TABLE OF CONTENTS

PAGE

1.0	INTRODUCTION					
	1.1	Use of	Aquifer Tracer Tests	1		
	1.2	Purpos	se of Present Study	2		
2.0	PRINCIPLES OF CONTAMINANT TRANSPORT					
	2.1	Introd	3			
	22	Groun	3			
		221	4			
		2.2.2	Transient Saturated Flow	5		
	23	Conta	6			
		2.3.1	Physical Processes	6		
			2.3.1.1 Advection	6		
			2.3.1.2 Hydrodynamic Dispersion .	7		
		2.3.2	Chemical Processes	8		
			2.3.2.1 Diffusion	8		
12	2.4	The A	dvective-Dispersive Equation \	9		
3.0	FIELD TRACER TESTS					
	3.1	Types	11			
		3.1.1	Temperature Tracers	12		
		3.1.2	Dye Tracers	12		
		3.1.3	Ionic Tracers	13		
		3.1.4	Radionuclide Tracers	14		
	3.2	Types of Tracer Tests		15		
		3.2.1	Single-Well Tracer Tests	15		
		3.2.2	Two-Well Tracer Tests	17		
4.0	FIELD DATA COLLECTION					
	4.1	Description of Field Site		19		
	4.2	Tracer Test Procedure		23		
		4.2.1	Wells	23		
		4.2.2	Equipment Used	25		
		4.2.3	Tracer Test No. 1	25		
		4.2.4	Tracer Test No. 2	28		
	43	Discus	sion of Results	32		

TABLE OF CONTENTS (Cont'd)

PAGE

36

37

49

50

18

- 5.0 METHODS OF DATA ANALYSES
 - 5.1 Description of Tracer Test Simulation
 - 5.2 Tracer Transport Modeling
- 6.0 CONCLUSIONS

5 A.

180

10

7.0 REFERENCES

FIGURES

PAGE

Figure 3.1	Single Well Tracer Test	16
Figure 3.2	Two Well Tracer Test	18
Figure 4.1	Site Location Map	20
Figure 4.2	Topographic Location Map	21
Figure 4.3	Site Map	22
Figure 4.4	Tracer Test Well Details	24
Figure 4.5	Tracer Test Control Box	26
Figure 4.6	Tracer Test Equipment Layout	27
Figure 4.7	Tracer Test No. 1 Breakthrough Curve	29
Figure 4.8	Tracer Test No. 2 Breakthrough Curve	31
Figure 4.9	Observed Recovery Well Drawdown	34
Figure 5.1	Pumping Stress at Screened Interval	38
Figure 5.2	Two Well Tracer Test - 0 Hours	40
Figure 5.3	Two Well Tracer Test - 2 Hours	41
Figure 5.4	Two Well Tracer Test - 4 Hours	42
Figure 5.5	Two Well Tracer Test - 6 Hours	43
Figure 5.6	Two Well Tracer Test - 26 Hours	44
Figure 5.7	Percent Tracer Recovery vs. Time	46
Figure 5.8	Two Well Tracer Test - 240 Hours	47
Figure 5.9	Two Well Tracer Test - 1000 Hours	48

APPENDICES

an the Links of the

20年4月1日1日1日1日1日1日1日1日1日

2

100

S. LYNNE

Appendix ATracer Test No. 1 DataAppendix BTracer Test No. 2 DataAppendix CComputer Modeling Data FilesAppendix DParticle Tracking Figures

1945.1.30

1.0 INTRODUCTION

1.1 Use of Aquifer Tracer Tests

Due to the increasing number of lawsuits being filed related to groundwater contamination sites, predictions concerning the source of the contamination, its present course and future destination have become the bread and butter of the subsurface hydrology business. In order to procure funding for most contamination remediation efforts, culpable parties and those at risk by the migration of the plume must be identified. The tools most often used to make these predictions are groundwater models.

Mathematical groundwater models require that the user input many site specific aquifer parameters that are used to describe the contaminant transport hydraulics and the subsurface conditions over a site. These parameters include hydraulic conductivity, hydrodynamic dispersion, and contaminant sorption and decay, either chemical or biological.

The hydraulic conductivity of an aquifer is a property of a water bearing formation that is defined as the capacity of a porous medium to transmit water. The conductivity when used in model calculations with the gradient and porosity determines the average direction and rate of groundwater flow. The transport of solutes in the direction of the flowing groundwater is called advection. Hydraulic conductivity can vary over a site not only in a horizontal plane but also vertically. In order to obtain accurate modeling results over a large area with different conductivities, these variations should be taken into account.

Hydrodynamic dispersion describes the spreading and dilution of a contaminant from the path that it would be expected to follow according to the bulk motion of the flowing groundwater. The spreading can occur in the longitudinal direction (the direction of the flowing groundwater) and in a transverse direction (perpendicular to the principle direction of flow). Hydrodynamic dispersion occurs due to mechanical mixing of the groundwater during advection and due to molecular diffusion of the contaminant.

Aquifer tracer tests may be performed to identify the spatial variability of hydraulic conductivity within an aquifer, and to estimate the effective hydrodynamic dispersion using tracer breakthrough data obtained during the test. This can be accomplished by packing off sections of fully penetrating well screens and performing tracer tests at different vertical locations within the aquifer. By separately analyzing these data sets, a set of hydraulic parameters can be estimated for each selected screened interval.

1.2 Purpose of Present Study

The main objective of this study was to obtain a better understanding of the groundwater flow pattern that is present at a particular area of a research site by measuring certain aquifer parameters. The groundwater at the site had become contaminated with gasoline due to the failure of underground storage tanks and associated piping. One of the first phases of the field study involved the installation of groundwater monitoring wells; these included two pairs of wells specifically designed for tracer studies. Two two-well field tracer studies were then performed using each pair of wells.

The tracer tests had three objectives: (1) estimate aquifer parameters of the area in question, (2) compare the field results to literature values; and (3) to confirm the field results with modeling.

2.0 PRINCIPLES OF CONTAMINANT TRANSPORT

2.1 Introduction

In order to adequately understand contaminant transport in groundwater, the processes and equations that are used to describe groundwater flow must be studied. The groundwater flow equations form the basis for the transport equations because the bulk of the contamination in the groundwater will propagate in the direction of and at a velocity equal to the average linear groundwater velocity. This process is known as advection.

In addition to advection, localized processes that affect the transport of solutes within a groundwater system are also very important to contaminant transport modeling. The phenomena of contaminant dispersion, sorption, and reaction are included in the contaminant transport equations to further describe these additional transport processes. The correct inclusion of these properties into a model is essential to adequately describe the location, shape, and concentration of a propagating contaminant plume.

2.2 Groundwater Flow Equations

The derivations of the equations used in groundwater flow applications are based on the conservation principles dealing with mass, momentum, and energy. The basic law of flow is Darcy's law. When Darcy's law is combined with an equation of continuity that describes the conservation of fluid mass during flow through a porous medium, a partial differential equation of flow is the result (Freeze and Cherry, 1979). Different forms of the flow equation result for steady-state, transient, and saturated versus unsaturated flow conditions.

3

The following sections review the three most commonly used forms of the groundwater flow equations. The sections are a summary of Chapter 2, Section 2.11, "Groundwater" by R. Allan Freeze and John A. Cherry (1979).

2.2.1 Steady-State Saturated Flow

The equation of groundwater flow under steady-state conditions through an anisotropic saturated porous medium:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) = 0 \quad (1)$$

The terms x and y refer to the principal horizontal axes with z representing the vertical axis. The hydraulic head at any point in the three-dimensional flow field is represented by h. The subscripted value of hydraulic conductivity, K, refers to the hydraulic conductivity in the direction of the three principle axes.

For the case of an isotropic medium, the hydraulic conductivities in the x, y, and z directions will be equal, i.e., $K_x = K_y = K_z$. Further simplification of the equation is possible if it can be assumed that the aquifer medium is homogeneous as well.

Therefore, for the case of steady-state flow through a homogeneous, isotropic medium the equation reduces to:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \quad (2)$$

This equation is known as the Laplace equation. The solution to the equation, the function h(x,y,z), is the hydraulic head, (h), at the point (x,y,z) in the flow field. The usual application of this equation is to a field site that has been divided into a 2-dimensional grid with each point in the grid having a known location described by the coordinates (x,y). The solution to the equation, the value of the hydraulic head, is then calculated for a range of depths (z) within the aquifer. Contour maps of the local groundwater equipotential lines at specific depths (z) within the aquifer, can be then generated.

2.2.2 Transient Saturated Flow

For the case of a transient flow condition, the time rate of change of the hydraulic head will be changing with time and must be accounted for in the equation. The groundwater flow equation used to describe transient flow through a saturated anisotropic porous medium is as follows:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial_z} \left(K_z \frac{\partial h}{\partial_z} \right) = S_s \frac{\partial h}{\partial_t}$$
(3)

The term S_s is the specific storage term defined as the volume of water that a unit volume of a saturated aquifer releases from storage under a unit decline in hydraulic head. The dimensions of S_s are [L]⁻¹.

For the special case of homogeneous and isotropic media, the equation reduces to:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S_s}{K} \frac{\partial h}{\partial t} (4)$$

Further reduction of the equation is possible for the special case of a horizontal confined aquifer of thickness b. The storage coefficient, S, is defined as:

In words, the storage coefficient or storativity of a saturated confined aquifer is the volume of water that is released from storage per unit surface area of aquifer per unit decline in hydraulic head. The storage coefficient is dimensionless. The transmissivity, T, of a confined aquifer is a parameter used as a measure of the available yield of a confined aquifer. T is defined as:

$$T = Kb$$
 (6)

The dimensions of transmissivity are [L2/T].

Inserting the storage coefficient and the transmissivity into the equation, and assuming a 2-dimensional analysis is required, the equation for the special case of a horizontal confined aquifer of thickness b, reduces to:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T} \frac{\partial h}{\partial t} (7)$$

The solution to the equation, h(x, y, t) predicts the groundwater hydraulic head at any point on a horizontal plane through the aquifer at any time, t.

2.3 Contaminant Transport Processes

2.3.1 Physical Processes

2.3.1.1 Advection

Advection is the process by which a dissolved solute or contaminant is carried by and in the direction of the flowing groundwater. The bulk of the contamination is transported by this process.

The rate of the transport is equal to the average linear groundwater velocity, \overline{v} , where $\overline{v} = v/n$, v being the specific discharge and n the porosity (Freeze and Cherry, 1979).

2.3.1.2 Hydrodynamic Dispersion

Dispersion is a mixing process that causes the spreading of the contaminant from its advective path. This phenomenon is caused in part by mechanical mixing and in part by molecular diffusion from thermal-kinetic energy of the solute. The spreading causes dilution of the contaminant. The dispersion caused by mechanical mixing of the groundwater alone is called mechanical dispersion. On a microscopic scale, mechanical dispersion is caused by three processes. The first is mixing of the molecules due to the varying velocities of the molecules in the individual pore spaces between particles. This is due to the frictional forces exerted on the molecules from the media. The second process is caused by the varying pore sizes between media causing the molecules to move at different pore velocities around the particles. The third process is related to the irregular and differing shapes of the pore channels.

The spreading of the contaminant in the direction of the bulk of the flowing groundwater is called longitudinal dispersion, whereas spreading in directions perpendicular to the direction of groundwater flow is referred to as transverse dispersion. As can be expected, the dispersion in the longitudinal direction is usually much larger than its transverse counterpart.

When using a 2-dimensional contaminant transport model, if the principal axes are aligned with the direction of flow, the x direction, the dispersion in the x direction is the longitudinal dispersion and in the y or z direction is the transverse.

7

For the one-dimensional case, the coefficient of hydrodynamic dispersion can be expressed in terms of two components (Freeze and Cherry, 1979):

$$\mathbf{D}_{t} = a \mathbf{N} + \mathbf{D}^{*} \quad (10)$$

where: D_{ℓ} is the coefficient of hydrodynamic dispersion, $[L^2/T]$

at is the dispersivity, [L]

D. is the coefficient of effective molecular diffusion for the solute in the porous medium,

[L2/T]

v is the pore velocity in the longitudinal direction, [L]

When doing transport modeling in 2 and 3-dimensions, the dispersion terms for each of the principle directions are used along with all the off-diagonal terms, i.e., D_{xx} , D_{yy} , D_{zz} , D_{xy} , D_{yz} , D_{xz} , D_{zz} , D_{zz} , D_{yz} , and D_{zy} . Equations for all six dispersion terms can be found in Chapter 7-3 of Bear, 1979.

2.3.2 Chemical Processes

2.3.2.1 Diffusion

Molecular diffusion is a microscopic physicochemical mixing process caused by varying concentration gradients. Diffusion in solutions is the process whereby ionic or molecular constituents move under the influence of their kinetic activity in the direction of their concentration gradient (Freeze and Cherry, 1979). During fluid motion, such as flowing groundwater, diffusion acts as an additional mechanism to provide solute mixing.

In the absence of concentration gradients, no diffusion occurs.

The coefficient of molecular diffusion, D, comes from Fick's first law which can be stated as follows (Freeze and Cherry, 1979):

 $F = -D(dC/dx) \quad (11)$

where: F = mass flux of the solute, [M/L²T]

D = aqueous diffusion coefficient, [L²/T]

C = solute concentration, [M/L3]

dC/dx = concentration gradient, [M/L4]

The diffusion coefficients for ions in aqueous solutions have been well documented and are available in many standard chemistry textbooks. Some of the major ions in groundwater (Na⁺, K⁺, Mg⁺², Ca⁺², Cl⁻, HCO₃⁻, SO₄⁺²) have diffusion coefficients in the range of 1 X 10⁻⁹ to 2 X 10⁻⁹ m/s @ 25 degrees Celsius (Freeze and Cherry, 1979). The coefficients are temperature dependent. For ions in porous media, however, the "apparent" diffusion coefficients are much smaller than in water due to adsorption and because the ions follow longer paths of diffusion caused by the presence of particles in the solid matrix (Freeze and Cherry, 1979).

The apparent diffusion coefficient for nonadsorbed particles in porous media, D^{*}, is represented by the following (Freeze and Cherry, 1979):

D' = D (12)

where \mathfrak{T} is an empirical coefficient which accounts for the effects of the solid matrix on the diffusion. In laboratory studies, experimental values for \mathfrak{T} of between 0.5 and 0.01 have been commonly observed (Freeze and Cherry, 1979).

2.4 The Advective-Dispersive Equation

The principle differential equation used to describe the transport of solutes, either naturally occurring dissolved minerals or artificially introduced tracers or pollutants, through a porous media

is called the advective-dispersive equation. One commonly used form of this equation is given below (for a complete derivation of the advective-dispersive equation, see Freeze and Cherry, 1979, Appendix X):

$$\frac{\partial c}{\partial t} = \left[D_x \frac{\partial^2 c}{\partial x^2} + D_y \frac{\partial^2 c}{\partial x^2} + D_z \frac{\partial^2 c}{\partial z^2} \right] \cdot \left[v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial x} + v_z \frac{\partial c}{\partial z} \right] \cdot q/n \quad (13)$$

$$\frac{\partial c}{\partial t} = \left[D_x \frac{\partial^2 c}{\partial x^2} + D_y \frac{\partial^2 c}{\partial x^2} + D_z \frac{\partial^2 c}{\partial x^2} \right] \cdot \left[v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial x} + v_z \frac{\partial c}{\partial x} \right] \cdot q/n \quad (13)$$

where: C = concentration of solute = mass of solute/unit volume of solution

q = rate of change of solute mass (sink)/unit volume of porous media

v = pore or seepage velocity

n = porosity of the media

 $D = (D_x, D_y, D_z)$: dispersion coefficients

The sink term q refers to the rate of loss of mass of solute/unit volume of porous media. The changes usually occurring to a dissolved contaminant in groundwater include sorption onto/into the media and losses due to chemical reactions and/or biological degradation. The form of Equation 13 above assumes that the aquifer medium in question is homogeneous, isotropic, and saturated. The flow conditions are assumed to be steady, and Darcy's Law is applicable. The equation also assumes that the effective transport mechanisms present are advection and dispersion. The solution to Equation 13 is a prediction of the concentration of the solute in question at a desired point in time at a known location.

Solving the equation requires approximation of the partial differentials by iterative numerical techniques using finite difference and finite element modeling or the use of analytical methods. Some analytical solutions exist for cases such as tracer slug injection into a column, with and without adsorption. (For a discussion of some of the currently available analytical solutions, see Section 7-9 in Bear, 1979.)

Equation 13 can be used to model a field tracer test by predicting the expected concentration of the tracer as a function of time at the point of withdrawal assuming that the tracer is conservative. By attempting to match the model results with the actual field breakthrough data, the aquifer parameters that were estimated in order to run the model can now be determined more accurately. Numerous model runs using different aquifer parameters may have to be made in order to achieve a close match of the two data sets.

3.0 FIELD TRACER TESTS

3.1 Types of Tracers

In their paper presented at a 1955 American Water Works Association meeting in Sacramento, California, Warren J. Kaufman and Gerald T. Orlob discuss characteristics of an ideal groundwater tracer. The authors site the following properties:

- A satisfactory tracer should be susceptible to quantitative determination in very low concentrations;
- It should be entirely absent from the injected water or present only at low concentrations in the displaced water;
- It must not react with the injected or displaced waters to form a precipitate;
- It must not be absorbed by the porous medium; and
- It must be cheap and readily available.

Although the authors were referring to the tracing of groundwater movement under natural gradient conditions for the purpose of watershed development and protection, their ideal tracer properties still hold true for the complicated forced and natural gradient groundwater tracing work that is common practice today. Bear (1979) describes an ideal tracer as one that is inert with respect to its liquid and solid surroundings and that does not affect the liquid's properties. In reality, however, the introduction of a tracer into an aquifer does cause changes to the groundwaters' density and viscosity. In situations where an artificial tracer is introduced in relatively low concentrations, the ideal tracer assumption may be appropriate. In other cases for example where the groundwater density may vary significantly within the aquifer due to seawater intrusion, the assumption that the chloride introduced by the intrusion will behave as an ideal tracer is not valid.

3.1.1 Temperature Tracers

Water temperature has the potential to be a fairly useful tracer although it has not been used extensively. The method seems to have the most potential in granular media, fractured rock, and karst regions (Davis et al., 1985). Temperature tracers have been used to trace vertical groundwater movement in boreholes (Keys and MacCarey, 1971; Sorey, 1971), and to trace the artificial recharge of a naturally heated lake water into an aquifer formation (Keys and Brown, 1978).

A problem with using temperature tracers exists, however, due to changes in the density and viscosity of groundwater caused by temperature changes. These changes affect the flow rate and the direction of the groundwater. Experiments conducted in a laboratory setting have attempted to illustrate these effects (Davis et al., 1985). In order to minimize these negative effects, the temperature difference between the tracer and the background should be kept as small as possible.

3.1.2 Dye Tracers

Various organic dyes have been used for surface water and groundwater tracing since the late 1800's with extensive use of fluorescent dyes beginning around 1960 (Davis et al., 1985). Dyes are easy to use and have high detectibility, however, dyes travel slower than water due to adsorption and therefore are not conservative as are ionic or radioactive tracers (Davis et al., 1985). Some of the

more commonly used dyes include fluorescein, pyranine, lissamine FF, rhodamine WT, and sulfo rhodamine B. A number of factors have been shown to interfere with the measurement of fluorescent dye concentration. These factors include temperature, pH, alkalinity, and salinity (Davis et al., 1985). Sorption and toxicity problems with the dye tracers have also been researched (Smart and Laidlaw, 1977).

Although dyes are more often used for surface water work, groundwater tracer experiments using dyes have been conducted. An experiment conducted using three different fluorescent dye tracers ran into problems when the injection slug of tracer was introduced too slowly and the dye was diluted below detection limits (Naymik and Sievers, 1985). Better results from groundwater tracing experiments can be obtained using conservative ionic or radioactive tracers.

3.1.3 Ionic tracers

Ionic compounds have been employed extensively and successfully as groundwater tracers. The most common and successful species used include chloride (CI[°]), bromide (Br[°]), lithium (Li⁺), ammonium (NH₄⁺), magnesium (Mg⁺⁺), potassium (K⁺), iodide (I[°]), sulfate (SO₄⁼), organic anions (such as benzoate), and fluorinated organic anions (Davis et al., 1985). Ionic tracers, especially anions, are considered to be conservative under most aquifer conditions. Anionic tracers are considered to be conservative under most aquifer conditions. Anionic tracers are considered to be undergo anion exchange.

Cations, on the other hand, have the tendency to react with the media by undergoing the process of cation exchange. This process occurs when naturally occurring background cations such as sodium and calcium are displaced and forced into solution by the introduction and the binding of the tracer cations. Under certain conditions, more than one ionic tracer should be used. In one of his papers on the 3-dimensional natural gradient tracer tests that were performed at the Canadian Forces Base Borden in Ontario, Canada, Freyberg (1986) discusses his reasons for using both chloride and bromide as tracers. The author explains that a contaminant plume containing elevated levels of chloride ions, but negligible levels of bromide ions, is emanating from an abandoned landfill upgradient from the experimental site. The plume is thought to lie below the experimental zone. By inspecting the chloride:bromide concentration ratios for the samples collected during the experiment, the author was able to identify the intersecting regions between the experimental and the landfill plumes.

Freyberg (1986) also discusses how the use of the two nonreactive tracers thought to behave so identically, provided additional information on aspects of sampling variability. Different analysts performed the data reduction for the two ions which allowed for observation of any variability by the analyst's judgment.

In their paper on groundwater contaminant migration from a landfill, Sudicky et al., (1986) describe their reasons for choosing a chloride tracer for their field experiments with a natural gradient dispersion test. The authors cite that chloride was selected for the tracer because it meets most of the criteria for an ideal tracer. In addition, chemical analyses for chloride ion are inexpensive with analytical precision being generally high.

3.1.4 Radionuclide Tracers

The majority of radioactive tracers used today are from sources of contamination already present in the aquifers. According to one source the use of artificially introduced radioactive tracers has declined in many countries including the United States (Davis et al., 1985). Field detection of radioactive tracers is possible at very low concentrations using fairly simple field equipment (Molz et al., 1986). In addition, tracers can be selected that have half-lives so short that they are essentially decayed after a few hours or a few days (Davis et al., 1985).

3.2 Types of Tracer Tests

It is generally agreed that tracer tests are currently the most reliable field methods for obtaining data to describe dispersion in groundwater (Molz et al., 1986). All tracer tests fall into one of two categories; forced or natural gradient.

Natural gradient tests involve the introduction of a conservative tracer into an aquifer and monitoring the movement of the tracer under natural groundwater flow conditions. Because the natural movement of groundwater is in most cases very slow, the projected duration of a natural gradient tracer test over even a small horizontal distance can take from weeks to months to complete. For this reason, forced gradient tests have been developed to allow tracer tests to be completed within much shorter time frames.

Forced gradient tracer tests introduce much higher hydraulic gradients than are present under natural flow conditions into the aquifer through the use of one or a series of pumping wells. The increased groundwater flow rate which is a response to the pumping stress, forces the groundwater to flow much faster than it would under natural flow conditions allowing a shorter duration test. The two most common types of forced gradient tracer tests are single-well and two-well tests.

3.2.1 Single-Well Tracer Tests

Figure 3-1 illustrates a typical set-up for a single-well tracer test. The term "single-well" refers to the fact that only one pumping well is required to perform the test (Molz et al., 1986).



During the test, a tracer solution having a known concentration, $C_{in}(t)$, is injected at a known rate, Q_{in} , for a known period of time into a well that is fully penetrating and screened over the entire thickness of the aquifer. After a certain period of time, the flow may be reversed and the tracer solution is pumped from the well. The recovered tracer solution pumped from the well at concentration, $C_{out}(t)$, may be used to develop a breakthrough curve of concentration vs. time data. In many cases it may be useful to calculate the percentage of tracer recovered.

In cases were the vertical conductivity distribution in the aquifer is desired, multi-level sampling wells can be used in conjunction with the injection well. Concentration vs. time measurements are then made at the different isolated points in each observation well during the experiment (Molz et al., 1986). Horizontal hydraulic conductivities are estimated using the tracer travel time and tracer concentration data measured at each vertical sampling interval.

3.2.2 Two-Well Tracer Tests

Figure 3-2 illustrates a typical two-well tracer test set-up. This configuration uses two wells, one for injection of the tracer solution and one for simultaneous withdrawal. The wells shown fully penetrate over the entire thickness of the aquifer.

Tracer solution in injected into the source well at a known concentration and flowrate. Water is pumped from the withdrawal well usually at the same rate. The concentration of the tracer pumped from the withdrawal well is recorded over time to develop a breakthrough curve for the test. Usually the tracer injection period is short compared to the duration of the entire test (Molz et al., 1986).



Two-well tests may be carried out in either a recirculating or non-recirculating mode (Molz et al., 1986). In the recirculating mode, the water pumped from the withdrawal well is reinjected back into the injection well. The injection concentration of tracer solution in this case will be equal to the sum of the tracer solution plus the concentration of the withdrawn water from the aquifer.

By using multi-level observation wells to collect groundwater samples during the test, horizontal conductivities may be estimated from the concentration and time data.

4.0 FIELD DATA COLLECTION

4.1 Description of Field Site

This study was conducted at the Terrawa Terrace site located at Camp Lejeune, North Carolina (Figures 4.1, 4.2, and 4.3). Geologically, the site is located within the North Carolina coastal plain which is characterized by sandy soils and a shallow groundwater table. Boring logs and published soil data maps indicate that approximately 200 feet of fine to medium grained sands mixed with varying amounts of clay (Mayer and Miller, 1988) comprise the surficial unconfined aquifer which is underlain by a confining layer. The average depth to groundwater at the site is approximately 25 feet.

A gas station at the site has been identified as the source of subsurface gasoline contamination caused by leaking underground storage tanks and associated piping. It is estimated that approximately 7400 gallons of leaded and unleaded gasoline were released between September 1985 and July 1986.





SCALE 1:50,000

1

2 MILES

CAMP LEJEUNE SPECIAL MAP

NORTH CAROLINA - EAST COAST

1978

PREPARED BY DWATC AND DWAHC PUBLISHED BY THE DEFENSE MAPPING ACENCY HYDROGRAPHIC CENTER WASHINGTON, D.C.

FIGURE 4.2 TOPOGRAPHIC LOCATION MAP



After the release was discovered, a consultant was retained to perform groundwater contamination assessment and remediation services. Eleven monitoring wells were installed during the initial phase of the investigation. Eventually, a pump and treat system designed to remove free gasoline from the surface of the water table and to remove dissolved gasoline constituents from the groundwater was designed and constructed at the site. The underground storage tanks were removed in May 1987 and the area served as a groundwater contamination research site.

During July and August of 1987, a UNC research team installed 16 additional groundwater monitoring wells including twelve multi-level sampling wells. A map of the site included as Figure 4.3 shows the well locations as of December 1987.

4.2 Tracer Test Procedure

4.2.1 Wells

Two two-well tracer tests were performed at the site using two different pairs of wells. Test No. 1 was conducted on August 25, 1987 using wells A-11 and A-13. Test No. 2 test took place on November 12, 1987 using wells A-10 and A-12. During the two tracer tests, the existing groundwater recovery and treatment system continued to operate. The average groundwater pumping rate from the recovery well as measured before the start of each tracer test was approximately 10 gpm. It is assumed that this average rate was maintained during the two tests.

Each pair of wells consists of an injection well and a withdrawal well. The injection wells, wells A-12 and A-13, are constructed of 48 feet of 2 inch diameter stainless steel casing with 2 feet of slotted stainless steel screen. The withdrawal wells, wells A-10 and A-11, are constructed of 50 feet of 4 inch diameter stainless steel casing with 2 ft. screen sections. Construction details of the two different types of wells are shown on Figure 4.4.



4.2.2 Equipment Used

In order to be certain that the pumps controlling the rate of tracer solution injection and the rate of groundwater withdrawal are producing identical yields, it is imperative during a tracer test that the injection and withdrawal flow rates be continuously monitored. In addition, sampling ports must be conveniently located to allow for frequent sample collection of tracer solution and withdrawn groundwater. With these ideas in mind, a tracer test control box was designed and constructed as shown in Figure 4.5.

To monitor and control the groundwater withdrawal rate from the pumping well, the box contained a flowmeter, a sampling port, and control valve. The groundwater was pumped from the withdrawal well using a stainless steel submersible pump. The tracer solution was pumped from the mixing tanks to the injection well via the magnetic motor pump housed in the control box. The injection line was also equipped with a flow control valve, a sampling port and an instantaneous readout flowmeter. An inline filter housing was plumbed in for use during a subsequent experiment. A filter cartridge was not placed in the housing during the two tracer tests. An equipment layout illustrating the hardware setup during the two tests is shown in Figure 4.6. The hardware setup for the two tests was identical.

4.2.3 Tracer Test No. 1

Tracer Test No.1 was started at approximately 11:00 am on August 25, 1987 and continued for a duration of 25.5 hours. Prior to the start of the test, 90 gallons of tracer solution were prepared using groundwater from the site. A measured amount of sodium chloride was added to bring the concentration of the solution equal to 250 mg/L of chloride plus whatever background chloride concentration was present (approximately 15 mg/L Cl-). A total of 85.16 grams of chloride were injected over the duration of the test.





The tracer solution was injected via the injection well, well A-13, at a flowrate of 0.25 gallons per minute (gpm) and the groundwater was withdrawn from the pumping well, well A-11, at a flowrate of 0.25 gpm. The flow rate was controlled by fine tuning with the control valves. When all of the tracer solution was injected, the influent line was switched to vessels containing background groundwater. For the duration of the test, the background groundwater was continuously injected at the 0.25 gpm flowrate to maintain a steady state system.

Groundwater samples from the pumping well were collected every 15 minutes for the duration of the test. A mobile on-site laboratory was set up to analyze the samples for chloride concentration. A complete listing of the data collected from Tracer Test No. 1 is included as Appendix A. The analytical method used to analyze the samples for chloride concentration was Method A (Mercurimetric Titration), ASTM D 512 - 80.

By reducing the collected data, the breakthrough curve, shown in Figure 4.7, was developed.

4.2.4 Tracer Test No. 2

Tracer Test No. 2 was started at approximately 6:34 am on November 12, 1987 and continued for a duration of 30 hours. Prior to the start of the test, 120 gallons of tracer solution were prepared using groundwater from the site. A measured amount of sodium chloride was added to bring the concentration of the solution equal to 250 mg/L of chloride plus whatever background chloride concentration was present (15 mg/L Cl-). A total of 113.55 grams of chloride were injected over the duration of the test.

The tracer solution was injected into the injection well, well 12, and the groundwater was withdrawn from the pumping well, well 10, at a flowrate of 0.5 gallons per minute (gpm). The flow rate was controlled by fine tuning with the control valves. As was done during the first tracer test, when all



FIGURE 4.7 TRACER TEST NO.1 BREAKTHROUGH CURVE

CHLORIDE CONCENTRATION IN mg/L

3

of the tracer solution was injected, background groundwater was injected at the same flowrate to maintain a steady state system.

Groundwater samples from the pumping well were collected every 30 minutes for the duration of the test. The mobile on-site laboratory used for Tracer Test No. 1 was used to analyze the samples for chloride concentration. A summary of the parameters for Tracer Tests No. 1 and 2 is as follows:

	TRACER TEST NO. 1	TRACER TEST NO. 2
Flowrate	0.25 gpm	0.5 gpm
Injection Well	A-13 (2" O.D.)	A-12 (2* O.D.)
Withdrawal well	A-11 (4° O.D.)	A-10 (4* O.D.)
Radial Distance	3.84 feet	2.63 feet
Test Duration	25.5 hours	30 hours
Tracer Injection Time	6 hours	4 hours
Injected tracer volume	90 gallons	120 gallons
Tracer concentration	250 mg/L chloride	250 mg/L chloride
Mass of Injected Tracer	85.162 grams	113.549 grams

By reducing the collected data, the breakthrough curve, shown in Figure 4.8, was developed. A complete listing of the data collected from Tracer Test 2 is included as Appendix B. The analytical method used to analyze the samples for chloride concentration was Method A (Mercurimetric Titration), ASTM D 512 - 80.



FIGURE 4.8 TRACER TEST NO.2 BREAKTHROUGH CURVE

CHLORIDE CONCENTRATION IN mg/L

A DY AGAINT 1

31

. .

4.3 Discussion of Results

The test parameters selected prior to Tracer Test No. 1 were chosen using the most reliable site data available. The breakthrough curve obtained from the test data was not as complete as it could have been because the "tail" of the curve did not approach the abscissa asymptotically. Additional data should have been collected until the flattening of the curve had been obtained. Although the samples collected were being analyzed in the field within a short time, the duration of the test, the frequency of sampling, and the field laboratory conditions which prohibited sample analysis at night, all contributed to misjudging what the true length of the test should have been.

In order to correct this problem for Tracer Test No. 2, the injection and withdrawal flow rate was doubled to allow for the capture of more tracer solution in a shorter period of time. It was also decided to lengthen the minimum duration of the test to 30 hours. By incorporating these two changes into the tracer test procedure, the plotted breakthrough data from Test No. 2 as shown in Figure 4.8 appear to be more representative of a complete test.

It is interesting to note the percent of the total mass of injected chloride recovered from each test; 37 percent for Tracer Test #1 and 52 percent for Tracer Test #2. With both injection and withdrawal wells only about three feet (one meter) apart, the tracer solution injected in the center of the screened interval of both of the injection wells, the submersible pumps installed in the center of the screened intervals of the withdrawal wells, and both wells having approximately the same screened interval, it would seem logical to expect to recover most if not all of the injected tracer during each of the tests.

Factors that could account for the difference in the amount of the tracer recovered between Test #1 and Test #2 include the difference in the flow rates and the duration of pumping.
Another factor that may have influenced the tracer test results is the construction of the withdrawal well for Test #2, well #A-11. The construction of this well is somewhat suspect due to problems that occurred in the field during drilling. The completed depth of the well is approximately 18 inches less than the other wells making the screened interval offset somewhat as compared to the other tracer wells. The percent of total mass of tracer recovered during Test #2 may have been even greater if the injection well had been completed to the same depth as the withdrawal well.

Because the point of injection of the tracer was at 50 feet below grade under a standing water column of approximately 25 feet, the tracer was injected under pressure. The hydraulics of injecting 0.25 to 0.5 gallons per minute of solution probably caused a radial flow of the solution to spread in all directions. Whether the pumping stress caused by the withdrawal well was strong enough to overcome the spreading of the tracer and pull it back toward the withdrawal well in the duration of the test could account for the majority of the tracer loss.

The other obvious possible cause of tracer loss is the apparent pumping stress induced by the recovery well located approximately 40 feet from the tracer wells. Water levels in the monitoring wells as measured around the time of the first tracer test are shown on Figure 4.9. Using this data and assuming that they are representative of steady state conditions and that the surface horizontal gradient is approximately equal to the gradient at 50 feet below grade, an estimate of the horizontal groundwater velocity in the vicinity of the tracer test wells can be calculated. Assuming a hydraulic conductivity of 1 x 10^{-4} ft/sec (Mayer and Miller, 1983), an effective porosity of 0.40 (typical for sandy coastal plain aquifers), a horizontal gradient in the vicinity of the tracer wells of approximately 0.018 (as estimated from Figure 4.9) and assuming Darcy's Law applies, the horizontal velocity can then be calculated to be approximately 4.5×10^{-6} ft/sec. Assuming that the duration of the tracer tests was approximately 30 hours, the groundwater would have moved less than 6 inches horizontally due to the induced recovery well pumping stress during the duration of the tracer test. Each tracer



withdrawal well is located between the recovery well and its respective tracer injection well. If the groundwater moved 6 inches in the direction toward the pumping well during each tracer test, one would expect that this would assist in the capture of the tracer as opposed to causing the tracer to be lost.

The loss of the tracer could also be attributed to the presence of a vertical gradient in the vicinity of the tracer test wells caused by the recovery well. In their modeling study of the hydraulics of the pumping recovery well at the Camp Lejeune site, Mayer and Miller (1988) determined that a vertical gradient did exist in the vicinity of the pumping well. The recovery well is screened at an interval of approximately 40 to 45 feet below grade (Mayer and Miller, 1988), whereas the tracer test wells are screened at 50 feet below grade and are located approximately 40 feet away from the recovery well. Using the data from the simulated hydraulic heads as a function of elevation in the immediate vicinity of the recovery well (Mayer and Miller, 1988) at a depth of 50 feet below grade, a vertical gradient due to the recovery well pumping stress of approximately 0.0075 and a vertical velocity of 1.8 x 10-6 ft/sec can be estimated. The actual vertical gradient in the vicinity of the tracer wells will be significantly less than at the recovery well as demonstrated in the areal graphical vertical head distributions shown in the referenced paper. Therefore, during the 30 hour duration of the tracer tests, it is estimated that the groundwater may have moved less than 3 inches vertically upward due to the stress induced by the recovery well. The stresses induced by the recovery well probably did have some effect on the movement of the tracer and could be accountable for some of the losses. However, these losses as estimated herein appear to be negligible. The effects of density and temperature differences were assumed to be negligible and were not taken into account in the analysis.

5.0 METHOD OF DATA ANALYSIS

5.1 Description of Tracer Test Simulation

By using equations that attempt to simulate the breakthrough response, certain aquifer parameters can be estimated. These equations are usually solved using computer models. To estimate the aquifer parameters using the tracer test breakthrough data, the preferred method of analysis was the use of a readily available public domain computer based curve matching model. With the assistance of the International Groundwater Modeling Center (IGWMC) of the Holcomb Research Institute at Butler University in Indianapolis, Indiana, the available models were identified. The list was narrowed to one potential model, since analytical solutions have not been derived for conditions similar to those investigated in this study. The model chosen for further evaluation was the Computer Aided Tracer Test Interpretation Code, "CATTI" by J.P. Sauty and W. Kinzelbach, May 1988. The model is a computer code used to estimate aquifer transport parameters from tracer test data by either manual adjustment or by automatic least-square determination. CATTI is a nonproprietary code and is distributed through the IGWMC.

Since the CATTI documentation did not provide a complete description of the underlying theory of the model, the author of the model, J. Sauty, was contacted in France. He was able to supply an additional reference (Sauty and Kinzel, 1988) which was carefully reviewed. Upon further review, it was determined that the CATTI program was an empirical solution, which was based upon a radially symmetric flow field. This was a clear violation of the conditions under which the experimental data was collected.

Also, CATTI simulates breakthrough data from either instantaneous or continuous tracer injection tests for the case of radial flow, however, the actual field tests involved injecting tracer over a 4 to 6 hour period. The injections were neither instaneous nor continuous. After reviewing these model limitations an alternate scheme was sought.

5.2 Tracer Transport Modeling

Since efforts to locate a satisfactory analytical solution failed, a numerical approach was deemed necessary. Several models exist in the public domain to simulate the tracer tests performed.

The groundwater hydraulics in the vicinity of the tracer wells were simulated using the McDonald-Harbaugh "Modular Three-Dimensional Finite-Difference Ground-water Flow Model" (McDonald and Harbaugh, 1988). In order to run this model, a finite difference grid was set up around the vicinity of the pair of wells used for Tracer Test #1. The model grid was set up with 17 columns with a total dimension of 33.83 feet, 34 rows with a total dimension of 38.83 feet, and nine layers with a total dimension of 134 feet. The grid was set up with varying size cells with the sizes of the cells decreasing as they approach the location of the wells. Cell sizes ranged from 2x2 inches to 6x6 feet. The exact dimensions of the model grid including each cell block are included in the MAIN.DAT input file included in Appendix C. Using the site parameters for hydraulic conductivity, the model was run to simulate steady state flow conditions. The model was set up with a constant head boundry on the perimeter and no flow boundaries on the top and bottom. The screened interval was used as a separate layer. The simulation was run neglecting any effects from the recovery well.

The hydraulic gradient as calculated from this three dimensional groundwater flow simulation for the screened interval of both wells is shown in Figure 5.1. According to the modeling results, no significant influences from the tracer withdrawal well were evident more than 15 feet from the wells. The hydraulic gradient appears to be very steep in the direct vicinity of the well screens indicating that the velocities of the tracer particles decrease as they leave the injection well and move toward the withdrawal well. The particles then begin accelerating as they approach the withdrawal well. The gradient does not extend very far from the wells indicating that the tracer particles exiting the side of the well screen away from the withdrawal well would travel very slowly toward that well.





FIGLEE 5.1 PLMPING STRESS AT SOPERALD NITHAUL

8

Assuming that the tracer particles move perpendicularly toward the equipotential lines, it appears from the results shown in Figure 5.1, that the tracer would indeed move radially outward from the well.

To track the path of the particles and to generate time of travel information to confirm whether the percentage of tracer recovered during the tracer tests was reasonable, the three dimensional particle tracking program, MODPATH, was used. MODPATH (Pollock, 1989) is a post-processing package developed to compute three dimensional path lines based on steady-state simulations obtained from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-water Flow Model.

MODPATH uses a semi-analytical partical tracking scheme based on the assumption that each directional velocity component varies linearly within a grid cell. Given the initial position of a partical anywhere in a cell, the coordinates of any other points along its pathinline within the cell, and the time of travel between them, can be computed by the model (Pollock, 1989).

Data is input to MODPATH through a combination of files and interactive dialogue. The model input data includes the input files BAS.DAT, BCF.DAT, WEL.DAT, OC.DAT, SIP.DAT and the output files BUDGET.OUT and HEAD.OUT used and generated in the execution of the Modular Three-Dimensional Finite-Difference Ground-water Flow Model. MODPATH also requires the data file MAIN.DAT. A detailed description of the input parameters for these two files are included in the model user manual (Pollock, 1989). A copy of each of the input files used to run the simulation is included in Appendix C. A companion program, MODPATH-PLOT, was used to generate the graphical presentation of the MODPATH particle tracking output as shown in Figures 5.2 through 5.6.



10000000000					
					a second second
	1.	1 1 1 1			
		1 1 11			
				E 13	1 I I I I I I I I I I I I I I I I I I I
	1 4	1 1 1 1		1.1.1	
		1 1 1 1			
		1 1 1 1		1.1.1.	1
		1 1 1 1		1	Mar
		1 1 1			
					A CONTRACTOR OF A
	• • • • • • • •			1	1
				1	
			+++		
				+	
				-	
			R-13	-	
		-+-++			
		1 1 1			
		-+++		-	
		-+++			
			11 4 44	-	
			A	-	
		_			

FIGURE 52

TWO WELL TRACER TEST - O HOURS



FIGURE 53

THO WELL TRACER TEST - 2 HOURS



191

FIGURE 5.4

TWO WELL TRACER TEST - 4 HOURS

42

00000000000000000000000000000000000000	100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,000 100,000 99,9991 99,9995 99,9995 99,9957 99,9955 99,9957 99,9955 99,9955 99,9955 99,9955 99,9955 99,9955	100.001 100.001 100.001 100.001 100.001 100.001 100.001 100.001 100.000 99.0007 99.0000 99.0005 99.0005 99.0005 99.0005 99.0055	100.001 100.001 100.001 100.001 100.001 100.001 100.001 100.001 100.000 99.0003 99.0003 99.0003 99.0003 99.0003 99.0005 99.0005 99.0005 99.0005 99.0005 99.0005 99.005 90.005 900	100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,000 99,9005 99,9005 99,9005 99,9005 99,9005 99,9005 99,9005 99,9005 99,9057 99,9057 99,9057 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055	100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,000 100,000 99,9996 99,9996 99,9996 99,9996 99,9996 99,9996 99,9996 99,9996 99,9996 99,9996 99,9985 99,9985 99,9985 99,9985 99,9985 99,9985 99,9985 99,9976 99,9976 99,9958	100.001 100.001 100.001 100.001 100.001 100.001 100.001 100.000 100.000 100.000 99.9994 99.9994 99.9994 99.9991 99.9991 99.9991 99.9995 99.9955 99.9959 99.9959	100.001 100.001 100.001 100.001 100.001 100.001 100.000 100.000 99.9998 99.9998 99.9998 99.9998 99.9998 99.9992 99.9992 99.9992 99.9992 99.9992 99.9992 99.9992 99.9993 99.9992 99.9993 99.9993 99.9985 99.9983 99.9983 99.9983 99.9983 99.9983 99.9985 99.9985 99.9985 99.9985 99.9985 99.9985 99.9985 99.9985 99.9985	100.001 100.001 100.001 100.000 100.000 100.000 100.000 100.000 100.000 99.9995 99.9995 99.9994 99.9994 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9991 99.9995 99.9991 99.9991 99.9995 99.9991 99.9995 99.9995 99.9995 99.9995 99.9995 99.9995 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955	
1.	·	NEAD IN LU	ATTE 3 AT END	OF TIME STEP	I IN STRESS PE	1 001			
	1	2	3	4	5		7	8	9
	100,006 100,005 100,003 100,002 100,002 100,002 100,002 100,002 100,002 100,002 100,002 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,002 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,001 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 100,000 99,9997 99,9975 99,9957	100.007 100.007 100.007 100.004 100.005 100.004 100.003 100.003 100.003 100.003 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.002 100.003 99.9995 99.9977 99.9977 99.9975 99.9951 99.9951 99.9951 99.9951 99.9951 99.9951 99.9951 99.9952 99.9951 99.9952	100.008 100.010 100.010 100.010 100.007 100.007 100.005 100.005 100.005 100.005 100.005 100.005 100.004 100.004 100.004 100.002 100.002 100.003 100.002 100.003 100.002 100.003 100.002 100.003 100.002 100.003 100.005 99.9950 99.9950 99.9951 99.9954 99.9955 99.9954	100.009 100.612 100.613 100.613 100.013 100.010 100.009 100.005 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.99555 99.995555 99.995555 99.995555 99.9955555555	100.009 100.012 100.014 100.013 100.013 100.011 100.011 100.011 100.009 100.009 100.009 100.009 100.009 100.009 100.001 100.001 100.001 100.005 99.9062 99.9062 99.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90.905 90	100.009 100.012 100.014 100.014 100.013 100.013 100.011 100.010 100.009 100.0000 100.0000 100.0000 100.0000 100.0000 100.0000 100.00000 100.00000000	100.009 100.012 100.014 100.015 100.014 100.013 100.012 100.011 100.010 100.001 100.001 100.003 100.004 100.005 100.004 100.005 100.004 100.005 100.00	100.009 100.012 100.014 100.013 100.013 100.012 100.011 100.010 100.009 99.9759 99.9759 99.9759 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855 99.9855	100,009 100,012 100,014 100,015 100,015 100,012 100,012 100,012 100,010 100,010 100,000 99,9959 99,9959 99,9959 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9055 99,9057 90,0000 100
1		NLO IN L	ATLE 3 AT DO	Co TIME STEP	1 IN SINCES P				
	10	11	12	13	14	15	14	17	
000000000000000000000000000000000000000	100.009 100.012 100.014 100.015 100.015 100.015 100.013 100.012	100.009 100.012 100.014 100.014 100.014 100.013 100.012 100.012	100.009 100.012 100.014 100.014 100.014 100.013 100.013 100.012 100.011	100.009 100.012 100.014 100.014 100.013 100.012 100.011 100.011	100.009 100.012 100.013 100.013 100.012 100.011 100.010 100.010	100.008 100.010 100.010 100.008 100.007 100.007 100.007	100.007 100.007 100.005 100.005 100.004 100.004 100.004 100.004	100.005 100.005 100.004 100.003 100.003 100.002 100.002 100.002	

- 25

***************************************	100.665 100.335 100.235 100.205 100.067 99.7532 99.7552 99.7552 99.441 99.4747 99.401 99.4747 99.401 99.4124 99.5772 99.57753 99.57753 99.57753 99.57753 99.5716 99.5941 99.6945	100.521 100.312 100.117 100.062 99.9379 99.8130 99.6476 99.5692 99.4757 99.4757 99.4451 99.3805 99.4625 99.4625 99.6227 99.6227 99.6227 99.8185 99.8061 99.9581 99.9685 8640 18 U	100.341 100.300 100.235 100.149 100.051 99,9455 99,4509 99,4509 99,4509 99,4509 99,4519 99,4519 99,4519 99,4519 99,4519 99,4519 99,4519 99,4519 99,5037 59,5036 99,5037 59,5036 99,5037	100.193 100.193 100.173 100.096 100.034 99.9040 99.8040 99.8040 99.8245 99.8047 99.7057 99.7057 99.7057 99.7057 99.7057 99.7057 99.7057 99.7057 99.7051 99.7051 99.7051 99.7051 99.7051 99.7051 99.9040 67.118E ELEP	100.078 100.077 100.059 100.040 100.014 99.9554 99.9599 99.9543 99.9291 99.9720 99.9720 99.9134 99.9034 99.9074 99.9078 99.9078 99.9078 99.9210 99.97210 99.97210 99.9725 99.9059 1 1# STREES P	100.017 100.017 100.010 100.003 99.9965 99.9965 99.99657 99.9857 99.9825 99.9825 99.9726 99.9775 99.9726 99.9775 99.9776 99.97	100.004 100.002 100.002 100.001 99.9972 97.9957 97.9959 97.9979 97.9979 97.9979 97.9979 97.9979 97.9979 97.9979	100.001 100.001 100.001 100.001 100.000 99.9907 99.9907 99.9955 99.9955 99.9955 99.9955 99.9955 99.9975 99.9975 99.9975 99.9975 99.9975 99.9975 99.9956 99.9955 99.9955 99.9955 99.9955 99.9955 99.9955	
	1	2	3	4	5	6	7	8	9
00000000000000000000000000000000000000	100.006 100.005 100.005 100.003 100.003 100.003 100.002 99.9991 99.9953 99.9973 99.9974 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9953 99.9955	100.005 100.010 100.010 100.007 100.005 99.9950 99.9953 99.9954 99.9954 99.9954 99.9954 99.9954 99.9956 90.0056 90.0056 90.0056 90.0056 90.0056 90.005	100.016 100.021 100.021 100.021 100.021 100.021 100.017 100.013 100.017 100.013 100.015 100.013 100.013 100.013 100.013 100.013 100.013 100.011 100.009 100.009 100.009 100.009 100.009 100.000 99.9975 99.9975 99.9855 99.9755 99.9855 99.9955 90.9555 90.9555 90.9555 90.9555 90.9555 90.9555 90.9555 90.955	100.011 100.019 100.032 100.045 100.045 100.045 100.045 100.045 100.045 100.045 100.045 100.05	100,011 100,021 100,025 100,045 100,045 100,045 100,045 100,045 100,045 100,057 100,05	100.011 100.021 100.038 100.055 100.075 100.075 100.075 100.075 100.078 100.074 100.074 100.074 100.074 100.074 100.074 100.074 100.074 100.046 100.04	100.011 100.021 100.056 100.057 100.085 100.087 100.085 100.08	100.011 100.022 100.039 100.057 100.057 100.057 100.057 100.057 100.059 100.059 100.059 100.059 100.059 100.059 100.059 100.057 100.059 100.057 100.059 99.954 99.954 99.952 99.902 99.902 99.902 99.902 99.902 99.902 99.9124 99.9280	100.011 100.022 100.039 100.057 100.052 100.052 100.001 100.052 100.001 100.092 100.051 100.051 100.051 100.051 100.051 100.051 100.051 100.051 100.051 100.051 100.055 99.96418 99.96418 99.96418 99.9052 99.9052 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9079 99.9075 99.9079
	10	11	12	13	14	15	16	17	
2343478901112314	100,022 100,039 100,072 100,072 100,072 100,090 100,090 100,091 100,091 100,091 100,091 100,070	100.021 100.039 100.056 100.051 100.055 100.055 100.055 100.055 100.055 100.055 100.055 100.055 100.055 100.055	100.621 100.035 100.047 100.075 100.075 100.075 100.077 100.078 100.074 100.074 100.056 100.066	100.021 100.036 100.063 100.065 100.065 100.065 100.065 100.059 100.059 100.059 100.053 100.058	100.019 100.012 100.041 100.045 100.045 100.043 100.043 100.043 100.028 100.038 100.033 100.033	100.014 100.021 100.023 100.022 100.013 100.013 100.015 100.014 100.013 100.013 100.012	100.010 100.009 100.005 100.005 100.005 100.005 100.005 100.005 100.005 100.005 100.005	100,005 100,005 100,003 100,003 100,002 100,002 100,002 100,002 100,002 100,002 100,002	
0 14 0 15	100,007	100.007	100,007	100.007	100,006	100,004	109,002	100.001	

.



17
34
9
0
10

1222222222
100
1.0
(1078.4)

6.0000
4.5000
3.0000
1.5000
0.7500
0.5000
0.3333
0.2500
0.1447

0.100
1.0
(1078.4)
0.5000
0.3333
0.2500
0.1447

0.1447
0.1447
0.1447
0.1447
0.1447
0.2500
0.3333
0.2500
0.1347

0.1447
0.1447
0.1447
0.1447
0.2500
0.3333
0.5000
1.5000
1.500
3.0000
4.0000
0.0001
1.2500
0.3333
0.4147
0.1447
0.2500
0.3333
0.5000
1.5000
0.3333
0.5000
0.3000
0.0000
1.0000
5.0000
0.0000
1.0000
5.0000
0.0000
1.0000
5.0000
0.0000
1.0000
5.0000
0.0000
1.0000
5.0000
1.0000
5.0000
1.0000
5.0000
1.0000
5.0000
1.0000
5.0000
1.0000
5.0000</t 34 17 å . ō 0.3333 0.2500 0.1667 0.2500 6.0000 0.1667 0.3333 0.7500

MANDAT

FORTELSE UNIT 100 = c:\sample\UALE.DAT FORTELSE UNIT 12 = c:\sample\UALE.DAT FORTELSE UNIT 50 = c:\sample\UALEST.OUT FORTELSE UNIT 23 = c:\sample\UALEST.OUT Current PC configuration supports 74500 elements in the A erray. HODPATE -- Version 1.2 -- April 27, 1990 MAXIMUM MUMBER OF PARTICLES IS 3310 74499 ELEMENTS OUT OF 74500 USED IN THE "A" ARRAY 17 COLUMNS 34 ROUS 9 LAYERS 0 CONFINING LAYERS IGRID (GRID TYPE CODE) IS 1 0 12 0 0 0 0 50 23 IUNIT ARRATS 1 2 2 2 2 2 2 2 2 2 2 2 NO CONFINING LATERS. NCON - O FOR ALL LATERS. DELZ ARRAY NON BEING READ DATA WAS READ BUT NOT PRINTED BOTTON ELEVATION OF LATER 1 IS .960000 -02 INCOME ARRAY FOR LAYER 1 NOU BEING READ. 1 1 ; 1 -----: 1 •1 -1 -1 -1 -1 -1 -1 INCOME ANEXY FOR LATER 2 NOV METHIG READ CONSTANT VALUE OF 1 IBOUND ARRAY FOR LAYER 3 NOW BEING READ ... CONSTANT VALUE OF 1 IBOLNO ARRAY FOR LATER 4 NOW BEING READ IBOUND ARRAY FOR LATER S NON BEING READ CONSTANT VALUE OF 1

-1

1

SUMMARY PTH

IBOLMO AREAT FOR LATER & MON BEING READ CONSTANT VALUE OF 1
IBOLND ARRAY FOR LATER 7 NOW BEING READ CONSTRANT VALUE OF 1
IBOAD AREAT FOR LATER & NOW BEING READ CONSTANT VALUE OF 1
IBOMO ARRAY FOR LATER 9 NOW BEING READ Constant value of 1
POROSITT ARRAT FOR LATER 1 NOV BEING READ CONSTANT VALUE OF
POROSITY AREAT FOR LATER 2 NOW BEINS READ CONSTANT VALUE OF
PORDSITY ARRAY FOR LATER 3 KOW BEING READ CONSTANT VALUE OF
POROSITY ARRAY FOR LATER 4 NOW BEING READ CONSTANT VALUE OF
PORDSITY ARRAY FOR LATER 5 NON BEING READ
PORDSITY ARRAY FOR LATER & NOW BEING READ CONSTANT VALUE OF
POROSITY ARRAY FOR LATER 7 NOU BEING READ CONSTANT VALUE OF
POROSITY ARRAY FOR LAYER & NOW BEING READ CONSTANT VALUE OF
PORCEITT ARRAY FOR LATER 9 NON BEING READ CONSTANT VALUE OF
NELOS NON BEING READ FOR LATER 1
NEADS NOW BEING READ FOR LATER 2
NEADS NOW BEING READ FOR LATER 3
KEADS NOW BEING BEAD FOR LATER 4
NEADS NOW BEING READ FOR LAYER 5
NEADE NOW BEINE BEAD FOR LAYER &
NTARE WER BEINE FEAR FOR LANSE 7
RUACE NOW DELINE READ FOR LATER B
NEADS NOW BEING READ FOR LAYER 9 NEADS NAVE BEEN READ ***** NEADS FOR INDIVIDUAL CELLS CAN BE CHECKED USING THE CELL-BY-CELL OPTION **
*
FLOW RATES FROM THE SCF PACKAGE NOW BEING BEAD BEF FLOW RATES MAVE BEEN HEAD
WELL DATA NOW BEING BEAD

,

.

.

•

----- FLOW MATES FROM BCT AND ALL STRESS PACKAGES HAVE BEEN READ -----

FORTRAM UNIT 100 . c:\sample\UAIM.DAT FORTEAU UNIT 12 = c:\sample\b.vel FORTEAU UNIT 12 = c:\sample\b.vel FORTEAU UNIT 50 = c:\sample\b.CCT.CUT FORTEAU UNIT 23 = c:\sample\b.CDS.CUT Current PC configuration supports 75000 elements in the A array. HODPATE-PLOT -- GES Graphics Version 1.0 -- March 1, 1990 NAVINAN NUMBER OF PARTICLES IS 16000 45208 ELEMENTS OUT OF 75000 USED IN "A" ARRAY 17 COLUMNS 34 ROWS 9 LATERS & CONFINING LATERS ICRID (CRID TTPE CODE) IS 1 IUNIT AREATS 0 12 0 0 0 0 50 23 LATCON (LATER TIPE CODES): 1 2 2 2 2 2 2 2 2 2 2 2 NO CONFINING LATERS. NCON - O FOR ALL LATERS. DELE ABRAT NON BEING READ DATA WAS READ BUT NOT PRINTED DELZ ARRAY NON BEING READ BOTTON ELEVATION OF LATER 1 IS .960008+02 LEGIND AREAT FOR LAYER 1 OUTS DUITS HOW -1 -1 ************************ : -1 -1 -1 -1 -1 -1 -1 -1 -1 INCOMO ADRAY FOR LAYER 2 NOW BEENG READ INCLAD AREAT FOR LATER 3 NOW BEING READ CONSTANT VALUE OF 1 INCOME ARRAY FOR LATER 4 NOW BEING READ CONSTANT VALUE OF 1 IBOUND ARRAY FOR LATER 5 NOW BEING READ ... CONSTANT VALUE OF 1

.....

:1

-1

-1-1

-1

SUMMARY PLT

IBOUND ARRAY FOR LAYER 6 NOW BEING READ CONSTANT VALUE OF 1
INCARD AREAY FOR LAYER 7 NOW BEING READ CONSTANT VALUE OF 1
INCAND ARRAY FOR LAYER & NOW BEING READ CONSTANT VALUE OF 1
IBCUND ARRAY FOR LATER 9 NOW BEING READ Constant Value of 1
NEADS NOW RETING READ FOR LATER 1
NEADS NOW BEING BEAD FOR LATER 2
NEADS NOW BEING READ FOR LAYER 3
BEADS NOW BEING BEAD FOR LATER 4
READS NOW REENS READ FOR LAYER 5
NAME WAS RELATED FOR LATER &
READS NOW RETING READ FOR LATER 7
READS NOW BEING READ FOR LAYER 8
READS NOW REEKS READ FOR LATER 9 READS NAVE BEEN READ
WELL DATA BEING READ

•

.

.

.

.

.

.

•

APPENDIX D PARTICLE TRACEING FIGURES 10



















FIGURE 5.5

TWO WELL TRACER TEST - 6 HOURS



FIGURE 5.6 TWO WELL TRACER TEST - 26 HOURS Using the three dimensional groundwater flow data and the MODPATH model, a simulation of the path of the tracer transport was modeled for Tracer Test #1. Figure 5.2 is the plot of the well locations within the designated grid prior to the start of the tracer test. Figures 5.3 through 5.6 illustrate the locations of the particles every two hours for the duration of the tracer test. A complete set of particle tracking figures is included in Appendix D. The location of the particles at the end of the tracer test sampling is shown in Figure 5.6.

By reducing the data from these figures, a graph of Percent of Tracer Recovery vs. Time was generated (Figure 5.7). The modeling results predict that after 25.5 hours of travel time, approximately 45 percent of the tracer should have been recovered. As determined by the breakthrough data, approximately 37 percent of the mass of the tracer was recovered after 25.5 hours for Tracer Test #1. Figures 5.8 and 5.9 show the results of the particle tracking simulation after 240 hours and 1000 hours of pumping. The model predicts that even if the test was run for 1000 hours, less than 75 percent of the tracer would have been recovered.

The model also predicts that the first tracer should appear in the withdrawal well after 4.25 to 5 hours of injection. In the field, detection of the tracer in the withdrawal well occurred after 4.25 to 4.5 hours. A crossectional view through the tracer wells showed that all the particles followed a nearly flat path on their way to the withdrawal well. No particles migrated up or down in the aquifer beyond the 2 ft. screened layer. This is most likely due to the minscule head difference between the two wells as shown in Figure 5.1.

The agreement between first arrival times was quite good considering model parameters were estimated independently. It should also be noted that the particle tracking method used did not account for dispersion. This suggests that advective transport variations are the key phenomenon for studies of this nature. This agrees with current theory.



FIGURE 5.7

46



4 FEET

FOURE 58

TWO WELL TRACER TEST - 240 HOURS



FOURE 5.9 TWO WELL TRACER TEST - 1000 HOURS

6.0 CONCLUSIONS

1. Methods were developed to conduct two-well tracer tests in the field.

 An empirical method was evaluated to reduce the field tracer data, but it was found to be inappropriate for conditions used in the tracer tests performed.

 A three dimensional flow and particle tracking model was used to simulate the flow field and solute transport conditions of one tracer test.

 Good agreement between the experimental data and model predictions was achieved using independent parameter estimation methods.

5. Variations in the velocity field were found to be the dominate factors affecting the distribution of solute arrival times, which is consistent with current theory.



7.0 REFERENCES

Bear, J. (1979), Hydraulics of Groundwater, McGraw-Hill, Inc., New York

Davis, S.N., et al., (1985), Ground Water Tracers: Library of Congress Cooperative Agreement Number CR-810036, pp. 21-133.

Freeze, R.A., and Cherry, J.A. (1979), Groundwater, Prentice-Hall, Inc., New Jersey

Freyberg, D.L. (1986), A Natural Gradient Experiment on Solute Transport in a Sand Aquifer 2. Spatial Moments and the Advection and Dispersion of Nonreactive Tracers, Water Resources Research, 22(13) pp. 2031-2046.

Freyberg, D.L., et al., (1986), A Natural Gradient Experiment on Solute Transport in a Sand Aquifer 1. Approach and Overview of Plume Movement, Water Resources Research, 22(13) pp. 2017-2029.

Kaufman, W.J. and G.T. Orlob, (1955), Measuring Ground Water Movement with Radioactive and Chemical Tracers, pp. 559-572.

Keys, W. S., and Brown, R. F., (1978), The Use of Temperature Logs to Trace the Movement of Injected Water, Ground Water, Vol. 16, No. 1, pp. 32-48.

Keys, W. S., and MacCary, L. M., (1971), Application of Borehole Geophysics to Water-Resources Investigations, U. S. Geological Survey Techniques in Water Resources Inv., Book 2, Chapter 1.

Mayer, A.S. and C.T. Miller (1988), A Three-Dimensional Flow Model for Analysis of Remediation Efforts at a Polluted Coastal Aquifer, Symposium on Coastal Water Resources, pp. 531-541.

McDonald, M.G., and Harbaugh, A.W., (1988), A Modular Three-Dimensional Finite-Difference Groundwater Flow Model.

Moltz, F.J., et al., (1986), Performance, Analysis and Simulation of a Two-Well Tracer Test at the Mobile Site, Water Resources Research, 22(2), pp. 1031-1037.

Moltz, F.J., et al., (1986), Performance and Analysis of Aquifer Tracer Tests with Implications for Contaminant Transport Modeling, pp. 1-85.

Naymik, T. G., and Sievers, M.E., (1983), Ground-water Tracer Experiment (II) at Sand Ridge State Forest, Illinois, Illinois State WAter Survey Division, SWS Contract Report 334.

Sauty, J.P. and W. Kinzelbach (1988), Of the Identification of the Parameters of Groundwater Mass Transport, Groundwater Flow and Quality Modeling, pp. 33-56.

Sauty, J.P. and W. Kinzelbach (1988), Computer Aided Tracer Test Interpretation Code.

Sauty, J.P. (1978), Identification Des Parameters Du Transport Hydrodispersif Dans Les Aquiferes Par Interpretation De Tracages En Ecoulement Cylindrique Convergent Ou Divergent, Journal of Hydrology 39.

Smart, P. L., and Laidlaw, I. M. S., 1977, An Evaluation of Some Fluorescent Dyes for Water Tracing, Water Resources Research, Vol 13, No. 1, pp 15-33.



Sorey, M. L., (1971), Measurement of Vertical Ground-water Velocity from Temperature Profiles in Wells, Water Resources Research, Vol. 7, No. 4, pp. 963-970.

Sudicky, E.A. (1986), A Natural Gradient Experiment on Solute Transport in a Sand Aquifer: Spatial Variability of Hydraulic Conductivity and Its Role in the Dispersion Process, Water Resources Research 22(13), pp. 2069-2082.





RESULTS FROM FIRST TRACER TEST

FLOWRATE OF INJECTION AND WITHDRAWAL PUMPS: 0.25 GPM

INJECTION WELL: WELL 13 (2" WELL) WITHDRAWAWL WELL: WELL 11 (4" WELL)

DURATION OF TEST: 25.5 HOURS

TRACER INJECTION TIME: 6 HOURS AMOUNT OF TRACER INJECTED: 90 GALLONS INITIAL CONCENTRATION OF TRACER: 250 sg/L CHLORIDE

TOTAL AMOUNT OF CHLORIDE INJECTED: 85.162 GRAMS C!

SAMPLE NO.	DATE	1	CHLORIDE C	(ag/L)	
		TIME (HOURS)	FIRST	SECOND TITRATION	AVERAGE
1	8-25-87	0.00	14.7	0.0	14.7
2	8-25-87	0.27	14.7	14.9	14.8
. 31	8-25-87	0.50	14.9	14.7	14.8
4	8-25-87	0.75	14.9	14.7	14.8
5 1	8-25-97	1.00	13.7	15.1	14.4
6	8-25-87	1.25	14.8	0.0	14.5
. 7	8-25-57	1.50	15.6	14.9	15.3
8	8-25-87	1.75	15.1	14.7	14.9
9	8-25-97	2.00	15.6	14.9	15.3
10	8-25-87	2.25	15.3	14.9	15.1
11	8-25-87	2.50	14.7	0.0	14.7
12	8-25-87	2.75	14.9	0.0	14.9
13	8-25-87	3.00	15.1	0.0	15.1
14	8-25-87	3.25	15.1	0.0	15.1
15	8-25-87	3.50	14.7	0.0	14.7
16	8-25-87	3.75	1 15.4	15.3	15.4
17	8-25-87	4.00	1 15.2	15.3	15.3
18	3-25-87	4.25	17.4	15.9	17.2




01/01/80

the second second in the part of the second se

....

TRACER1

	DATE	I FLADGED	CHLORIDE C	(ag/L) !	
NO.	BHIE	TIME (HOURS)	FIRST	SECOND : TITRATION	AVERASE
19	8-25-87	4.50	18.3	18.1	18.2
20 1	8-25-87	4.75	19.7	19.5	19.6
21	8-25-87	5.00	19.9	20.1	20.0
22	8-25-87	5.25	21.5	22.0	21.8
23	8-25-87	5.50	23.6	23.1	23.4
24	8-25-87	5.75	24.3	23.8	24.1
25	8-25-87	6.00	26.1	25.7	25.9
25	8-25-87	6.25	28.4	27.5	28.0
27	8-25-87	6.50	28.8	28.8	28.8
28	8-25-87	6.75	29.3	29.3	29.3
29	8-25-87	7.00	30.9	30.7	30.8
30	8-25-87	7.25	31.8	32.0	31.9
31	8-25-87	7.50	33.7	33.9	33.8
32	8-25-87	7.75	35.1	34.8	35.0
· 33 1	8-25-87	8.00	36.4	35.2	36.3
34	8-25-87	8.25	38.5	38.2	38.4
35	8-25-87	8.50	40.8	42.2	41.5
36	8-25-87	8.75	41.9	42.1	42.0
37	8-25-87	9.05	45.8	47.0	45.4
38	8-25-87	9.25	45.3	44.4	44.9
39	8-25-87	9.50	45.5	45.6	46.1
40	8-25-87	9.75	47.9	47.0	47.5
. 41	8-25-87	10.00	48.3	48.6	48.5
42	8-25-87	10.25	49.7	50.1	49.9
43	8-25-97	10.50	51.5	51.1	51.3

•

TRACER1

	1			CHLORIDE C	ONCENTRATION	(ag/L)	
	NO.	DATE	TIME (HOURS)	FIRST TITRATION	SECOND TITRATION	AVERAGE	
	44	8-25-87	10.75	52.5	52.5	52.5	
	45	8-25-87	11.00	52.0	53.3	52.7	
	46	8-25-87	1 11.27	54.5	54.1	54.4	
	47	8-25-87	11.50	54.6	53.9	54.3	
	48	8-25-87	11.75	54.5	54.1	54.4	
	49	8-25-87	12.00	54.5	54.6	54.6	
1	50	8-25-87	12.25	54.1	53.4	53.8	
	51	8-25-87	12.50	54.5	53.9	54.2	
	52	8-25-87	12.75	54.3	54.5	54.4	
	53	8-25-87	13.00	53.9	53.6	53.8	
	54	8-25-87	13.25	52.7	53.6	53.2	
	55	8-26-87	13.50	53.3	53.1	53.2	
	55	8-25-87	13.75	53.2	52.7	53.0	
	57	8-25-87	14.00	52.4	52.9	52.7	
	58	8-25-97	1 14.25	51.9	52.5	52.2	
	59	8-25-87	14.50	52.4	52.4	52.4	
	60	8-26-87	14.75	52.0	52.4	52.2	
	61	8-25-87	1 15.00	50.5	51.0	50.8	
	52	8-25-87	1 15.25	49.8	50.0	49.9	
	53	8-25-87	15.50	50.0	50.3	50.2	
	64	8-25-97	1 15.75	48.9	49.4	49.2	
	65	8-26-87	16.00	48.7	49.3	49.0	
	66	8-26-87	16.25	48.2	48.2	48.2	
	67	8-26-87	16.50	46.8	47.5	47.2	
	68	8-26-97	1 16.75	46.7	45.0	45.4	

ī

•

TRACER1

	DATE	1	CHLORIDE C	(ag/L)	
ND.	SAIL	I TIME I (HOURS)	FIRST TITRATION	SECOND TITRATION	AVERAGE
69	8-25-87	17.00	45.0	45.0	45.0
70	8-25-87	17.25	45.1	45.1	45.1
71	8-25-87	17.50	45.1	44.9	45.0
72	8-25-87	17.75	44.2	44.6	44.4
73	8-25-87	18.00	43.4	43.0	43.2
74	8-25-87	18.25	42.1	42.7	42.4
75	8-25-87	18.50	42.1	41.8	42.0
76	8-25-87	18.75	40.9	40.6	40.8
77	8-25-87	19.00	40.6	40.9	40.8
78	8-25-37	1 19.25	40.2	40.8	40.5
79	8-25-87	19.50	39.9	39.5	39.3
80	8-26-87	19.75	38.7	38.9	38.1
81	8-26-87	20.00	40.1	39.4	39.1
82	8-26-87	20.25	39.2	38.9	39.
83	8-26-87	20.50	39.4	38.5	39.
84	8-26-37	20.75	39.3	38.0	39.3
85	8-26-87	21.00	38.2	38.7	38.
85	8-26-87	21.25	37.5	37.3	37.
87	8-26-87	21.50	37.3	37.6	37.
88	8-26-87	21.75	36.7	35.4	36.
89	8-26-87	22.00	36.4	35.4	36.
90	8-26-87	22.25	25.0	35.2	36.
91	8-26-87	22.50	35.7	35.5	35.
92	8-26-87	22.75	35.5	35.5	35.
93	8-25-87	23.00	35.3	34.8	35.

01/01/80

.

TRACER1

.

•

:		DATE	1	CHLORIDE CONCENTRATION				
-	NO.	DAIE	TIME (HOURS)	FIRST	SECOND I TITRATION	AVERAGE		
-	94	8-26-87	23.25	35.5	34.8	35.2		
i	95	8-25-87	23.50	34.1	. 34.4	34.3		
i	96 1	8-26-87	23.75	34.2	34.1	34.2		
i	97	8-26-87	24.00	33.4	33.7	33.6		
i	98	8-26-87	24.25	33.0	33.2	33.1		
i	99	8-25-87	24.50	33.0	33.7	33.4		
i	100	8-26-87	24.75	32.1	32.6	32.4		
i	101	8-26-97	25.00	31.9	32.1	32.0		
i	102	8-26-87	25.25	31.7	32.1	31.9		
1	103	8-25-87	25.52	31.6	31.2	31.4		



RESULTS FROM SECOND TRACER TEST

FLOWRATE OF INJECTION AND WITHDRAWAL PUMPS: 0.50 GPM

INJECTION WELL: WELL 12 (2" WELL) WITHDRAWAWL WELL: WELL 10 (4" WELL)

DURATION OF TEST: 30 HOURS

TRACER INJECTION TIME: 4 HOURS AMOUNT OF TRACER INJECTED: 120 GALLONS INITIAL CONCENTRATION OF TRACER: 250 mg/L CHLORIDE

TOTAL AMOUNT OF CHLORIDE INJECTED: 113.549 GRAMS CI

	DATE	EI ADGED	CHLORIDE C	(ag/L)	
NO.	DATE	I TIME I (HOURS)	FIRST	SECOND TITRATION	AVERAGE
11	11-12-87	0.0	15.3	14.9	15.1
2 1	11-12-87	0.5	14.7	14.6	14.7
3 1	11-12-87	1.0	15.3	14.9	15.1
4	11-12-87	1.5	21.2	20.5	20.5
5	11-12-87	2.0	27.1	27.1	27.1
6	11-12-87	2.5	33.9	34.0	33.9
7	11-12-87	3.0	41.5	41.8	41.7
8	11-12-87	3.5	49.8	49.8	49.6
9 1	11-12-87	4.0	52.3	53.1	53.2
10	11-12-87	4.5	61.7	60.9	61.3
11	11-12-87	5.0	53.3	62.8	53.1
12	11-12-87	5.5	65.7	66.1	65.9
13	11-12-87	5.0	68.9	68.2	68.6
14	11-12-87	6.5	65.1	65.1	65.1
15 1	11-12-87	7.0	63.8	63.8	63.8
16	11-12-87	7.5	59.1	59.7	59.4
17	11-12-87	8.0	54.6	54.5	54.6
18 1	11-12-87	8.5	50.3	50.5	50.4







AMPLE	DATE	ELAPSED		cug/c/	
NO.		TIME (HOURS)	FIRST	SECOND	AVERAGE
19	11-12-87	9.0	46.8	46.5	46.7
20	11-12-87	9.5	43.7	43.7	43.7
21	11-12-87	10.0	40.8	41.1	41.0
22	11-12-87	10.5	38.2	38.8	39.5
23	11-12-87	11.0	37.5	37.6	37.6
24	11-12-87	11.5	35.4	36.6	35.5
25	11-12-87	12.0	34.7	34.7	34.7
26	11-12-87	12.5	34.2	33.8	34.0
27	11-12-87	13.0	33.3	33.1	33.2
28	11-12-87	13.5	31.7	31.7	31.7
. 29	11-12-87	14.0	30.0	30.4	30.2
30	11-12-87	14.5	29.1	29.5	29.3
31	11-12-87	15.0	29.0	29.0	29.0
32	11-12-87	15.5	27.9	28.1	28.0
, 33	11-12-87	16.0	27.1	27.1	27.1
34	11-12-87	16.5	25.2	25.8	25.0
35	11-12-87	17.0	25.8	25.0	25.9
36	11-13-87	17.5	24.8	25.2	25.0
37	11-13-87	1 18.0	23.4	23.8	23.6
38	11-13-87	18.5	23.8	23.4	23.5
39	11-13-87	1 19.0	22.5	23.1	22.8
40	11-13-87	19.5	23.1	22.9	23.0
41	11-13-87	20.0	22.4	22.0	22.2
42	11-13-87	20.5	21.3	21.7	21.5
43	11-13-87	21.0	21.5	21.3	21.4

01/01/00

•

.

SAMPLE NO.				CHLORIDE C	(sg/L)	
		DATE	TIME (HOURS)	FIRST	SECOND I TITRATION	AVERAGE
	44	11-13-97	21.5	21.2	20.8	21.0
	45	11-13-87	22.0	20.6	20.1	20.4
	45	11-13-87	22.5	19.9	19.8	19.9
	47	11-13-87	23.0	19.6	19.1	19.4
	48 1	11-13-87	23.5	18.9	19.1	19.0
	49	11-13-87	24.0	19.1	19.1	19.1
	50	11-13-97	24.5	18.9	19.1	19.0
	51	11-13-87	25.0	18.9	18.9	18.9
	52	11-13-87	25.5	18.5	18.5	18.6
	53	11-13-87	25.0	19.6	18.7	19.7
	54	11-13-87	26.5	18.7	18.5	18.7
'	55	11-13-97	27.0	18.0	17.9	18.0
	55	11-13-97	27.5	17.7	19.0	17.5
	57	11-13-87	28.0	18.0	17.9	18.0
	58	11-13-87	28.5	17.5	17.5	17.5
	59	11-13-87	29.0	17.3	17.5	17.4
	60 1	11-13-87	29.5	17.7	17.5	17.5
	61	11-13-87	30.0	17.5	17.7	17.6
						100

1.0

. .

-

÷

.

.





.

BASDAT

1 50 0 0 0 0 0 0 0 0 .1005+01 11 .1005+01(7±11.4) 000 4.500 3.000 12 1.500 6.000 .2500 3.000 .2500 .2500 .3333 .1667 .5000 .5000 .3333 1.500 4.300 3.600 .1647 .2500 4.300 4.600 .1002+01(7011.4) 4.000 2.600 .1647 .1647 .4167 .500 .1647 .1647 .7500 1.250 12 .7500 .1447 .4167 .1467 4.000 11 .5000 .1447 .3333 .2500 8.000 1288 1.250 .1447 .5000 .1647 2.000 .720E+02 .421E+00 .1122+ 910E+00 .1922+01 .2592+02 .3462+01 1734-02 .1732+02 .3442+01 .2592+02 .1922+01 .5182+02 .9102+00 .1122+03 .2742+00 .4322+03

÷

BCFDAT

ļ

?







BOLMOARY ARRAY FOR LATER 1 WILL BE READ ON UNIT 1 USING FORMATE (1712)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
											:							
0 1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
0 Z	-1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	-1	
0 2	-1	1	1	1	1	1	1	1	1	۱.	1	1	1	1	1	1	-1	
0 4	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 5	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 6	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 7	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 8	+1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0.9	-1	1	i	i	i	i	i	i	i	i	i	i	i	i	i	i	-1	
0 10	-1	÷	1	1	i	1	÷	- 1	÷	i	i	i	- 1	1	1	1	-1	
0 11	-1	÷	i	i	i	i	÷	i	÷	i	i	i	i	i	i	i	-1	
0 12	-1	÷	. i	i	÷		- 6	÷			i	÷	•	÷				
0 13	-1	- 6	÷	÷	÷	- 6	. 6	. 6	- 6		•	÷		- 6				
0 14	-1	- 6			. 6	- 6	- 6	- 6			- 6							
0.15		- 6	. 6			. 6	. 6	. 6										
												:						
1.12		- 2								:		:	:				-	
1.11			:							. :		:		:				
U 10	-	- 2	1	1		- 1	- 1	1	1	1	1	1	1	1	1	1	-1	
0 17	-1			1	1	1	1	1		1			1	1	1	1	-1	
0 20	-1	1	1	1	1			1	1	1	1	1	1	1	1	1	-1	
9 21	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 22	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 Z3	-1	. 1	- 1	1	1	- 1	1	- 1	1	- 1	1	1	1	1	1	- 1	-1	
0 24	-1	1	1	- 1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
025	•1	. 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 25	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 27	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 28	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 29	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 30	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	
0 31	-1	1	1	1	1	1	1	1	1	1	1	Ť.	1	1	1	1	-1	
0 32	-1	1	1	1	1	1	÷	1	1	1	1	1	1	1	1	1	-1	
17.0					- 6	- 6		- 6	- 6	÷		i	÷		•	÷	-1	
																•		

BECKYHRD

-1 -1 -1 -1 -1 -1			
BOINCAST ABELY .		1 FOR LATER	2
BUNDLEY APPLY -		1 FOR LATER	3
BUILDING AND A		1 FOR LAYER	-
		I ICO LANTE	÷.
BOOMWALL MARKET		I FOR LANEA	- 2
BOUNCAUT ADAT -		1 FOR LATER	
BOUNDARY ARRAY -		1 FOR LATER	1
BOLNDART ARRAY =		1 FOR LATER	
BOLNDARY ARRAY =		1 FOR LAYER	
AT ALL NO-FLOW WODES (INCUMD-0).			
INITIAL NEAD .	100,0000	FOR LAYER	1
INITIAL MEAD .	100.0000	FOR LAYER	2
INITIAL HEAD -	100,0000	TOR LATER	3
INITIAL MEAD .	100,0000	FOR LAYER	4
INITIAL WEAD -	100.0000	FOR LAYER	
INITIAL WEAD -	100.0000	TOP LAYER	ā
THITTH WITH -	100.0000	TOR LATTE	÷
	100.0000	FOR LATER	-
INITIAL NEAD -	100.0000	FOR LATER	
INITIAL MEAD .	100,0000	FOR LATER	. 9
CRANDOW PRINT FORMAT IS FORMAT MURBER	-2		
DOWNS WILL BE SAVED ON UNIT O			
STEP			
COLUMN TO HOW ANISOTHOPT .	1.000000		
	-1 -1 -1 -1 -1 BOLDOLY AREAY - BOLDOLY	-1 -1 -1 -1 -1 -1 BOLGOARY AREAY - BOLGOARY AR	-1 -1 -1 -1 -1 -1 BOURDARY AREAY = 1 FOR LATTER BOURDARY AREAY = 100,0000 FOR LATTER INITIAL MEAD = 100,0000 FOR LATTER INITIAL

DELR WILL BE READ ON UNIT 11 USING FORMATE (7011.4)

...

6.0000	4.5000	3.0000	1.5000	.75000	.50000	.33330	.25000	.16670	.25000
.11110	-\$0000	.75000	1.5000	3.0000	4.5000	6.0000			

DELC WILL BE READ ON UNIT 11 USING FORMATE (7011.4)

	8.0000	4.0000	2.0000	1.2500	.75000	.50000	.33330	.25000	-16670	.16673
	.10070	-10070	.10070	.25000	1333374					.33333
	1.2500	2,0000	4.0000	8.0000	*16610	.16670	.25000	.33350	.50000	.75000
0					KTD. COND.	ALONG BONS .	8.640000	FOR LATER	1	
ō.						BOTTON .	77.00000	FOR LATER	1	
ō.					VERT KITS COM	/TRICOUTT .	.4210000	FOR LAYER	1	
ō.					TRANSMEN	ALCHE BOUT -	112.0000	TOP LAYER	2	
ă					VERT KOD COM	/talmarst .	\$100000	TOP LATER	5	
ě.					TRANCHIC	ALCHE BOUT .	51.80000	TOP LATER		
ŏ					VERT NO COM	duimint -	1.920000	FOR LATER	1	
ñ.					This will	HONG BOUR -	35 00000	ENR LAVER	1	
ě.					WEST WOD COM	ALLING RUNS -	1.440000	FOR LAVER	2	
č					TRANSPORTE	ALCHE BOLS -	17 10000	FOR LATER	2	
×.					LEAST LOD COURSE	ALCHO FORS	11.30000	FOR LATER	-	
×.					VERI ATO COM	/inicoliss .	3.400000	FOR LATER	2	
×.					TRAISHIS.	ALONS HONS .	25.90000	FOR LATER	2	
					VERT MID COR	/INICOLSS -	1.920000	FOR LATER	0	
9					TRUISHIS.	ALONG HOUS .	51,80000	FOR LATER	1	
9					VERT NID CON	/micozss -	.9100000	FOR LATER	1	
ġ.,					TRANSMIS.	ALONG BOUS .	112,0000	FOR LATER	8	
Q.					VERT NTO COM	· TRICOLESS ·	.2740000	FOR LAYER	8	
0					TRANSMIS.	ALONG BOUS .	432,0000	FOR LATER	9	
0										
					SOLUTION	AT THE STRONG	-	eocrose a		

MAXIMUM ITERATIONS ALLOWED FOR CLOSURE = 50 ACCELERATION PARAMETER = 1,0000 MEAD CANNET CRITERION FOR CLOSURE = ,10000E-G3 SIP MEAD CANNET PRIMITANT INTERVAL = 1 CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED STRESS PERIOD NO. 1, LENGTH = 1,000000
MARLE OF TIME STEPS - 1

MATIPLIER FOR DELT . ,000

INITIAL TINE STEP SIZE - 1.000000

HOW COL STRESS RATE WELL NO. LATER

2 WELLS

CAVERACE SEED - .00016713 NINIM SEED - .00000060 n

Ó

ITERATION PARAMETERS CALCULATED FROM AVERAGE SEEDS

.000000001+00 .85629892+00 .9670721E+00 .9985301E+00 .00053206+00

5

11

36 ITERATIONS FOR TIME STEP 1 IN STRESS PERIOD 1 OWITHIN HEAD CHURCE FOR EACH ITERATION: 0 HEAD CHURCE LATER, POU, COL HEAD CHURCE LATER, POU, COL HEAD CHURCE LATER, POU, COL HEAD CHURCE LATER, POU, COL

.1716 (5, .37552-01 (5, .19612-01 (2, .61462-02 (8, .25072-02 (8, .10032-02 (8, .302592-03 (8, -1.005 (5, 24, 9) -.65356-01 (5, 17, 4) .126376-01 (5, 17, 4) .126376-01 (6, 16, 3) .26556-03 (2, 32, 1) .29127-03 (8, 1, 2) -.14556-03 (2, 30, 1) .35118-04 (8, 20, 3) .4232 (5, 12, 8) -.72208-01 (5, 18, 5) .13042-01 (5, 4, 1) .29508-02 (7, 16, 5) .64327-03 (2, 31, 2) .26244-03 (3, 2, 3) .10608-03 (5, 4, 1) 4042 (5, 10, 44871-01 (6, 7, 16412-01 (6, 12, 30621-02 (7, 21, 12597-02 (4, 12, -34992-03 (2, 21, -14772-03 (8, 10, 4042 16, 5, 19, 21, 16, 11, -.2692 -.3372E-01 83 5) 5) 5) 4) 5) 7) -.53721-01 (-.1115E-01 (.10362-01 (.23672-02 (.95832-03 (10) 73 30 40 50 70 1) 23 43 8) 33 14. ٥

DERAD/DRAIDOWN PRENTOUT FLAG = 1 TOTAL COUTINUT FLAGS FOR ALL LAVERS ARE THE SAMET HEAD DEALDOWN HEAD DEALDOWN PRENTOUT PRENTOUT SAVE SAVE TOTAL BLOCET PRINTOUT FLAG . 1 CELL-ST-CELL FLOW TERM FLAS = 1

.................. 1 0 1 0

CONSTANT NEAD- RECET VALUES WILL BE SAVED ON UNIT 50 AT DO OF TIME STEP 1, STRESS PERICO "TLON BIGHT FACE - RECET VALUES WILL BE SAVED ON UNIT 50 AT DO OF TIME STEP 1, STRESS PERICO "TLON FRONT FACE - RECET VALUES WILL BE SAVED ON UNIT 50 AT DO OF TIME STEP 1, STRESS PERICO "TLON LOACE FACE - RECET VALUES WILL BE SAVED ON UNIT 50 AT DO OF TIME STEP 1, STRESS PERICO 1 1 NEAD IN LATER 1 AT END OF TIME STEP 1 IN STRESS PERICO 1

1 7 2 3 5 4 . -9 4 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100,000 100.000 100.000 100.000 0 1254567 100.000 100.000 100,000 100,000 100,000 0 100.000 100,000 100,000 100.000 100,000 100.000 100,000 0 102,000 100.000 100.000 100.000 100.000 100.000 100,000 100,000 100,000 100.000 100.000 100.000 100,000 100.000 100.000 00 0000 -100.000 100,000 100,000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100,000 100.000 100,000 100,000 100,000 100.000 100,000 10 100,000 100,000 100.000 100,000 100.000 100,000 100,000 100.000 100.000 100.000 100.000 100.000 100.000 11 100,000 100.000 100,000 100.000 100,000 100.000 0 12 100,000 100.000 100.000 100.000 100.000 13 0 14 0 15 0 15 0 17 0 18 0 19 100.000 100.000 100,000 100,000 100,000 100.000 100,000 100.000 100.000 100.000 100,000 100.000 100.000 100,000 100,000 100,000 100,000 100,000 100,000 100.000 100,000 100.000 100,000 100,000 100,000 100.000 100,000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100,000 100.000 100.000
100.000
100.000
99.9999
99.9999 100.000 100,000 100,000 100,000 \$00,000 100,000 100,000 100,000 99,9099 99,9099 99,9999 0 20 100,000 100.000 100,000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100,000 100.000 99.9999 99.9999 100.000 100.000 99.9999 59.0009 99.0009 99.0009 99.0009 99.0009 99.0009 99.9999 97.9999 97.9999 99.9999 99.9999 99.9999 90.0000 00.0000 90.0000 90.0000 90.0000 90.0000 100.000 90.0000 90.0000 90.0000 100.000 97.9999 \$9.9999 90.0000 90.0000 90.0000 90.0000 90.0000 90.0000 100.000 09,9000 99.9999 99.9999 100,000 100,000 99.9999 100,000 99.9999 99.9000 99.9999 99.9999 99.9999 100.000 99.9000 100.000 90,0000 90,0000 90,0000 90,0000 99.0000 99.0000 99.0000 99.0000 99.0000 99.9999 99.9999 99.9999 99.9900 100.000 99.9999 99.99999 99.9999 0 12 99.9000 90.0000 99,9999 100.000 0 34 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100.000 100,000 READ IN LAYER 1 AT END OF TIME STEP 1 IN STREES PERIOD 1 ------

		10	11	12	13	14	15	14	W
		**********					***********		**************
0	1	100.000	100,000	100,000	100,000	100.000	100,000	100,000	100,000
.0	2	100,000	100,000	100,000	100.000	100,000	100,000	100.000	100,000
. 0	3	100.000	100,000	100,000	100,000	100.000	100.000	100,000	100.000
0	4	100.000	100.000	100.000	100,000	100,000	100,000	100.000	100.000

48,100

1

	100.000	100.000	100.000	100.000	100.000	100 000	100.000	100.000	
	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
07	100,000	100.000	100.000	100,000	100.000	100.000	100.000	100.000	
0 8	100,000	100.000	100.000	100,000	100.000	100,000	100.000	100.000	
0 9	100.000	100,000	100.000	100,000	100.000	100,000	100,000	100.000	
0 10	100,000	100.000	100,000	100,000	100.000	100,000	100.000	100.000	
0 11	100.000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	
0 12	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
	100.000	100.000	100.000	100.000	500.000	100.000	100.000	100.000	
0 13	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
0 14	100.000	100.000	100.000	100.000	100.000	100,000	100.000	100.000	
0 15	100,000	100,000	100.000	100,000	100.000	100,000	100.000	100,000	
0 16	100.000	100.000	100,000	100,000	100.000	100.000	100.000	100.000	
0 17	100,000	100,000	100.000	100,000	100,000	100,000	100,000	100,000	
0 18	100.000	100.000	100.000	100.000	100.000	100.000	100,000	100.000	
0 19	100.000	100,000	100,000	100,000	100,000	100,000	100,000	100.000	
0 20	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
0.21	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
2 21	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
9 66	100,000	100,000	100.000	100,000	100.000	100.000	100.000	100.000	
¢ 21	\$7,9999	100.000	100.000	100,000	100,000	100,000	105,000	100.000	
0 24	99,9999	99.9999	99,9999	99,9999	100,000	100.000	100,000	100.000	
0 25	99,9999	99,9999	99,9999	99,9999	99,9999	100,000	100,000	100.000	
AC 8	00 0000	00 0000	0000	00 0000				100 000	
1.24	\$5.5399	30.0006		00.0000	00.0000	99,9999	100,000	100,000	
0.30	00 0000	00 0000	00 0000	00 0000	00 0000	00 0000	100.000	100.000	
							00.0000	100.000	
	11.1111	11.1111	m.mm	11.1111	m.mm	m.mm	11.1111	100.000	
0 21	99,9999	99.9999	99.9999	99.9999	99.9999	99.9999	W.WW	100.000	
D 32	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	100,000	
0 33	99,9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	100.000	
0 34	103.000	100,000	100.000	100.000	100.000	100,000	100.000	100.000	and the second se
1		1240 18-0	MEE-PAPED	OF THE SILP	T 18 318253 P	Ekilo ,			
	1	2	3	4	5	6	7		9
0 1	100.003	100.004	100.004	100.004	100.004	100.004	100.004	100.004	100.004
5 0	100,003	100.003	100,003	100,004	100.004	100,004	100,004	100.004	100.004
5 3	100.002	100.002	100.005	100.003	100.003	100.003	100.003	100.003	100.003
4 6	100.001	100.002	100.002	100.002	100.002	100.002	100.002	100.002	100.002
	100.001	100.001	100.000	100.003	100.002	100.003	100.003	100.002	100.002
	100.001	100.001	100.002	100.002	100.002	100.002	100.002	100.002	100.002
	100.001	100.001	100,001	100.002	100.002	100.002	100.002	100,002	100.002
07	100,001	100.001	100.001	100.001	100,001	100,001	100.001	100.001	100.001
	100,001	100.001	100,001	100,001	100,001	100,001	100,001	100.001	100,001
0 9	100.001	100,001	100.001	100,001	100.001	100,001	100.001	100.001	100.001
0 10	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001
0 11	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001
	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001
1 17	100.000	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.001
1 12				100.001	100.001	100.001	100.001	100.001	100.005
	100 000								
								******	• ••

99.9991

90,0001

00,9001

00 0005

 0
 3
 100.003
 100.003
 100.003
 100.003
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.002
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001
 100.001</t

99.9991

99.9992

99.9993

0 21

99.9994



.

