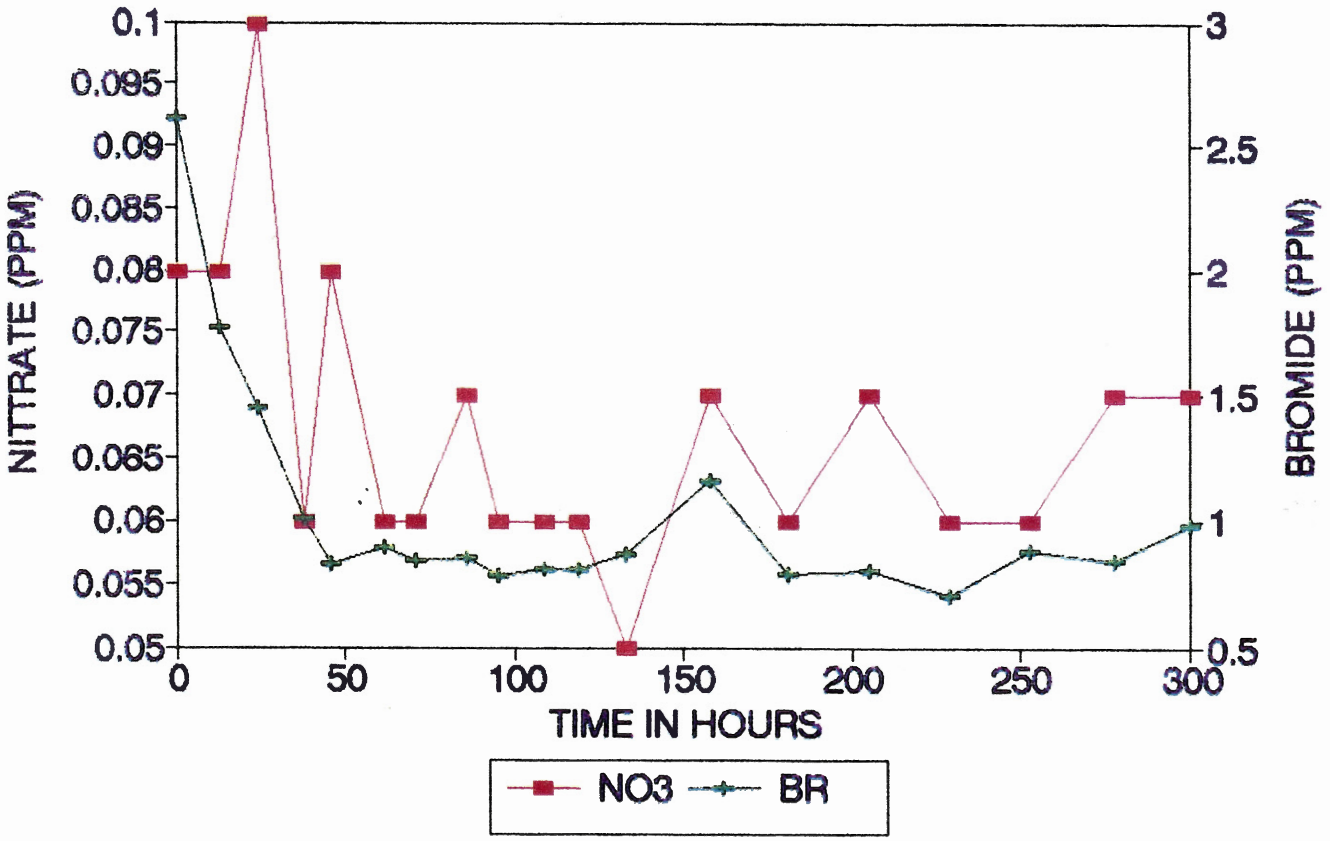


Figure 24 . Nitrate and Bromide for Well 16.

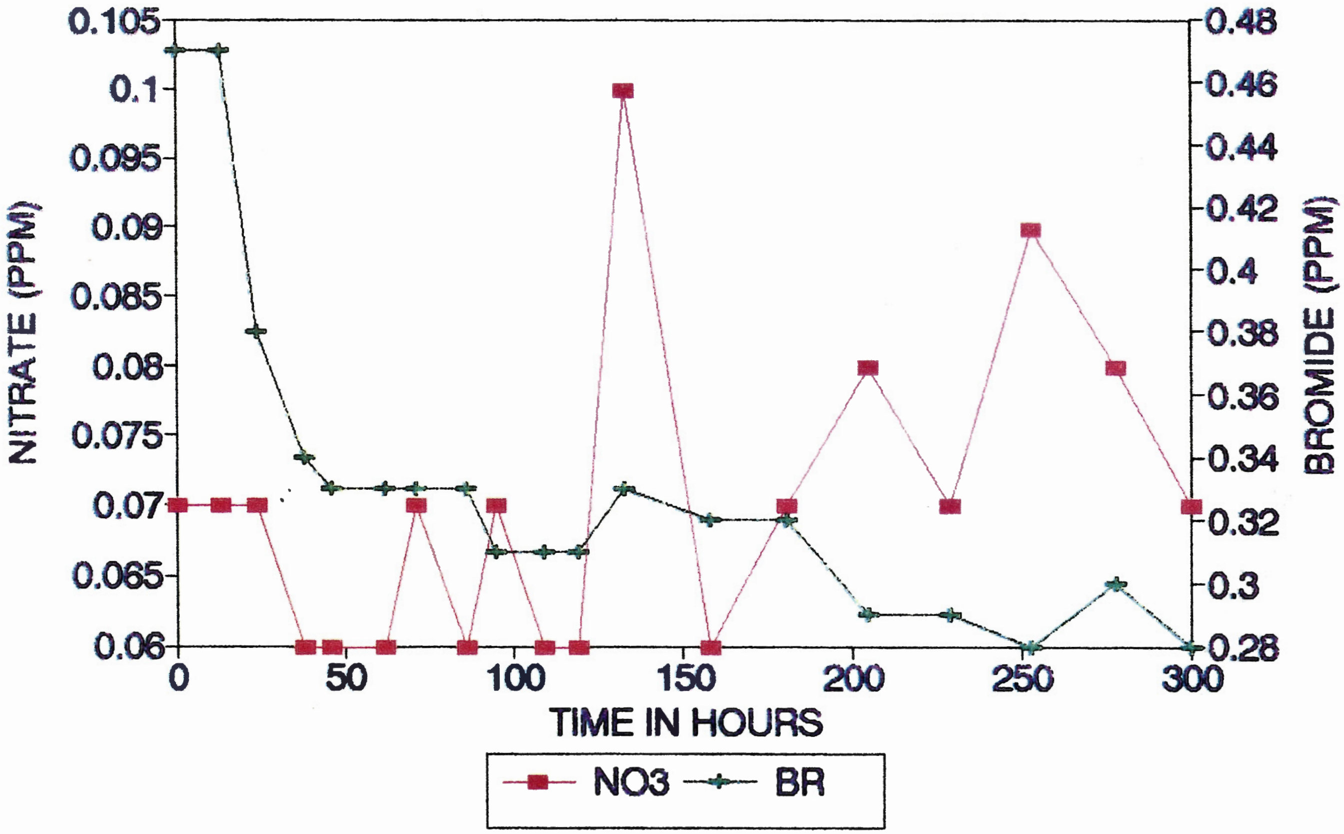


Figure 25 . Nitrate and Bromide for Well 17.

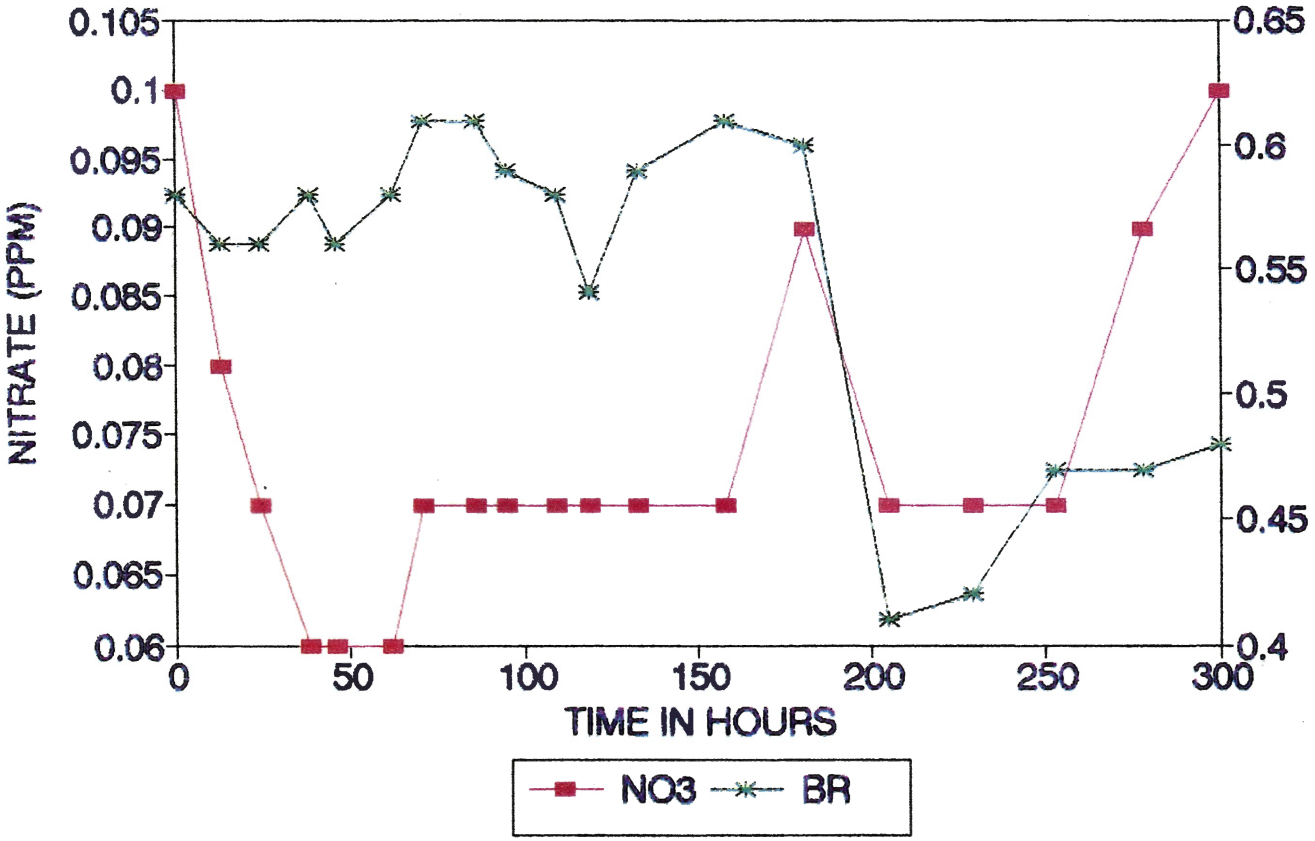


Figure 26 . Nitrate and Bromide for Well 18.

A complete set of plots for each well is included in Appendix A. Polynomials of different degree were used to best fit the data points.

Figures 27, 28 and 29 represent comparisons between 1989 data and 1992 data for Nitrate, Potassium and Bromide for well 18.

Hydraulic Conductivity calculated from aquifer testing was discussed earlier ranges from 250 to 650 gpd/ft2. In order to represent this range of hydraulic conductivity in all plots, it was necessary to perform a series of calculations, which help to convert the hydraulic conductivity obtained to time representing a peak for each constituents for each well; the calculations were based on the following assumptions:

- Range of K = 250 to 650 gpd/ft2.
- Darcian Velocity $V = K * dh/dl$ (1)

$$K = V * dl/dh$$

where

dl/dh is the gradient which was calculated 0.1

- Time of arrival of any constituents $V = dl/t$ (2)

where

dl is the distance from source well

t is the time of arrival which is our goal.

An example of calculations for well 16 as follows:

A- For <u>K = 250 gpd/ft2.</u> at well 16

$$K = (250 \text{ gpd/ft2} * 1 \text{ ft3})/7.48$$

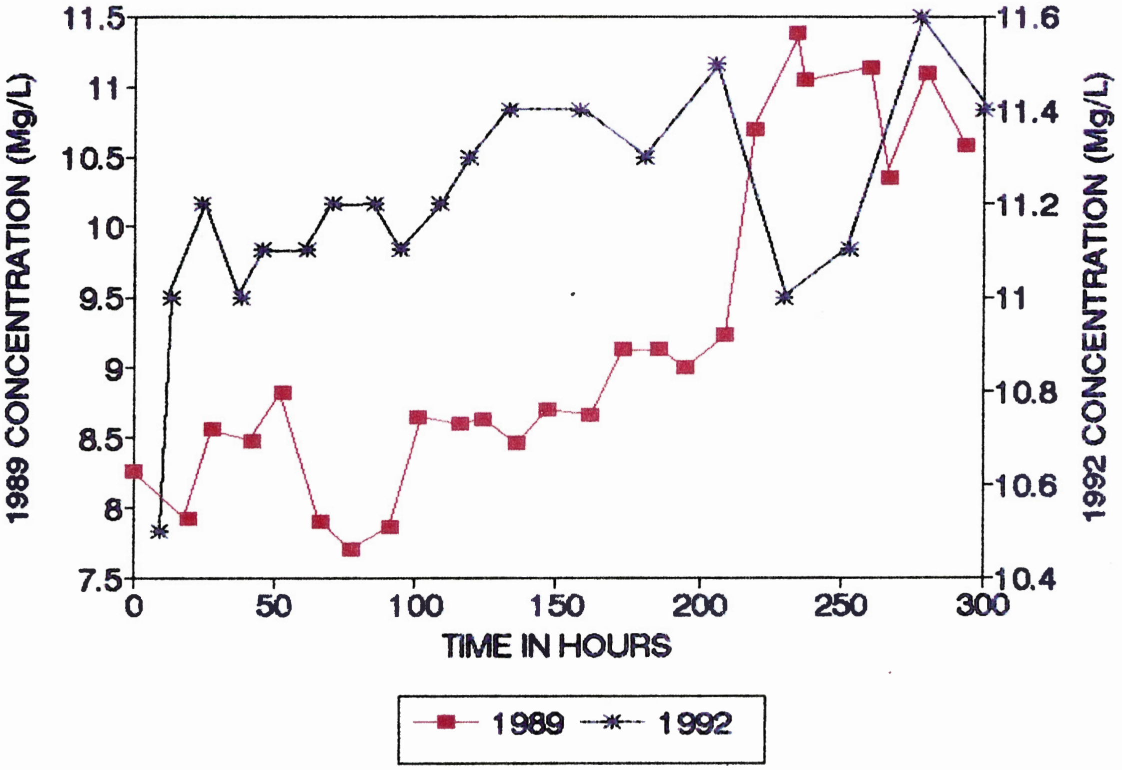


Figure 27. Nitrate Comparison Between 1989 & 1992 For Well 18

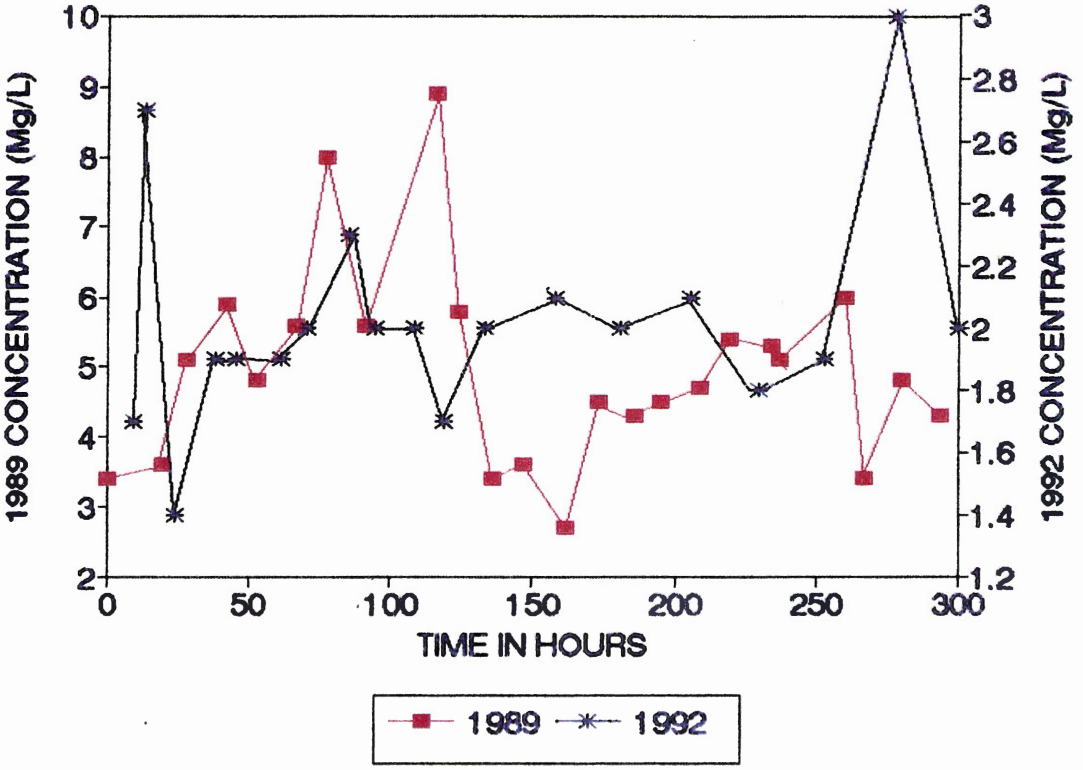


Figure 28 . Potassium Comparison Between 1989 & 1992 For Well 18

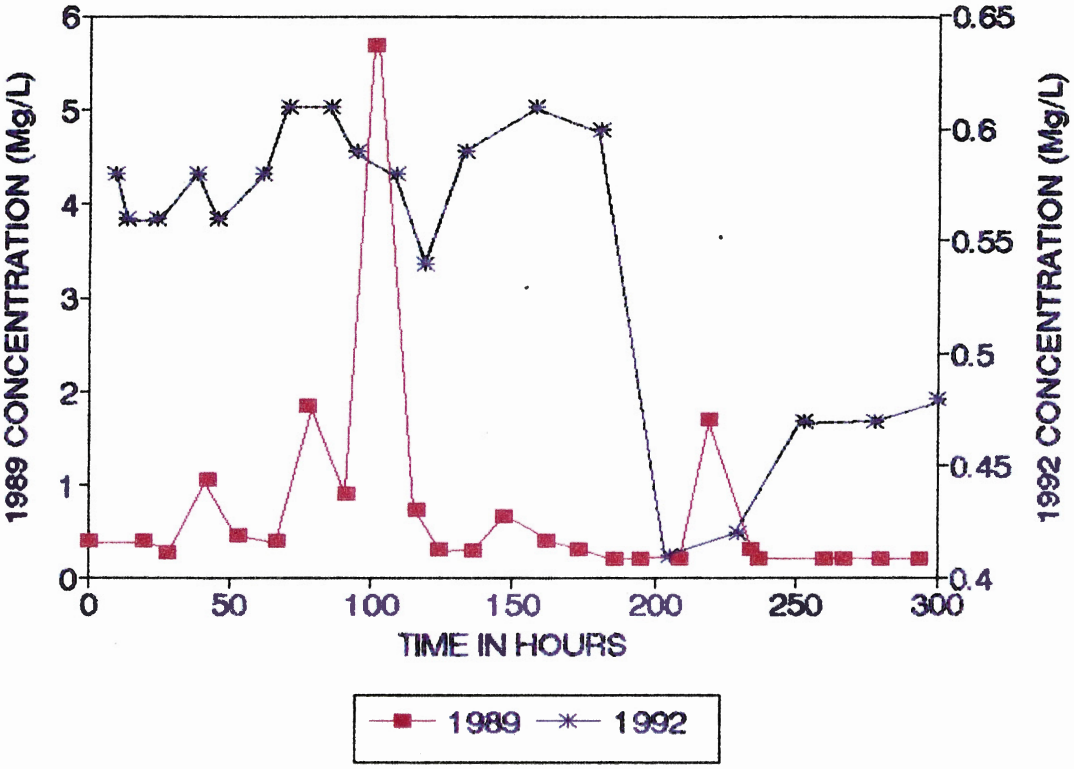


Figure 29. Bromide Comparison Between 1989 & 1992 For Well 18

= 33.42 ft/day

from equation (1), we have:

V = K * dh/dl

by substitution we obtain:

V = 33.42 ft/day * 0.1 = 3.3 ft/day

V = (3.3 ft/day)/ 24 = 0.13 ft/hr

from equation (2), we have:

V = dl/t

where

dl for well 16 = 9.2 ft

V = 0.13 ft/hr.

by substitution we obtain:

t = 9.2 ft / 0.13 ft/hr = <u>70.76 hr</u>

B-For <u>K = 650 gpd/ft2.</u> at well 16

K = (650 gpd/ft2 * 1 ft3)/7.48

= 86.9 ft/day

from equation (1), we have:

V = K * dh/dl

by substitution we get:

V = 86.9 ft/day * 0.1 = 8.69 ft/day

V = (8.69 ft/day)/ 24 = 0.36 ft/hr

from equation (2), we have:

V = dl/t

where

dl for well 16 = 9.2 ft

V = 0.36 ft/hr.

by substitution we obtain:

$$t = 9.2 \text{ ft} / 0.36 \text{ ft/hr} = \underline{25.5 \text{ hr}}$$

This calculations show that the range of K value obtained from the aquifer testing (250 to 650 gpd/ft2), can be represented in a time scale for well 16 ranging from 70.76 hr to 25.5 hr, respectively. This range of time was labelled on the plotted data of the tracer test. It is observed that this range agree with the second peak of the observed data for Fl and Cl.

Similar calculations were done for all wells; Table VIII represent the range of time calculated for each well.

TABLE VIII

RANGE OF TIME

WELL #	RANGE (hr)
15	35.4 to 11.8
16	76.6 to 25.5
17	74.16 to 24.7
18	107 to 35.7

This range of time was labelled on all observed tracer-test plots. Table IX, represents the matching peaks for all wells and all constituents.

TABLE IX

MATCHING PEAKS

WELL #	Fl	Cl	Br	NO3	K
15	1st	1st	N/M	1st	N/M
16	2nd	2nd	N/M	N/M	N/M
17	2nd	1st 2nd	2nd	N/M	N/M
18	2nd	2nd	2nd	N/M	2nd

NOTES:

- 1st = Matching with First Peak.
- 2nd = Matching with Second peak.
- N/M = No Matching.

MODELLING

A selective printout of the model is included in Appendix B. It should be noted that both Simulated Procedures discussed earlier have the same output format except for the data obtained. A selective plot for each simulated procedure is also included in Appendix B.

Results obtained from the Second Simulated Procedure, do not conform with the observed data as shown in Figures 61 and 62 in Appendix B; however when applying the First Simulated Procedure it was observed that fluorescein, Bromide and Chloride (Figure 68 through 73 included in Appendix B), show the calibrations of observed data and simulated data for wells 15, 16, 17 and 18. Simulated data for Potassium and Nitrate do not show any conformity with the observed data.

It was observed also the variations of concentration with distance is very meaningful, and correspond to the variations in the observed data.

GRAPHING AND STATISTICAL ANALYSIS

A graph is a pictorial presentation of the relationship between variables (Spiegel, 1991). Many type of graphs are employed in statistics, depending on the nature of data and the purpose for which the graph is intended.

For the tracer-test purpose the main intent is to know the relationship between concentration versus time, for this reason, the way to graph the obtained data was the Line Graph which is simply the X-Y plot. This graphs showed large variations, and it was necessary to draw a best fitting curve which will show the overall variation of the concentration versus time.

Several ways of best fitting were applied, among them Logarithmic, Polynomial, Linear, Exponential and Cubic Spline. The Polynomial Best-fit type, has proved to be the best way to fit large quantities of data. Polynomials can be represented by different degrees or grades, depending on the number of data points desired to plot. An example of the equations for polynomials is presented below.

$$Y = a0 + a1X \tag{1}$$

$$Y = a0 + a1X + a2X2 \tag{2}$$

$$Y = a0 + a1X + a2X2 + \dots + anXn \tag{3}$$

All letters other than X and Y represent constants. Equation (1) is a polynomial of first degree, the second equation is a polynomial of the second degree, and the third equation is a polynomial of (nth) degree (Spiegel, 1991).

All data were plotted using polynomials of high degree according to the number of data points analyzed.

Figures 30 through 36, represent selective observed data plots with different grades of polynomials. The range of the K value is labelled according to Table IX, and shown as a horizontal straight line, the vertical dashed line represent the average K value (450 gpd/ft2), which match with different peaks.

Additional plots are included in Appendix A.

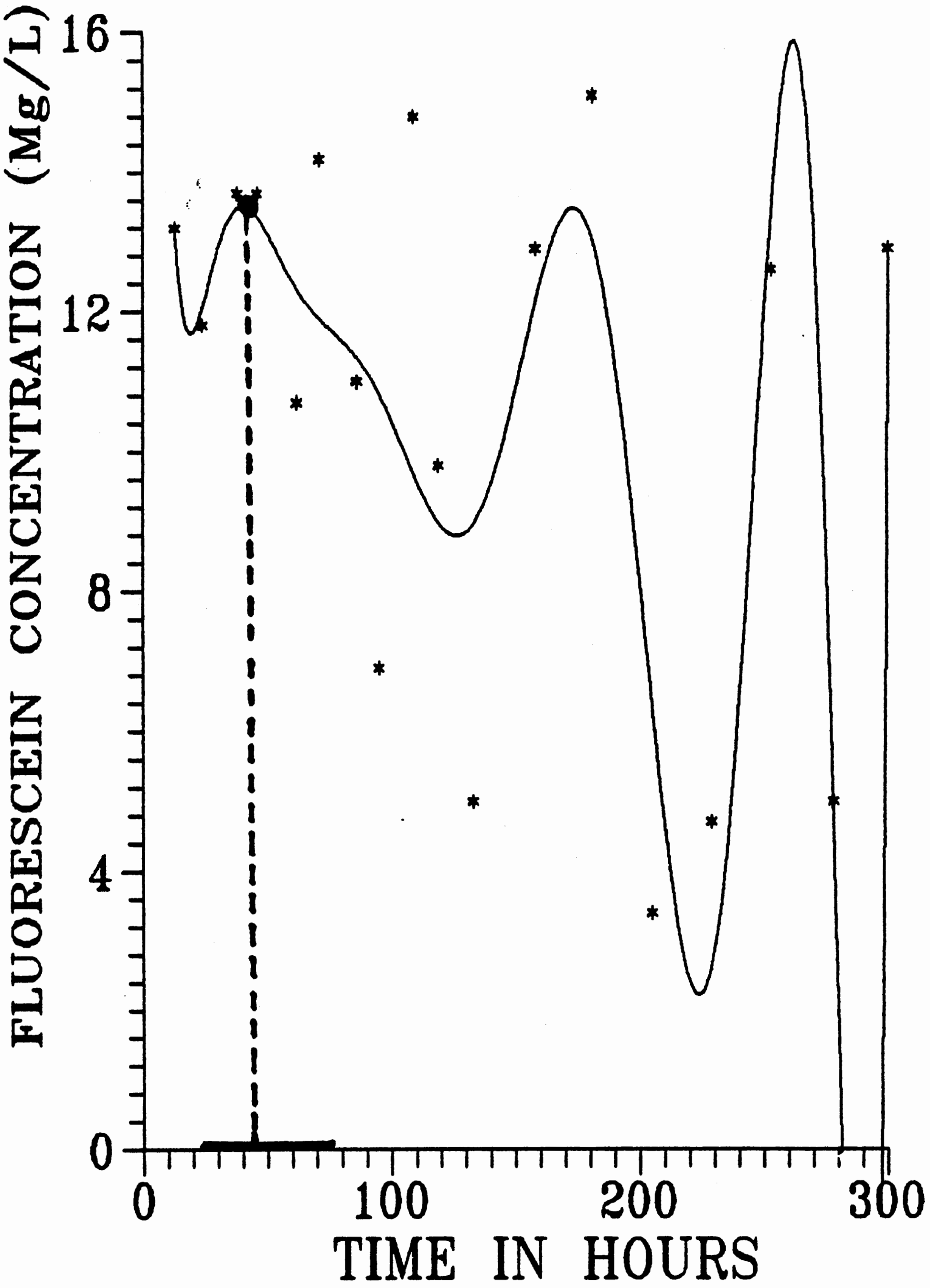


Figure 30. Observed data for Fluorescein for well 16. Polynomial grade 10 for best fit.

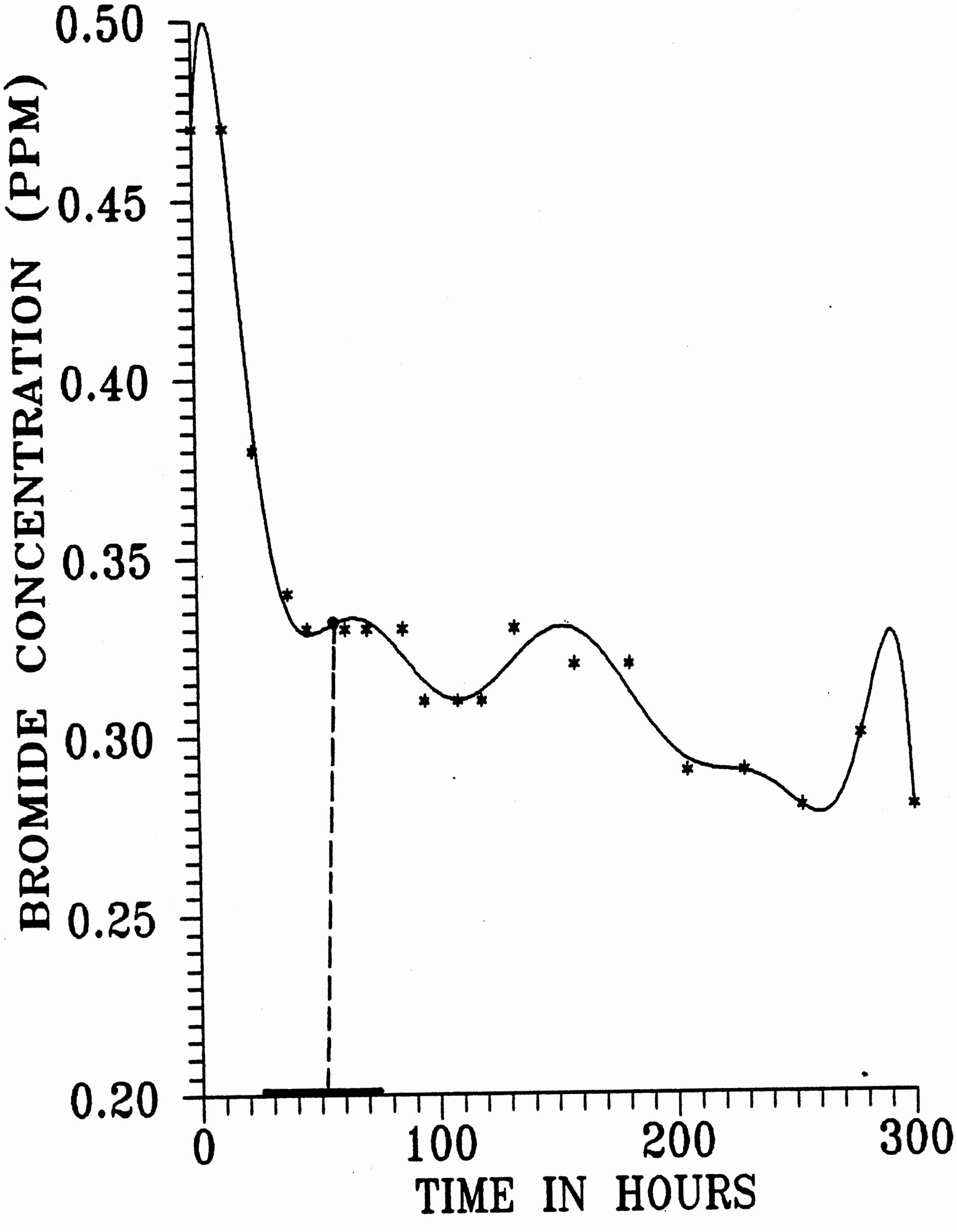


Figure 31. Observed data for Bromide for well 17. Polynomial grade 10 best fit.

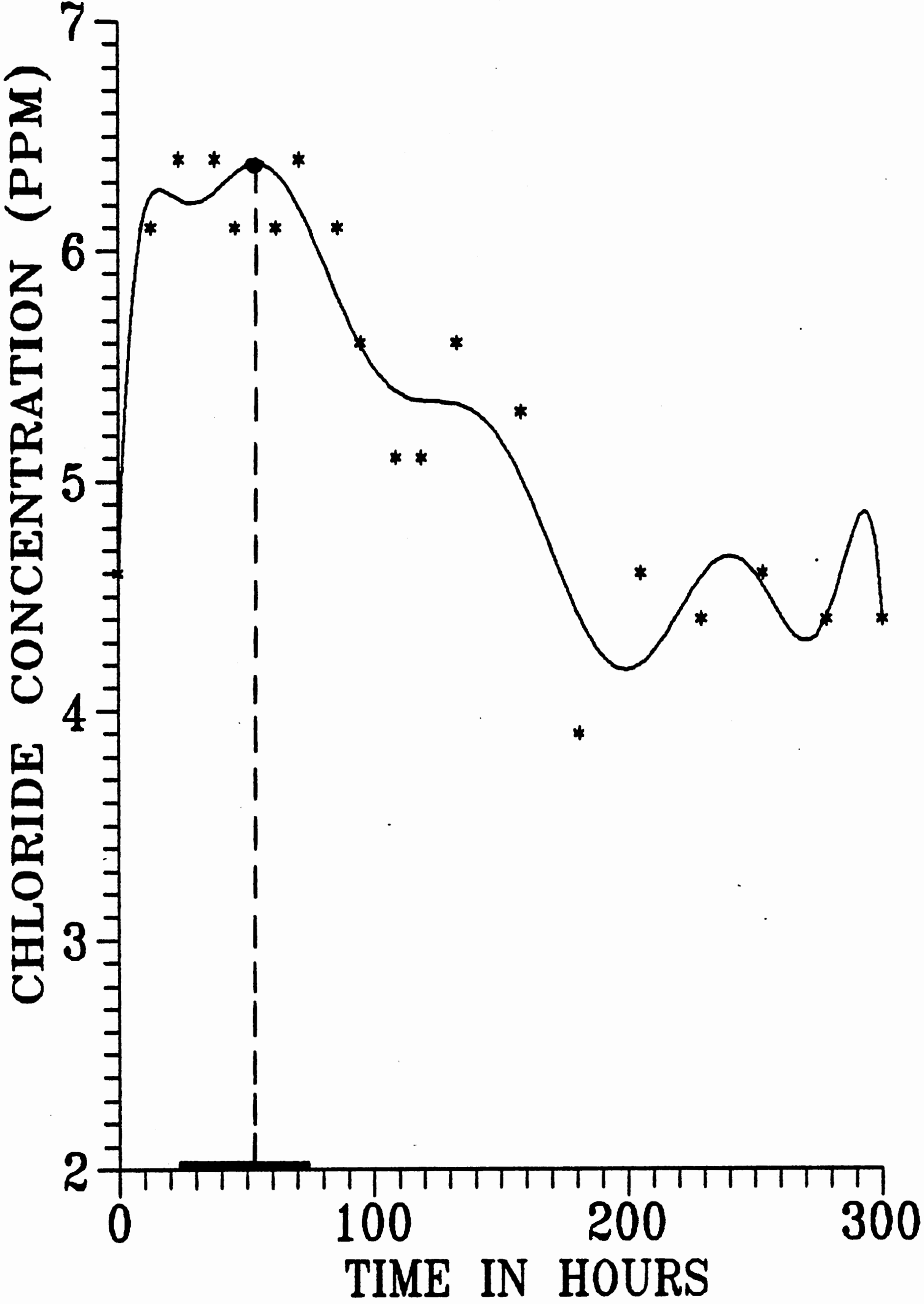


Figure 32. Observed data for Chloride for well 17. Polynomial grade 10 for best fit.

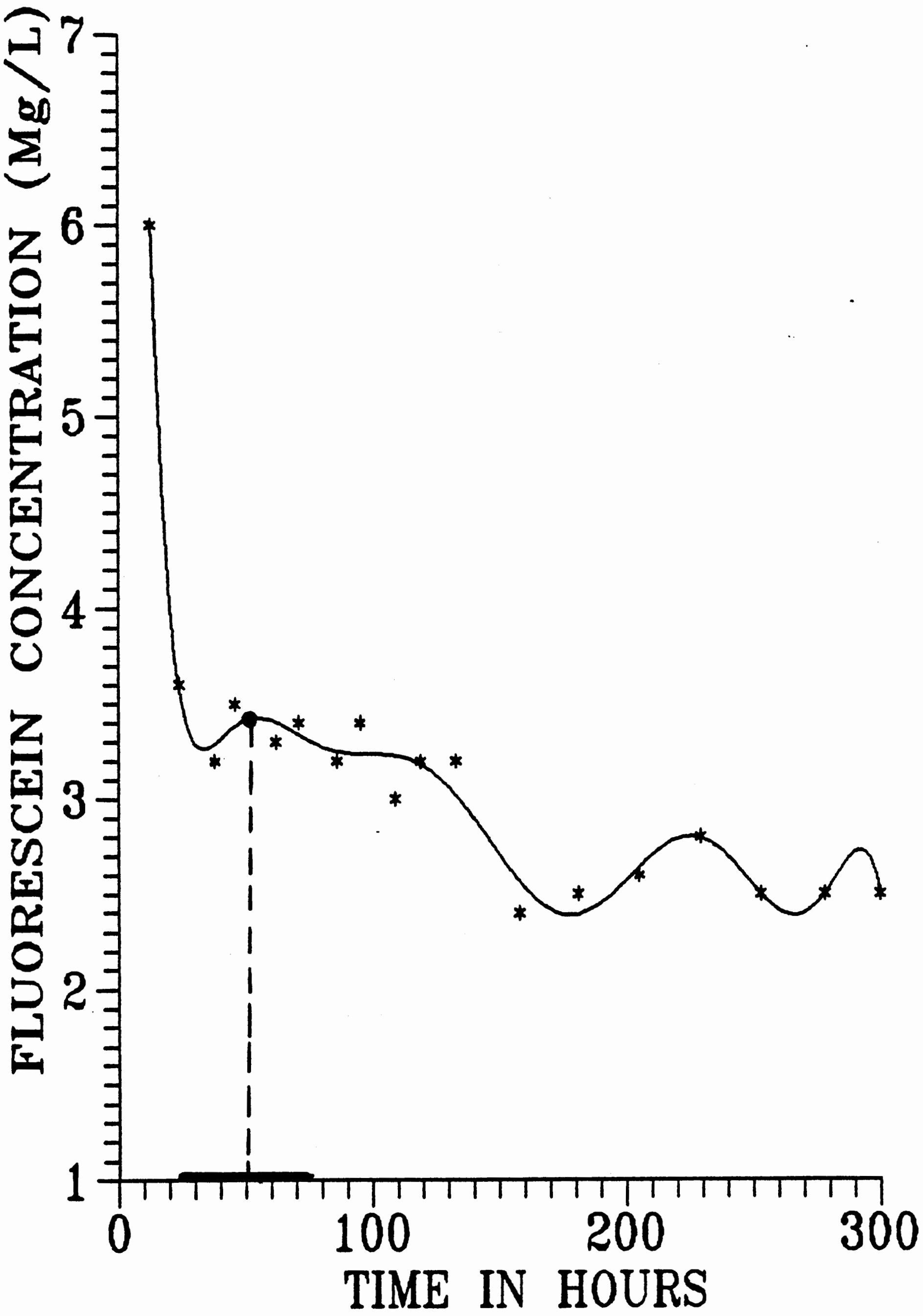


Figure 33. Observed data for Fluorescein for well 17. Polynomial grade 10 for best fit.

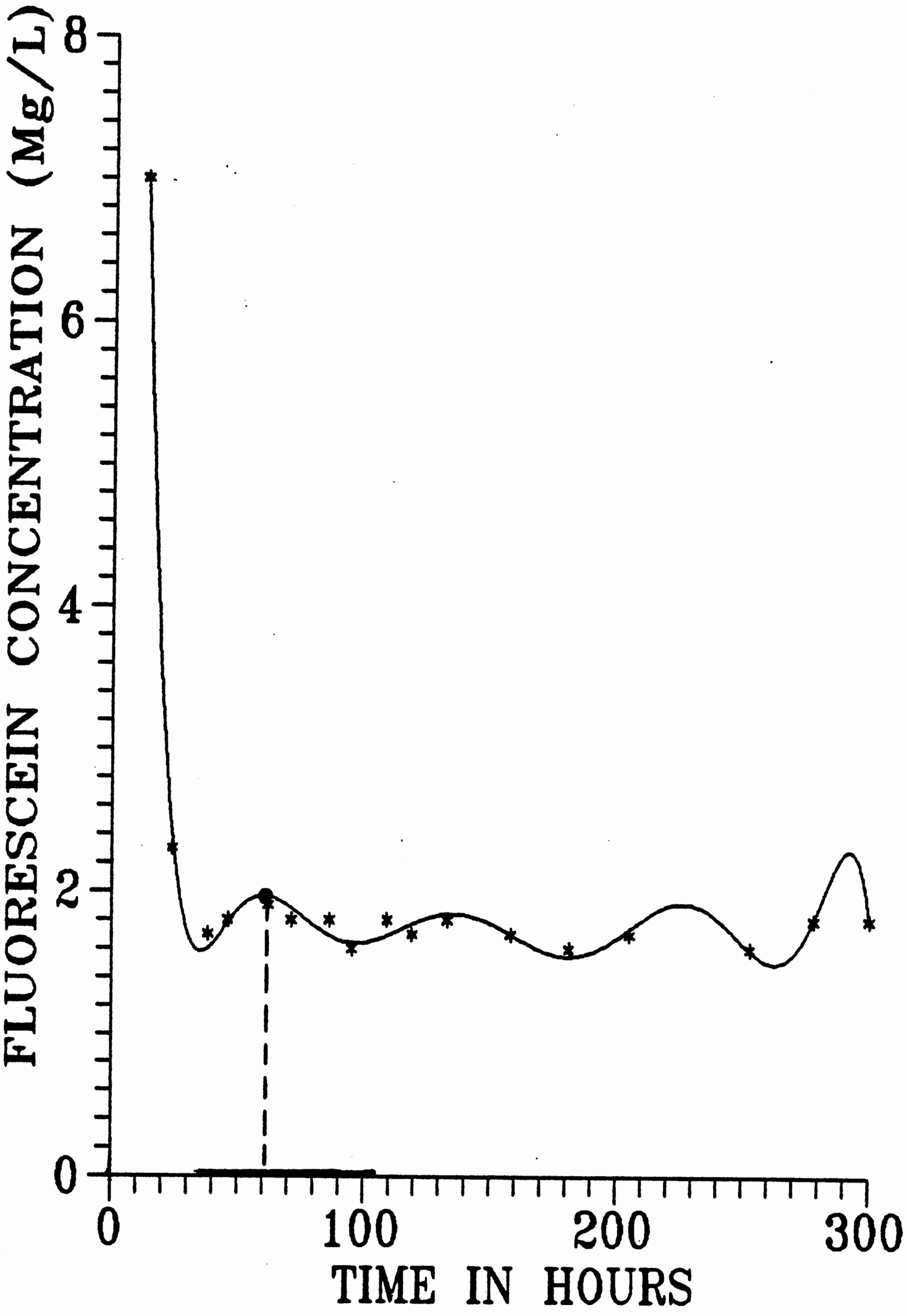


Figure 34. Observed data for Fluorescein for well 18. Polynomial grade 9 for best fit.

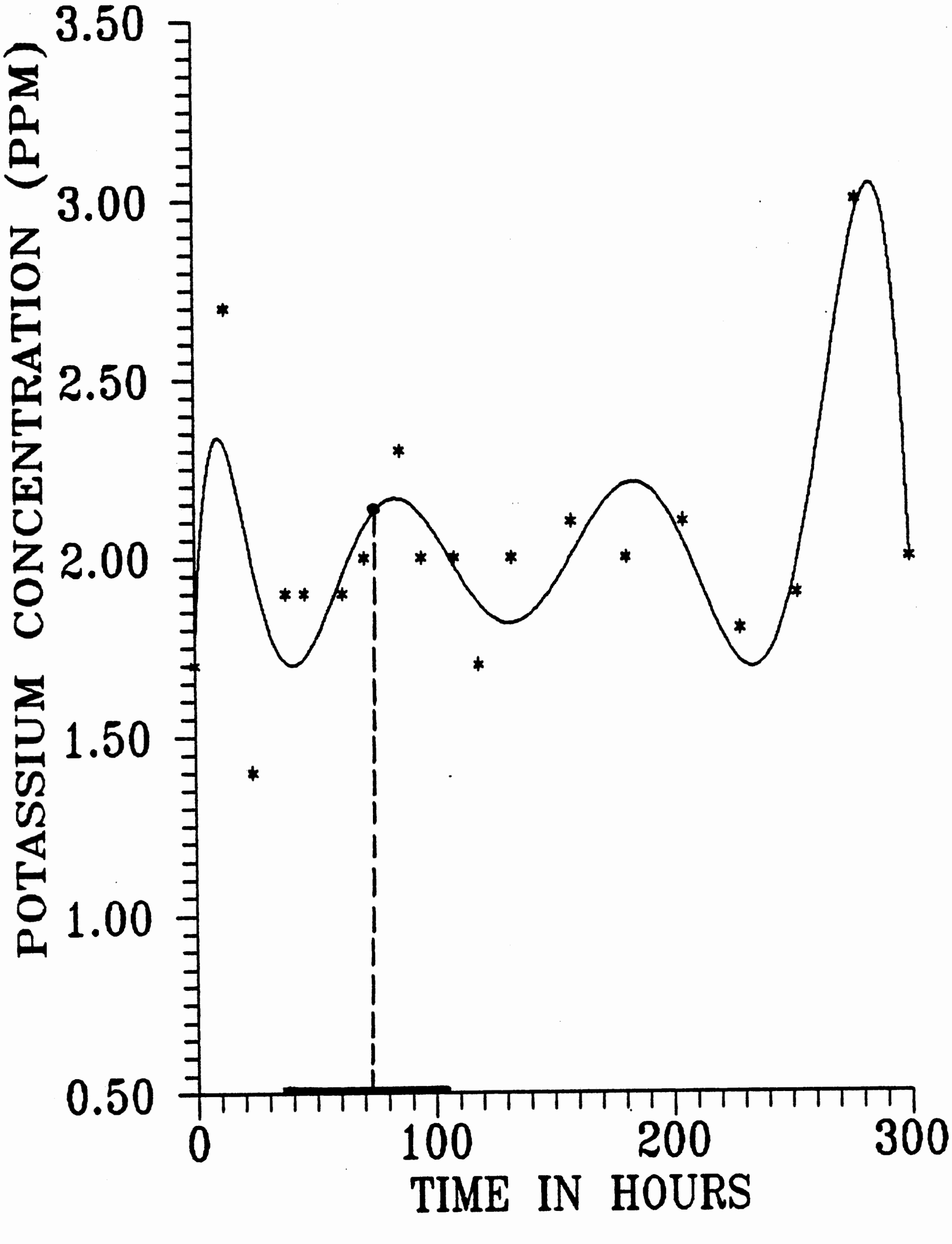


Figure 35. Observed data for Potassium for well 18. Polynomial grade 9 for best fit.

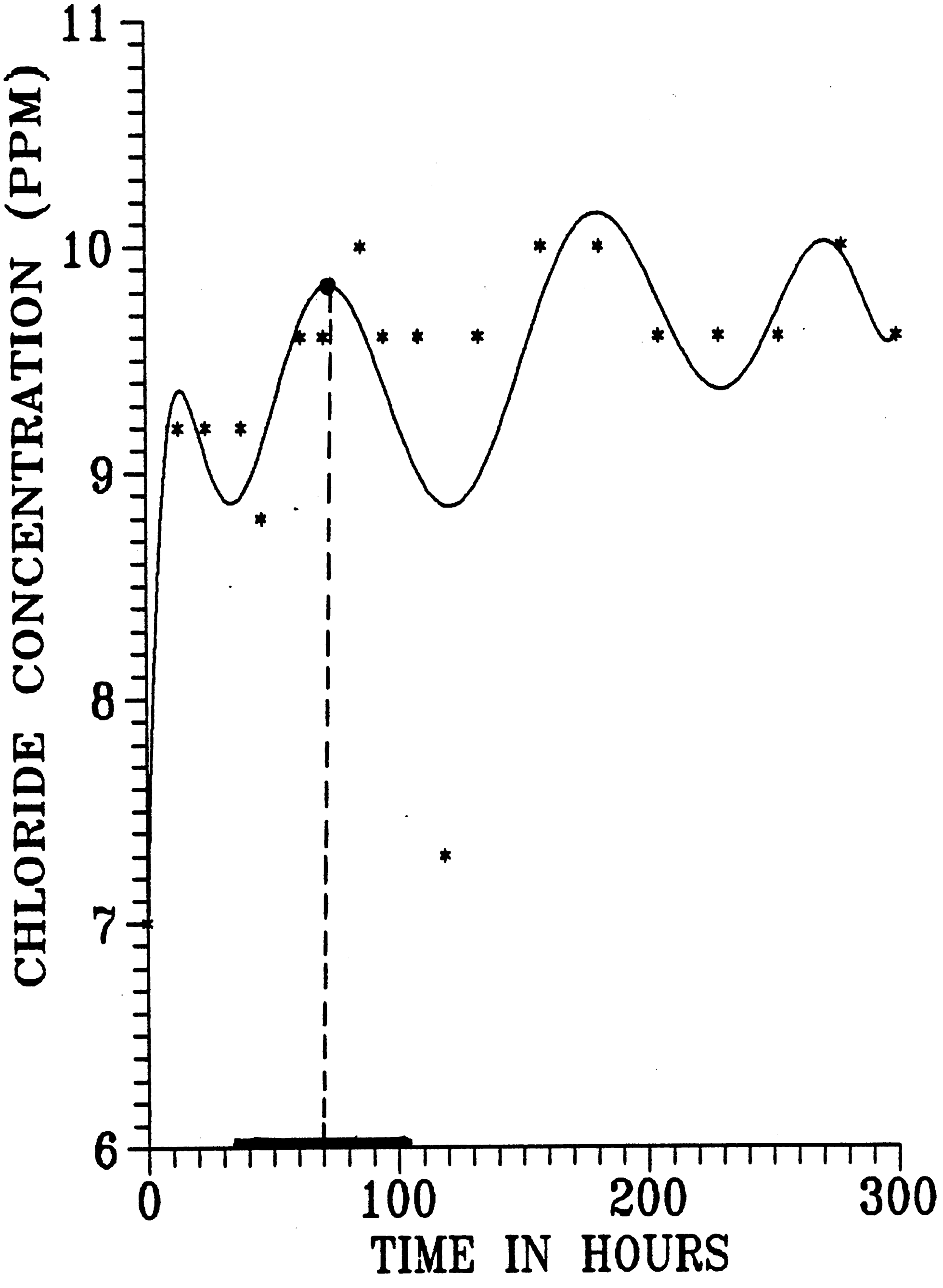


Figure 36. Observed data for Chloride for well 18. Polynomial grade 10 for best fit.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study has shown several important points regarding Tracer Test behavior and Model application which could be summarized as follows:

1- The high concentration of injected materials on 1992 tracer test is considered as the direct cause of observed differences in 1989 data and 1992 data as shown in Figures 27, 28 and 29.

2- Data from well 18 does not agree when comparing 1989 and 1992, due to amount of concentration injected and rate of pumping, which was higher in 1989 (32 to 35 gpm).

3- Hydraulic Conductivity calculated from pumping test correspond to the first peak for well 15 as shown in Figure 37, and correspond to the second peak for Fluorescein, Chloride and Bromide for wells 16, 17 and 18, which indicates that the second peak for these wells is the real time of arrival for these constituents at specified points. Figures 30 throught 36 included in earlier chapter show this observations, also Firgures 38 and 39 show the same phenomenon.

4- It appears that well 16 has very strong variation in the concentrations of constituents which is caused by the

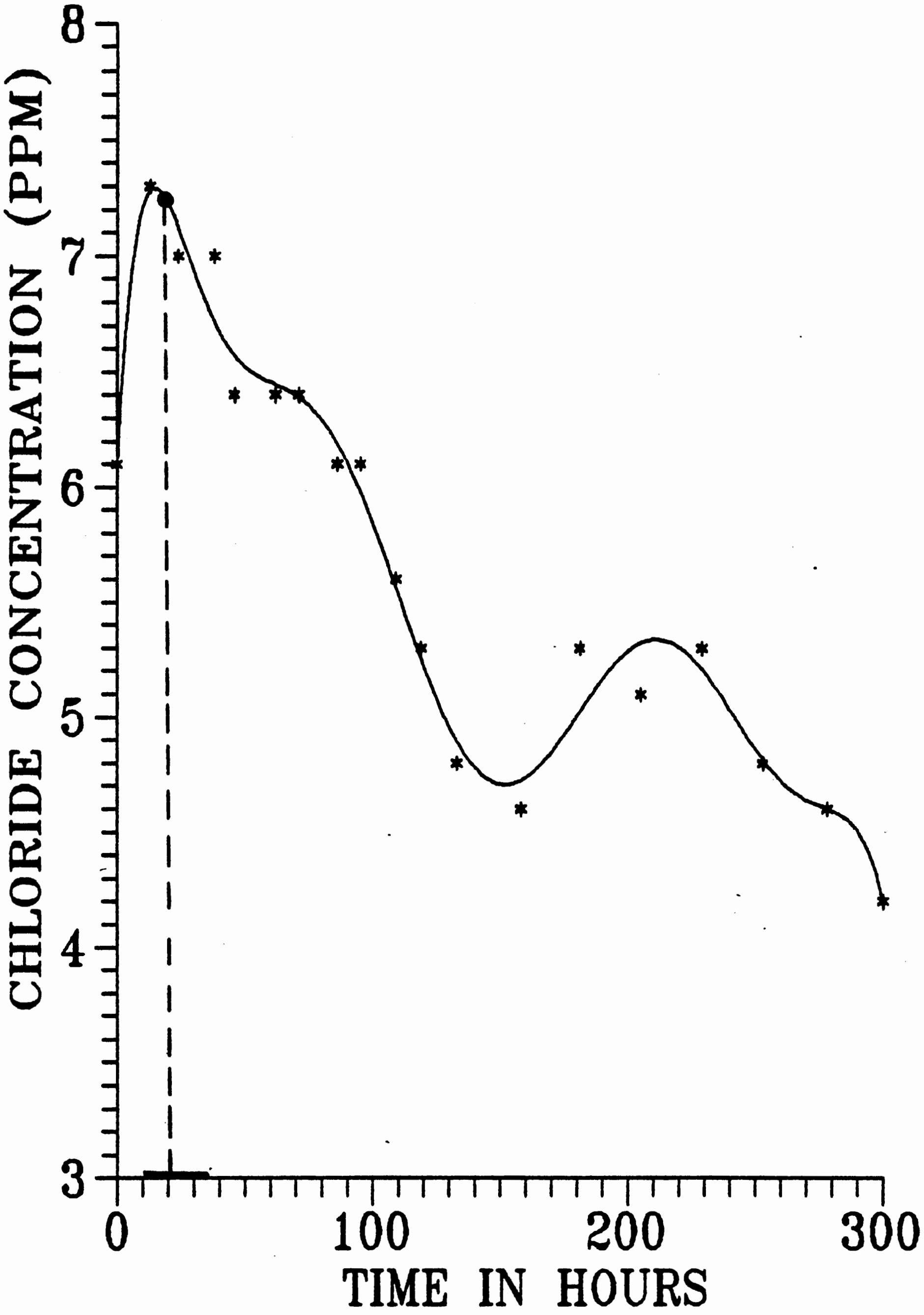


Figure 37. Observed data for Chloride for well 15. Polynomial grade 9 for best fit.

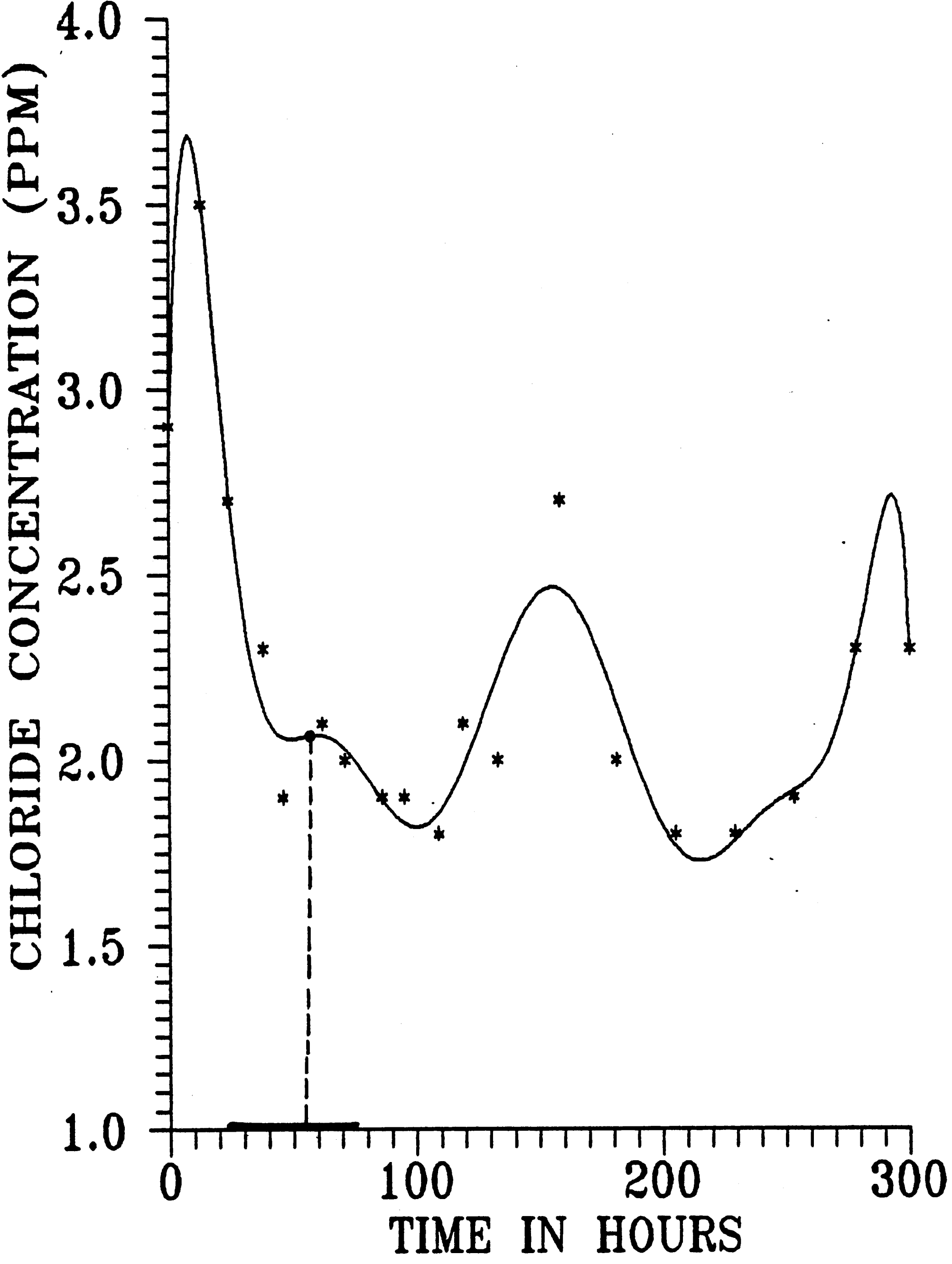


Figure 38. Observed data for Chloride for well 16. Polynomial grade 10 for best fit.

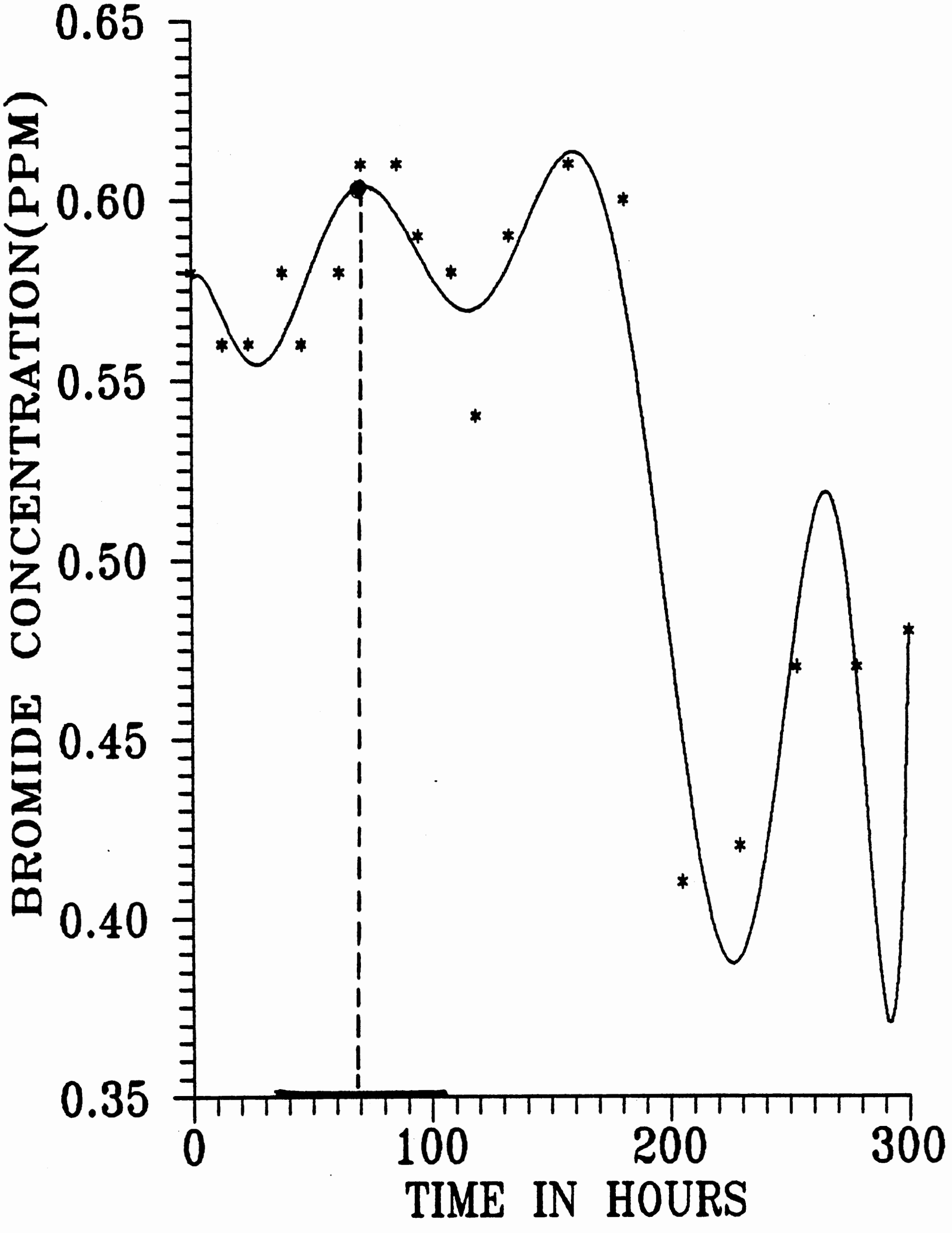


Figure 39. Observed data for Bromide for well 18. Polynomial grade 10 for best fit.

shallow depth of this well as shown in Figure 19.

5- It is observed that the late peak calculated for bromide in well 15 is the same for both data sets, also the late peak for Nitrate in well 17 and Late peak of Potassium in well 16 correspond to one another in the 1989 and 1992 data.

6- It is observed from the matching peak (Table IX), that the Fl and Cl match first in all wells.

TABLE IX

MATCHING PEAKS

	Fl	Cl	Br	NO3	K
WELL #					
15	1st	1st	N/M	1st	N/M
16	2nd	2nd	N/M	N/M	N/M
17	2nd	1st 2nd	2nd	N/M	N/M
18	2nd	2nd	2nd	N/M	2nd

7- The model application for the first Simulated Procedure has proved to be the best match for the tracer test observed data as shown in Figure 40.

8- The model application for the Second Simulated Procedure proves that this type of scenario is not applicable for tracer test where slugs are used. This is based on the fact that the obtained data does not match wich the observed data. An example of the ploted Simulation result is presented in Figure 41.

9- All constituents generally conform with the water table elevation fluctuation as shown in Figure 42 and 43.

10- Conductivity is inversely proportional with water table elevation as shown in Figure 44 and 45.

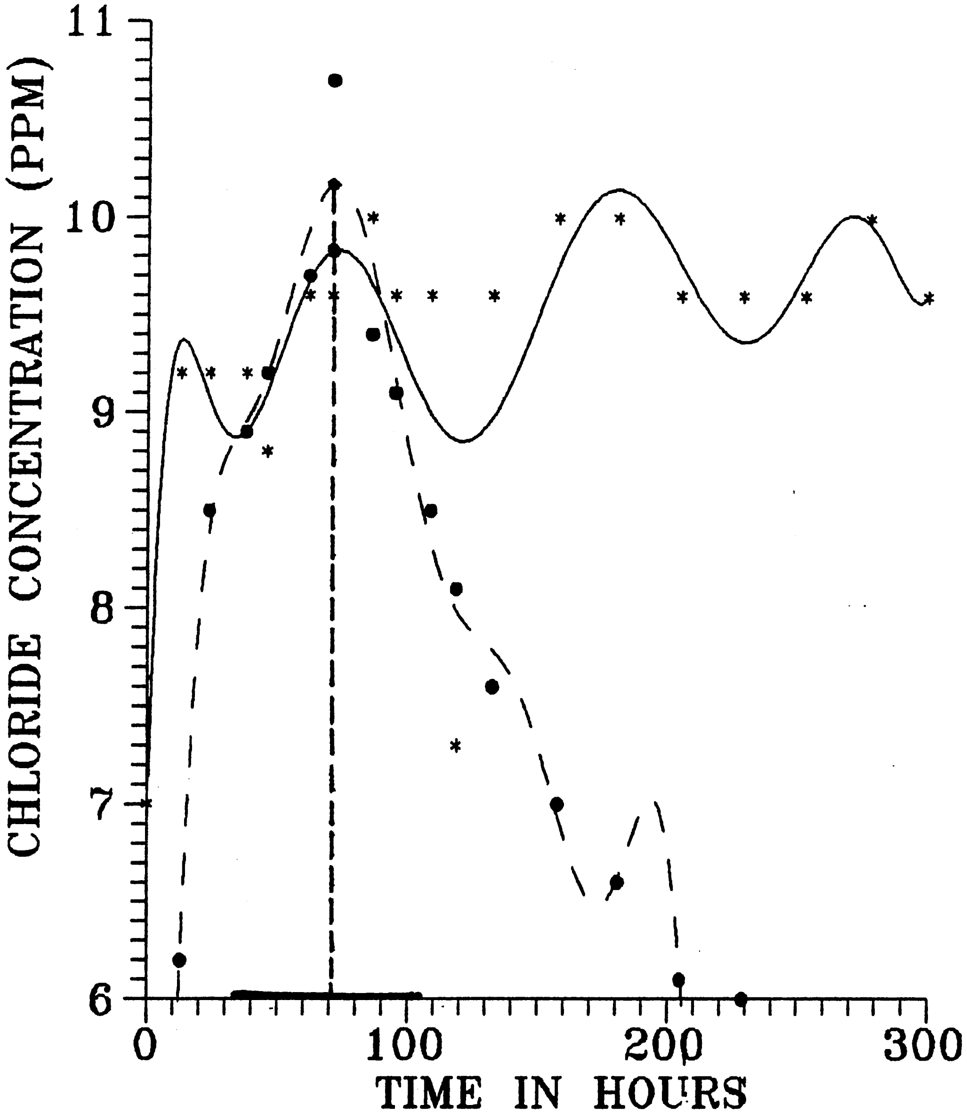


Figure 40. Observed data (*) and Simulated data (dots and dashes) for Chloride for well 18. Polynomial grade 10 for best fit.

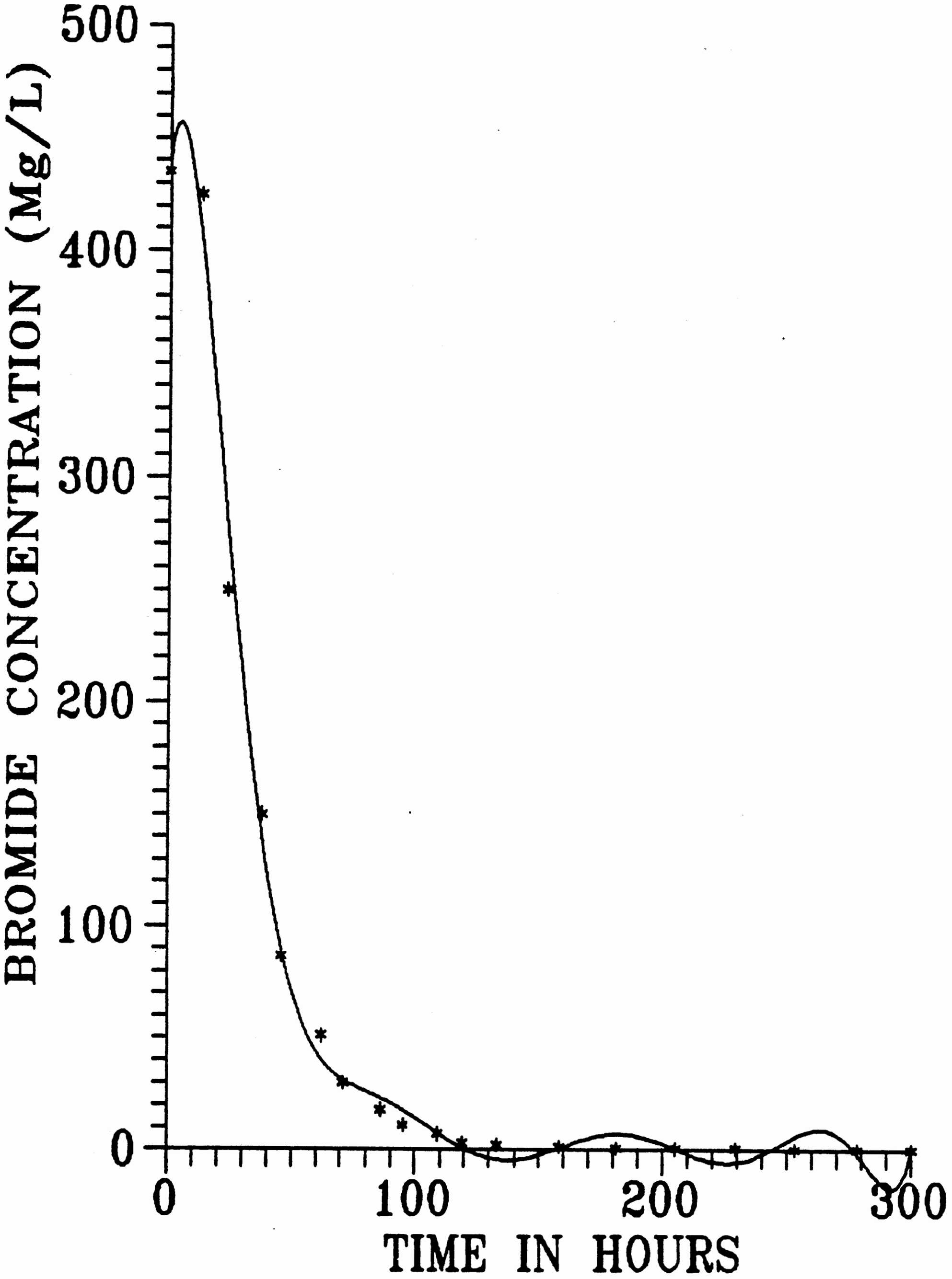


Figure 41. Simulated data for Bromide for well 16. Polynomial grade 8 for best fit.

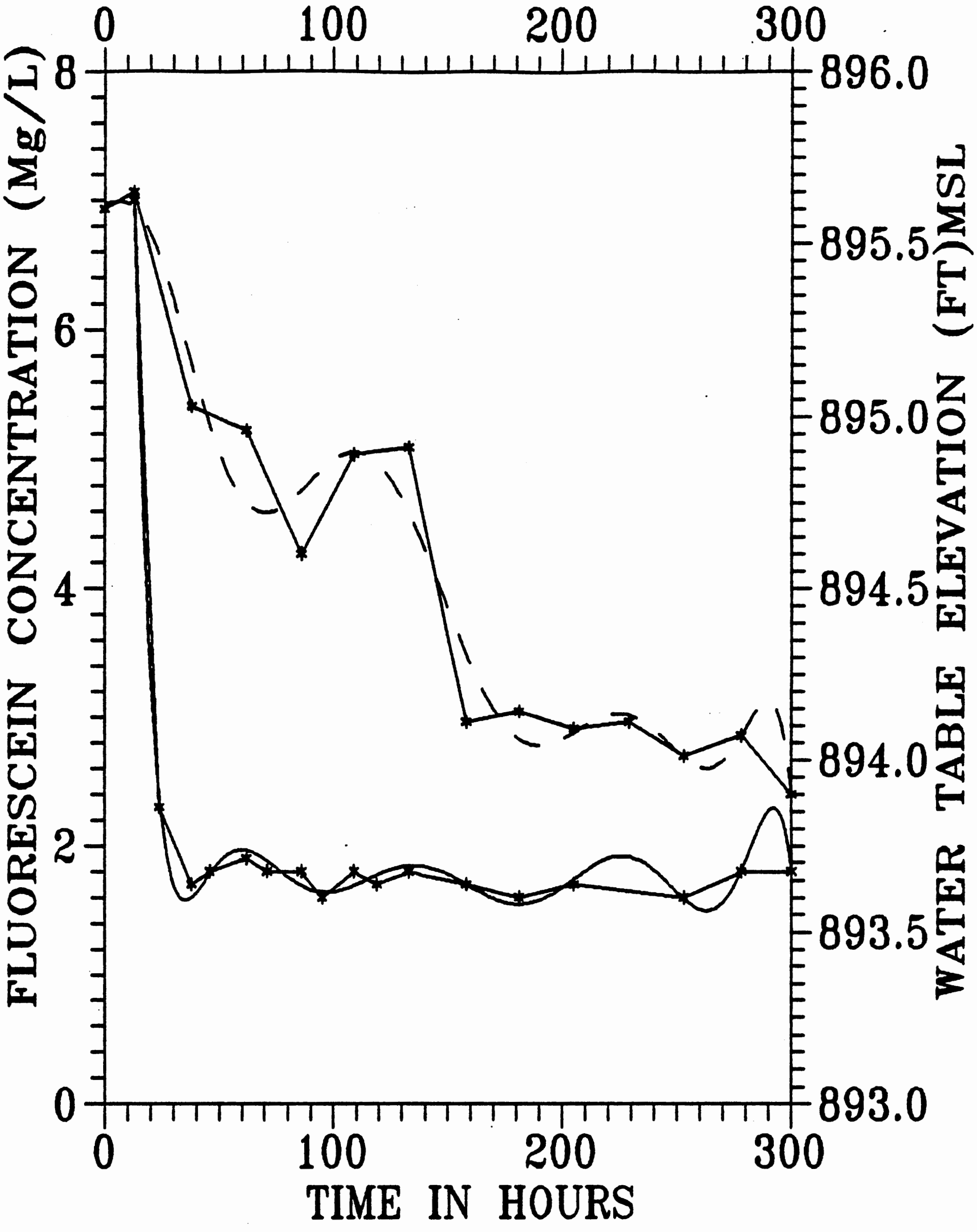


Figure 42. Observed data for Fluorescein and water table elevation (Dashed) versus time for well 18. Polynomial grade 9 for best fit for both curves.

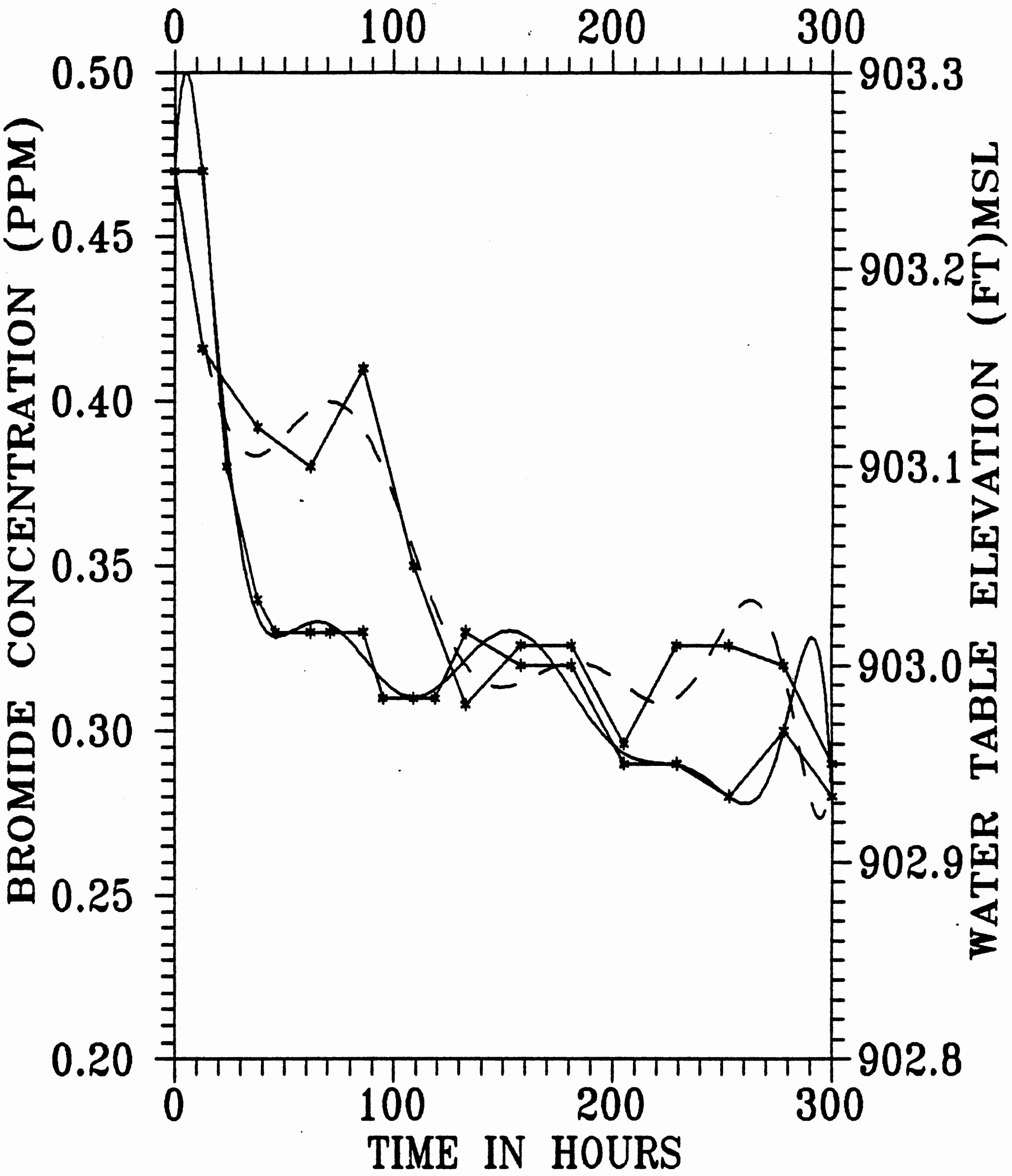


Figure 43. Observed data for Bromide and water table elevation (Dashed) versus time for well 17. Polynomial grade 10 for best fit for both curves.

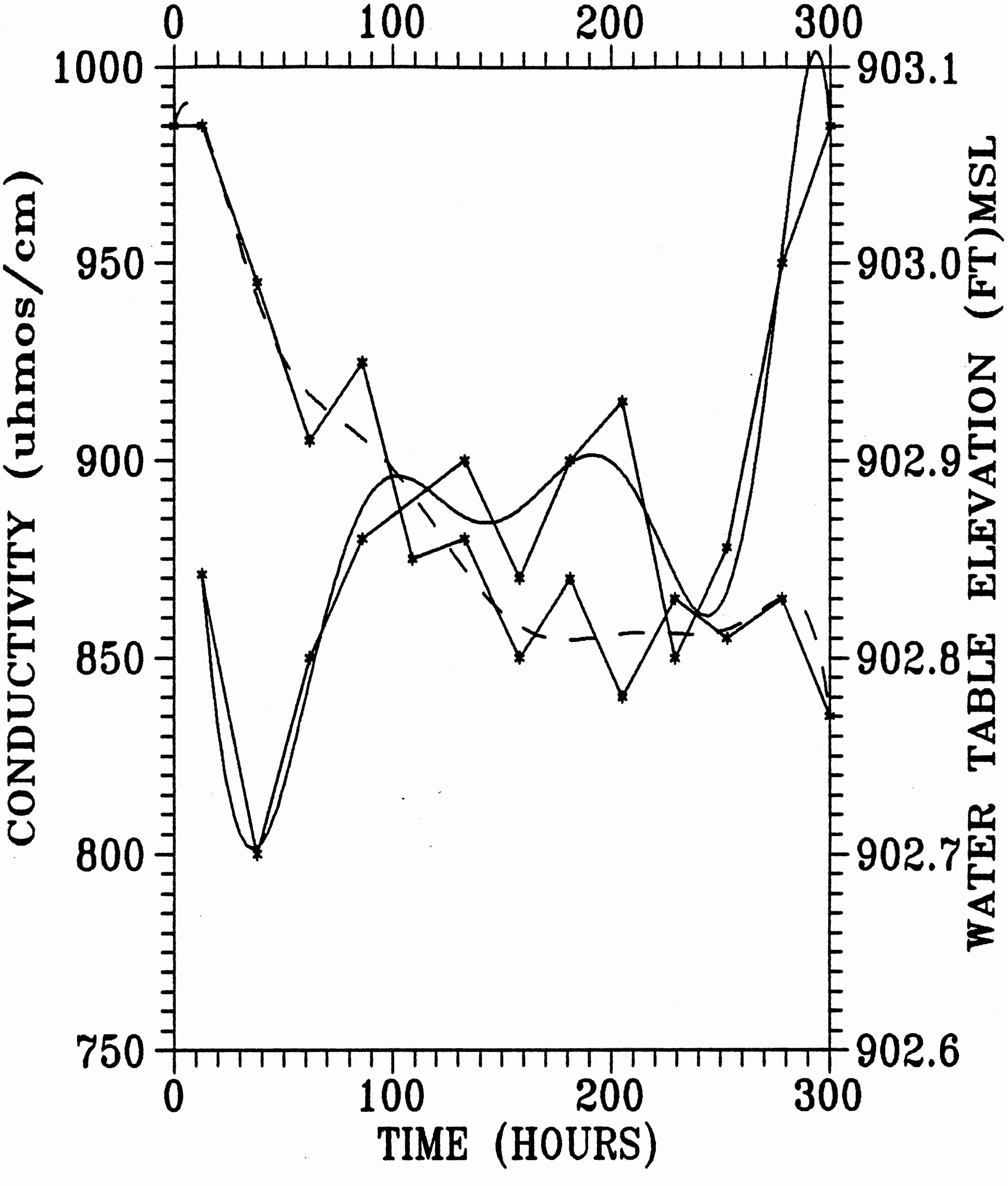


Figure 44. Observed data for Conductivity and water table elevation (Dashed) versus time for well 15. Polynomial grade 8 for best fit for both curves.

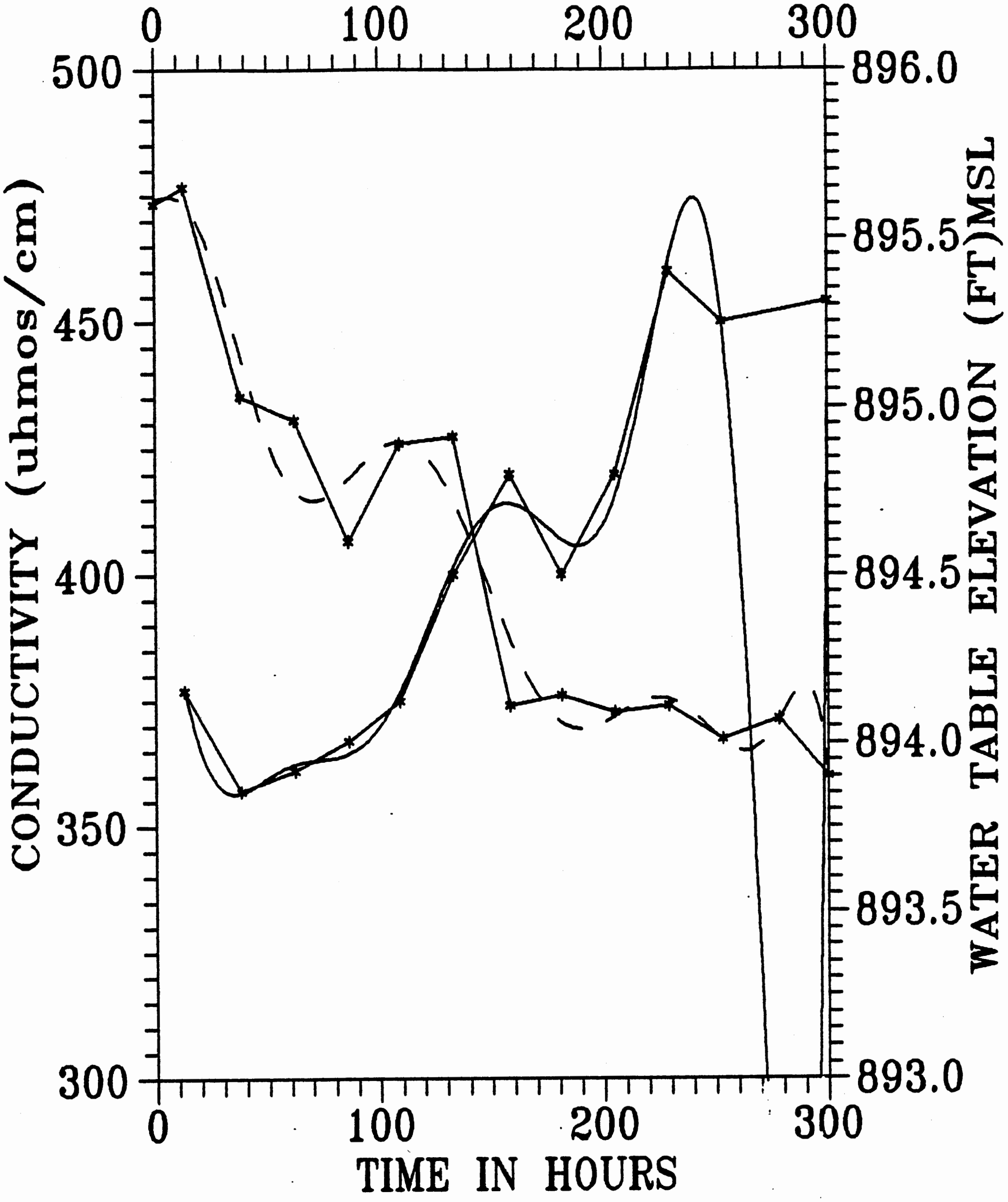


Figure 45. Observed data for Conductivity and Water table elevation (Dashed) versus time for well 18. Polynomial grade 9 for best fit for both curves.

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APPENDIX A

TRACER TEST GRAPHING AND STATISTICAL PRESENTATION

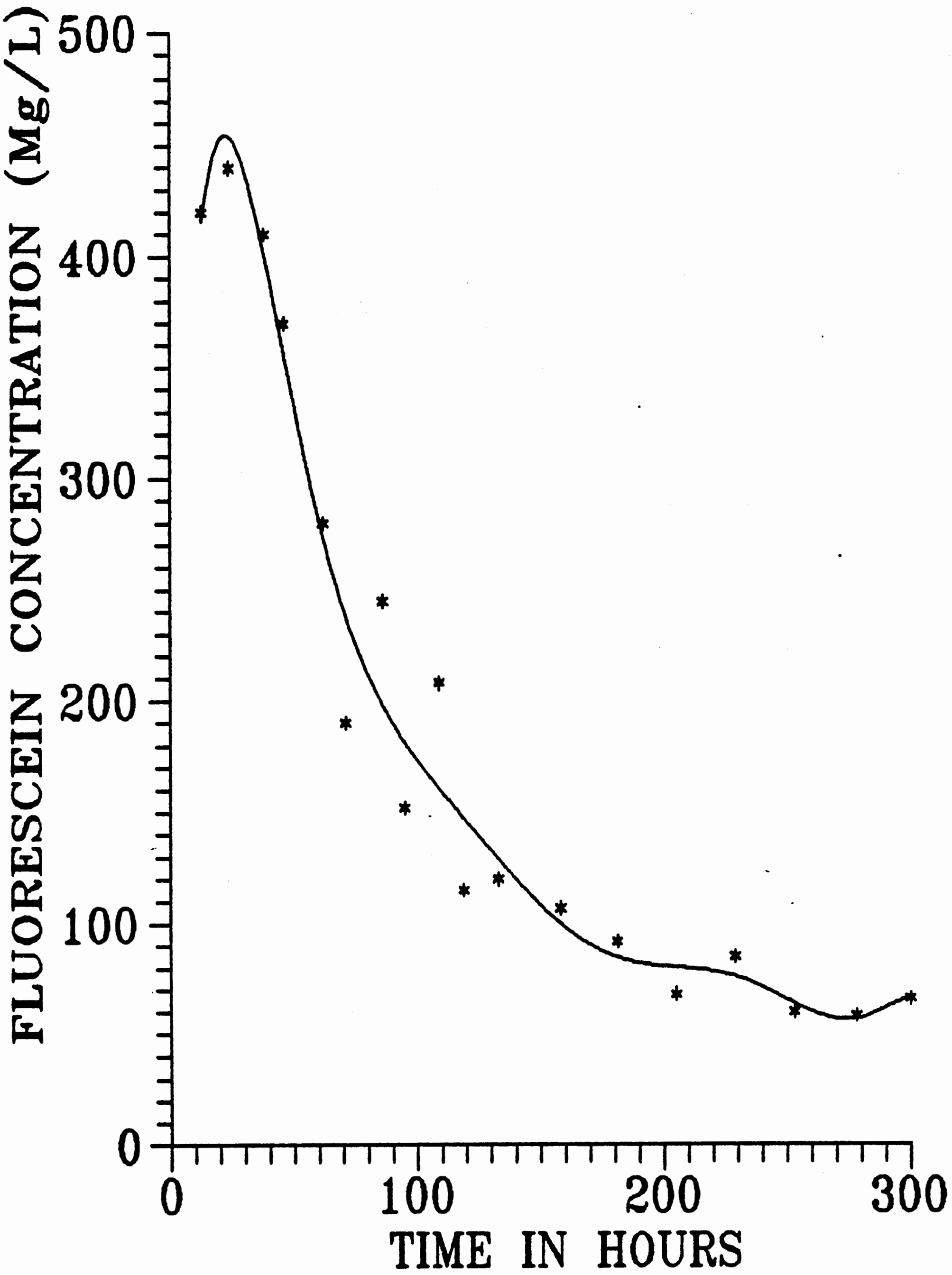

Figure 46. Observed data for Fluorescein for well 14. Polynomial grade 8 for best fit.

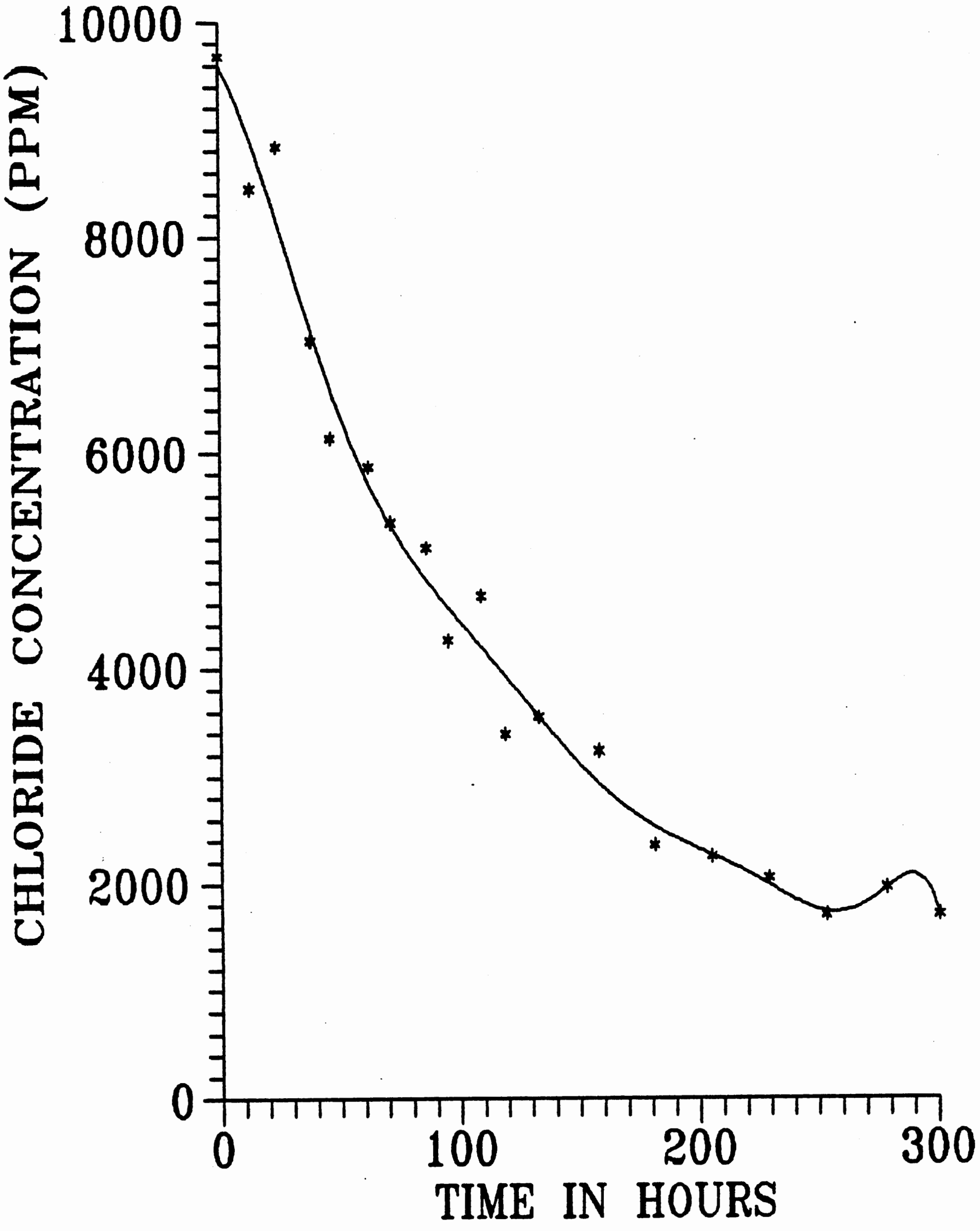

Figure 47. Observed data for Chloride for well 14. Polynomial grade 9 for best fit.

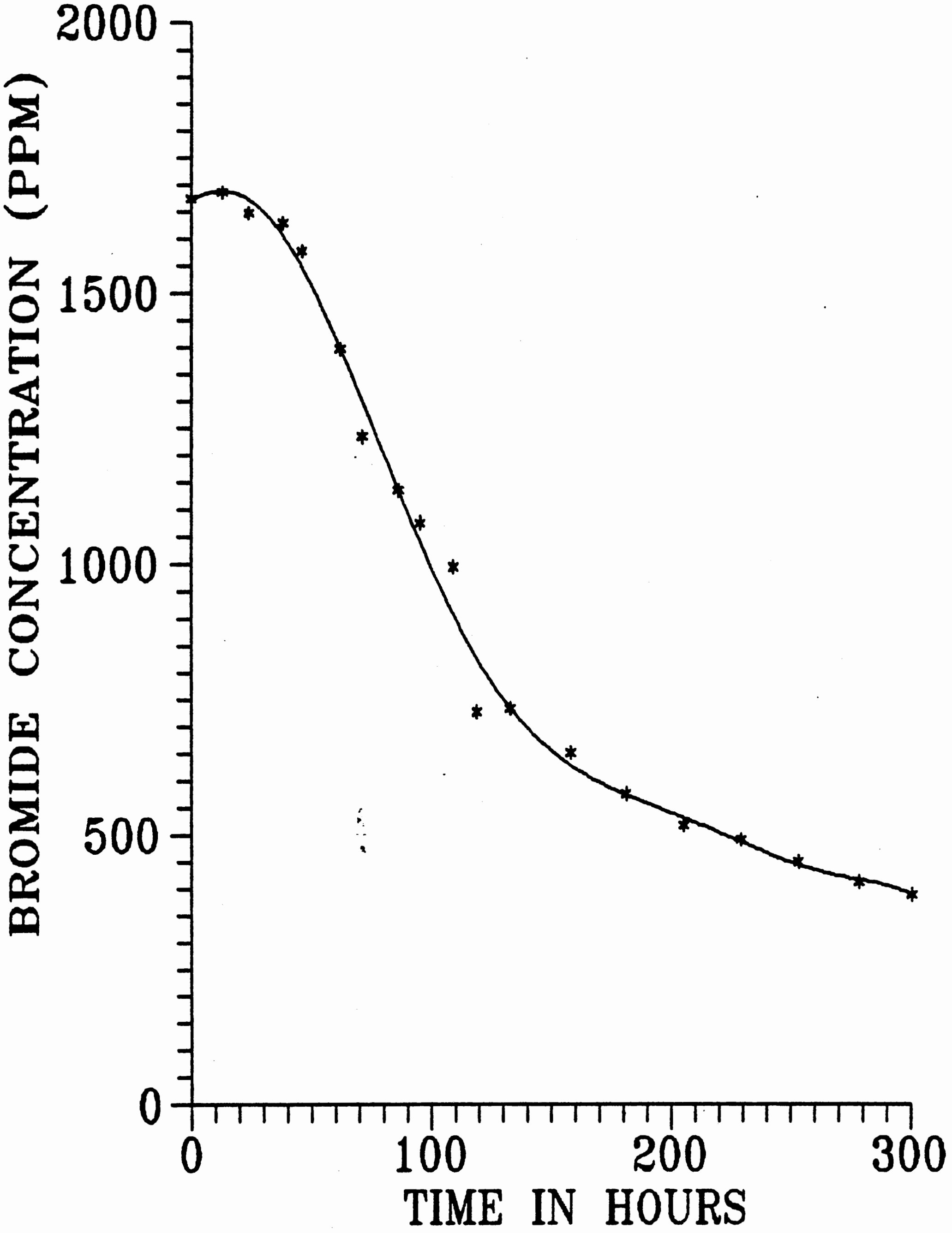

Figure 48. Observed data for Bromide for well 14. Polynomial grade 7 for best fit.

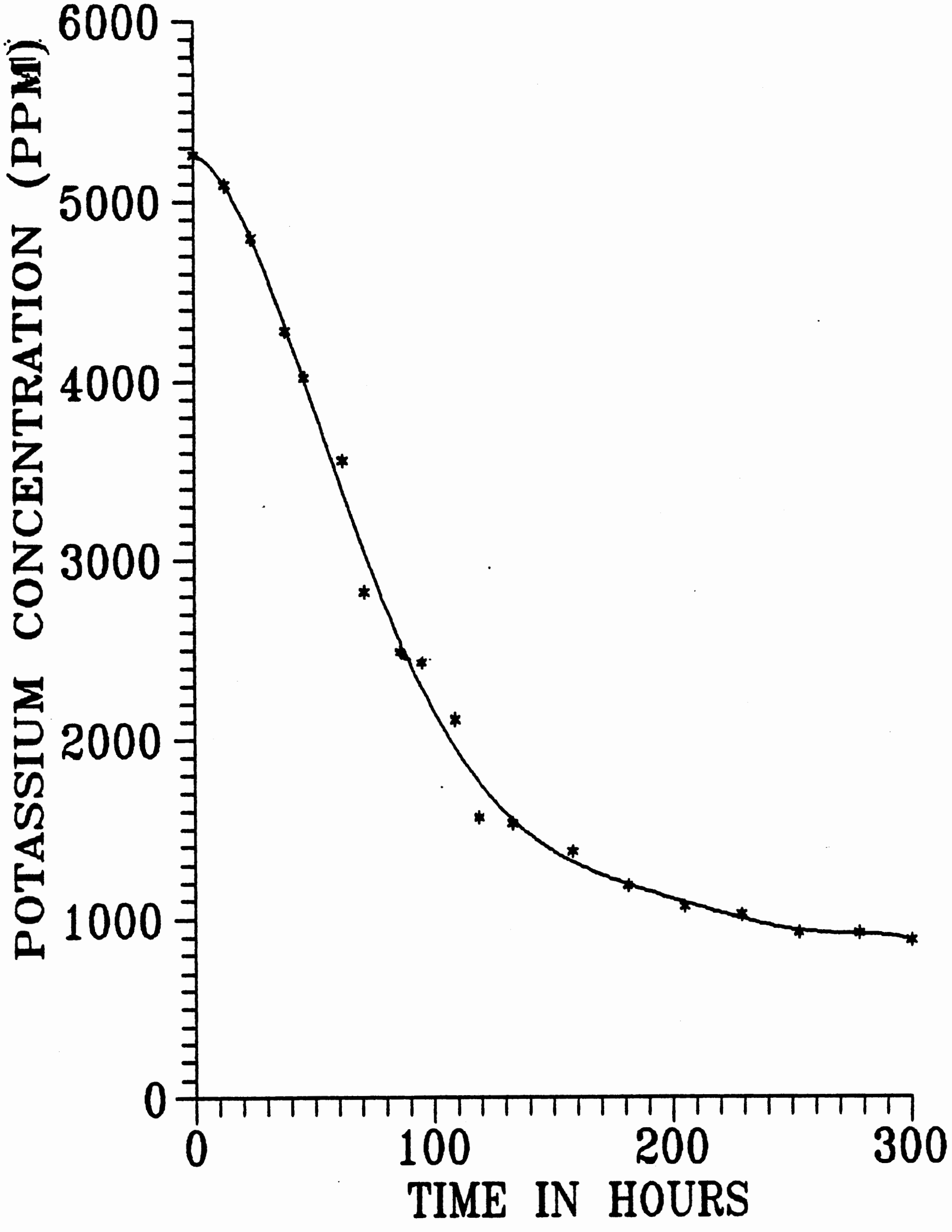

Figure 49. Observed data for Potassium for well 14. Polynomial grade 7 for best fit.

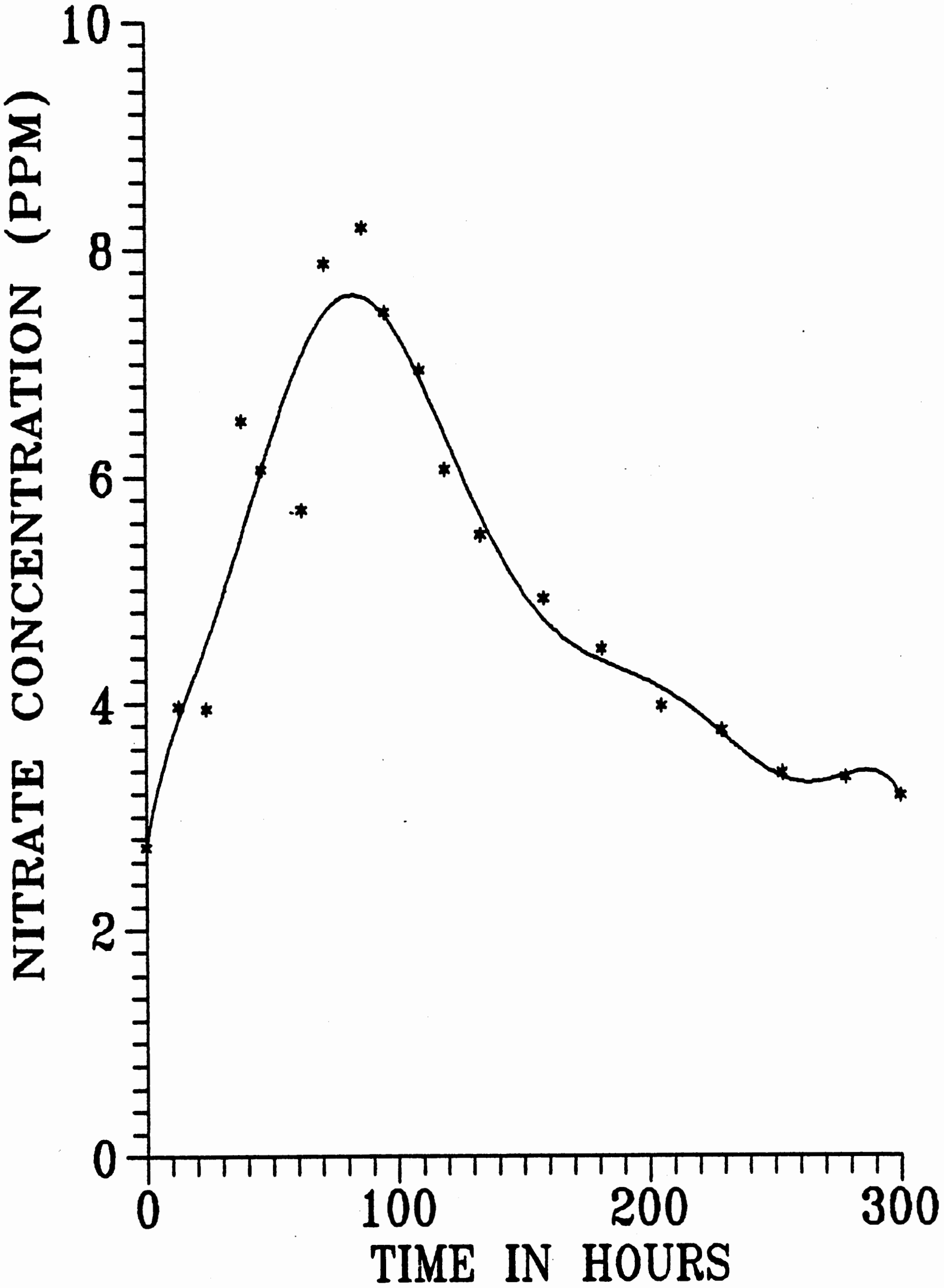

Figure 50. Observed data for Nitrate for well 14. Polynomial grade 9 for best fit.

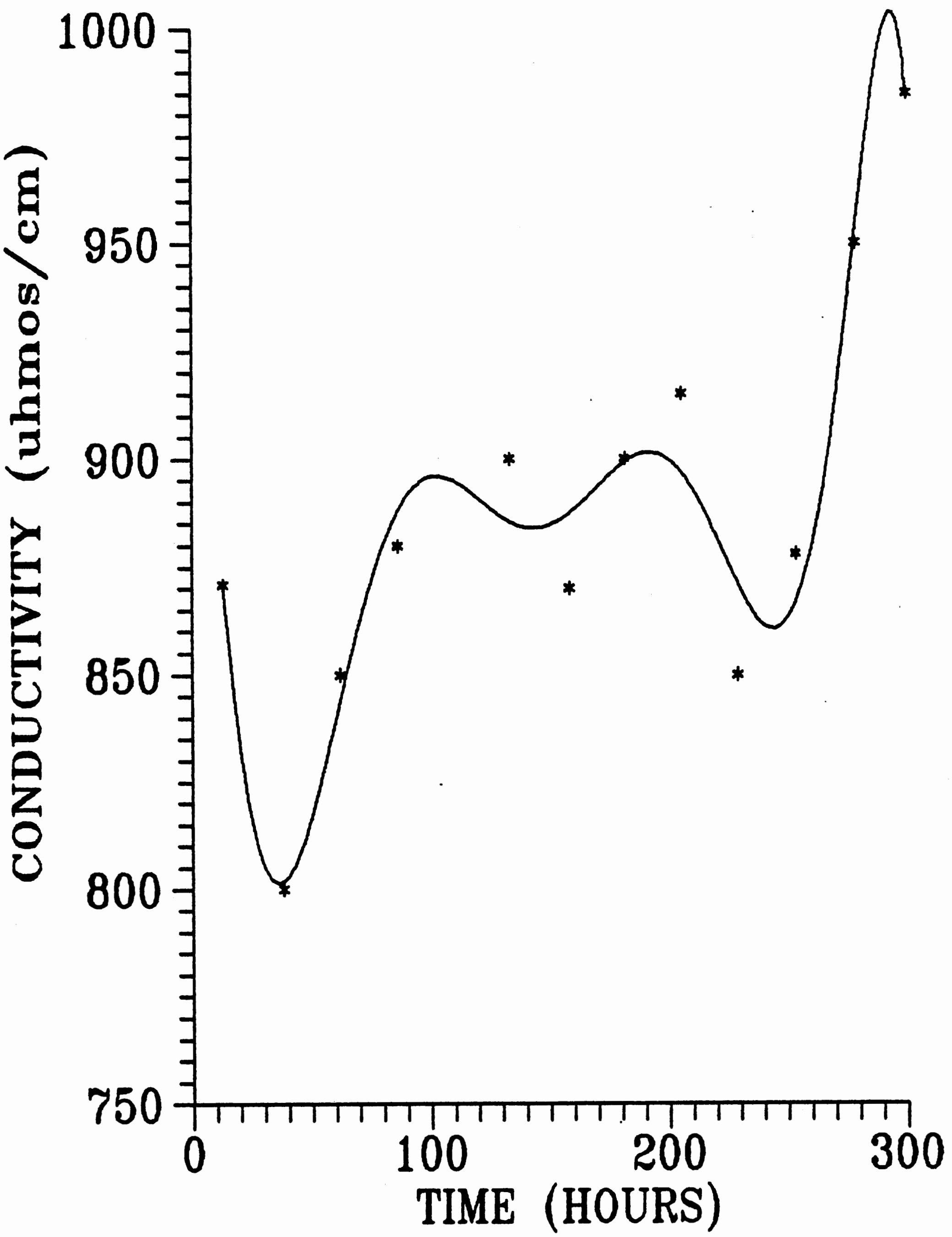

Figure 51. Observed data for Conductivity for well 15. Polynomial grade 8 for best fit.

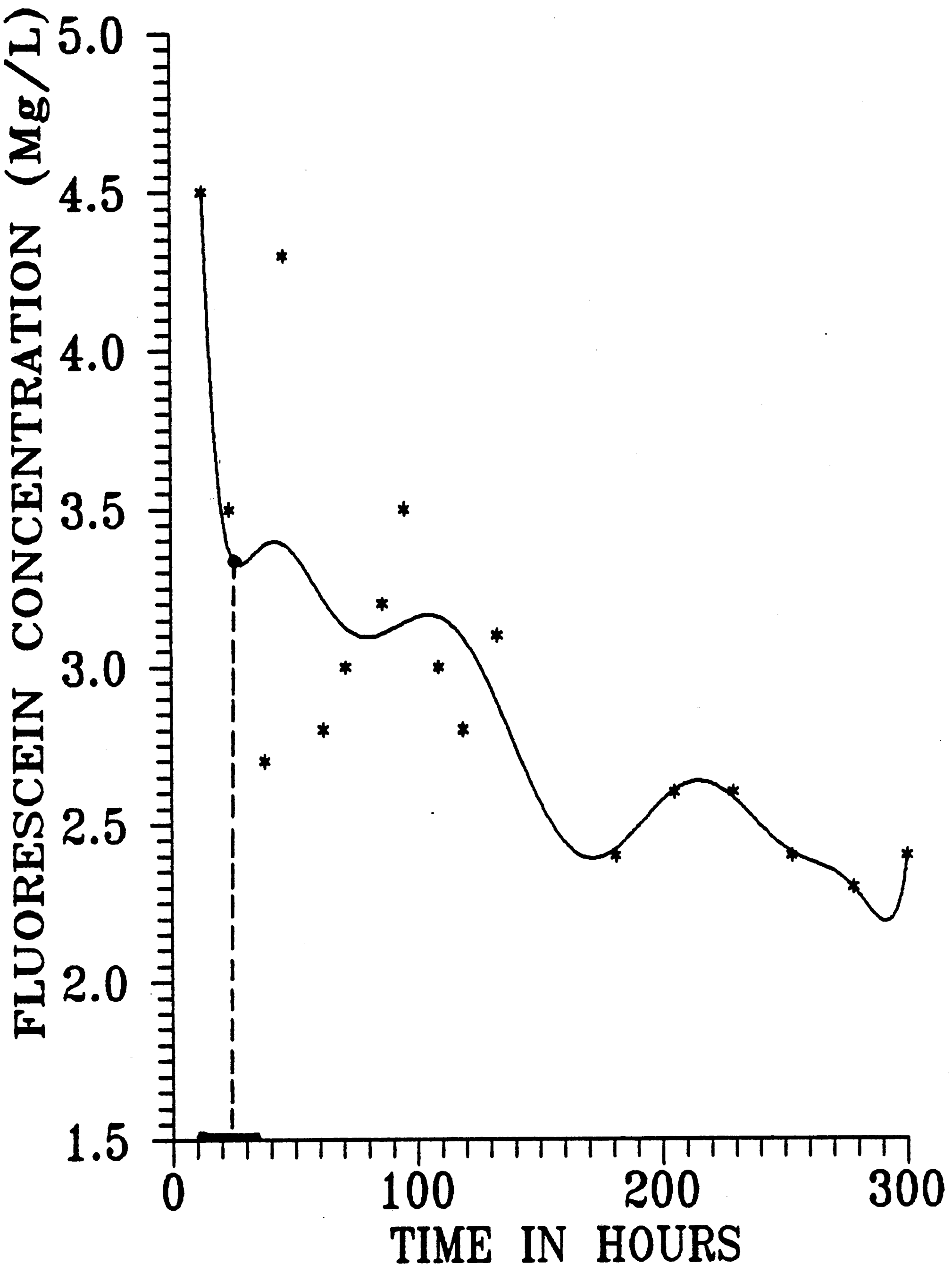

Figure 52. Observed data for Fluorescein for
well 15. Polynomial grade 10 for
best fit.

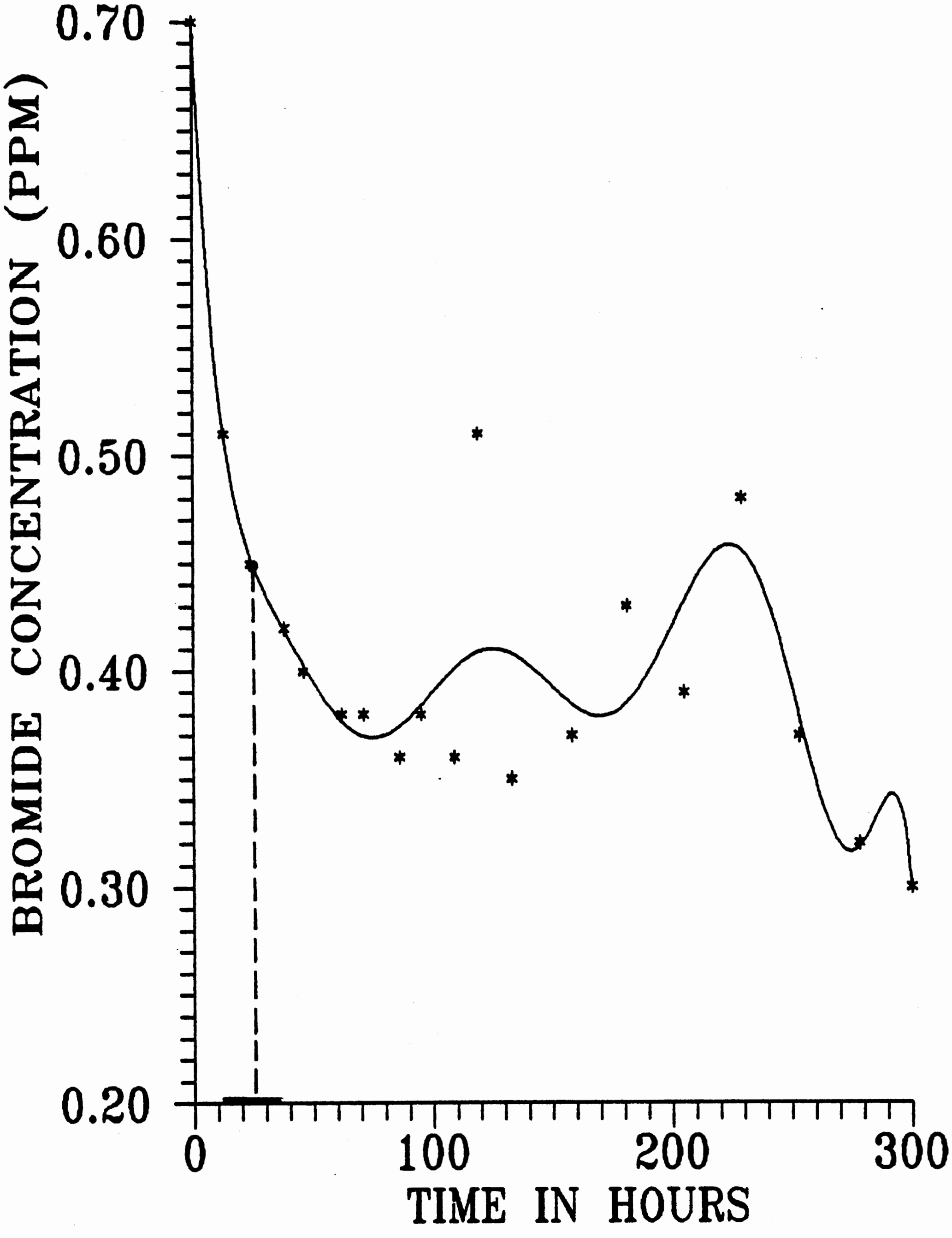

Figure 53. Observed data for Bromide for well 15. Polynomial grade 10 for best fit.

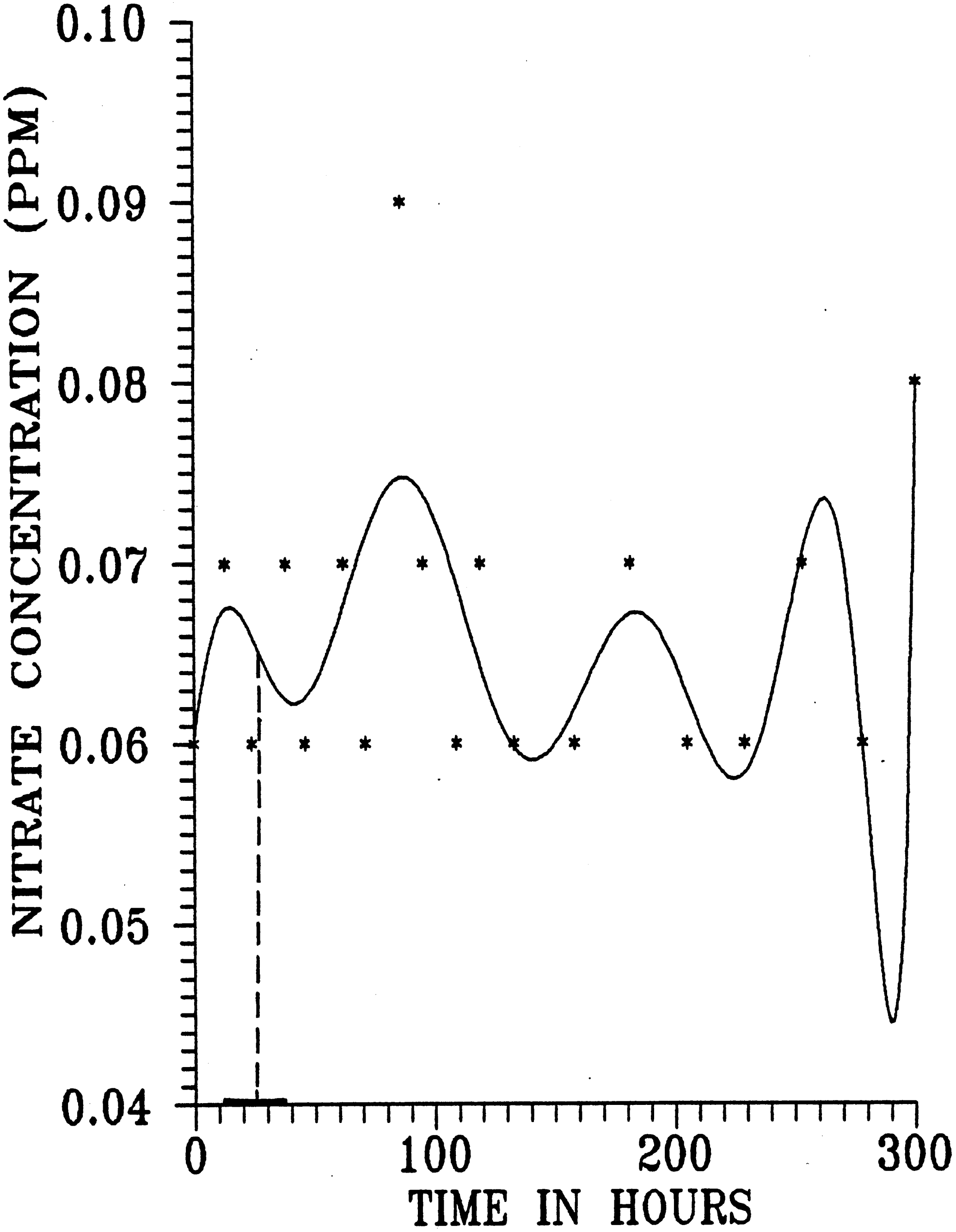

Figure 54. Observed data for Nitrate for well 17. Polynomial grade 10 for best fit.

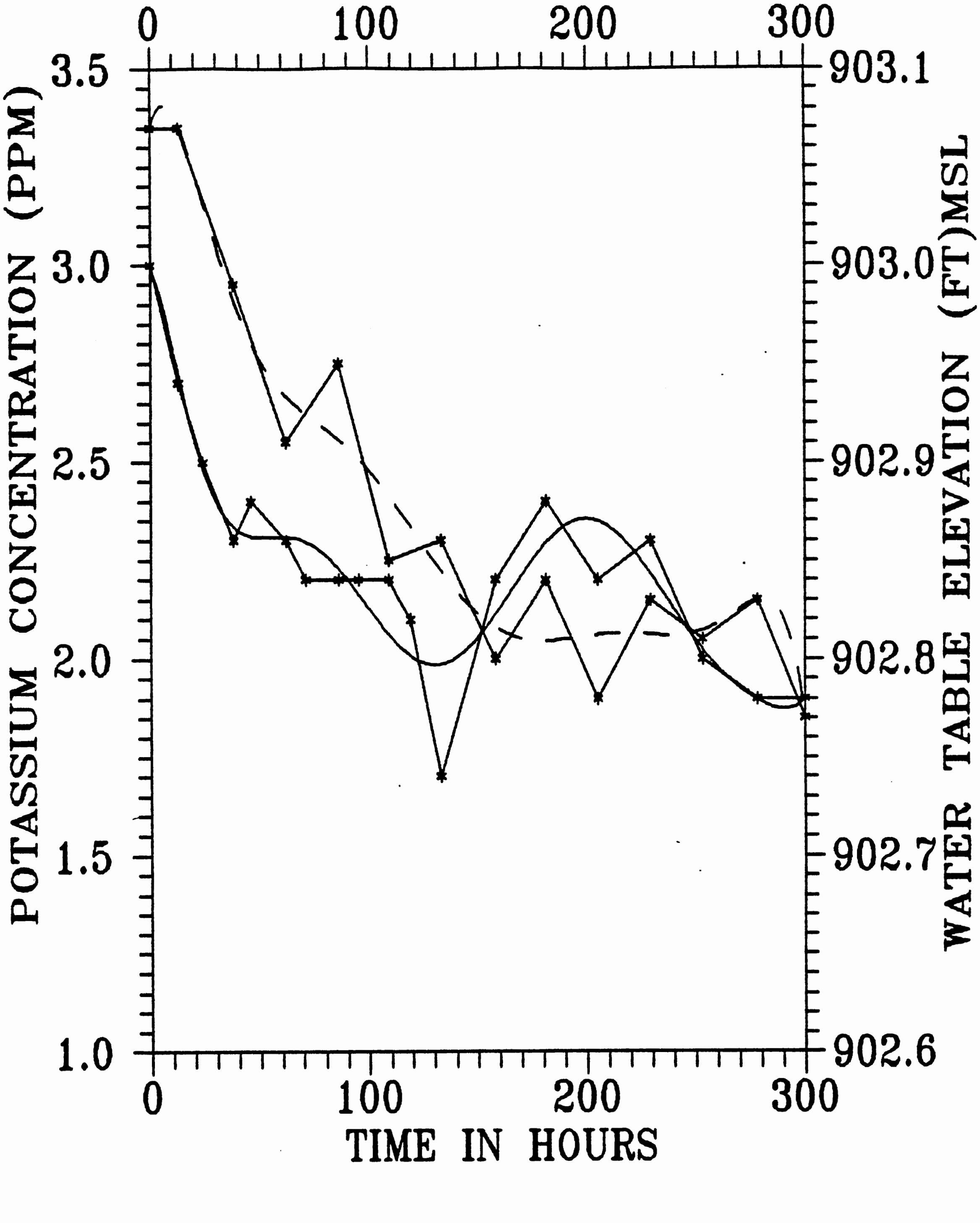

Figure 55. Observed data for Potassium and water table elevation (Dashed) versus time.for well 15. Polynomial grade 9 for best fit for both curves.

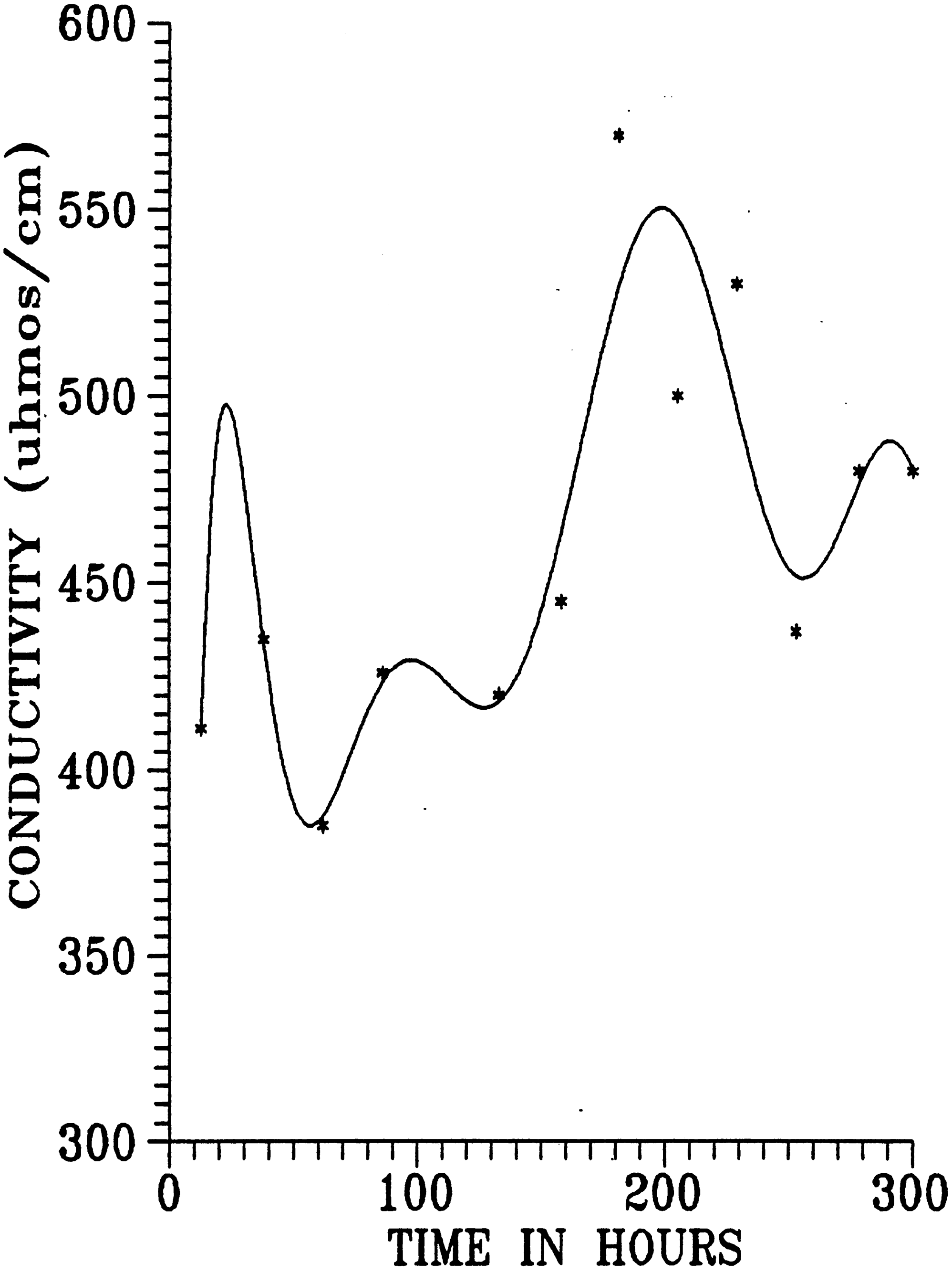

Figure 56. Observed data for Conductivity for well 16. Polynomial grade 9 for best fit.

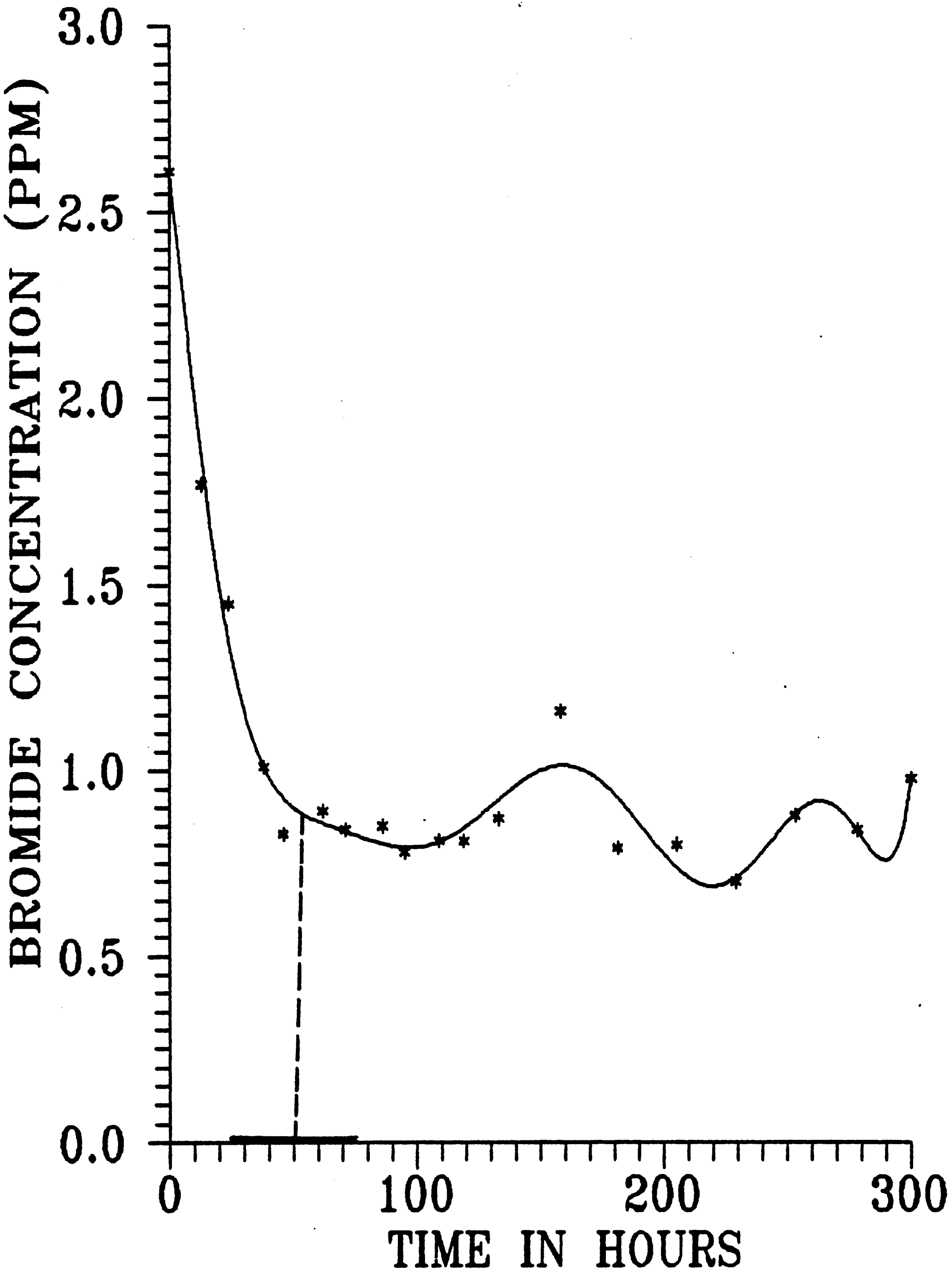

Figure 57. Observed data for Bromide for
well 16. Ploynomial grade 10
for best fit.

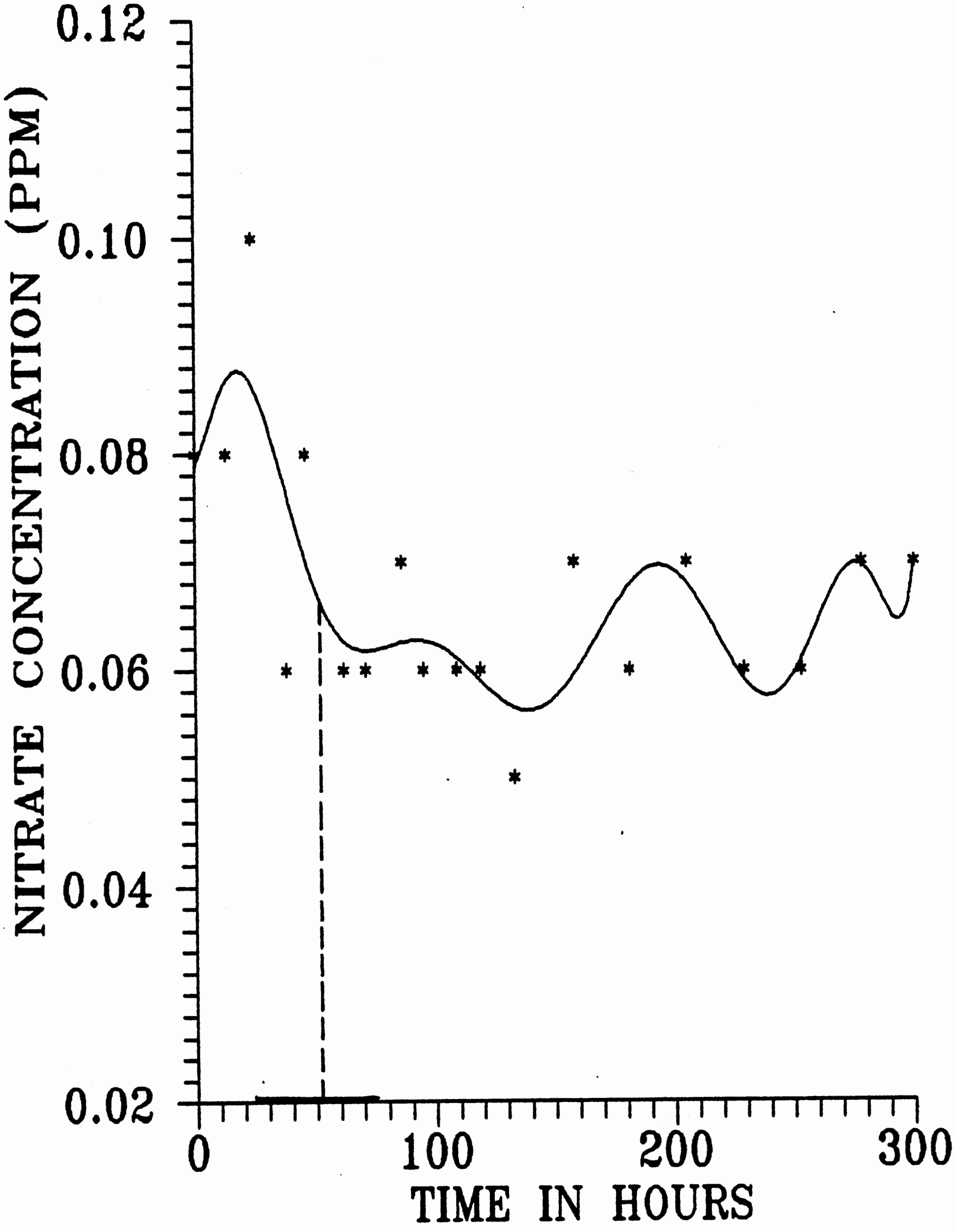

Figure 58. Observed data for Nitrate for well 16. Polynomial grade 10 for best fit.

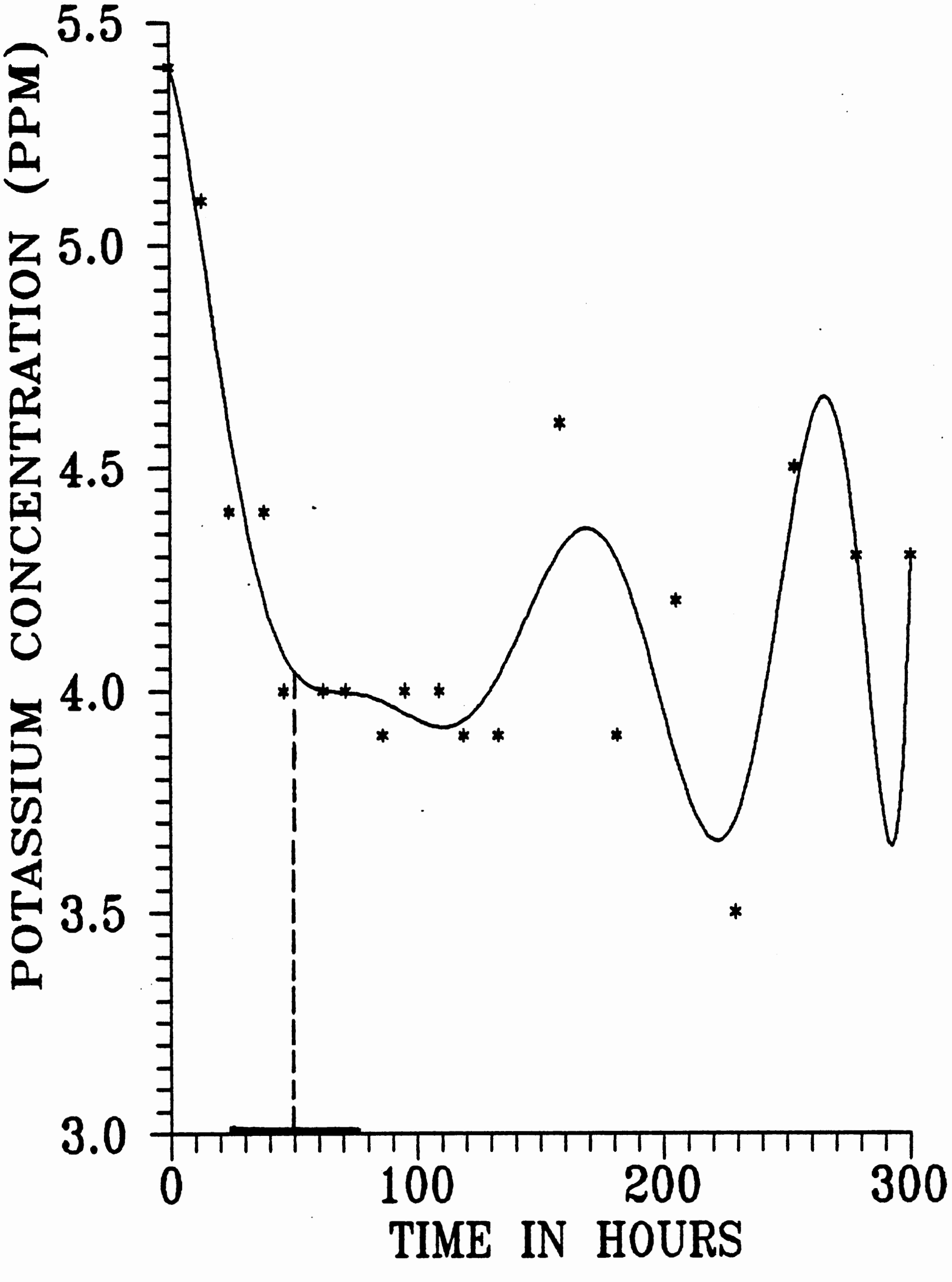

Figure 59. Observed data for Potassium for well 16. Polynomial grade 9 for best fit.

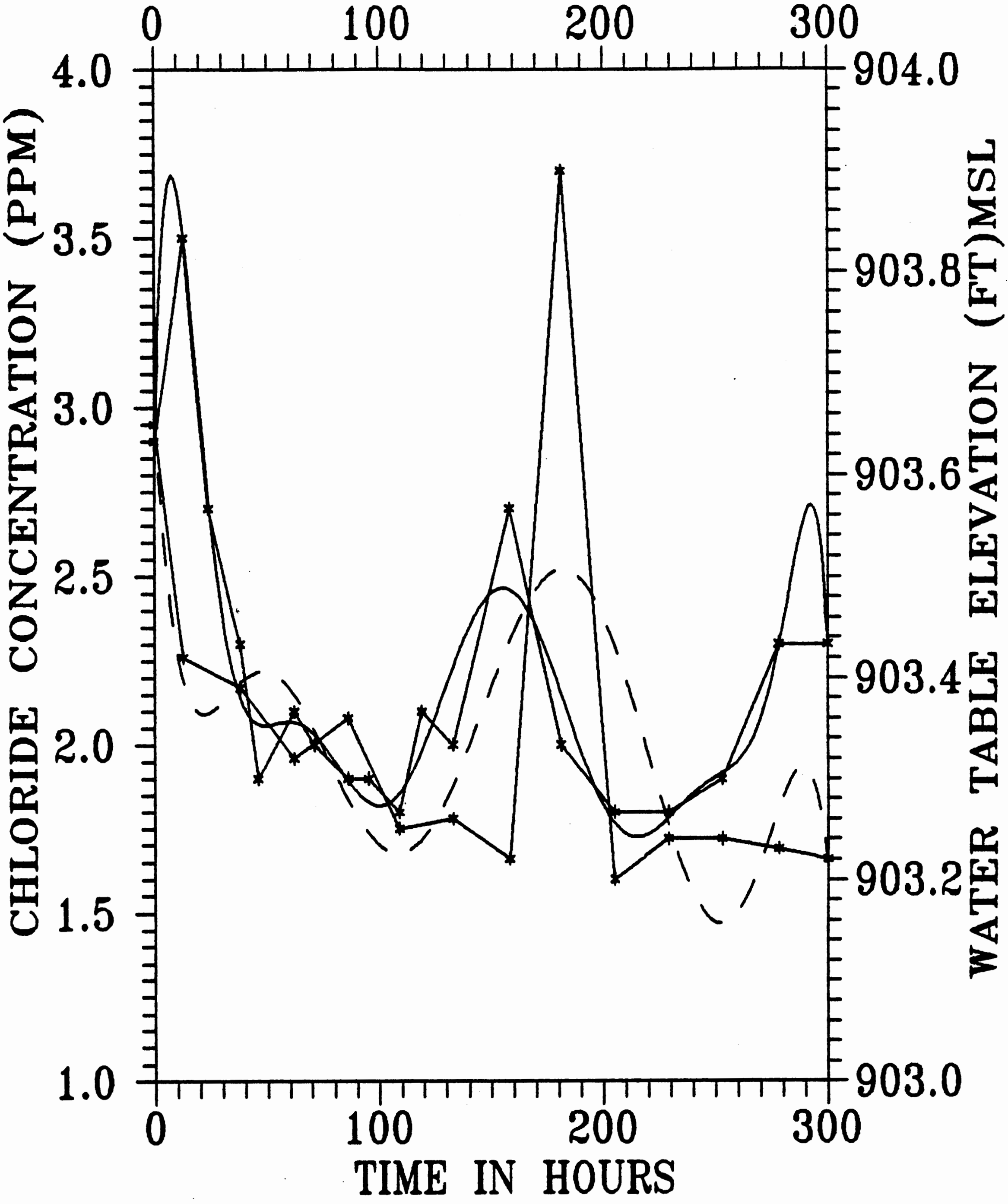

Figure 60. Observed data for Fluorescein and water table elevation (Dashed) for well 16. Polynomial grade 10 for best fit for both curves.

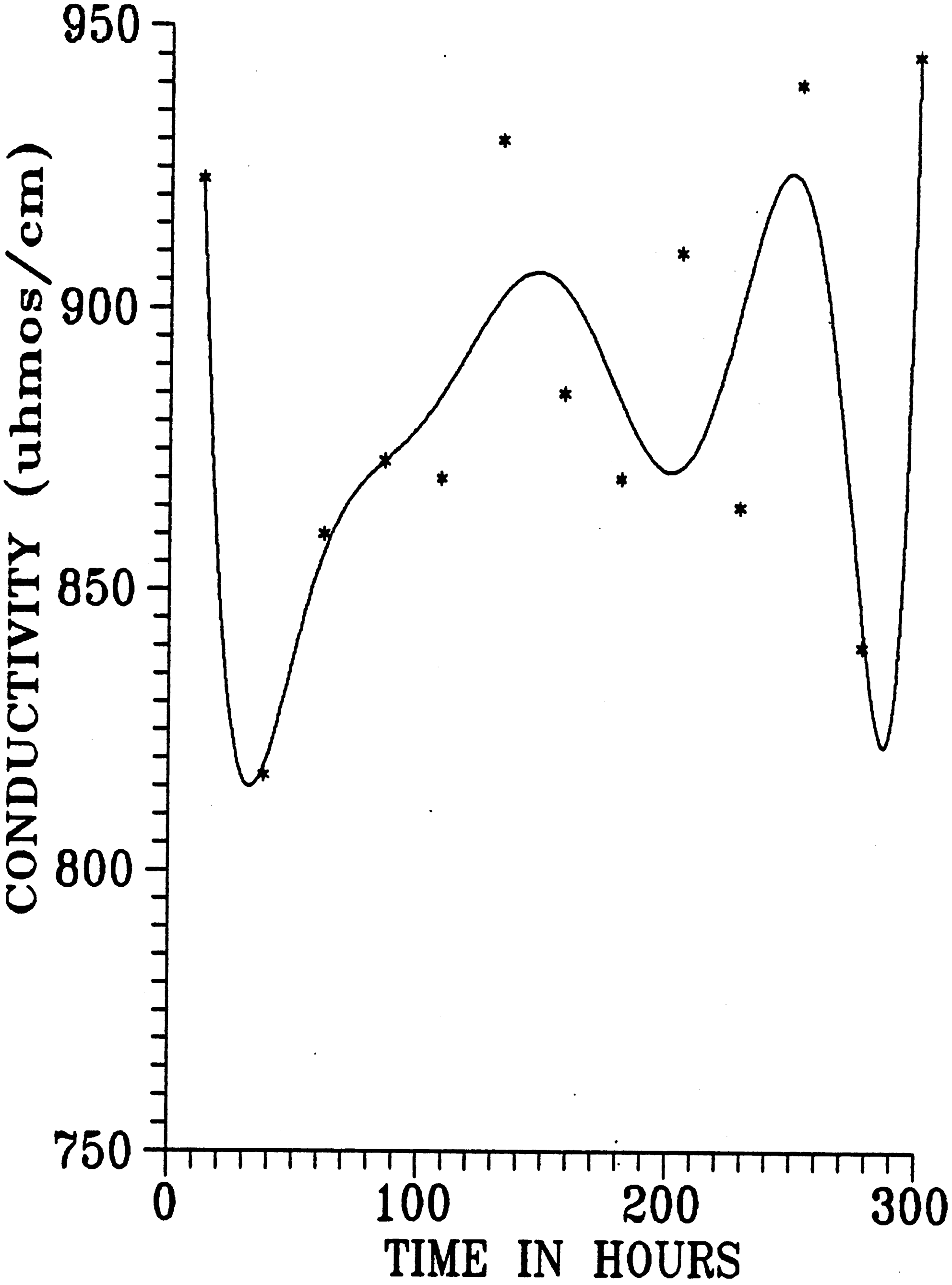

Figure 61. Observed data for Conductivity for well 17. Polynomial grade 9 for best fit.

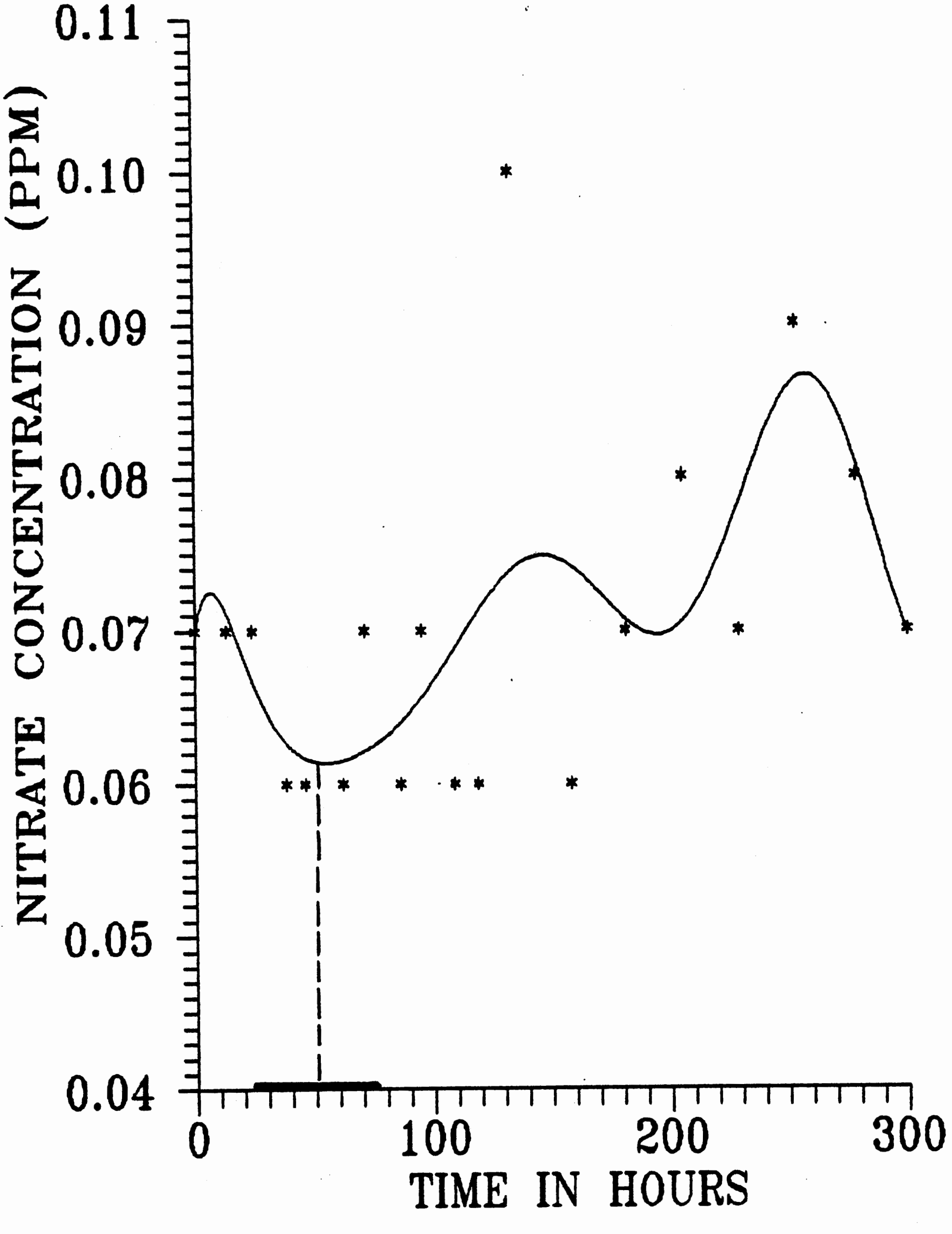

Figure 62. Observed data for Nitrate for
well 17. Polynomial grade 10
for best fit.

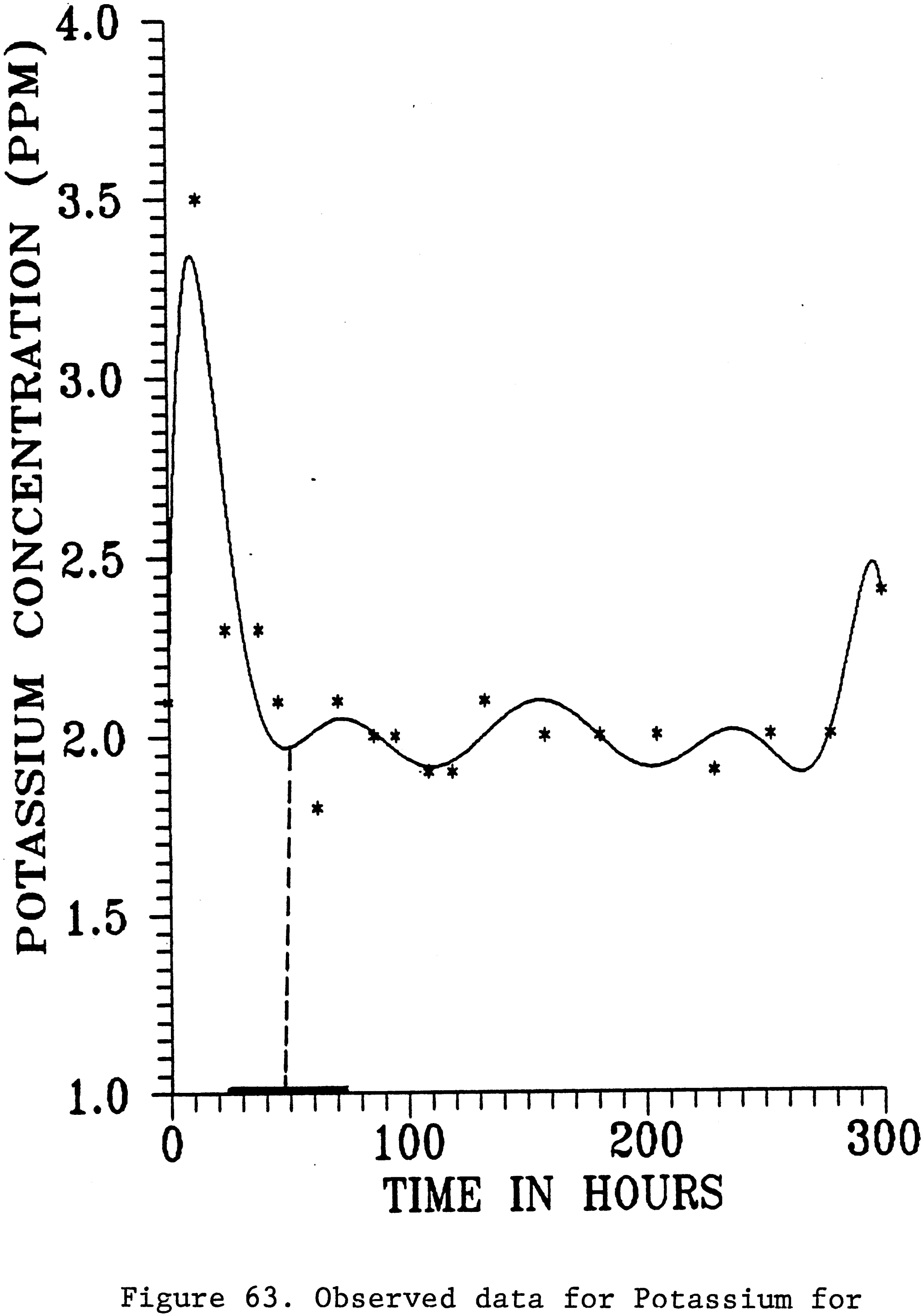

Figure 63. Observed data for Potassium for well 17. Polynomial grade lo for best fit.

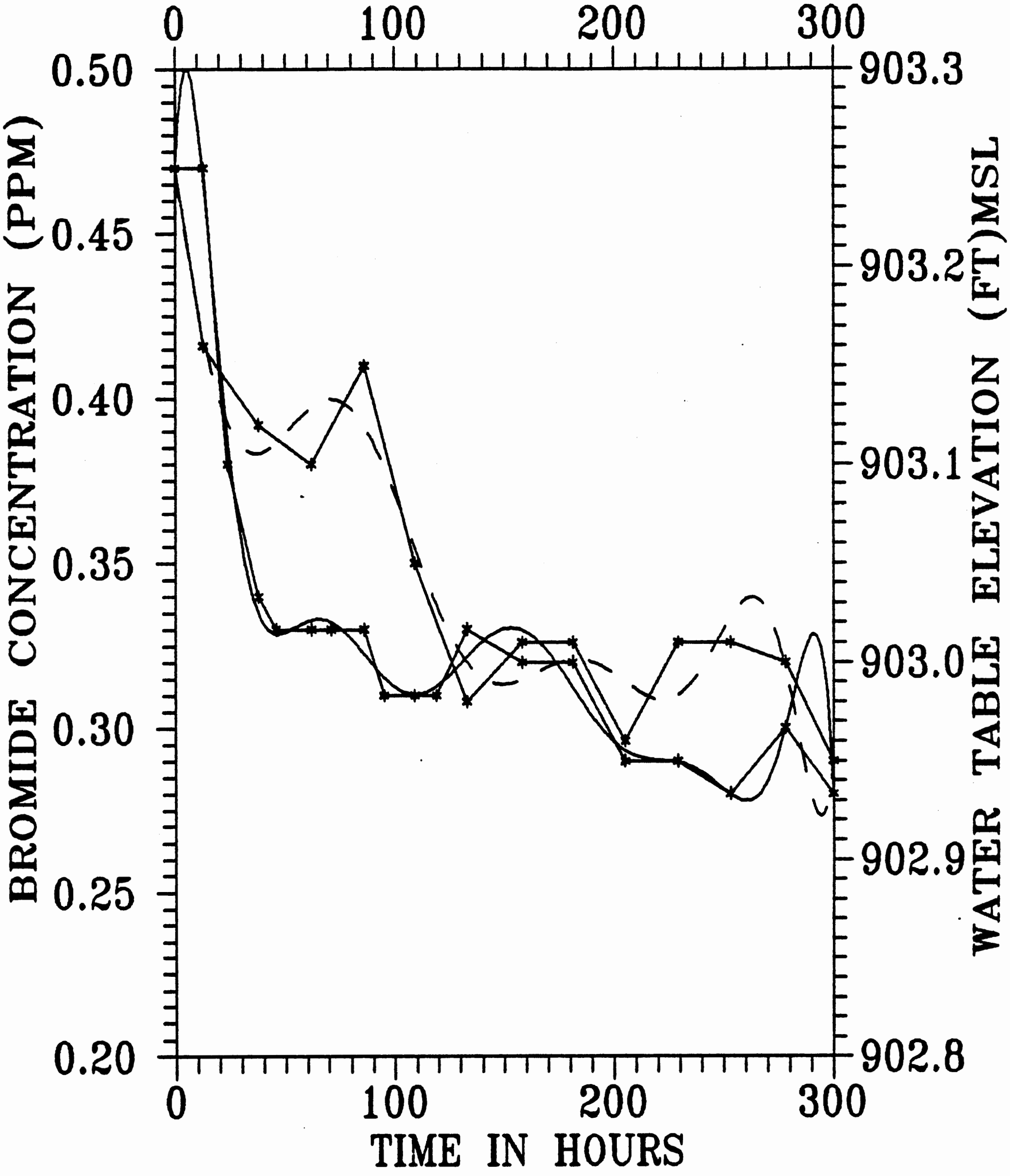

Figure 64. Observed data for Bromide and Water table elevation (Dashed) versus time for well 17. Polynomial grade 10 for best fit for both curves.

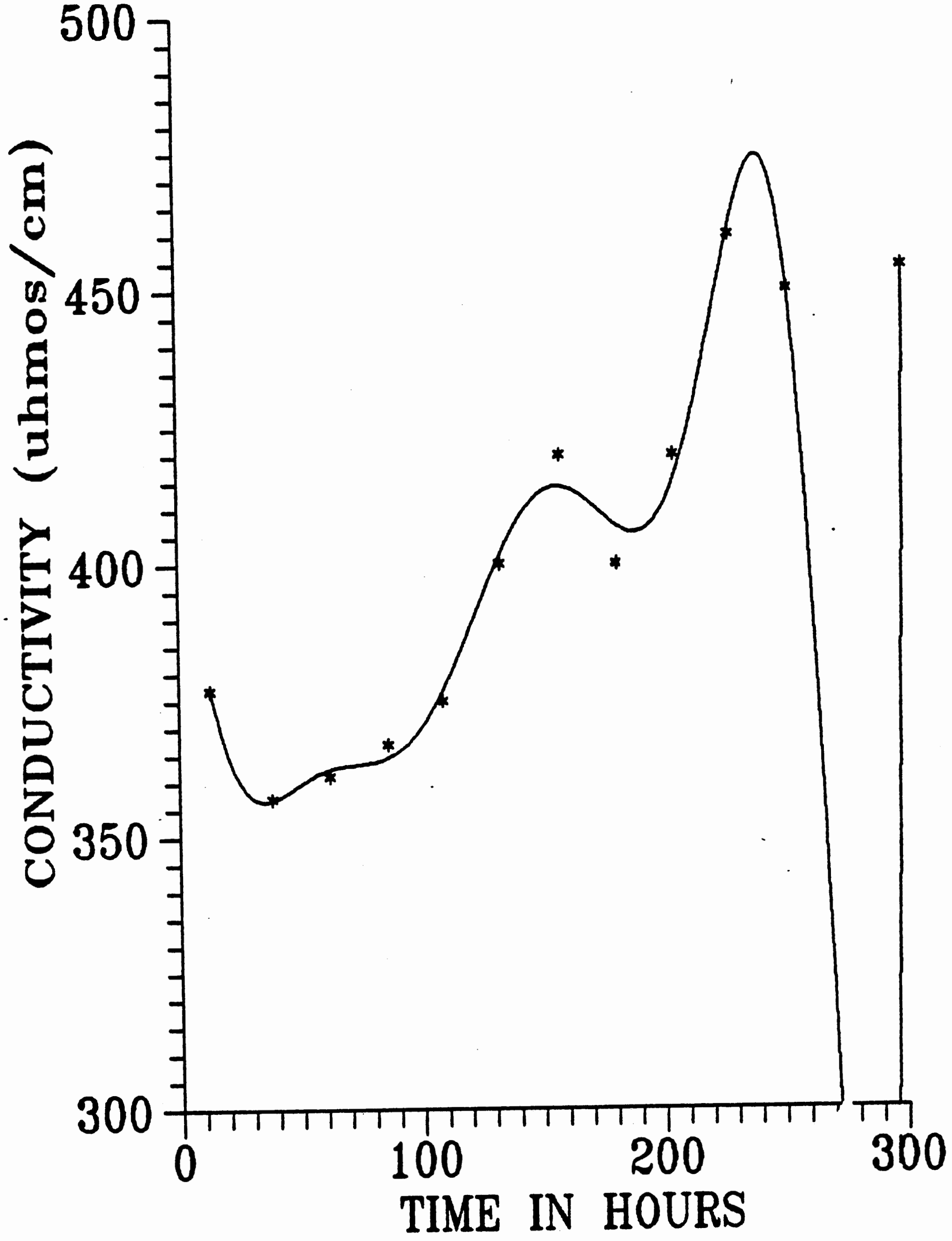

Figure 65. Observed data for Conductivity for well 18. Polynomial grade 9 for best fit.

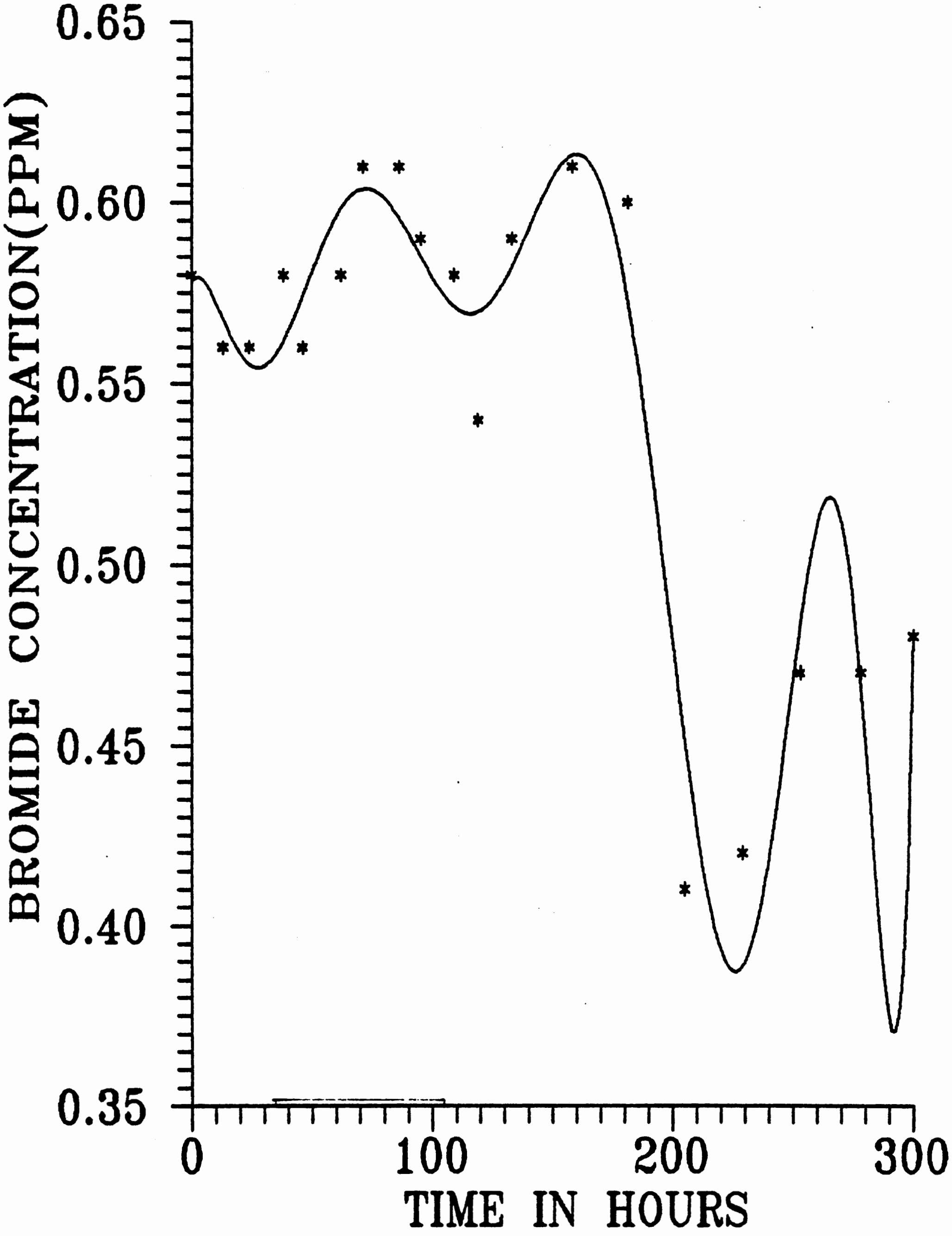

Figure 66. Observed data for Bromide for well 18. Polynomial grade 10 for best fit.

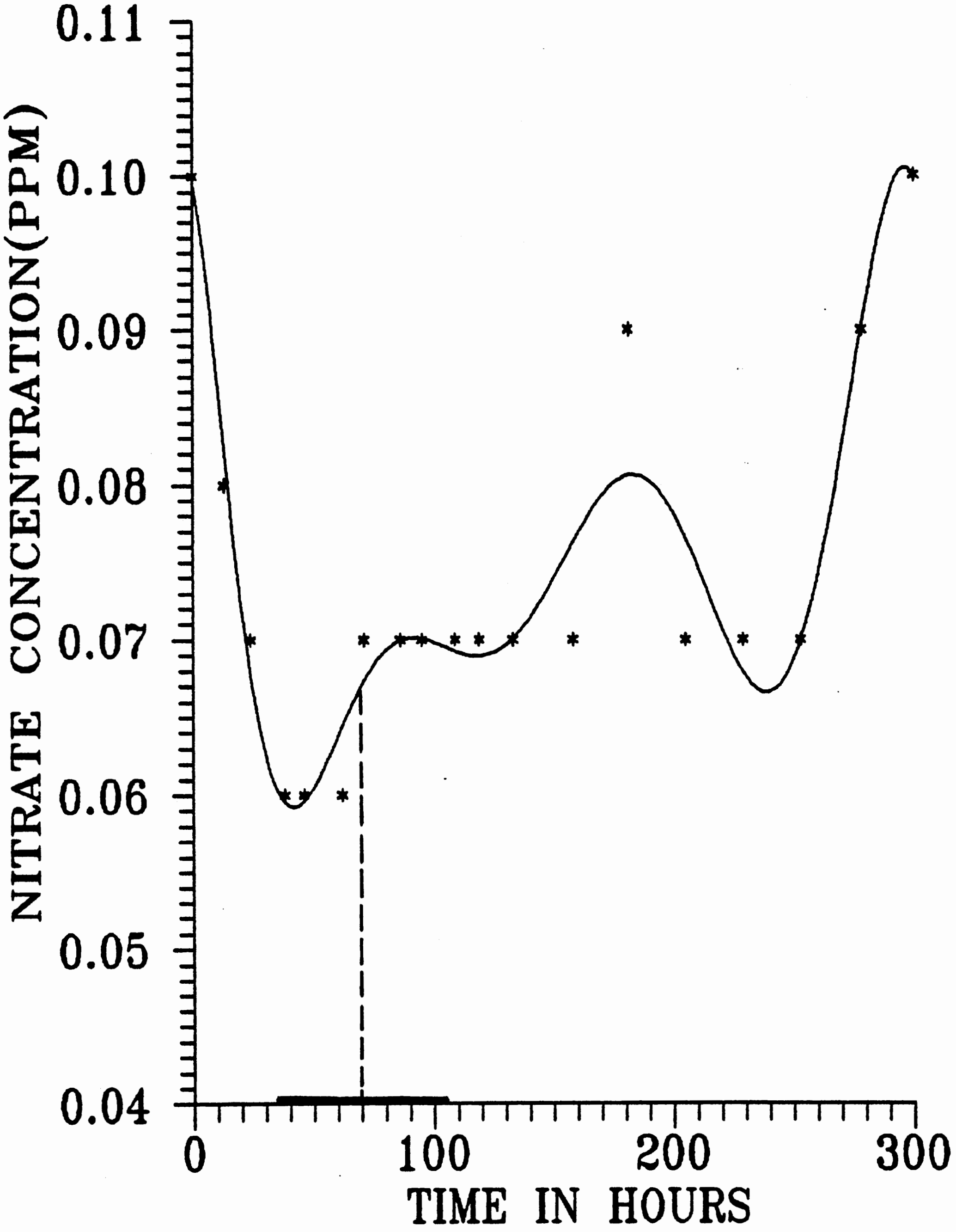

Figure 67. Observed data for Nitrate for well 18. Polynomial grade 9 for best fit.

APPENDIX B

KONIKOW MODEL (MOC, NRC)

```
     METHOD-OF-CHARACTERISTICS MODEL FOR SOLUTE
TRANSPORT IN GROUND WATER
BROMO, 1PP.
                     I N P U T    D A T A
                       GRID DESCRIPTORS
             NX    (NUMBER OF COLUMNS)  =    20
             NY    (NUMBER OF ROWS)     =    20
             XDEL  (X-DISTANCE IN FEET) =     2.0
             YDEL  (Y-DISTANCE IN FEET) =     2.0
                       TIME  PARAMETERS
             NTIM   (MAX. NO. OF TIME STEPS)       =     14
             NPMP   (NO. OF PUMPING PERIODS)       =      1
             PINT   (PUMPING PERIOD IN YEARS)     =     .038
             TIMX  (TIME INCREMENT MULTIPLIER)    =     1.00
             TINIT (INITIAL TIME STEP IN SEC.)   =  .86E+05
              HYDROLOGIC AND CHEMICAL PARAMETERS
             S      (STORAGE COEFFICIENT)       =     .400000
             POROS   (EFFECTIVE POROSITY)        =         .20
             BETA    (CHARACTERISTIC LENGTH)     =      75.0
             DLTRAT  (RATIO OF TRANSVERSE TO
                     LONGITUDINAL DISPERSIVITY)  =         .20
             ANFCTR  (RATIO OF T-YY TO T-XX)    =    1.000000
 ***NON-DECAYING SPECIES***
 ***NON-SORBING SPECIES***
 ***ADIP USED***
 ***UNCONFINED AQUIFER***
                     EXECUTION PARAMETERS
             NITP   (NO. OF ITER. PARAM  - ADIP)  =    4
             TOL    (CONVERGENCE CRITERIA)       =     .0100
             ITMAX  (MAX.NO.OF ITERATIONS)        =   50
             CELDIS (MAX.CELL DISTANCE PER MOVE
                        OF PARTICLES - M.O.C.)    =      .200
             NPMAX  (MAX. NO. OF PARTICLES)       = 6400
             NPTPND (NO. PARTICLES PER NODE)      =     4
                       PROGRAM OPTIONS
             NPNT   (TIME STEP INTERVAL FOR
                     COMPLETE PRINTOUT)      =     1
             NPNTMV (MOVE INTERVAL FOR CHEM.
                     CONCENTRATION PRINTOUT) =     0
             NPNTVL (PRINT OPTION-VELOCITY
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)       =     0
             NPNTD  (PRINT OPTION-DISP.COEF.
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)       =     0
             NUMOBS (NO. OF OBSERVATION WELLS
                     FOR HYDROGRAPH PRINTOUT) =    4
             NREC   (NO. OF PUMPING WELLS)    =    0
             NCODES (FOR NODE IDENT.)         =    1
             NPNCHV (PUNCH VELOCITIES)        =    0
             NPDELC (PRINT OPT.-CONC. CHANGE) =    0
```

```
LOCATION OF OBSERVATION WELLS
            NO.     X     Y
             1     19    10
             2     18    10
             3     16    10
             4     15    10
     AREA OF ONE CELL =   4.0000E+00
     X-Y SPACING:
          2.0000
          2.0000
```

```
        OBS.WELL NO.     X     Y
               2         18    10

HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

.9000E+03      .0000E+00       .0000E+00

.9002E+03      .2117E+04       .2725E-02

.9002E+03      .3771E+04       .5450E-02

.9002E+03      .7880E+04       .8176E-02

.9002E+03      .1680E+04       .1090E-01

.9002E+03      .1622E+04       .1363E-01

.9002E+03      .7795E+05       .1635E-01

.9002E+03      .2665E+05       .1908E-01

.9002E+03      .3079E+04       .2180E-01

.9002E+03      .7875E+02       .2453E-01

.9002E+03     -.2650E+01       .2725E-01

.9002E+03     -.3540E-01       .2998E-01

.9002E+03     -.5194E-02       .3270E-01

.9002E+03     -.1606E-03       .3543E-01

.9002E+03     -.2340E-03       .3800E-01
```

```
          OBS.WELL NO.     X      Y

                 3          16    10
   HEAD (FT)      CONC.(MG/L)     TIME (YEARS)

  .9000E+03        .0000E+00        .0000E+00

  .9008E+03        .2147E+04        .2725E-02

  .9008E+03        .3966E+04        .5450E-02

  .9008E+03        .7913E+03        .8176E-02

  .9008E+03        .1733E+03        .1090E-01

  .9008E+03        .3628E+02        .1363E-01

  .9008E+03        .7774E+02        .1635E-01

  .9008E+03        .1672E+02        .1908E-01

  .9008E+03        .3595E+01        .2180E-01

  .9008E+03       -.7708E+01        .2453E-01

  .9008E+03       -.1657E-01        .2725E-01

  .9008E+03       -.3552E-01        .2998E-01

  .9008E+03       -.7627E-02        .3270E-01

  .9008E+03       -.1634E-02        .3543E-01

  .9008E+03       -.3355E-03        .3800E-01
```

```
    TIME VERSUS HEAD AND CONCENTRATION AT SELECTED OBSERVATION
                       POINTS
                PUMPING PERIOD NO.    1
                TRANSIENT  SOLUTION
                   OBS.WELL NO.    X     Y
                        1         19    10

     HEAD (FT)      CONC.(MG/L)     TIME (YEARS)

    .9000E+03        .0000E+00        .0000E+00

    .9002E+03       .2017E+04        .2725E-02

    .9002E+03       .3751E+04        .5450E-02

    .9002E+03       .7879E+03        .8176E-02

    .9002E+03       .1686E+03        .1090E-01

    .9002E+03       .1612E+03        .1363E-01

    .9002E+03       .7744E+02        .1635E-01

    .9002E+03       .1665E+02        .1908E-01

    .9002E+03       .3579E+01        .2180E-01

    .9002E+03      -.7675E-01         .2453E-01

    .9002E+03      -.1650E-01         .2725E-01

    .9002E+03      -.3538E-02         .2998E-01

    .9002E+03      -.7594E-02         .3270E-01

    .9002E+03      -.1626E-03         .3543E-01

    .9002E+03      -.3341E-03         .3800E-01
```

```
           OBS.WELL NO.      X     Y
                   4        15    10
     HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

    .9000E+03        .0000E+00       .0000E+00

    .9013E+03        .2122E+04       .2725E-02

    .9014E+03        .3806E+04       .5450E-02

    .9014E+03        .8006E+03       .8176E-02

    .9014E+03        .1712E+03       .1090E-01

    .9014E+03        .3670E+02       .1363E-01

    .9014E+03        .7853E+02       .1635E-01

    .9014E+03        .1690E+02       .1908E-01

    .9014E+03        .3639E+01       .2180E-01

    .9014E+03       -.7793E+01       .2453E-01

    .9014E+03         -.1677E-01       .2725E-01

    .9014E+03         -.3588E-01       .2998E-01

    .9014E+03         -.7713E-02       .3270E-01

    .9014E+03         -.1651E-02       .3543E-01

    .9014E+03         -.3391E-03       .3800E-01
```

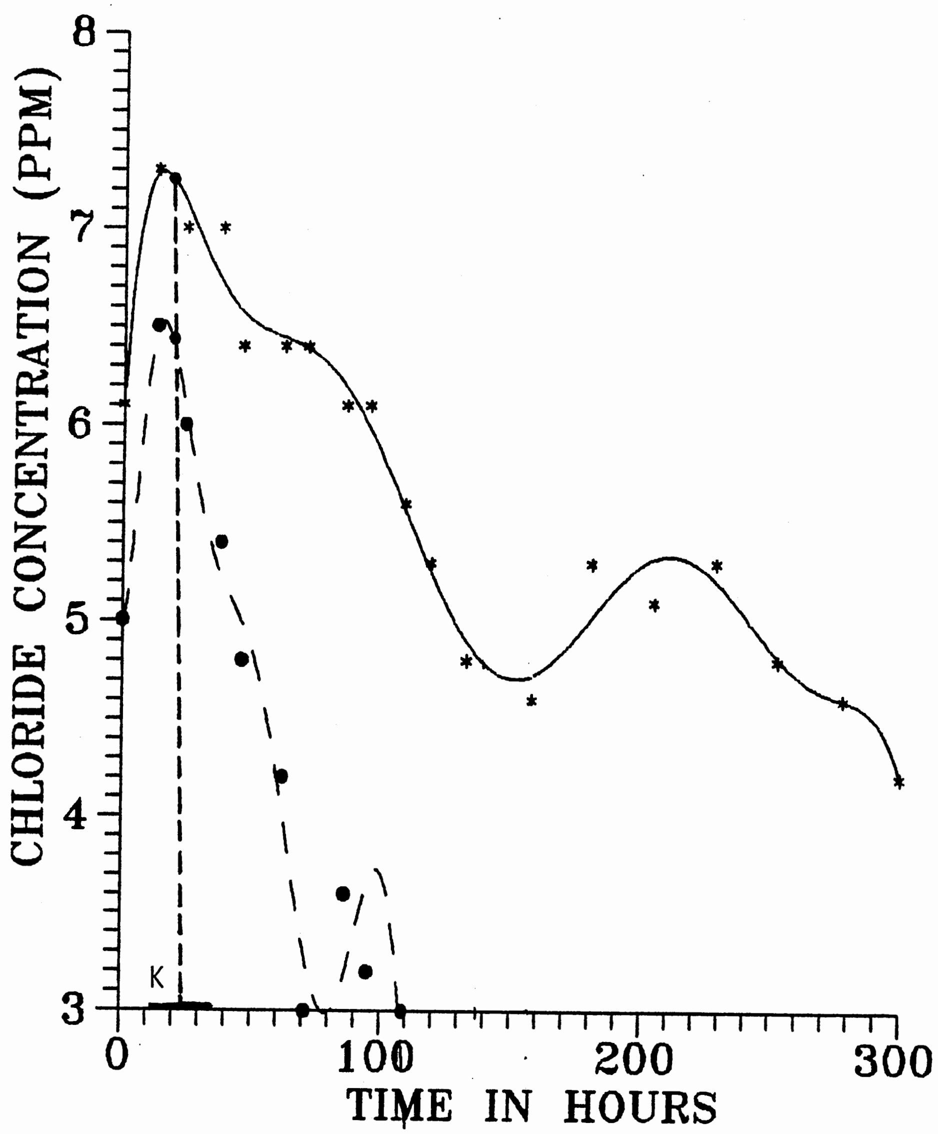

Figure 68. Observed data (*) and Simulated data (dots and dashed) for Chloride for well 15 Polynomial grade 9 for best fit.

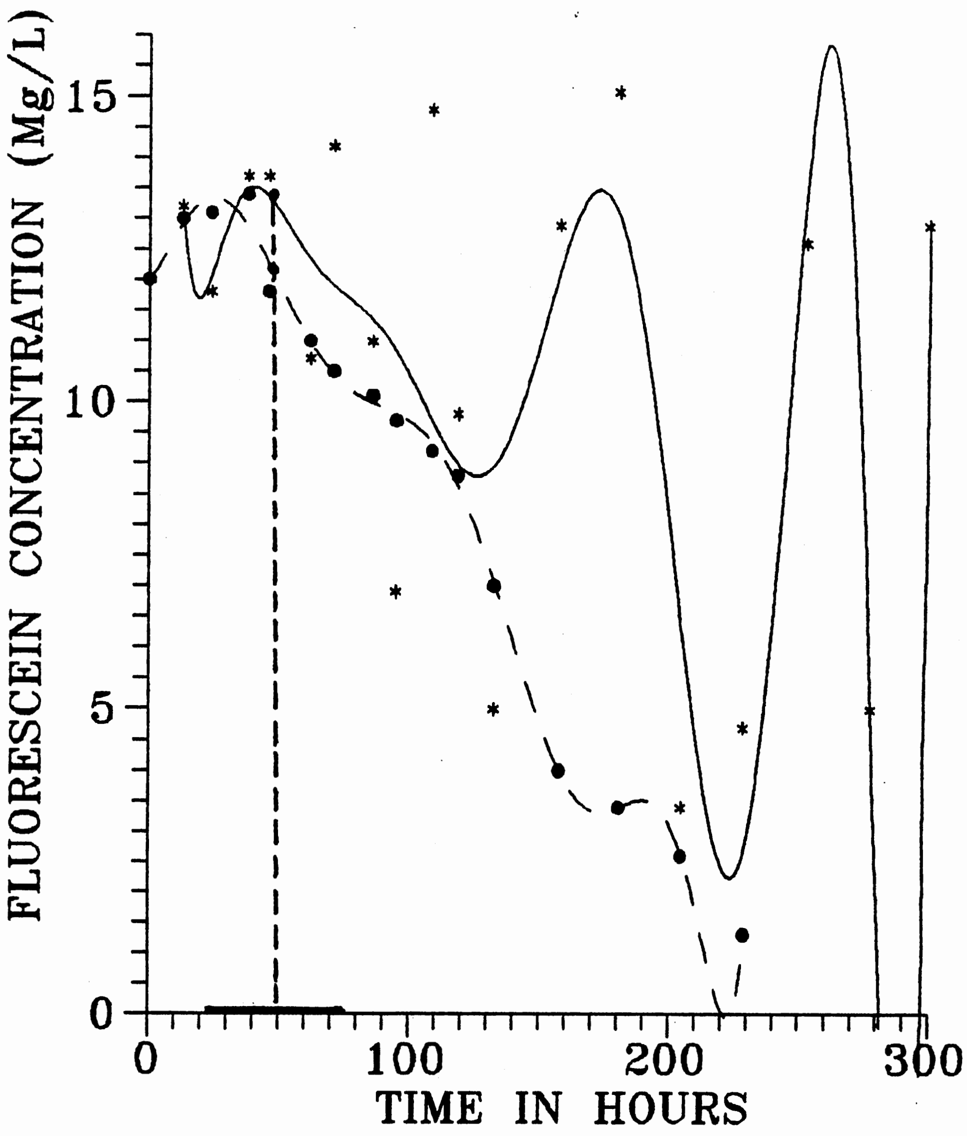

Figure 69. Observed data (*) and Simulated data (dots and dashed) for Fluorescein for well 16. Polynomial grade 10 for best fit.

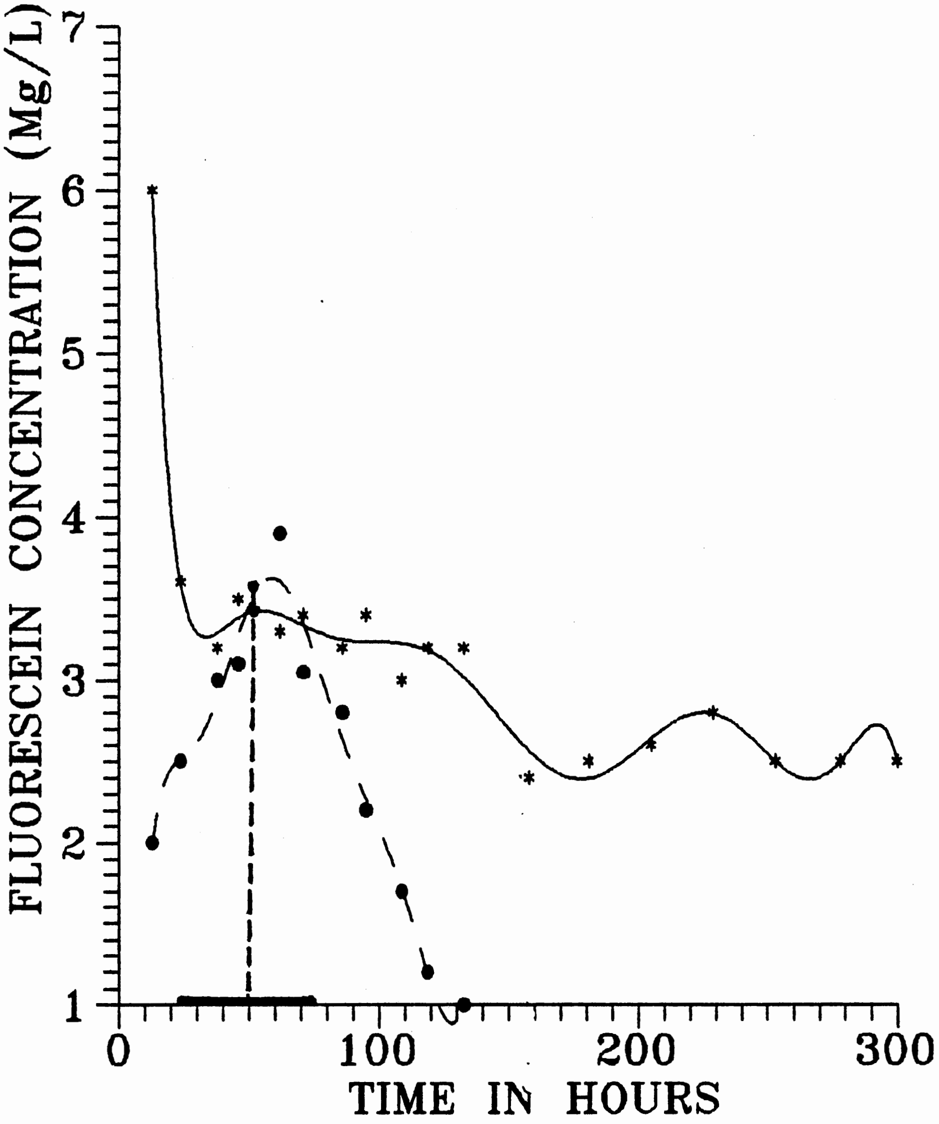

Figure 70. Observed data (*) and Simulated data (dots and dashed) for Fluorescein for well 17. Polynomial grade 10 for best fit.

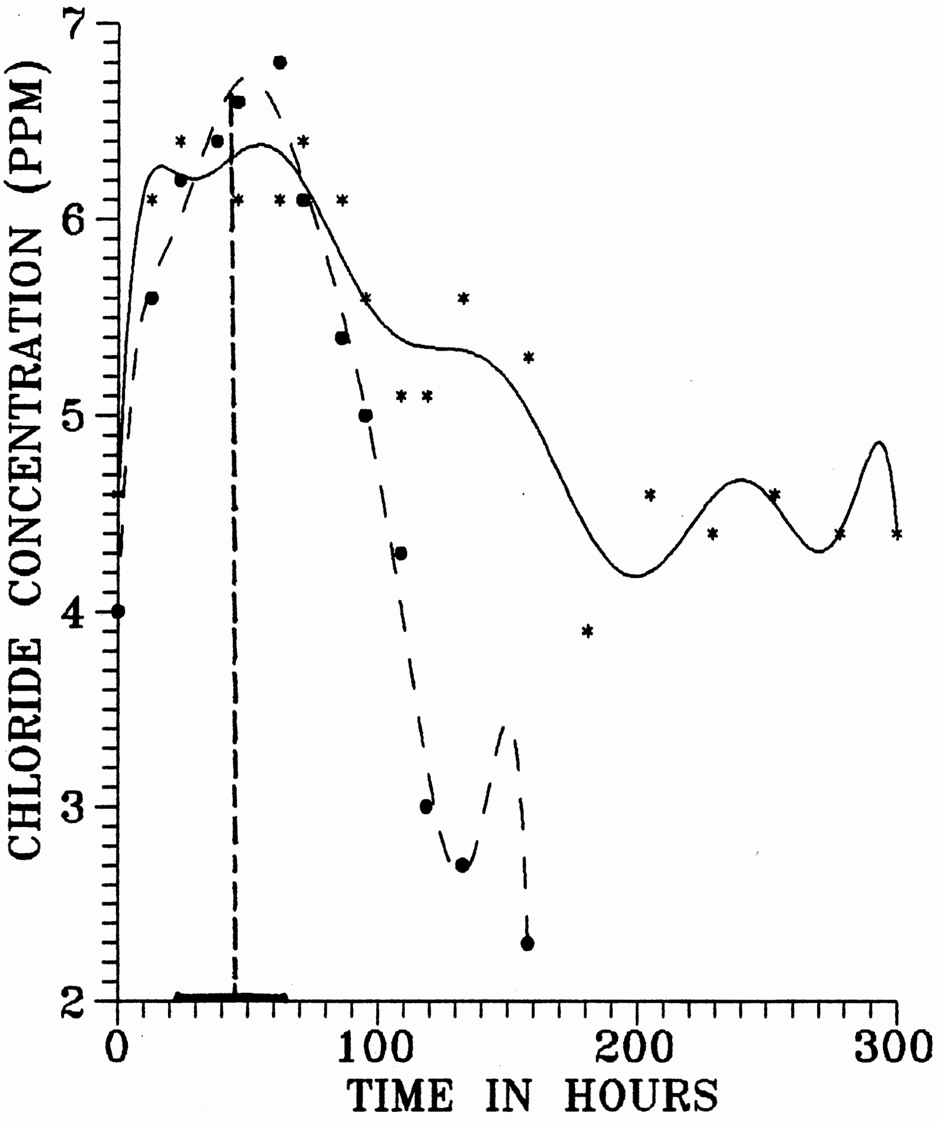

Figure 71. Observed data (*) and Simulated data (dots and dashed) for Chloride for well 17. Polynomial grade 10 for best fit.

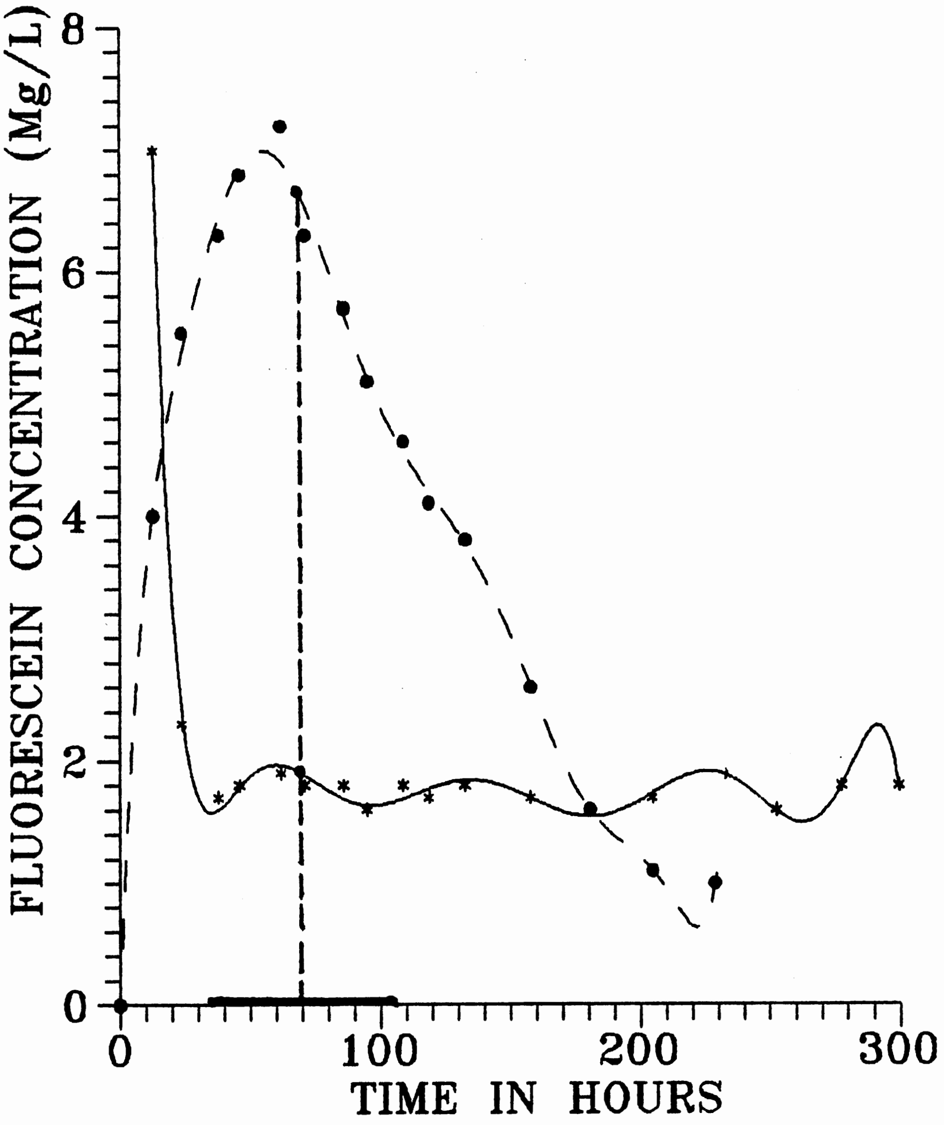

Figure 72. Observed data (*) and Simulated data (dots and dashed) for Fluorescein for well 18. Polynomial grade 9 for best fit.

```
U.S.G.S. METHOD-OF-CHARACTERISTICS MODEL FOR SOLUTE TRANSPORT
IN GROUND WATER
FLUOROCEIN   SIMULATION,   30   GAL,   1/14/1992,   INITIAL
CONCENTRATION
                     I N P U T    D A T A
                       GRID DESCRIPTORS
             NX    (NUMBER OF COLUMNS)  =    20
             NY    (NUMBER OF ROWS)     =    20
             XDEL  (X-DISTANCE IN FEET) =     2.0
             YDEL  (Y-DISTANCE IN FEET) =     2.0
                       TIME  PARAMETERS
             NTIM   (MAX. NO. OF TIME STEPS)        =      4
             NPMP   (NO. OF PUMPING PERIODS)        =      4
             PINT   (PUMPING PERIOD IN YEARS)      =    0.011
             TIMX   (TIME INCREMENT MULTIPLIER)    =     1.00
             TINIT  (INITIAL TIME STEP IN SEC.)    =   .86E+05
              HYDROLOGIC AND CHEMICAL PARAMETERS
             S  (STORAGE COEFFICIENT)             =   .400000
             POROS    (EFFECTIVE POROSITY)        =       .20
             BETA     (CHARACTERISTIC LENGTH)     =     75.0
             DLTRAT  (RATIO OF TRANSVERSE TO
                     LONGITUDINAL DISPERSIVITY)  =       .20
             ANFCTR (RATIO OF T-YY TO T-XX)      =  1.000000
 ***NON-DECAYING SPECIES***
 ***NON-SORBING SPECIES***
 ***ADIP USED***
 ***UNCONFINED AQUIFER***
                     EXECUTION PARAMETERS
             NITP   (NO. OF ITER. PARAM  - ADIP)  =    4
             TOL    (CONVERGENCE CRITERIA)       =      .0100
             ITMAX  (MAX.NO.OF ITERATIONS)        =   50
             CELDIS (MAX.CELL DISTANCE PER MOVE
                        OF PARTICLES - M.O.C.)    =      .200
             NPMAX  (MAX. NO. OF PARTICLES)       = 3200
             NPTPND (NO. PARTICLES PER NODE)      =     4
                       PROGRAM OPTIONS
             NPNT   (TIME STEP INTERVAL FOR
                     COMPLETE PRINTOUT)        =     5
             NPNTMV (MOVE INTERVAL FOR CHEM.
                     CONCENTRATION PRINTOUT)   =     0
             NPNTVL (PRINT OPTION-VELOCITY
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)         =     0
             NPNTD  (PRINT OPTION-DISP.COEF.
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)         =     0
             NUMOBS (NO. OF OBSERVATION WELLS
                     FOR HYDROGRAPH PRINTOUT) =     3
             NREC   (NO. OF PUMPING WELLS)     =    18
                NCODES (FOR NODE IDENT.)          =      1
                NPNCHV (PUNCH VELOCITIES)         =      0
                NPDELC (PRINT OPT.-CONC. CHANGE)  =      0
```

```
LOCATION OF OBSERVATION WELLS
                                NO.     X     Y

                                 1      2    15
                                 2      2    17
                                 3      2    18
                       LOCATION  OF  PUMPING  WELLS

                        X    Y   RATE(IN CFS)   CONC.

                       19    2   -.124E-03        .00
                       19    3   -.124E-03        .00
                       19    4   -.124E-03        .00
                       19    5   -.124E-03        .00
                       19    6   -.124E-03        .00
                       19    7   -.124E-03        .00
                       19    8   -.124E-03        .00
                       19    9   -.124E-03        .00
                       19   10   -.124E-03        .00
                       19   11   -.124E-03        .00
                       19   12   -.124E-03        .00
                       19   13   -.124E-03        .00
                       19   14   -.124E-03        .00
                       19   15   -.124E-03        .00
                       19   16   -.124E-03        .00
                       19   17   -.124E-03        .00
                       19   18   -.124E-03        .00
                       19   19   -.124E-03        .00
                      AREA OF ONE CELL =   4.0000E+00
                              X-Y SPACING:
                                2.0000
                                2.0000
```

```
TIME VERSUS HEAD AND CONCENTRATION AT SELECTED OBSERVATION
              POINTS PUMPING PERIOD NO. 1
                   TRANSIENT  SOLUTION

                    OBS.WELL NO.    X    Y

                         1          2   15

   N      HEAD (FT)    CONC.(MG/L)    TIME (YEARS)

    0    .9037E+03      .0000E+00      .0000E+00

    1    .9037E+03      .0000E+00      .2725E-02

    2    .9037E+03      .0000E+00      .5450E-02

    3    .9037E+03      .0000E+00      .8176E-02

    4    .9037E+03      .0000E+00      .1090E-01
                OBS.WELL NO.    X    Y
                     2          2   17
   N      HEAD (FT)    CONC.(MG/L)    TIME (YEARS)

  0         .9037E+03      .0000E+00       .0000E+00

    1    .9037E+03      .0000E+00      .2725E-02

    2    .9037E+03      .0000E+00      .5450E-02

    3    .9037E+03      .0000E+00      .8176E-02

    4    .9037E+03      .0000E+00      .1090E-01
                 OBS.WELL NO.    X    Y
                    3          2   18
       HEAD (FT)    CONC.(MG/L)    TIME (YEARS)

    0    .9037E+03      .0000E+00      .0000E+00

    1    .9037E+03      .0000E+00      .2725E-02

    2    .9037E+03      .0000E+00      .5450E-02

    3    .9037E+03      .0000E+00      .8176E-02

    4    .9037E+03      .0000E+00      .1090E-01
```

```
START PUMPING PERIOD NO.  2

THE FOLLOWING TIME STEP, PUMPAGE, AND PRINT PARAMETERS
                HAVE BEEN REDEFINED:

                          NTIM    =    4
                           NPNT   =     5
                           NITP   =     4
                           ITMAX  =    50
                           NREC   =    36
                           NPNTMV =     0
                           NPNTVL =     0
                           NPNTD  =     0
                           NPDELC =     0
                           NPNCHV =     0
                      PINT    =          .011
                      TIMX    =         1.000
                      TINIT   =  86000.000

                LOCATION  OF  PUMPING  WELLS

                 X    Y   RATE(IN CFS)   CONC.

                19    2   -.124E-03         .00
                19    3   -.124E-03         .00
                19    4   -.124E-03         .00
                19    5   -.124E-03         .00
                19    6   -.124E-03         .00
                19    7   -.124E-03         .00
                19    8   -.124E-03         .00
                19    9   -.124E-03         .00
                19   10   -.124E-03         .00
                19   11   -.124E-03         .00
                19   12   -.124E-03         .00
                19   13   -.124E-03         .00
                19   14   -.124E-03         .00
                19   15   -.124E-03         .00
                19   16   -.124E-03         .00
                19   17   -.124E-03         .00
                19   18   -.124E-03         .00
                 19   19   -.124E-03         .00
                13    2    .371E-02         .00
                13    3    .371E-02         .00
                13    4    .371E-02         .00
                13    5    .371E-02         .00
                13    6    .371E-02         .00
                13    7    .371E-02         .00
```

```
13   8   .371E-02        .00
13   9   .371E-02        .00
13  10   .371E-02        .00
13  11   .371E-02        .00
13  12   .371E-02        .00
13  13   .371E-02        .00
13  14   .371E-02        .00
13  15   .371E-02        .00
13  16   .371E-02        .00
13  17   .371E-02        .00
13  18   .371E-02        .00
13  19   .371E-02        .00
```

```
TIME VERSUS HEAD AND CONCENTRATION AT SELECTED OBSERVATION
             POINTS PUMPING PERIOD NO.    2

                      TRANSIENT  SOLUTION

                   OBS.WELL NO.    X    Y

                      1            2   15

  N      HEAD (FT)     CONC.(MG/L)     TIME(YR) 0
      .9037E+03       .0000E+00       .0000E+00

   1    .9037E+03       .0000E+00       .1363E-01

   2    .9037E+03       .0000E+00       .1635E-01

   3    .9037E+03       .0000E+00       .1908E-01

   4    .9037E+03       .0000E+00       .2180E-01
                   OBS.WELL NO.    X    Y
                        2          2    17

   N      HEAD (FT)     CONC.(MG/L)     TIME (YEAR)
   0    .9037E+03       .0000E+00       .0000E+00

   1    .9037E+03       .0000E+00       .1363E-01

   2    .9037E+03       .0000E+00       .1635E-01

   3    .9037E+03       .0000E+00       .1908E-01

   4    .9037E+03       .0000E+00       .2180E-01
                  OBS.WELL NO.    X    Y
                     3            2   18
  N      HEAD (FT)    CONC.(MG/L)     TIME (YEARS)

   0    .9037E+03       .0000E+00       .0000E+00

   1    .9037E+03       .0000E+00       .1363E-01

   2    .9037E+03       .0000E+00       .1635E-01

   3    .9037E+03       .0000E+00       .1908E-01

   4    .9037E+03       .0000E+00       .2180E-01
```

```
 START PUMPING PERIOD NO.  3
THE FOLLOWING TIME STEP, PUMPAGE, AND PRINT PARAMETERS
                HAVE BEEN REDEFINED:
                           NTIM    =    1
                            NPNT    =    1
                            NITP    =    4
                            ITMAX  =   50
                            NREC    =   36
                            NPNTMV =   36
                            NPNTVL =    0
                            NPNTD  =    0
                            NPDELC =    0
                            NPNCHV =    0
                        PINT    =        .003
                        TIMX    =       1.000
                        TINIT   =  86000.000
                  LOCATION  OF  PUMPING  WELLS
                   X    Y   RATE(IN CFS)   CONC.
                  19    2   -.124E-03    9270.00
                  19    3   -.124E-03    9270.00
                  19    4   -.124E-03    9270.00
                  19    5   -.124E-03    9270.00
                  19    6   -.124E-03    9270.00
                  19    7   -.124E-03    9270.00
                  19    8   -.124E-03    9620.00
                  19    9   -.124E-03    9270.00
                  19   10   -.124E-03    9270.00
                  19   11   -.124E-03    9270.00
                  19   12   -.124E-03    9270.00
                  19   13   -.124E-03    9270.00
                  19   14   -.124E-03    9270.00
                  19   15   -.124E-03    9270.00
                  19   16   -.124E-03    9270.00
                  19   17   -.124E-03    9270.00
                  19   18   -.124E-03    9270.00
                  19   19   -.124E-03    9270.00
                  13    2    .371E-02        .00
                  13    3    .371E-02        .00
                  13    4    .371E-02        .00
                  13    5    .371E-02        .00
                  13    6    .371E-02        .00
                  13    7    .371E-02        .00
                  13    8    .371E-02        .00
                  13    9    .371E-02        .00
                  13   10    .371E-02        .00
                  13   11    .371E-02        .00
                  13   12    .371E-02        .00
```

```
                    13  13    .371E-02         .00
                    13  14    .371E-02         .00
                    13  15    .371E-02         .00
                    13  16    .371E-02         .00
                    13  17    .371E-02         .00
                    13  18    .371E-02         .00
                    13  19    .371E-02         .00




TIME VERSUS HEAD AND CONCENTRATION AT SELECTED OBSERVATION
               POINTS PUMPING PERIOD NO.    3
                          TRANSIENT  SOLUTION

                    OBS.WELL NO.     X     Y
                           1          2    15
          HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

        0     .9037E+03       .0000E+00       .0000E+00

        1     .9037E+03       .1288E+04       .2453E-01
                    OBS.WELL NO.     X     Y
                           2          2    17

          HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

        0     .9037E+03       .0000E+00       .0000E+00

        1     .9037E+03       .1289E+04       .2453E-01
                      OBS.WELL NO.     X     Y
                               3       2    18
     N        HEAD (FT)     CONC.(MG/L)   TIME (YEAR)
             .9037E+03       .0000E+00      .0000E+00

        1     .9037E+03       .1290E+04       .2453E-01
```

```
                 START PUMPING PERIOD NO.  4
      THE FOLLOWING TIME STEP, PUMPAGE, AND PRINT PARAMETERS
                   HAVE BEEN REDEFINED:
                             NTIM    =   14
                              NPNT    =    1
                              NITP    =    4
                              ITMAX  =   50
                              NREC    =   36
                              NPNTMV =    0
                              NPNTVL =    0
                              NPNTD  =    0
                              NPDELC =    0
                              NPNCHV =    0
                         PINT    =        .038
                         TIMX    =       1.000
                         TINIT  =  86000.000
                     LOCATION  OF  PUMPING  WELLS
                      X    Y   RATE(IN CFS)   CONC.
                     19    2   -.124E-03        .00
                     19    3   -.124E-03        .00
                     19    4   -.124E-03        .00
                     19    5   -.124E-03        .00
                     19    6   -.124E-03        .00
                     19    7   -.124E-03        .00
                     19    8   -.124E-03        .00
                     19    9   -.124E-03        .00
                     19   10   -.124E-03        .00
                     19   11   -.124E-03        .00
                     19   12   -.124E-03        .00
                     19   13   -.124E-03        .00
                     19   14   -.124E-03        .00
                     19   15   -.124E-03        .00
                     19   16   -.124E-03        .00
                     19   17   -.124E-03        .00
                     19   18   -.124E-03        .00
                     19   19   -.124E-03        .00
                     13    2    .371E-02        .00
                     13    3    .371E-02        .00
                     13    4    .371E-02        .00
                     13    5    .371E-02        .00
                     13    6    .371E-02        .00
                     13    7    .371E-02        .00
                     13    8    .371E-02        .00
                     13    9    .371E-02        .00
                     13   10    .371E-02        .00
                     13   11    .371E-02        .00
                     13   12    .371E-02        .00
```

```
13  13    .371E-02        .00
13  14    .371E-02        .00
13  15    .371E-02        .00
13  16    .371E-02        .00
13  17    .371E-02        .00
13  18    .371E-02        .00
13  19    .371E-02        .00
```

```
TIME VERSUS HEAD AND CONCENTRATION AT SELECTED OBSERVATION
             POINTS PUMPING PERIOD NO.    4
                       TRANSIENT  SOLUTION

                        OBS.WELL NO.     X     Y

                                1        2    15

     N       HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

       0    .9037E+03      .0000E+00       .0000E+00

        1    .9037E+03      .1264E+04       .2725E-01

       2    .9037E+03      .7455E+03       .2998E-01

       3    .9037E+03      .4370E+03       .3270E-01

       4    .9037E+03      .2569E+03       .3543E-01

       5    .9037E+03      .1506E+03       .3815E-01

       6    .9037E+03      .8833E+02       .4088E-01

       7    .9037E+03      .5185E+02       .4360E-01

       8    .9037E+03      .3043E+02       .4633E-01

       9    .9037E+03      .1784E+02       .4905E-01

      10     .9037E+03      .1048E+02       .5178E-01

      11     .9037E+03      .6146E+01       .5450E-01

      12     .9037E+03      .3607E+01       .5723E-01

      13     .9037E+03      .2119E+01       .5995E-01

      14     .9037E+03      .1244E+01       .6268E-01
```

```
                 OBS.WELL NO.     X     Y

                             2          2    17
   HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

 0     .9037E+03       .0000E+00       .0000E+00

 1     .9037E+03       .1264E+04       .2725E-01

 2     .9037E+03       .7454E+03       .2998E-01

 3     .9037E+03       .4371E+03       .3270E-01

 4     .9037E+03       .2570E+03       .3543E-01

 5     .9037E+03       .1506E+03       .3815E-01

 6     .9037E+03       .8835E+02       .4088E-01

 7     .9037E+03       .5186E+02       .4360E-01

 8     .9037E+03       .3043E+02       .4633E-01

 9     .9037E+03       .1784E+02       .4905E-01

10      .9037E+03       .1048E+02       .5178E-01

11      .9037E+03       .6147E+01       .5450E-01

12      .9037E+03       .3608E+01       .5723E-01

13      .9037E+03       .2119E+01       .5995E-01

14      .9037E+03       .1244E+01       .6268E-01
```

```
                            OBS.WELL NO.     X    Y
                                 3           2   18

        HEAD (FT)     CONC.(MG/L)     TIME (YEARS)

      0     .9037E+03        .0000E+00        .0000E+00

      1     .9037E+03        .1265E+04        .2725E-01

      2     .9037E+03        .7454E+03        .2998E-01

      3     .9037E+03        .4372E+03        .3270E-01

      4     .9037E+03        .2570E+03        .3543E-01

      5     .9037E+03        .1506E+03        .3815E-01

      6     .9037E+03        .8836E+02        .4088E-01

      7     .9037E+03        .5186E+02        .4360E-01

      8     .9037E+03        .3043E+02        .4633E-01

      9     .9037E+03        .1784E+02        .4905E-01

     10      .9037E+03        .1048E+02        .5178E-01

     11      .9037E+03        .6147E+01        .5450E-01

     12      .9037E+03        .3608E+01        .5723E-01

     13      .9037E+03        .2119E+01        .5995E-01

     14      .9037E+03       .1244E+01       .6268E-01
1FLUOROCEIN SIMULATION, 30 GAL, 1/14/1992, INITIAL
                  CONCENTRATION
```

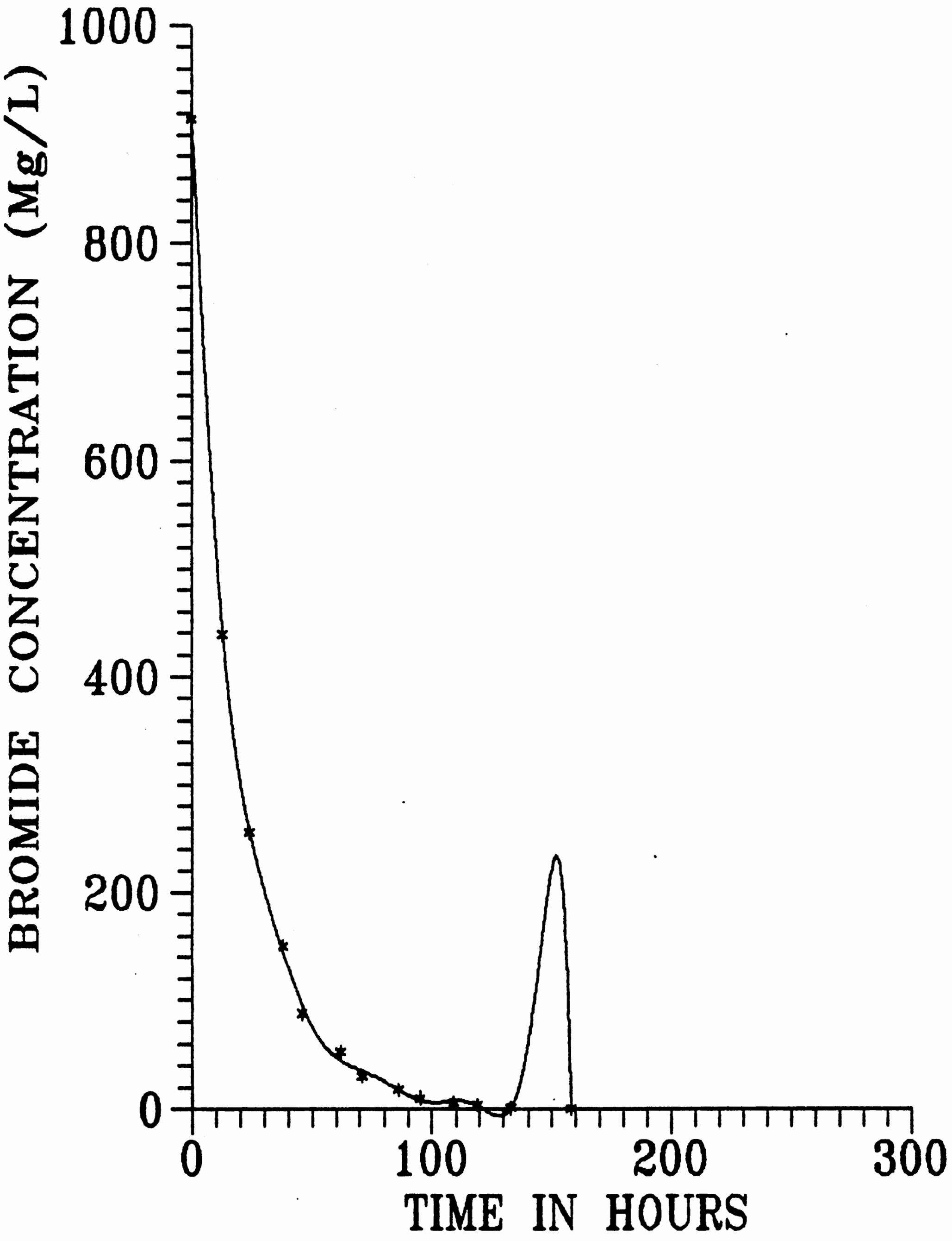

Figure 73. Simulated data for bromide for well 18.

VITA

Atef K. Saad

Candidate For the Degree of

Master of Science

Thesis: THE COMBINED USE OF TRACER TESTS AND GROUND WATER MODELS TO CHARACTERIZE SOLUTE TRANSPORT OF AGRICULTURAL CHEMICALS IN AN ALLUVIAL AQUIFER

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