A FIELD STUDY OF THE APPROPRIATENESS OF THE PRZM AQUIFER LINKAGE FOR MODELING THE TRANSPORT OF INDUSTRIAL POLLUTANTS

By

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CHAPTER I

INTRODUCTION

The presence of industrial pollutants in the ground water is of major concern and the realistic modeling of contaminants moving into the ground water and dispersing through the system is critical to the design of effective remediation projects. One of the problems with modeling point source chemical applications to the environment has been the inability to effectively predict the movement of contaminants through the unsaturated zone. This being the case, the contamination is generally loaded directly to the receiving aquifer.

Dr. Jan Wagner and Dr. Carlos Ruiz-Calzada (1986) designed an aquifer linkage to connect the USEPA's Pesticide Root Zone Model (PRZM) with PRZMAL, an aquifer transport model. PRZM is used to predict the migration of contaminants through the soil column to a depth equal to that of the top of the aquifer. A loading file is created within PRZM and imported into PRZMAL, which is a version of Plume3D altered to accept the PRZM loading file. This linkage allows the modeler to predict contaminant movement, in a continuous manner, from the point of application into the aquifer. The PRZM-PRZMAL linkage has been tested, by the authors, with Aldicarb applications in potato fields located on Long Island, New York. One of the advantages of this model is its ability to function on a personal computer.

The objective of this study was to test the appropriateness of this linkage for the prediction of the leaching and transport of industrial pollutants in the subsurface. The method of investigation involved determining the leaching of organic hydrocarbons from the lagoons using the EPA's Organic Leachate Model and simulating transport through the unsaturated zone to the top of the water table. PRZM provided the mechanism for contaminant movement through the unsaturated zone to the water table. Contaminant movement within the aquifer was predicted by the PRZMAL model using time series loading data developed within PRZM.

The Glen Wynn Lagoons, a portion of the Sand Springs Petrochemical Complex Superfund Site, Tulsa County, Oklahoma, was chosen for the study. This facility provides a good testing ground since a fairly comprehensive study has been done at the site and many of the parameters required by the models have been determined, thereby eliminating the need for extensive parameter estimations. The linkage developed by Wagner and Ruiz was used to simulate the leaching and transport of Toluene and 1,1,1 Trichloroethane from the Glen Wynn Lagoons into the alluvial aquifer and to predict the resultant plume. Where possible, reported and original estimated values were used in order to make comparison of results more meaningful. Model results were then compared with monitoring well data and soil concentration data collected at the site by the Oklahoma State Health Department (OSHD), the EPA, and various consulting firms involved in the study of this site.

This linkage model was applicable to the investigation for several reasons. The PRZM equation was written for organic contaminants which exist at the Glen Wynn lagoons and the PRZM-PRZMAL model is a fairly simple model with relatively few parameter requirements, most of which were available within previous studies. Mounding of the water table was not likely considering the low permeability sludge overlying high permeability soils. Therefore, PRZM was acceptable as a model for an unsaturated soil column.

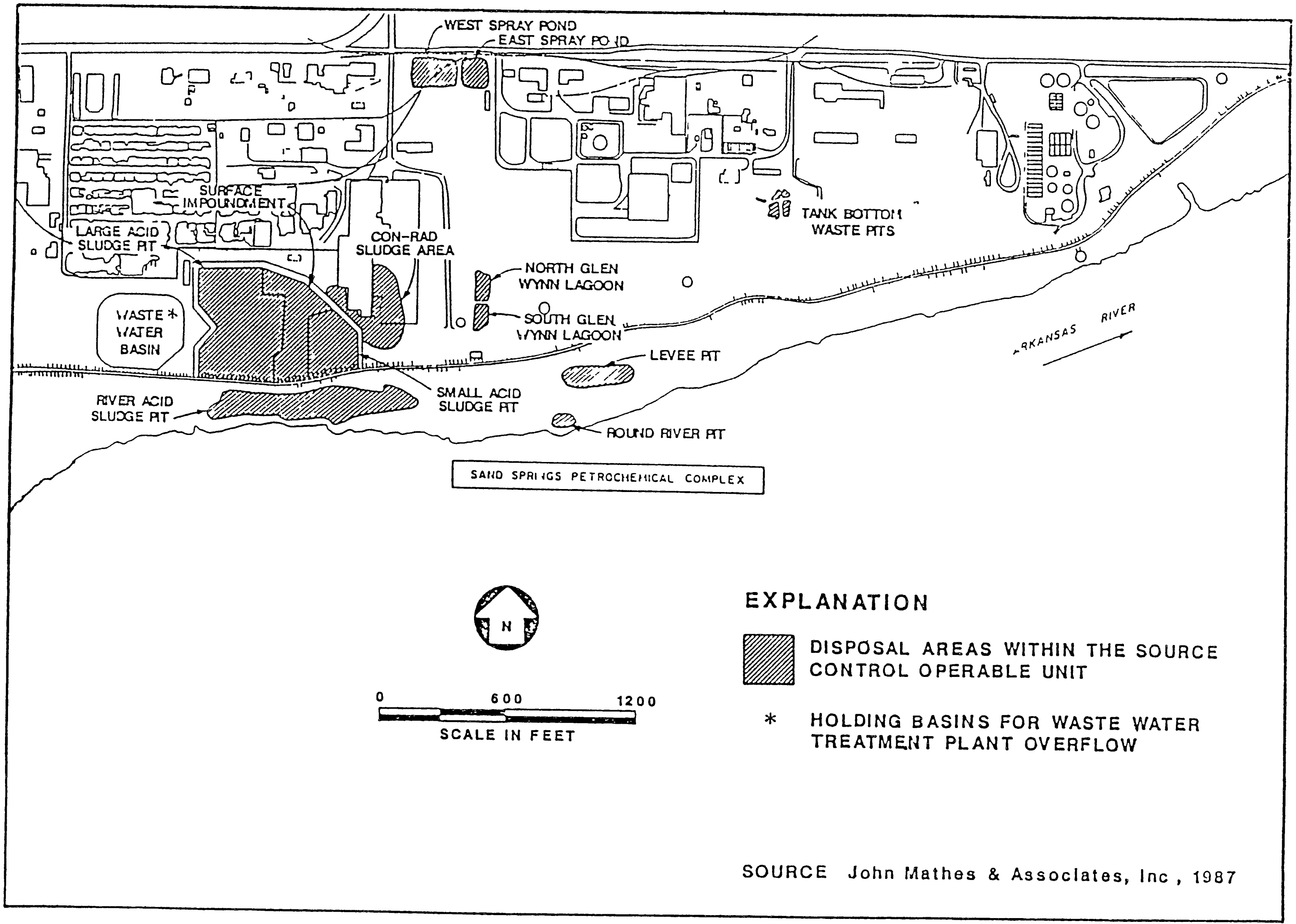
CHAPTER II

SITE DESCRIPTION

Site Location

The Glen Wynn Lagoons (Fig 1) are located on the Sand Springs Petrochemical Complex Superfund Site in western Tulsa County, Oklahoma. The Sand Springs Superfund Site is on the location of the former Sinclair Refining Company facility in Sand Springs, Oklahoma. The site consists of approximately 200 acres and is located in Sections 13 and 14, Township 19 North, Range 11 East (Mathes 1988). This site was divided, by the EPA (Mathes 1988), into the Source Control Operable Unit and the Main Site Operable Unit. The Glen Wynn Lagoons (north and south) are included in the Source Control Operable Unit, along with several other waste disposal units.

The site is bordered on the south by the Arkansas River, on the north by 21st Street and Morrow Road, on the west by the Sand Springs Railway tracks, and on the east by the Sand Springs Waste Water Treatment Plant. The Glen Wynn Lagoons, which consists of two unlined earthen pits covering a total area of 1,124 square meters, are situated on the alluvial flood plain adjacent to and approximately 160



SOURCE John Mathes & Associates, Inc , 1987

Figure 1 Waste Disposal Areas

meters north of the Arkansas River.

Site History

Pierce Petroleum Corporation Refinery occupied the site early in the 1900's and records indicate several refineries were in operation throughout the 1920's. In 1930, Sinclair Refining Company purchased the plant. There are also indications that a Chestnut and Smith Corporation Refinery and a Phoenix Corporation Refinery operated on the property during the 1920's. The Phoenix Refinery occupied the western portion of the present Superfund site (Mathes 1988).

According to Oklahoma State Health Department records (Mathes 1988), the Sinclair Sand Springs plant operated from 1930 to 1947 when operations ceased and the plant was dismantled (Mathes 1988). At that time most of the property was sold to, the Sand Springs Home, a local charitable organization, and the remainder was transferred to the Atlantic Richfield Corporation (ARCO) with the 1969 Sinclair merger. Figure 2 shows the location of current and former industries on the Sand Springs Petrochemical Complex.

The Glen Wynn facility reportedly received waste oils and solvents from 2300 customers in four states during its operational lifetime. While this facility was in operation, numerous hazardous substances were "stored or disposed of in

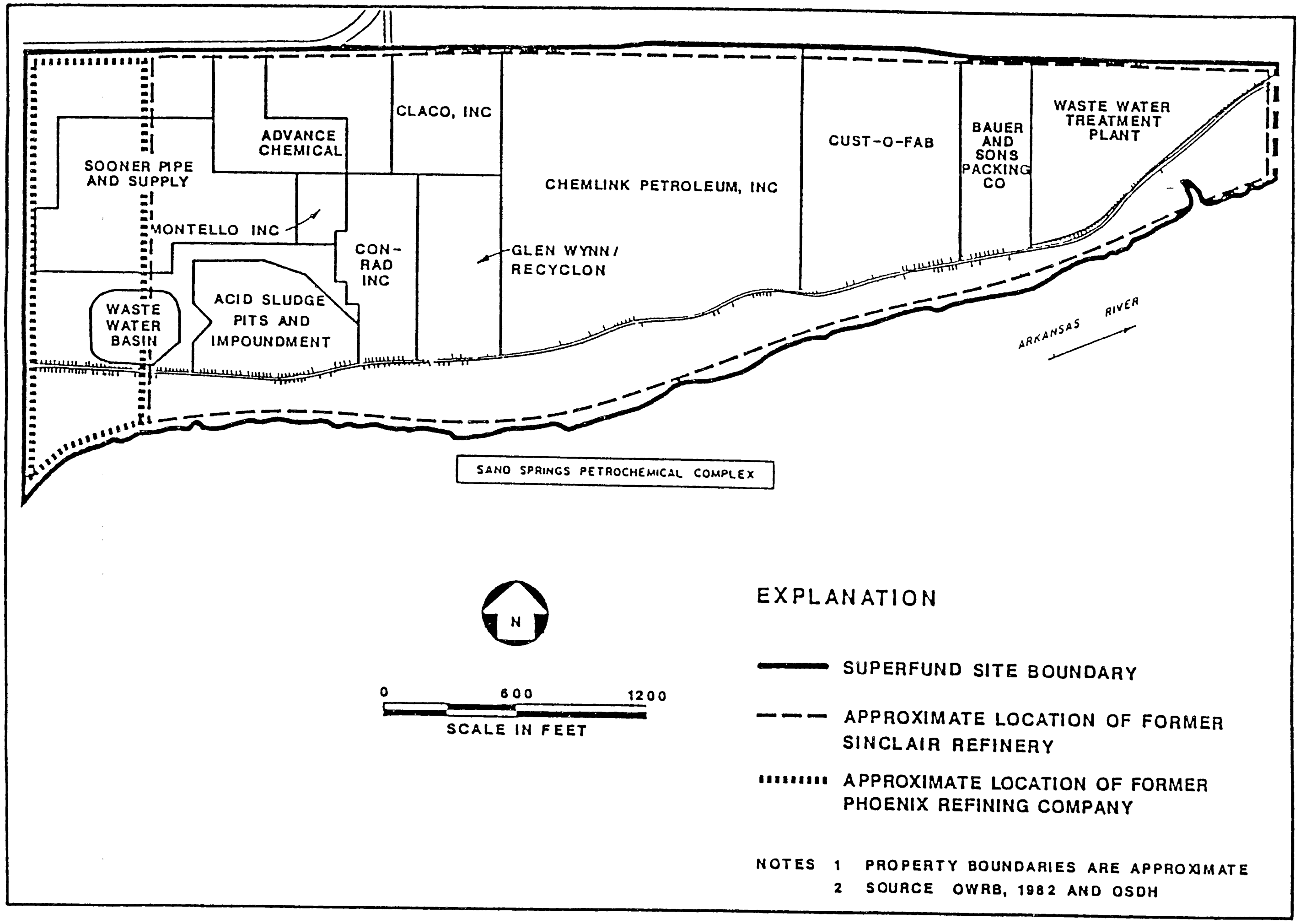


Figure 2 Existing and Former Industries

drums, tanks, unlined pits, and lagoons or buried on-site (Mathes 1988)." These substances included chlorinated solvents, heavy metals, caustics, inorganic and organic volatiles and non-volatiles. Wastes on the site a primarily hydrocarbon sludges and liquid phase solvents.

Operating practices at the facility led to the contamination of the alluvial aquifer beneath the site and the subsequent transport of contaminants to the Arkansas River (Mathes 1988; Environmental Resources Management 1989). According to an assessment report on ground water quality issued by Environmental Resources Management, Inc. (1989), the site ceased operations sometime in 1964.

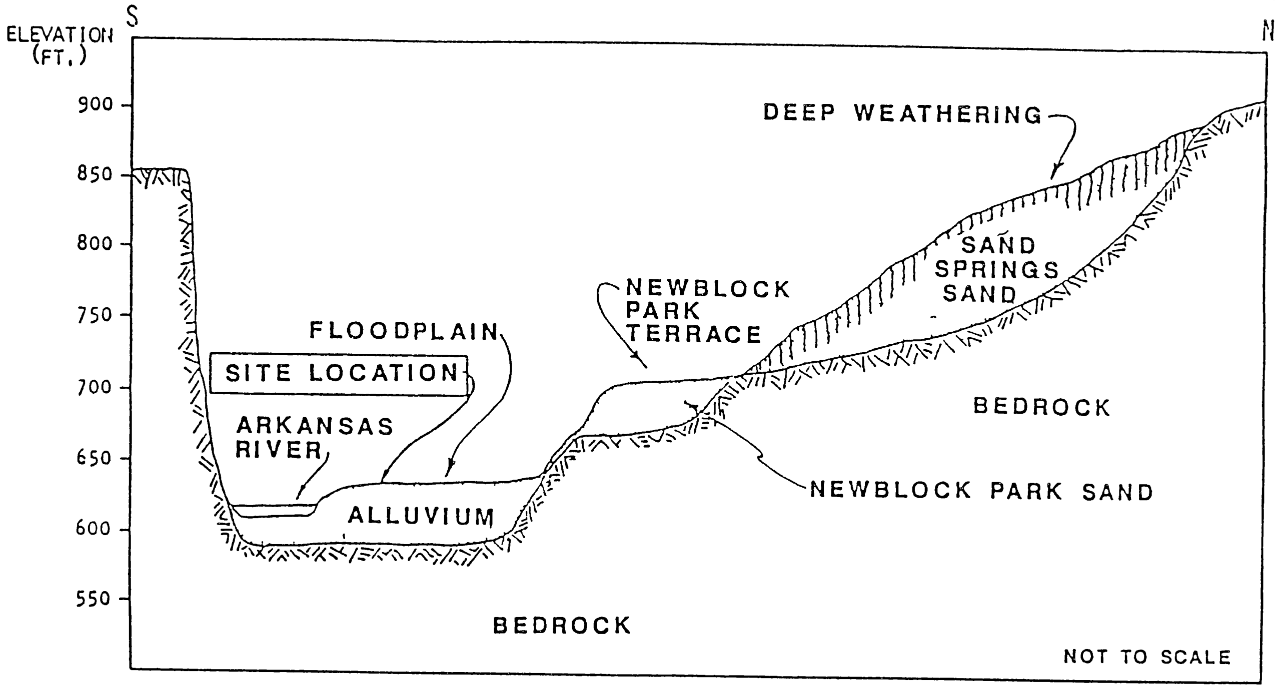
Hydrogeologic Setting

According to boring logs from the site (Mathes 1987), this alluvium is 7.62 to 12.55 meters thick. Thickness averages 10 to 11 meters near the river and thins to the north. The alluvial material consists mostly of silt and fine to medium grain sands (Tulsa Geological Society 1973). North and up gradient of the site there are terrace deposits, primarily thick alluvial deposits comprised of fine to medium grained sands. The Coffeyville Formation, a low permeability bedrock consisting of shales, thin bedded sandstones, and siltstones, underlies the site and is estimated to be 85 meters thick (OSHD 1986).

Recharge of the alluvial aquifer is by infiltration of rainfall and surface water through Newblock Park Terrace deposits and the Arkansas River alluvium. Figure 3 (Stone, et. al. 1972) provides a generalized cross section of the Arkansas River Valley. Under normal conditions, the groundwater flow discharges, in a southeasterly direction, to the Arkansas River (Tulsa Geological Society 1973). There are indications that ground water flow may be reversed during periods of flood (Mathes 1988), but this has not been documented and is not taken into account in this study.

The presence of the Keystone Dam and Reservoir upstream further complicates the hydrological characterization of this site. The release of water through Keystone Dam does not necessarily coincide with rainfall events and the effect on ground water flow and hydraulic gradients is unknown.

Slug tests run on monitoring wells (Table 1) indicate hydraulic conductivities ranging between 1.9E-2 to 6.0E-2 cm/sec with an average of 3.26E-2 cm/sec. The hydraulic gradient is 0.18 to 0.33 cm/meter, in the vicinity of the lagoons, based on estimations made from fluid elevation maps constructed by Mathes and Associates (1988). Effective porosity was not tested and was assumed to be 30 percent by previous studies (Mathes 1988; Environmental Resources Management 1989).



SOURCE STONE, AND OTHERS, 1972

Figure 3 Generalized Cross Section Through the Arkansas River Valley

TABLE I

MONITORING WELL SLUG TEST DATA

MW #	APPROXIMATE HORIZONTAL HYDRAULIC CONDUCTIVITY (cm/s)
MW - 6	2.9E-2
MW - 7	6.0E-2
MW - 9	4.5E-2
MW - 13	3.3E-2
MW - 14	2.8E-2
MW - 18	1.9E-2
MW - 19	2.8E-2
MW - 21	2.6E-2
MW - 24	2.6E-2

NOTE: Values calculated by variable head method

Source: Mathes & Associates 1988

CHAPTER III

MODELING GLEN WYNN LAGOONS

Site Definition

There have been 32 monitoring wells installed on the site, but only three of these (Fig. 4) are directly down gradient from the Glen Wynn Lagoons. Monitoring well #1, located at the south end of the lagoon complex, tested Toluene levels at 0.30 mg/L and 1,1,1 Trichloroethane levels at 1.40 mg/L in 1986 (Mathes 1988). Monitoring well #4, approximately 76 meters due south of the lagoons, had measured Toluene levels of 0.076 mg/L and 1,1,1 Trichloroethane levels of 0.079 mg/L in 1986. Toluene was below the detection limits of the laboratory (.005 mg/L) in monitoring well #19 which is located approximately 130 meters south and east of the lagoons. Trichloroethane levels were not tested in Monitoring well #19. Both Toluene and 1,1,1 Trichloroethane were below laboratory detection limits (.005 mg/L) in monitoring wells #2 and #3, which are up gradient to the lagoons.

The modeling of the Toluene and 1,1,1 Trichloroethane contamination present from the Glen Wynn lagoons was under taken in three phases:

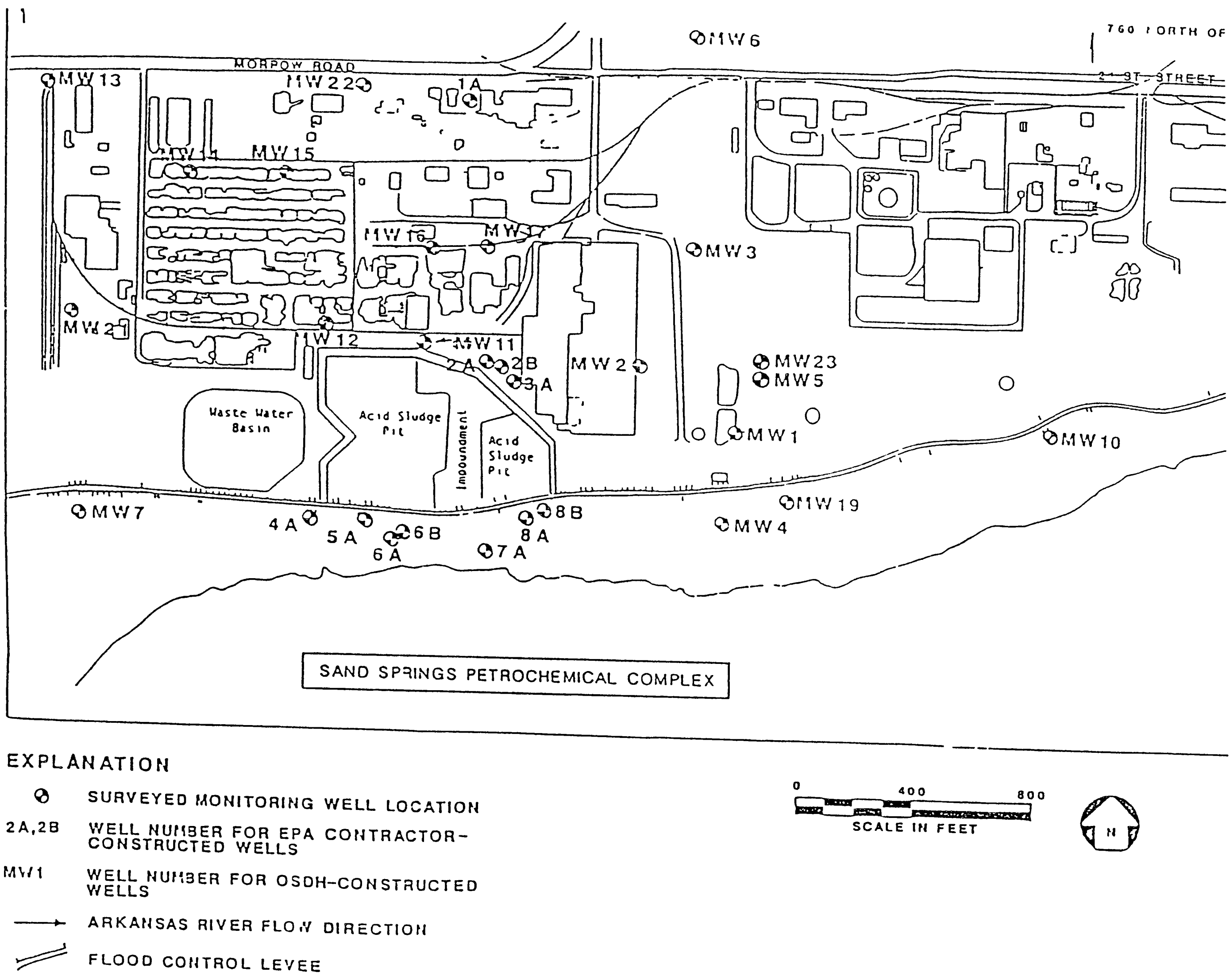


Figure 4 Map of Monitoring Well Locations

1) Developing a mass loading to the subsurface soils
2) Defining parameters and calibrating the PRZM model
3) Linking the PRZM loading to PRZMAL and calibrating PRZMAL.

Retardation and biodegradation were not accounted for in this study. This approach was taken because previous studies ignored these parameters and every effort was made to duplicate the assumptions of those studies where possible in order to obtain the best comparison of model results attainable.

Mass Loading

The Glen Wynn Lagoons cover a total area of 1,124 square meters. The average thickness of sludge in the lagoons is 6.46E-01 meters (Figure 5) with an average Toluene concentration of 2.75E+03 mg/L (OSHD 1986b) and an average 1,1,1 Trichloroethane concentration of 3.73E+03 mg/L (OSHD 1986b). There is a water layer over the sludges which averages 5.3E-01 m in depth. The infiltration of water through the sludges associated with the Glen Wynn Lagoons provides a mechanism for transport of those contaminants (Hounslow 1983; Miller & Webber 1984) into the soils beneath the lagoons. The ponded lagoons provide a relatively constant driving head, though this will vary slightly with seasonal rainfall and evaporation cycles.

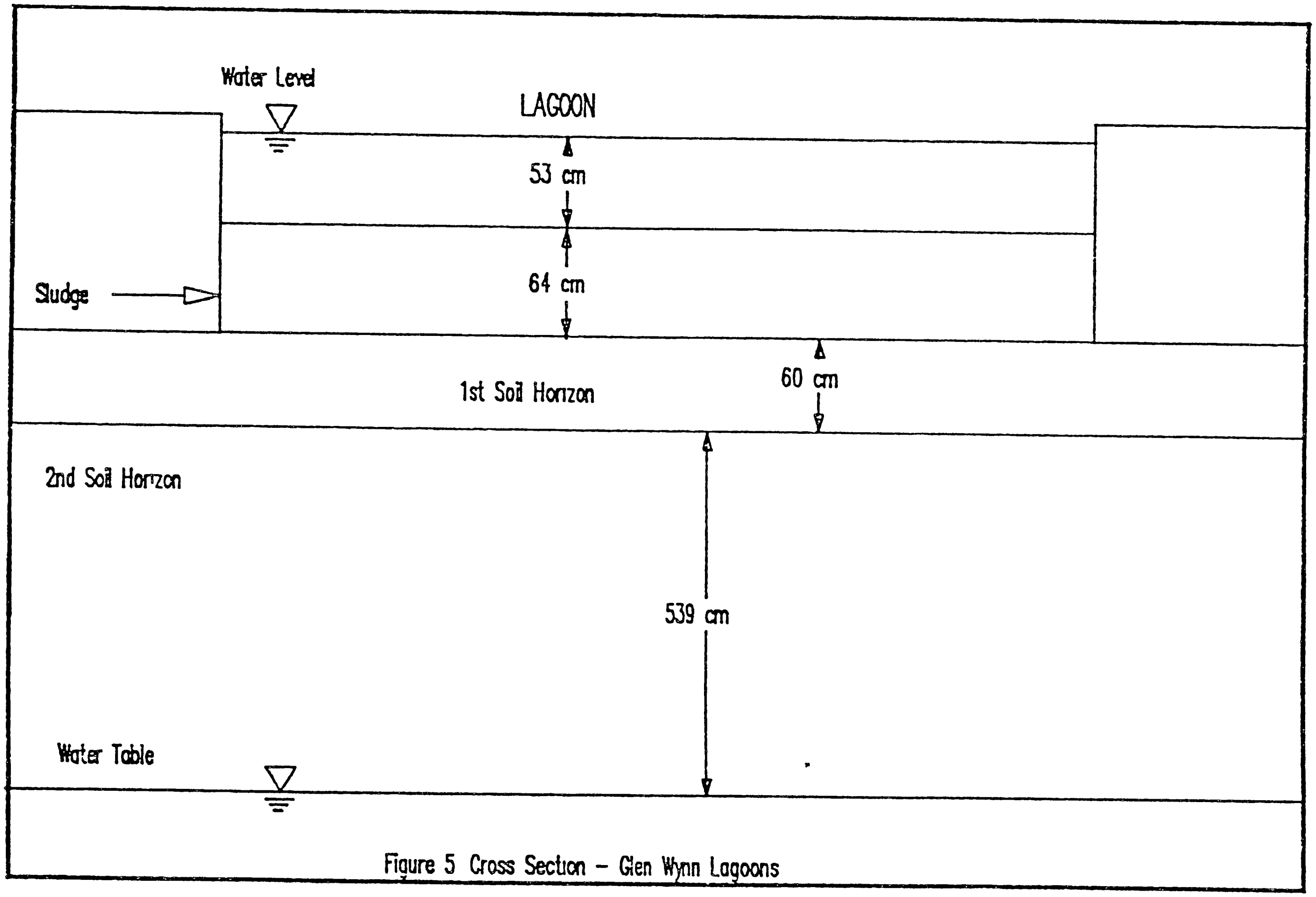


Figure 5 Cross Section – Glen Wynn Lagoons

The USEPA's Organic Leachate Model (OLM) (Environmental Resources Management 1989) was used to predict concentration of the leachate infiltrating from the sludge (Figure 5) in order to calculate the loading of contaminants to the soil column beneath the lagoons. Those values provide the data used to determine the loading to PRZM. It should be noted that the OLM model does not possess a rate function and, therefore, will probably overestimate leachate concentrations (Environmental Resources Management 1989). The OLM model consists of the following equation:

$$C_L = 0.0021 * C_0^{0\ 678} * S^{0\ 373}$$

where:

C_L = predicted constituent leachate concentration (mg/L)

C_0 = initial concentration of the constituent in the source (mg/L)

S = solubility of constituent (mg/L)

The average concentration of Toluene in the lagoons sludge was 2.75E+03 mg/L (OSHD 1986b) and the solubility of Toluene in water at 25 degrees Celsius is 535 mg/L (Verschueren 1983). 1,1,1 Trichloroethane had an average sludge concentration of 3.73E+03 mg/L (OSHD 1986b) and Verschueren (1983) reports a solubility of 1500 mg/L at 25 degrees Celsius.

Using these values and applying them to the OLM model predicted concentration of leachate from the lagoons was calculated to be 4.69 mg/L of Toluene and 8.48 mg/L of 1,1,1 Trichloroethane.

The ponding in the lagoons provides a driving force for leachate from the sludge which can be calculated using Darcy's equation. No measurement of the hydraulic conductivities of the lagoon sludge was reported, therefore, it was necessary to characterize the nature of the sludge in order to predict this value. The sludge, which consists of fine particles, is assumed to best be characterized by the hydraulic properties consistent with that of a silt and would have hydraulic conductivities in the range of 10E-7 to 10E-8 (Verruijt 1970).

Estimating hydraulic conductivities of the sludge to be approximately equal to 1.0E-08 meters per second (Verruijt 1970) and applying Darcy's law:

$$Q = K * A * (h/L)$$

where:

Hydraulic Conductivity (K) = 1.0E-08 m/s

Area (A) = 1.124E+03 m^2

Head (h) = 5.3E-01 m

Thickness of Sludge (L) = 6.46E-01 m

a flow rate of 9.23E-06 cubic meters per second (3.32E-02 cubic meters per hour) was determined. This value compares quite favorably with value of 4.15E-2 cubic meters per hour derived by Environmental Resources Management (1989) when that company undertook a predictive study at the Glen Wynn Lagoons facility.

The mass loading to the soil column is based on the infiltration of water over the entire area and the average concentration of the Toluene and 1,1,1 Trichloroethane leachate entering the system. Mass loading calculations:

$$ML = (Q) * (C) * (1.0E+03\ L/m^3) * (1.0E-06\ kg/mg) * (8.76E+3\ hr/yr)$$

where:

Q = 3.32E-02 cubic meters per hour
C = concentration of contaminant

indicate an input of approximately 1.37 kg/yr of Toluene and 2.47 kg/yr of 1,1,1 Trichloroethane to the soil column from the lagoons.

Initial runs of PRZM used only the leachate predicted from the sludges to calculate contaminant loading (1.37 kg/yr of Toluene and 2.47 kg/yr of 1,1,1 Trichloroethane). Efforts to calibrate PRZM with this loading resulted in concentration levels of 1,1,1 Trichloroethane at monitoring well #1 of 1.12 mg/l and at monitoring well #4 of 0.072

mg/l on December 31,1986. These levels were below the reported values of 1.40 mg/l and 0.076 mg/l for monitoring wells #1 and #4 respectively. In order to more accurately predict levels of contamination consistent with measured data, it was necessary to incorporate leachate from the soils beneath the lagoons, as well as those from the sludges. One method is to incorporate known Toluene and 1,1,1 Trichloroethane levels in the soils with predicted leachate from the lagoons. This requires that concentration of leachate from the soils also be calculated.

Analytical analysis of the soils beneath the Glen Wynn Lagoons (Mathes 1987 & 1988), in 1986, indicated the presence of Toluene with an average concentration of 189.79 mg/kg and an average concentration of 1,1,1 Trichloroethane of 105.46 mg/kg. The OLM model was used to determine concentrations of Toluene and 1,1,1 Trichloroethane leachate expected from the soil, adding an additional 0.76 mg/L of Toluene and 0.75 mg/L of 1,1,1 Trichloroethane leaching from the soils. Incorporating this value with leachate coming from the lagoon sludges provides a total leachate concentration of 5.45 mg/L of Toluene and 9.23 mg/L of 1,1,1 Trichloroethane to PRZM. Therefore, based on the leachate concentration, the total mass loading to the soil column is 1.59 kg/yr of Toluene and 2.69 kg/yr of 1,1,1 Trichloroethane.

PRZM

The PRZM model derives from the conceptual, compartmentalized representation of the soil profile. The model is written as two mass balance equations, one for the surface zone and one for the subsurface zone. The equation for the surface zone is:

$$Adx\ \delta(C_w\Theta)/\delta t = -J_D - J_v - J_{DW} - J_u - J_{QR} - J_{ADS} + J_{DES} + J_{APP} + J_{FOF} \qquad (1)$$

$$Adx\ \delta(C_s p_s)/\delta t = -J_{DS} - J_{ER} - J_{DES} + J_{ADS} \qquad (2)$$

where:

A = cross sectional area of soil column; L^2

dx = depth dimension of compartment; L

C_w = dissolved concentration of pesticide; ML^{-3}

C_s = sorbed concentration of pesticide; MM^{-1}

0 = volumetric water content of soil; L^3L^{-3}

p_s = soil bulk density; ML^{-3}

t = time; T

J_D = mass rate of change by dispersion; MT^{-1}

J_v = mass rate of change by advection; MT^{-1}

J_{DW} = mass rate of change by transformation of dissolved phase; MT^{-1}

J_u = mass rate of change by plant uptake of dissolved phase; MT^{-1}

J_{QR} = mass rate of change by removal in runoff; MT^{-1}

J_{APP} = mass rate of change by pesticide application; MT^{-1}

J_{FOF} = mass rate of change by washoff from plants to soil; MT^{-1}

J_{DS} = mass rate of change by transformation of sorbed phase; MT^{-1}

J_{ER} = mass rate of change by removal of eroded recliments; MT^{-1}

J_{ADS} = mass rate of change by adsorption; MT^{-1}

J_{DES} = mass rate of change by desorption; MT^{-1}

If the kinetic representation of sorption and desorption are equated:

$$J_{ADS} = J_{DES}$$

this results in the instantaneous equilibrium assumption.

Equations for the subsurface are identical to the previous two equations with the exception that the terms J_{ER}, J_{FOF}, and J_{QR} are excluded. The term J_{APP} applies in the subsurface only when pesticides are incorporated into the soil. For further definition of terms in equations 1 and 2, please refer to Appendix A.

The Pesticide Root Zone Model (PRZM) simulates the vertical movement of contaminants in the unsaturated soil, within and below the root zone, and extending to the water table (EPA 1984). The model contains both hydrological and chemical components that simulate erosion, plant uptake, leaching of contaminants, runoff, decay, and foliar washoff. PRZM is a compartmentalized representation of the soil column consistimg of three major components: (1) water balance in the soil profile; (2) erosion from the soil surface; and (3) chemical transport in the soil.

Water balance equations are developed for the surface, the root zone, and below the root zone:

1) Surface Zone

$$(SW)_1^{t+1} = (SW)_1^t + p + SM - I_1 - Q - E_1$$

2) Root Zone

$$(SW)_1^{t+1} = (SW)_1^t + I_{1-1} - U_1 - I_1$$

3) Below Root Zone

$$(SW)_1^{t+1} = (SW)_1^t + I_{1-1} - I_1$$

where:

$(SW)_1^t$ = soil water in layer "i" of noted zone on day "t" (cm)

p = precipitation as rainfall minus crop interception cm day^{-1}

SM = snowmelt cm day^{-1}

Q = runoff cm day^{-1}

E_1 = evaporation cm day^{-1}

U_1 = transpiration cm day^{-1}

I_1 = percolation out of zone "i" cm day^{-1}

Input precipitation is read into the model from the meteorologic file and partitioned between snow and rainfall depending on temperature. The potential energy for evapotranspiration is taken from pan evaporation data and/or air temperature. Precipitation first encounters plant interception and when the user-supplied storage is used up it becomes available for runoff calculations.

Runoff calculations within PRZM are the key element in the water balance (EPA 1984). These calculations partition available water between surface runoff and infiltration. The infiltrating water is then available for leaching. Runoff is calculated using a modification of the USDA Soil Conservation Service curve number approach (Equation #1). Curve numbers are a function of soil type, crop type, drainage properties and management practices.

PRZM requires two input files; 1) the meteorological data file, which was supplied by the Oklahoma Climatological Survey, Norman, Oklahoma: and 2) the parameter file. The meteorological data includes daily precipitation, pan evaporation, high temperature and low temperature from January 1,1964 to December 31,1988, at the Keystone Reservoir observation site, which is approximately 10 miles west of the Glen Wynn Lagoon Site. This is sufficiently close to the Glen Wynn site to be considered valid. Daily average sunlight was estimated based on latitude (Criddle 1958).

Data for the parameter file (Tables 2 and 3) was provided, in part, by the extensive work of the Environmental Protection Agency, the Oklahoma State Health Department, and studies conducted by consulting firms with regard to the Superfund project. Soil moisture content and soil constituent analysis was supplied by Adenike Akolade (1991), a PhD candidate at Oklahoma State University, and organic carbon content was calculated (Hounslow 1988) from the data she provided. Other input data were estimated based on the best available information (EPA 1990; Hounslow 1983; Ruiz-Calzada 1991; Stone 1972; Todd 1980).

Dispersion and retardation were not accounted for in the PRZM simulation. Previous studies (Mathes 1987 & 1988) at this site ignored these values and this investigation attempted to remain as close as possible to the original parameters. The retardation coefficients of Toluene and 1,1,1 Trichloroethane, with respect to the movement of the water front measured on aquifer material with 0.02% organic carbon, are 0.9 and 1.0 (Wilson, et. al. 1985) respectively. Values of organic carbon used in this model were 0.01% and the retardation coefficients calculated were the same as those calculated by Wilson, etal. Koc values (EPA 1990) for Toluene is 3.0E+2 ml/g and for 1,1,1 Trichloroethane is 1.52E+2 ml/g. These chemicals would exhibit little retardation and are expected to exhibit a moderate to high degree of mobility in the soil column.

TABLE 2

TOLUENE - PRZM PARAMETERS

Start Simulation - January 1,1964

End Simulation - December 31,1988

SOIL PARAMETERS

Depth of soil column - 599 cm

Compartments - 50

1st soil horizon: 60 cm

% Sand - 70.0

% Clay - 23.9

% Organic Matter - 3.0

2nd soil horizon: 539 cm

% Sand - 80

% Clay - 10.0

% Organic Matter - 1.0

CONTAMINANT PARAMETERS

Toluene Application - 1.591 kg/yr

Solubility - 535 mg/L

TABLE 3

1-1-1 TRICHLOROETHANE - PRZM PARAMETERS

Start Simulation - January 1,1964

End Simulation - December 31,1988

SOIL PARAMETERS

Depth of soil column - 599 cm

Compartments - 50

1st soil horizon: 60 cm

% Sand - 70.0

% Clay - 23.9

% Organic Matter - 3.0

2nd soil horizon: 539 cm

% Sand - 80

% Clay - 10.0

% Organic Matter - 1.0

CONTAMINANT PARAMETERS

1-1-1 Trichloroethane Application - 2.688 kg/yr

Solubility - 1500 mg/L

In order to develop a model which would simulate the ponded lagoons present at the Glen Wynn site it was neces sary to select input data very carefully, since PRZM was not originally designed to deal with this scenario.

The first consideration, since this system was under a constant driving head, was to ensure that no evaporation or evapotranspiration from the soil column was allowed to take place. Negating the effect of evaporation was achieved by setting the pan factor (PFAC) flag to zero and the minimum depth of evaporation extraction (ANETD) flag to a low number (15 cm). Next, the maximum interception storage of the crop (CINTCP) was set to zero, the active root depth (AMXDR) was set to 1.0 cm, and, since the area model was specifically the lagoons and the area covered by vegetation was minimal, the areal coverage of the crops were estimated at 5 percent. Crop interception and uptake of water and contaminant were negligible, thus allowing for the infiltration of most of the water present.

Within PRZM there exist two choices for the movement of water through the system; free flowing and restricted. The soils involved in this study are alluvial in nature and mostly sand size (Akolade 1991; Tulsa Geological Society 1973). Water moving through the low permeable zone (sludge) to a higher permeable zone (soils), is slow enough to allow for sufficient drainage. Therefore, movement of water through the soil column was considered to be free flowing and not effected by mounding. Erosion was set at a zero value to account for the fact that this scenario was a ponded lagoon and erosion would not be expected beneath the lagoon. The application of the contaminants was, to soil only, through leaching.

The soil column consists of two soil horizons. The first horizon, as described by Adenike Akolade (1991), 60 centimeters deep and consists of 70% sand, 23.9% clay, and 6.1% organic matter, with a soil moisture content of approximately 11 percent. Organic carbon content calculated to be 3 percent. The second horizon is 539 centimeters deep and the relative constituents of this zone are estimated, from boring descriptions (Mathes 1987), to be 80 % sand, 10 % clay and 1 % organic carbon. Soil moisture content was not known, therefore the calculation flag for soil field capacity and wilting point water contents (THFLAG) was set at 1 and that value was calculated by PRZM.

Fifty compartments were used and contaminant leachate was applied once a year for the twenty five years of the simulation. Figures 6 and 7 demonstrates the loading of Toluene and 1,1,1 Trichloroethane, respectively, to the aquifer from January 1964 to December 1988 as well as the yearly rainfall. The change in concentration of leachate passing through the unsaturated zone, allowing for percolation time, appears to be greater during years of higher rainfall. Computer outputs of the PRZM model are presented in Appendix C.

PRZMAL

PRZMAL performs the following functions (Wagner and Ruiz-Calzada 1986):

Data Input
Calculation of aquifer properties based on texture
Calculation of K_d based on water solubility models
Contaminant loading time series data input
Calculation of contaminant concentrations
Preparation of time series output files

Material Balance Equation

Description of the conservation of mass of a component in a saturated, homogeneous aquifer with uniform steady flow in the x-direction can be written as the differential equation:

$$\delta C_t/\delta t + V\ \delta C/\delta x = D_x\ \delta^2(\theta C)/\delta x^2 + D_y\ \delta^2(\theta C)/\delta y^2 + D_z\ \delta^2(\theta C)/\delta z^2 \qquad (1)$$

where:

C = Component mass per unit of fluid phase; M/L^3

C_t = total component mass per unit volume of aquifer; M/L^3

D_x = dispersion coefficient in the x-direction; L^2/t

D_y = dispersion coefficient in the y-direction; L^2/t

D_z = dispersion coefficient in the z-direction; L^2/t

r_t = rate of degradation of mass per unit volume of aquifer; M/L^3t

V = Darcy (seepage) velocity in the x-direction; L/t

0 = porosity

For further discussion see Appendix B.

There are two input files required by the PRZMAL program in order to generate predictions of contaminant concentrations in the aquifer.

One is a load file developed during a PRZM simulation. This data file was written in conjunction with the PRZM runs and exported to the PRZMAL program by the operator. The

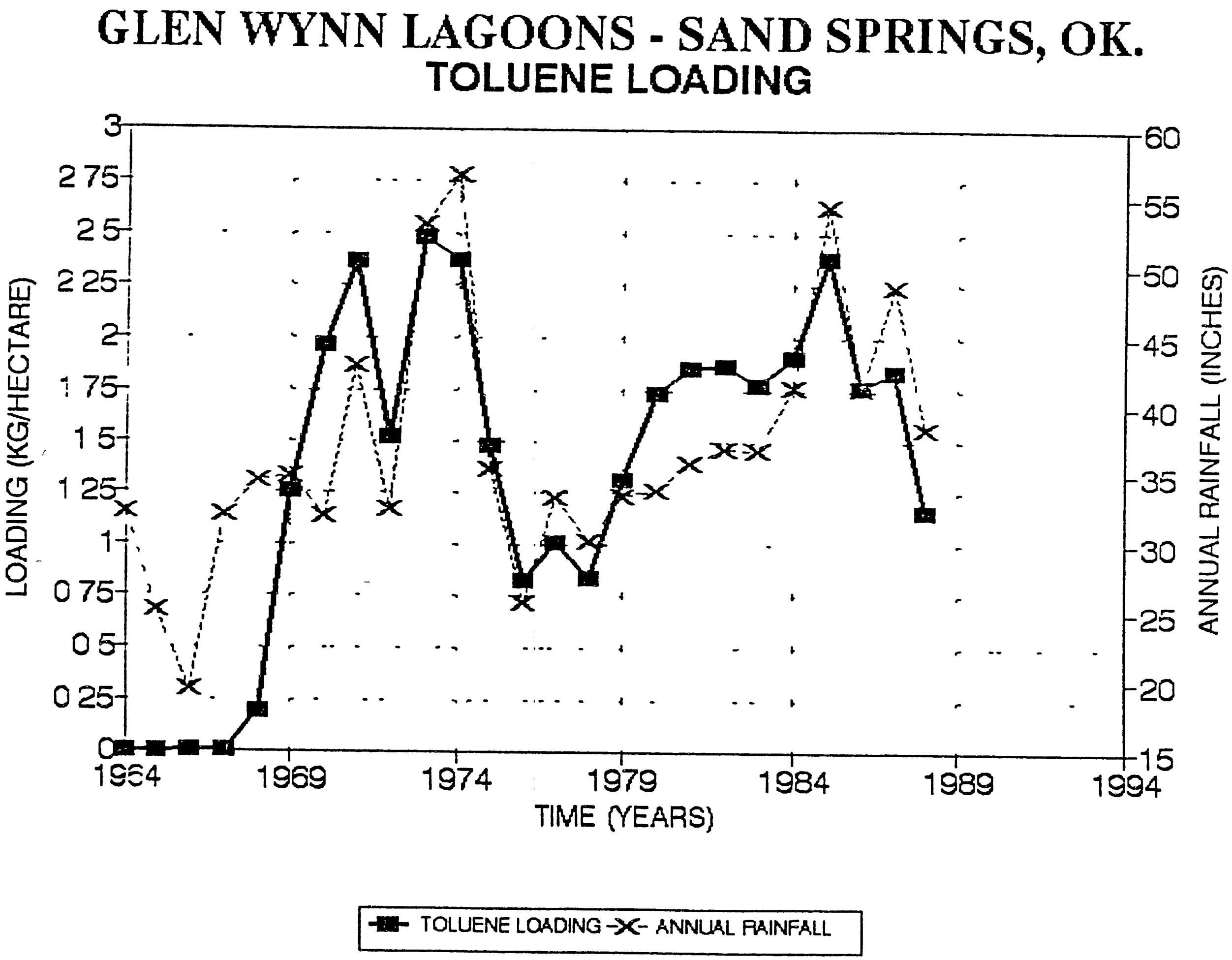


Figure 6. Toluene Loading

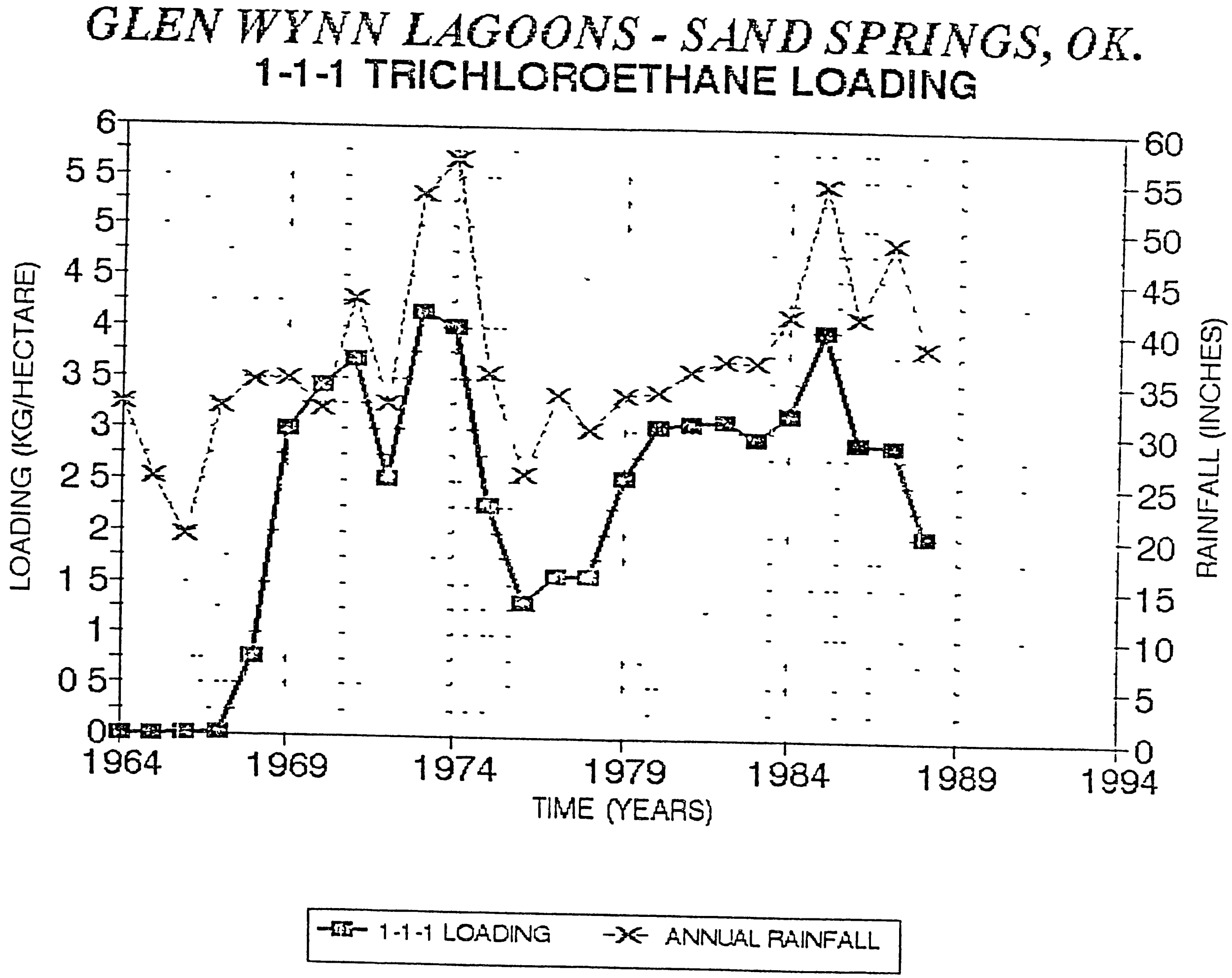


Figure 7. 1-1-1 Trichloroethane Loading

time series of contaminant fluxes and concentrations leaving the last soil compartment that are generated by PRZM are used as input for a three dimensional, transient model (Wagner and Ruiz-Calzada, 1986). This file is used to model the transport of contaminants into the aquifer.

The other data file required is the aquifer and contaminant parameter file. PREPAL is a preprocessor for the PRZMAL program which allows the user to interactively create and edit input files. The data file created here will define the aquifer and contaminant parameters, and use the PRZM loading file, along with aquifer parameters, to supply PRZMAL the data necessary for predicting the contaminant plume movement.

Minimum values required for aquifer definition include aquifer thickness, aquifer texture, porosity or bulk density, and hydraulic gradient. Superficial velocity and dispersion coefficients may be input directly or the model will calculate them based on previous aquifer parameters.

Contaminant parameters required by the model include decay rate, detection limits, partition coefficient, and dimensions of the source. Partition coefficients may be entered directly or the program will calculate them based on one of three partition models and chemical solubilities. The data used to create the operational file for the Glen Wynn Lagoons site may be found in Tables 4 and 5.

Calibration of PRZMAL

The calibration procedure started with gathering known values for as many parameters as possible. Much of the input (Tables 4 and 5) needed for the development of an accurate model of the contaminant movement connected with the Glen Wynn Lagoons was available through previous work done at the site (Mathes 1987 and 1988; Environmental Resource Management 1989; OSHD 1986).

There is little specific information in the reports as to the geology of the aquifer beneath the lagoons, particularly in terms of texture, constituent percentages and makeup, porosity, or dispersion. Parameters for aquifer texture were estimated based on available regional data (Stone 1972; Tulsa Geological Society 1973) and geologic experience. Those values were: sand = 92.0 %; clay = 7.5 %; organic carbon = 0.01 %.

Data was available from slug tests which allowed for the calculation of hydraulic conductivities and aquifer thickness was fairly well established (Mathes 1988), giving some indication of the nature of the aquifer but, specific numbers are still tentative.

Saturated thickness averages 7.93 meters. Bulk and mineral densities were estimated at 1.65 gm/cm^3 with effective porosity set at 30 percent since these values were used

TABLE 4

PARAMETERS FOR GLEN WYNN LAGOONS MODELING

TOLUENE

AQUIFER AND HYDRAULIC PARAMETERS

Saturated Thickness = 7.93 meters

Bulk Density = 1.65

Mineral Bulk Density = 1.65

Porosity = 30%

Superficial velocity = 43.72 cm/day

Hydraulic gradient = 0.18 - 0.20 cm/m

Longitudinal Dispersion = 110

Transverse Dispersion = 0.19

Vertical Dispersion = 0.19

AQUIFER TEXTURE

Sand = 92.0 %

Clay = 7.5 %

Organic Carbon = 0.01 %

CONTAMINANT PARAMETERS - TOLUENE

Partition Coefficient = 0.014 cm^3/gm (calculated)

Solubility = 535 mg/L

Decay Rate = 0

Detection Limit = 0.1E-08

TABLE 5

PARAMETERS FOR GLEN WYNN LAGOONS MODELING

1-1-1 TRICHLOROETHANE

AQUIFER AND HYDRAULIC PARAMETERS

Saturated Thickness = 7.93 meters

Bulk Density = 1.65

Mineral Bulk Density = 1.65

Porosity = 30%

Superficial velocity = 43.72 cm/day

Hydraulic gradient = 0.18 - 0.20 cm/m

Longitudinal Dispersion = 110

Transverse Dispersion = 0.19

Vertical Dispersion = 0.19

AQUIFER TEXTURE

Sand = 92%

Clay = 7.5%

Organic Carbon = 0.01%

CONTAMINANT PARAMETERS - 1-1-1 TRICHLOROETHANE

Partition Coefficient = 0.008 cm^3/gm (calculated)

Solubility = 1500 mg/L

Decay Rate = 0

Detection Limit = 0.1E-08

---

by the original investigators (Mathes 1988). Superficial (Darcy) velocity was a measured value of 43.72 cm/day. Hydraulic gradient was calculated from water levels present in monitoring wells (Mathes 1988) to be between 0.18 and 0.20 cm/m. The major unknown is dispersion and since these values were the most tentative calibration of PRZMAL was accomplished using dispersion coefficients.

Dispersion depends not only on the aquifer characteristics, but, also on the relative concentration of the contaminant (Todd 1980). The relative concentration of the contaminant within the system is controlled by solubility, retardation, and the partitioning tendencies of a constituent. Determination of the exact dispersion coefficients required must take these variables into account. The PRZMAL program was capable of calculating values for dispersion coefficients based on the texture of the aquifer.

Initially, values for dispersion were selected based on estimates of the aquifer characteristics and knowledge of the contaminants involved (Tables 4 and 5). 1,1,1 Trichloroethane was chosen to calibrate the model since it was present in the greatest amount and was expected to exhibit the least retardation within the aquifer. Numerous test runs, based on these estimates were made, varying longitudinal, horizontal, and vertical dispersion. The results of each run were compared with the known concentration of 1,1,1 Trichloroethane in the down gradient monitoring wells. The dispersion coefficients were then adjusted and more runs were made until such time as the predicted concentration were within an acceptable range with respect to measured values.

Monitoring wells #1 and #4, down gradient of the lagoons, were of great importance in the calibration of the model. The measured values of 1,1,1 Trichloroethane in these wells were 1.4 mg/L and 0.079 mg/L, respectively (Mathes 1988), when tested in December of 1986.

With longitudinal dispersion set at 110 cm^2/day and transverse and vertical dispersion set at 0.19 cm^2/day the model predicted concentrations of 1,1,1 Trichloroethane at monitoring well #1 and #4 to be 1.4 mg/L and 0.079 mg/L respectively. These values match those measured in the monitoring wells in 1986 (Table 6).

Once the model was calibrated, Toluene was introduced into the system and tests were run with the model using the dispersion coefficients established with for 1,1,1, Trichloroethane. The model predictions of Toluene downgradient from the lagoons indicated concentrations of 0.77 mg/L at monitoring well #1 and 0.045 mg/L at monitoring well #4 as of December 1986. These predictive values were within a factor of 2.5 of the measured concentration at monitoring well #1 and a factor of 1.6 of the measured concentration at monitoring well #4.

TABLE 6

RESULTS OF PRZMAL CALIBRATION

Longitudinal Dispersion - 110 cm^2/day

Transverse Dispersion - 0.19 cm^2/day

Vertical Dispersion - 0.19 cm^2/day

1,1,1 Trichloroethane

Measured concentration (mg/L)	Predicted concentration (mg/L)
MW #1 - 1.40	MW #1 - 1.40
MW #4 - 0.079	MW #4 - 0.079

Toluene

Measured concentration (mg/L)	Predicted concentration (mg/L)
MW #1 - 0.30	MW #1 - 0.77
MW #4 - 0.076	MW #4 - 0.045

Since the spatial distribution of various soil and aquifer properties and the specific interactions taking place between contaminants and the subsurface environment is generally unknown, predictive models are unlikely to exactly match measured field data. Hedden (1986) reported that criteria for model acceptance had been agreed on at the Predictive Exposure Assessment Workshop sponsored by the EPA in Atlanta, Georgia in 1982. For applications of model where there exists limited site specific data and the model was not calibrated to previous data from the site, the model should be able to replicate measured field data within an order of magnitude. For site specific situations with sufficient measurement of on site data and calibrating the model to the site, the model should match field observations within a factor of two.

The modeling of the Sand Springs site falls somewhere between these two criteria. Although the model was calibrated to measured on site data, that data were very limited both in time and space. There are only two monitoring wells downgradient from which data was available and these measurements were reported for one time frame only, December 1986.

Using the criteria suggested by the participants of the Predictive Exposure Assessment Workshop, the modeling effort was within a factor of 2.5 to 1.6 of measured concentrations and most certainly within an order of magnitude. Despite the conditions, the model predictions for the attenuation of 1,1,1 Trichloroethane and Toluene within the aquifer where within the limits set forth by Hedden (1986).

PRZMAL Model Results

Once the model was calibrated a series of runs were made to establish the historical development of the Toluene and 1,1,1 Trichloroethane plumes. These simulations track the attenuation and growth of the plume, on a daily basis, from 1964 through 1986 at fourteen different observation points within the model. Those observation points (Figure 8) were randomly chosen within the area of the lagoons in order to establish a basis for plume definition.

The point 0,0,0, was set to represent the position of the Glen Wynn Lagoons. All observation points generated within the model were positive values of x and y; the negative values are considered to be mirror images. This gives two data points for each data set, with the exception of those data sets located on an x axis. The information gathered from those simulations was then contoured with respect to time.

Two separate contour maps were constructed to illustrate the concentrations of Toluene and 1,1,1 Trichloro ethane, Figures 9 and 10 respectively, present at and down gradient of the Glen Wynn Lagoons during the period from 1964 to 1988. Computer model output is in Appendix B.

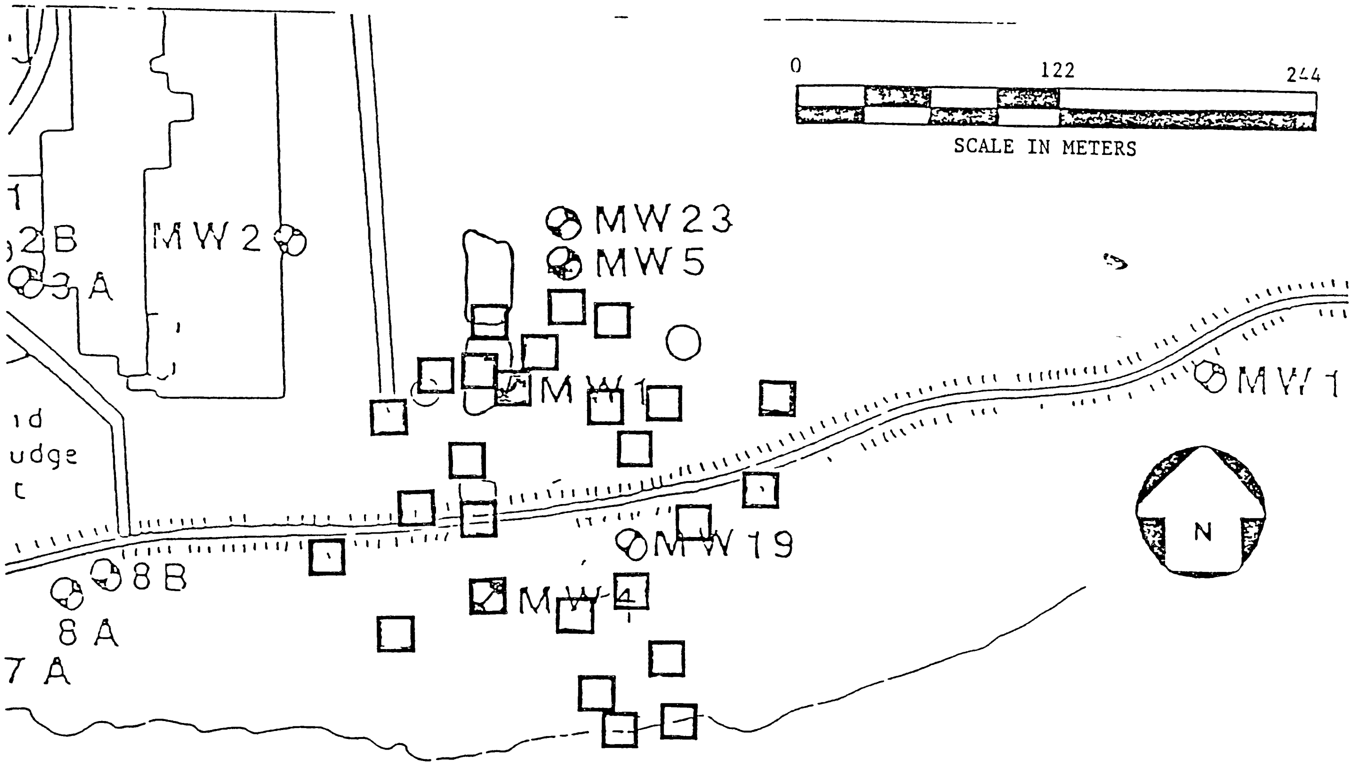
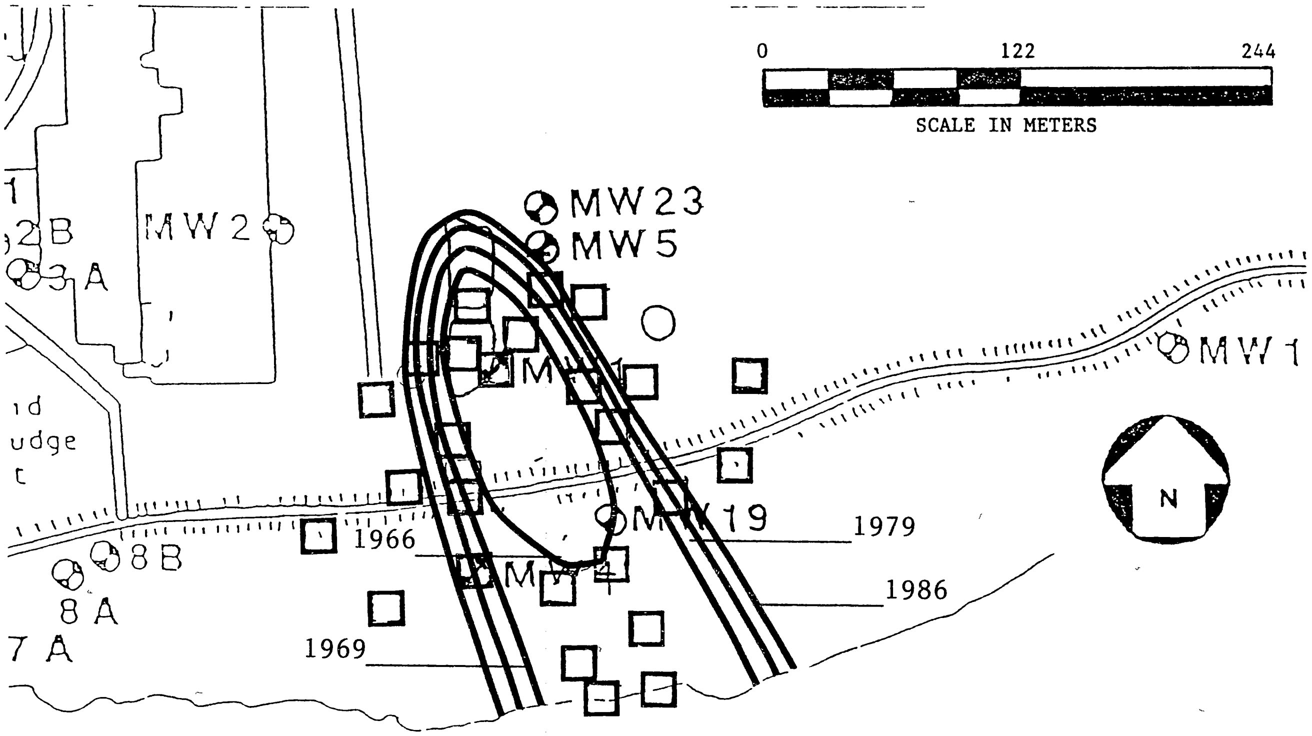


Figure 8 Model Observation Points



Concentration = 0.10 mg/L

Figure 9 Map of Toluene Plume

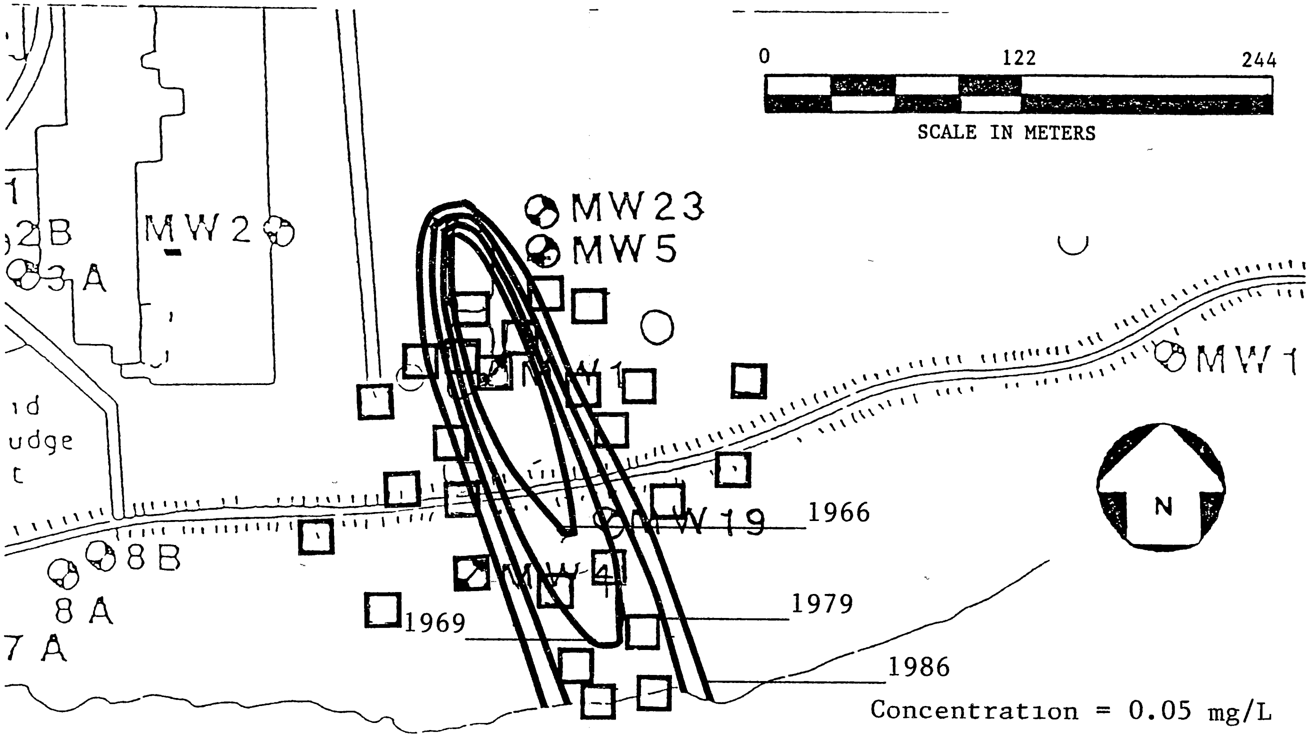


Figure 10 Map of 1,1,1 Trichloroethane Plume

CHAPTER IV

SUMMARY AND CONCLUSIONS

The PRZM - PRZMAL linkage developed by Wagner and Ruiz-Calzada (1986) provides the modeler with the opportunity to investigate a problem continuously from its inception. This model uses PRZM to simulate contaminant movement through the unsaturated soil column and links it with PRZMAL, a variation of PLUME 3D, to predict transport within the aquifer. The result is a continuous simulation of contaminant movement from the point of spill to the development of a plume in the aquifer.

Organic hydrocarbon pollutants leaching from an unlined, water filled lagoon is a somewhat different situation than PRZM was intended to deal with. Therefore great care must be taken when defining the problem within the PRZM model. Attention to evaporation, evapotranspiration, crop parameters, and application of contaminant are critical.

This linkage was tested at the Glen Wynn Lagoons, Sand Springs, Oklahoma using Toluene and 1,1,1 Trichloroethane leachate from the lagoons as test constituents. The PRZM - PRZMAL linkage model was initially calibrated using 1,1,1 Trichloroethane leachate and then verified by the application of Toluene. The Glen Wynn Lagoons were active for a number of years previous to closing in 1964 and the contamination of the soils beneath the lagoons was quite advanced before this modeling effort was undertaken. Initial runs used lagoon leachate only, but the system would not close on a contaminant concentration value sufficiently close to the measured values reported at the monitoring wells. While this was accounted for in the study, it is important that great care is taken in the parameterization of a problem in order to account for all sources of potential contamination.

Once leachate from the soils was taken into account, the results of the calibration effort predicted 1,1,1 Trichloroethane concentrations equal to those measured at monitoring wells #1 and #4, 1.40 mg/l and 0.079 mg/l respectively. Predicted concentrations of Toluene for monitoring well #1 was 0.77mg/l and 0.045 mg/l for monitoring well #4.

Those values were within a factor of 2.5 of the measured value of monitoring well #1 (0.30 mg/l) and 1.6 of monitoring well #4 (0.076 mg/l). Values of 1.6 are well within the criteria set forth as acceptable by the EPA sponsored Predictive Exposure Assessment Workshop (Hedden 1986) and a match of 2.5 only slightly exceeds the optimum. Given careful selection of data input and proper calibration, the PRZM-PRZMAL linkage model will do a credible job of simulating the movement of organic hydrocarbons through the unsaturated zone and linking the results to an aquifer to provide a continuous evaluation of contaminant transport in the subsurface environment.

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APPENDIX A

PRZM EQUATIONS

1) Dispersion and Diffusion Terms (J_D)

$$(J_D) = -[(A)(dx)(D)(\delta^2)(C_w)(\Theta)/\delta x^2] \qquad (1)$$

where:

D = diffusion-dispersion coefficient (constant); cm^2/day

C_w = dissolved concentration of pesticide; g cm^{-3}

0 = volumetric soil water content; cm^3 cm^{-3}

x = soil depth dimension; cm

dx = depth of soil; cm

A = cross sectional area of soil column, cm^2

2) Advective Term (J_v)

$$J_v = [(A)(dx)\delta(C_w)(\Theta)(V)/\delta x] \qquad (2)$$

where:

V = velocity of water movement; cm/day

3) Dissolved Phase (J_{DW}) and Sorbed Phase (J_{DS})

$$J_{DW} = (K_s)(C_w)(\Theta)(A)(dx) \qquad (3)$$

$$J_{DS} = (K_s)(C_s)(p_s)(A)(dx) \qquad (4)$$

where:

K_s = lumped 1st order rate constant; day^{-1}

C_s = sorbed concentration of pesticide g/gm

p_s = soil bulk density g/cm^3

4) Plant Uptake (J_u)

$$J_u = (f)(C_w)(\Theta)(\epsilon)(A)(dx) \qquad (5)$$

where:

f = fraction of total water in the zone used for evapo transpiration; day^{-1}

ϵ = uptake effeciency factor - dimensionless

5) Runoff (J_{QR}) and Erosion (J_{ER}) Losses

$$J_{QR} = (Q/A_w)(C_w)(A) \qquad (6)$$

$$J_{ER} = [a(X_e)(r_{om})(K_d)(C_w)(A)]/(A_w) \qquad (7)$$

where:

Q = daily runoff depth; cm day^{-1}

a = a units conversion factor

X_e = erosion sediment loss; tonnes day^{-1}

r_{om} = enrichment ratio for organic matter; g g^{-1}

K_d = adsorption partition coefficient; cm^3 g^{-1}

A_w = watershed area; cm^2

6) Pesticide Applications

Pesticide applications can be made either to the bare soil or to the crop canopy. The pesticide application rate must be partitioned between soil and crop in a proportional manner. There are two options within the PRZM model to deal with this situation. The first partitions the application proportional to the ground surface covered by plant canopy. The second defines the fraction (F) of the application intercepted by the plants:

$$F = 1 - \exp[(-u)(W_0)] \qquad (8)$$

where:

u = a filtration parameter; m^2 kg^{-1}

W_o = herbage areal density on a dry weight basis; kg m^{-2}

7) Washoff

Pesticides applied to the canopy are transported to the soil surface through rainfall washoff.

$$J_{FOF} = (E)(P_r)(M)(A) \qquad (9)$$

where:

E = extraction coefficient cm^{-1}

P_r = daily rainfall depth cm day^{-1}

M = mass of pesticide on plant surface per cross sectional area; g cm^{-2}

8) Adsorption and Desorption

Adsorption and desorption are treated as seperate kinetic processes in the basic PRZM transport equations. Simplification by asssuming that each process is very rapid reduces the sorption to the expression:

$$C_s = (K_d)(C_w) \qquad (10)$$

This equation establishes a linear, instantaneous, and reversible equilibrium condition in the soil/water matrix. This offers a convenient means for combining the two basic transport equations into a single expression which is written in terms of dissolved pesticide concentration:

$$\begin{aligned} \delta[C_w(\theta + K_d p_s)]/\delta t = {} & D\,\delta^2(C_w\theta)/\delta x^2 - \delta(C_w\theta V)/\delta x - \\ & C_w[K_s(\theta + K_d p_s) + f\theta e + Q/dx + aX_e r_{om} k_d] + \\ & J_{APP}/dx[(1-F)/A + FEP_r M] \qquad (11) \end{aligned}$$

Equation 11 is a variation of the advection-dispersion model generally used as the basis for groundwater models. The plant uptake term is not included in most representations of this expression and the erosion and runoff terms are rarely included.

It is necessary to develop additional equations for v and 0 since these parameters are seldom measured as part of a routine monitoring program:

$$\delta\theta/\delta t = \delta/\delta x\ [k(\delta\phi)/\delta x] \qquad (12)$$

where:

k = hydraulic conductivity
Phi = hydraulic potential

$$v = -k\ \delta\phi/\delta x$$

Equation 11 can now be solved numerically.

FOR FURTHER DISCUSSION OF THE INTERNAL WORKINGS OF THE PRZM CODE REFER TO EPA-600/3-84-109 DECEMBER 1984:

Users Manual For The Pesticide Root Zone Model (PRZM)
Release 1

APPENDIX B

PRZMAL

The total mass of a component per unit volume of aquifer is distributed as dissolved solute in the fluid phase and adsorbed on the solid matrix. Therefore:

$$C_t = \theta \; C + p_b \; C_s \qquad (1)$$

where:

p_b = bulk density of the aquifer; M/L^3

C_s = component mass per unit mass of solid; M/M

Based on equation 2 one can define the rate of accumulation of mass in the aquifer as:

$$\delta C_t/\delta t = \theta \; \delta C/\delta t + p_b \; \delta C_s/\delta t \qquad (2)$$

In general, $C_s = f(C)$ and

$$\delta C_s/\delta t = dC_s/dC \; \delta C/\delta t \qquad (3)$$

For a linear equilibrium adsorption isotherm,

$$dC_s/dC = K_d \; (M/M)/(M/L^3) \qquad (4)$$

where K_d is the distribution constant.

The change in concentration per unit volume of porous media, $\delta C_t/\delta t$, can be written in terms of fluid phase concentration, C, by substituting Equations 3 and 4 into equation 2:

$$\delta C_t/\delta t = \theta \; \delta C/\delta t + p_b \; K_d \; \delta C/\delta t \qquad (5)$$

Since the rate of degradation of componenet mass per unit volume of porous media is also distributed between solid and liquid phases the rate of change in total mass per unit volume of aquifer due to reaction can be written as:

$$r_t = \delta C_T/\delta t = \theta \; \delta C/\delta t + p_b \; \delta C_s/\delta t$$

The concentration on the solid, C_s, is related to the concentration in the liquid, C, through the linear isotherm previously assumed.

FOR FURTHER DISCUSSION OF THE INTERNAL WORKINGS OF THE PRZMAL CODE REFER TO:

Users Manual For PRZM - Aquifer Link (PRZMAL)
DECEMBER 1986:

APPENDIX C

PRZM COMPUTER OUTPUT
GLEN WYNN LAGOONS
SAND SPRINGS
OKLAHOMA

```
*** PRZM DATA SET FOR PRZMAL MODEL TEST - 1991 ***
   1 164          311288
***** HYDROLOGY PARAMETERS FOR SAND SPRINGS OKLAHOMA *****
   0.000   0.200       2  15.000       0       1
   9.900  10.700  11.800  12.900  13.900  14.400
  14.100  13.700  12.200  11.100  10.100   9.600
       0
       1
       1   0.000   1.000   5.000       1  30  30  30 0.7 0.4
0.7
      25
  10 464  25 564  301164       1
  10 465  25 565  301165       1
  10 466  25 566  301166       1
  10 467  25 567  301167       1
  10 468  25 568  301168       1
  10 469  25 569  301169       1
  10 470  25 570  301170       1
  10 471  25 571  301171       1
  10 472  25 572  301172       1
  10 473  25 573  301173       1
  10 474  25 574  301174       1
  10 475  25 575  301175       1
  10 476  25 576  301176       1
  10 477  25 577  301177       1
  10 478  25 578  301178       1
  10 479  25 579  301179       1
  10 480  25 580  301180       1
  10 481  25 581  301181       1
  10 482  25 582  301182       1
  10 483  25 583  301183       1
  10 484  25 584  301184       1
  10 485  25 585  301185       1
  10 486  25 586  301186       1
  10 487  25 587  301187       1
  10 488  25 588  301188       1
```

```
***** PESTICIDE APPLICATION FOR 1-1-1 TRICHLOROETHANE *****

      25
   1 164   2.688  00.000
   1 165   2.688  00.000
   1 166   2.688  00.000
   1 167   2.688  00.000
   1 168   2.688  00.000
   1 169   2.688  00.000
   1 170   2.688  00.000
   1 171   2.688  00.000
   1 172   2.688  00.000
   1 173   2.688  00.000
   1 174   2.688  00.000
   1 175   2.688  00.000
   1 176   2.688  00.000
   1 177   2.688  00.000
   1 178   2.688  00.000
   1 179   2.688  00.000
   1 180   2.688  00.000
   1 181   2.688  00.000
   1 182   2.688  00.000
   1 183   2.688  00.000
   1 184   2.688  00.000
   1 185   2.688  00.000
   1 186   2.688  00.000
   1 187   2.688  00.000
   1 188   2.688  00.000
       1

*** SOIL AND POLLUTANT PARAMETERS FOR GLEN WYNN LAGOON ***

 599.147   0.000      50       0       1       1       0
       2    1500
       2
       1  60.147  1.860   0.000   0.000   0.110   1.500
           0.700   0.239   0.030
       2 539.000  1.860   0.000   0.000   0.110   1.500
           0.800   0.100   0.010
       0       0
    WATR    YEAR       5    PEST    YEAR       5    CONC
YEAR       5
       1
    AFLX    TSER      20 1.0
   1    PRZMLD
```

```
           ***PRZM - ANNUAL CONTAMINANT OUTPUT (KG/HA)***

                      1,1,1 TRICHLOROETHANE

        PREVIOUS     LEACHING     LEACHING     CURRENT      ANNUAL
        STORAGE      INPUT        OUTPUT       STORAGE      PRECIP

 1964   0.000E+00    0.000E+00    0.000E+00    0.000E+00     32.38
 1965   0.000E+00    0.000E+00    0.000E+00    0.000E+00     25.15
 1966   0.000E+00    3.633E-05    2.140E-05    1.493E-05     19.50
 1967   1.493E-05    2.751E-02    1.981E-02    7.714E-03     32.10
 1968   7.714E-03    8.988E-01    7.672E-01    1.393E-01     34.65
 1969   1.393E-01    3.148E+00    2.996E+00    2.913E-01     34.92
 1970   2.913E-01    3.395E+00    3.423E+00    2.638E-01     32.08
 1971   2.638E-01    3.629E+00    3.682E+00    2.118E-01     42.92
 1972   2.118E-01    2.520E+00    2.522E+00    2.098E-01     32.52
 1973   2.098E-01    4.132E+00    4.153E+00    1.892E-01     53.19
 1974   1.892E-01    4.018E+00    4.003E+00    2.042E-01     56.65
 1975   2.042E-01    2.210E+00    2.278E+00    1.369E-01     35.55
 1976   1.369E-01    1.334E+00    1.325E+00    1.455E-01     25.72
 1977   1.455E-01    1.553E+00    1.585E+00    1.132E-01     33.43
 1978   1.132E-01    1.650E+00    1.590E+00    1.734E-01     30.17
 1979   1.734E-01    2.610E+00    2.549E+00    2.340E-01     33.46
 1980   2.340E-01    3.055E+00    3.053E+00    2.360E-01     33.94
 1981   2.360E-01    3.083E+00    3.087E+00    2.314E-01     35.90
 1982   2.314E-01    3.094E+00    3.106E+00    2.199E-01     36.93
 1983   2.199E-01    2.945E+00    2.953E+00    2.126E-01     36.88
 1984   2.126E-01    3.162E+00    3.174E+00    2.008E-01     41.41
 1985   2.008E-01    3.989E+00    3.994E+00    1.959E-01     54.40
 1986   1.959E-01    2.887E+00    2.905E+00    1.782E-01     41.27
 1987   1.782E-01    2.829E+00    2.880E+00    1.274E-01     48.67
 1988   1.274E-01    2.034E+00    2.002E+00    1.592E-01     38.40
```

```
*** PRZM DATA SET FOR PRZMAL MODEL TEST - 1991 ***
   1 164          311288
***** HYDROLOGY PARAMETERS FOR SAND SPRINGS OKLAHOMA *****
   0.000   0.200       2  15.000       0       1
   9.900  10.700  11.800  12.900  13.900  14.400
  14.100  13.700  12.200  11.100  10.100   9.600
       0
       1
       1   0.000   1.000   5.000       1  30  30  30 0.7 0.4
0.7
      25
  10 464  25 564  301164        1
  10 465  25 565  301165        1
  10 466  25 566  301166        1
  10 467  25 567  301167        1
  10 468  25 568  301168        1
  10 469  25 569  301169        1
  10 470  25 570  301170        1
  10 471  25 571  301171        1
  10 472  25 572  301172        1
  10 473  25 573  301173        1
  10 474  25 574  301174        1
  10 475  25 575  301175        1
  10 476  25 576  301176        1
  10 477  25 577  301177        1
  10 478  25 578  301178        1
  10 479  25 579  301179        1
  10 480  25 580  301180        1
  10 481  25 581  301181        1
  10 482  25 582  301182        1
  10 483  25 583  301183        1
  10 484  25 584  301184        1
  10 485  25 585  301185        1
  10 486  25 586  301186        1
  10 487  25 587  301187        1
  10 488  25 588  301188        1
```

***** PESTICIDE APPLICATION FOR TOLUENE *****

```
       25
   1 164    1.591  00.000
   1 165    1.591  00.000
   1 166    1.591  00.000
   1 167    1.591  00.000
   1 168    1.591  00.000
   1 169    1.591  00.000
   1 170    1.591  00.000
   1 171    1.591  00.000
   1 172    1.591  00.000
   1 173    1.591  00.000
   1 174    1.591  00.000
   1 175    1.591  00.000
   1 176    1.591  00.000
   1 177    1.591  00.000
   1 178    1.591  00.000
   1 179    1.591  00.000
   1 180    1.591  00.000
   1 181    1.591  00.000
   1 182    1.591  00.000
   1 183    1.591  00.000
   1 184    1.591  00.000
   1 185    1.591  00.000
   1 186    1.591  00.000
   1 187    1.591  00.000
   1 188    1.591  00.000
        1
```

*** SOIL AND POLLUTANT PARAMETERS FOR GLEN WYNN LAGOON ***

```
 599.147    0.000       50       0       1       1       0
       2      535
       2
       1  60.147  1.860   0.000   0.000   0.110
            0.700   .239    .030
       2 539.000  1.860   0.000   0.000   0.110
            0.800   .100    .010
       0        0
    WATR     YEAR        5    PEST    YEAR       5    CONC
YEAR         5
       1
    AFLX     TSER       20 1.0
   1     PRZMLD
```

```
                ***PRZM - ANNUAL CONTAMINANT OUTPUT (KG/HA)***

                                  TOLUENE

       PREVIOUS     LEACHING     LEACHING     CURRENT      ANNUAL
       STORAGE      INPUT        OUTPUT       STORAGE      PRECIP

1964   0.000E+00    0.000E+00    0.000E+00    0.000E+00     32.38
1965   0.000E+00    0.000E+00    0.000E+00    0.000E+00     25.15
1966   0.000E+00    2.214E-06    9.658E-07    1.248E-06     19.50
1967   1.248E-06    4.413E-03    3.029E-03    1.385E-03     32.10
1968   1.385E-03    2.421E-01    1.960E-01    4.752E-02     34.65
1969   4.752E-02    1.371E+00    1.259E+00    1.595E-01     34.92
1970   1.595E-01    1.993E+00    1.967E+00    1.857E-01     32.08
1971   1.857E-01    2.325E+00    2.365E+00    1.457E-01     42.92
1972   1.457E-01    1.515E+00    1.524E+00    1.365E-01     32.52
1973   1.365E-01    2.477E+00    2.479E+00    1.347E-01     53.19
1974   1.347E-01    2.367E+00    2.372E+00    1.299E-01     56.65
1975   1.299E-01    1.465E+00    1.487E+00    1.075E-01     35.55
1976   1.075E-01    8.133E-01    8.290E-01    9.175E-02     25.72
1977   9.175E-02    9.940E-01    1.005E+00    8.096E-02     33.43
1978   8.096E-02    8.527E-01    8.390E-01    9.465E-02     30.17
1979   9.465E-02    1.356E+00    1.314E+00    1.365E-01     33.46
1980   1.365E-01    1.754E+00    1.732E+00    1.578E-01     33.94
1981   1.578E-01    1.850E+00    1.857E+00    1.512E-01     35.90
1982   1.512E-01    1.858E+00    1.862E+00    1.470E-01     36.93
1983   1.470E-01    1.770E+00    1.776E+00    1.404E-01     36.88
1984   1.404E-01    1.905E+00    1.912E+00    1.336E-01     41.41
1985   1.336E-01    2.379E+00    2.384E+00    1.289E-01     54.40
1986   1.289E-01    1.751E+00    1.758E+00    1.220E-01     41.27
1987   1.220E-01    1.810E+00    1.835E+00    9.673E-02     48.67
1988   9.673E-02    1.159E+00    1.160E+00    9.531E-02     38.40
```

```
                   ***PRZM - ANNUAL WATER OUTPUT (IN)***

         PREVIOUS  LEACHING  TRANSPIRATION  LEACHING   CURRENT
         STORAGE   INPUT                    OUTPUT     STORAGE

1964      1.314    0.000E+00   0.000E+00    0.000E+00   1.314
1965      1.314    0.000E+00   0.000E+00    0.000E+00   1.314
1966      1.314    1.329E+01   0.000E+00    1.208E+01   2.516
1967      2.516    3.210E+01   0.000E+00    3.210E+01   2.516
1968      2.516    3.465E+01   0.000E+00    3.465E+01   2.516
1969      2.516    3.492E+01   0.000E+00    3.492E+01   2.516
1970      2.516    3.208E+01   0.000E+00    3.208E+01   2.516
1971      2.516    4.292E+01   0.000E+00    4.292E+01   2.516
1972      2.516    3.252E+01   0.000E+00    3.252E+01   2.516
1973      2.516    5.319E+01   0.000E+00    5.139E+01   2.516
1974      2.516    5.665E+01   0.000E+00    5.665E+01   2.516
1975      2.516    3.555E+01   0.000E+00    3.555E+01   2.516
1976      2.516    2.572E+01   0.000E+00    2.572E+01   2.516
1977      2.516    3.343E+01   0.000E+00    3.343E+01   2.516
1978      2.516    3.017E+01   0.000E+00    3.017E+01   2.516
1979      2.516    3.346E+01   0.000E+00    3.346E+01   2.516
1980      2.516    3.394E+01   0.000E+00    3.394E+01   2.516
1981      2.516    3.590E+01   0.000E+00    3.590E+01   2.516
1982      2.516    3.693E+01   0.000E+00    3.693E+01   2.516
1983      2.516    3.688E+01   0.000E+00    3.688E+01   2.516
1984      2.516    4.141E+01   0.000E+00    4.141E+01   2.516
1985      2.516    5.440E+01   0.000E+00    5.440E+01   2.516
1986      2.516    4.127E+01   0.000E+00    4.127E+01   2.516
1987      2.516    4.867E+01   0.000E+00    4.867E+01   2.516
1988      2.516    3.840E+01   0.000E+00    3.840E+01   2.516
```

APPENDIX D

PRZMAL PROGRAM COMPUTER OUTPUT
GLEN WYNN LAGOONS
SAND SPRINGS
OKLAHOMA

```
PRZMAL DATA FILE
GLEN WYNN LAGOONS - TOLUENE LOADING

       0       0       0       0       1
     7.9    1.68    0.30   43.72  110.00    0.19    0.19
0.0000  0.0000 0.1E-08
   92.00    7.50    0.01    0.18       2  535.00
    73.8    15.2
       2
   180.0    17.0     0.0
    65.0    65.0     0.0
   1 164  311288
ALDBLD
YEAR
   2    ALDCSER
       10.10E+01        20.10E+01
```

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	122.00	36.00
Y (meters)	56.00	0.00
Z (meters)	0.00	0.00
1964 DEC 31	0.2117E-07	0.2050E-05
1965 DEC 31	0.9698E-04	0.3952E-02
1966 DEC 31	0.3925E-02	0.3300E+00
1967 DEC 31	0.6245E-01	0.5614E+00
1968 DEC 31	0.1164E+00	0.3044E+00
1969 DEC 31	0.1752E+00	0.1827E+01
1970 DEC 31	0.5139E-01	0.3959E+00
1971 DEC 31	0.8123E-01	0.7727E+00
1972 DEC 31	0.6440E-01	0.3625E+00
1973 DEC 31	0.3079E-01	0.7352E+00
1974 DEC 31	0.2810E-01	0.6024E-01
1975 DEC 31	0.4212E-01	0.1160E+00
1976 DEC 31	0.5974E-02	0.1634E+00
1977 DEC 31	0.1062E-01	0.5386E+00
1978 DEC 31	0.3815E-01	0.3737E+00
1979 DEC 31	0.3665E-01	0.3001E+00
1980 DEC 31	0.8279E-02	0.2369E+01
1981 DEC 31	0.9617E-01	0.4383E+00
1982 DEC 31	0.4184E-01	0.1650E+01
1983 DEC 31	0.7968E-01	0.5155E+00
1984 DEC 31	0.1195E+00	0.4098E+00
1985 DEC 31	0.5044E-01	0.2622E+01
1986 DEC 31	0.4599E-01	0.7715E+00

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	130.00	50.00
Y (meters)	15.00	35.00
Z (meters)	0.00	0.00
1964 DEC 31	0.5215E-06	0.8226E-07
1965 DEC 31	0.1064E-02	0.9104E-03
1966 DEC 31	0.4545E-01	0.6871E-01
1967 DEC 31	0.5321E+00	0.1089E+00
1968 DEC 31	0.7760E+00	0.5891E-01
1969 DEC 31	0.1036E+01	0.1435E+00
1970 DEC 31	0.3861E+00	0.2469E+00
1971 DEC 31	0.5176E+00	0.2161E+00
1972 DEC 31	0.3452E+00	0.5119E+00
1973 DEC 31	0.1680E+00	0.8433E-01
1974 DEC 31	0.1749E+00	0.4927E-01
1975 DEC 31	0.2219E+00	0.6010E-01
1976 DEC 31	0.4475E-01	0.8828E-01
1977 DEC 31	0.1228E+00	0.1849E+00
1978 DEC 31	0.2631E+00	0.9974E-01
1979 DEC 31	0.2805E+00	0.3054E+00
1980 DEC 31	0.7812E-01	0.2120E+00
1981 DEC 31	0.5268E+00	0.1082E+00
1982 DEC 31	0.2010E+00	0.3471E+00
1983 DEC 31	0.5494E+00	0.2250E+00
1984 DEC 31	0.7301E+00	0.1376E+00
1985 DEC 31	0.2968E+00	0.1575E+00
1986 DEC 31	0.3153E+00	0.1158E+00

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	195.00	10.00
Y (meters)	5.00	35.00
Z (meters)	0.00	0.00
1964 DEC 31	0.2808E-06	0.7246E-07
1965 DEC 31	0.3740E-03	0.2871E-03
1966 DEC 31	0.2377E-01	0.2316E-01
1967 DEC 31	0.1900E+00	0.3731E-01
1968 DEC 31	0.2739E+00	0.1004E-01
1969 DEC 31	0.4026E+00	0.1003E+00
1970 DEC 31	0.2385E+00	0.2240E-01
1971 DEC 31	0.3487E+00	0.6473E-01
1972 DEC 31	0.2649E+00	0.5372E-01
1973 DEC 31	0.1787E+00	0.3242E-01
1974 DEC 31	0.7822E-01	0.6952E-02
1975 DEC 31	0.1115E+00	0.1286E-01
1976 DEC 31	0.4814E-01	0.1993E-01
1977 DEC 31	0.2473E+00	0.9368E-04
1978 DEC 31	0.1213E+00	0.4554E-01
1979 DEC 31	0.2614E+00	0.2329E-01
1980 DEC 31	0.9411E-01	0.1177E+00
1981 DEC 31	0.3839E-01	0.6954E-01
1982 DEC 31	0.6875E-01	0.5173E-01
1983 DEC 31	0.2310E+00	0.3331E-01
1984 DEC 31	0.1603E+00	0.5914E-01
1985 DEC 31	0.1609E+00	0.6669E-01
1986 DEC 31	0.1760E+00	0.2430E-01

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	95.00	16.00
Y (meters)	45.00	57.00
Z (meters)	0.00	0.00
1964 DEC 31	0.1124E-06	0.5650E-08
1965 DEC 31	0.5975E-03	0.1693E-04
1966 DEC 31	0.3657E-01	0.1786E-02
1967 DEC 31	0.2058E+00	0.1398E-02
1968 DEC 31	0.1576E+00	0.5035E-04
1969 DEC 31	0.1592E+00	0.4590E-02
1970 DEC 31	0.2416E+00	0.1410E-02
1971 DEC 31	0.1426E+00	0.1178E-01
1972 DEC 31	0.3442E+00	0.1609E-02
1973 DEC 31	0.4098E-01	0.1912E-02
1974 DEC 31	0.6241E-01	0.2121E-03
1975 DEC 31	0.4561E-01	0.4504E-03
1976 DEC 31	0.2854E-01	0.2078E-02
1977 DEC 31	0.5571E-01	0.1333E-01
1978 DEC 31	0.9577E-01	0.1350E-02
1979 DEC 31	0.2452E+00	0.1246E-02
1980 DEC 31	0.4877E-01	0.9554E-02
1981 DEC 31	0.2380E+00	0.7160E-02
1982 DEC 31	0.2101E+00	0.3572E-02
1983 DEC 31	0.2307E+00	0.8845E-02
1984 DEC 31	0.3470E+00	0.3246E-02
1985 DEC 31	0.3132E-01	0.4779E-02
1986 DEC 31	0.9281E-01	0.3404E-02

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	0.00	116.00
Y (meters)	0.00	97.00
Z (meters)	0.00	0.00
1964 DEC 31	0.6199E-05	0.3265E-08
1965 DEC 31	0.1172E-01	0.1453E-04
1966 DEC 31	0.6778E+00	0.6307E-03
1967 DEC 31	0.1018E+01	0.6156E-02
1968 DEC 31	0.4499E+00	0.1244E-01
1969 DEC 31	0.2788E+01	0.1059E-01
1970 DEC 31	0.2847E+00	0.3679E-02
1971 DEC 31	0.6109E+00	0.8056E-02
1972 DEC 31	0.5287E+00	0.6531E-02
1973 DEC 31	0.9504E+00	0.3428E-02
1974 DEC 31	0.5686E-01	0.3003E-02
1975 DEC 31	0.9690E-01	0.5155E-02
1976 DEC 31	0.1195E-01	0.7152E-03
1977 DEC 31	0.4393E+00	0.5700E-03
1978 DEC 31	0.4953E+00	0.2508E-02
1979 DEC 31	0.1470E+00	0.2457E-02
1980 DEC 31	0.3366E+01	0.9010E-03
1981 DEC 31	0.3711E+00	0.6338E-02
1982 DEC 31	0.2547E+01	0.2683E-02
1983 DEC 31	0.1994E+00	0.7072E-02
1984 DEC 31	0.3054E+00	0.9617E-02
1985 DEC 31	0.3647E+01	0.6511E-02
1986 DEC 31	0.1027E+01	0.4630E-02

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	20.00	76.00
Y (meters)	17.00	112.00
Z (meters)	0.00	0.00
1964 DEC 31	0.2099E-05	0.2201E-09
1965 DEC 31	0.1537E-02	0.5855E-06
1966 DEC 31	0.1743E+00	0.2292E-04
1967 DEC 31	0.2090E+00	0.6913E-03
1968 DEC 31	0.1517E+00	0.3128E-03
1969 DEC 31	0.7665E+00	0.2539E-03
1970 DEC 31	0.2509E+00	0.2465E-03
1971 DEC 31	0.7502E+00	0.2349E-03
1972 DEC 31	0.2947E+00	0.2985E-03
1973 DEC 31	0.2946E+00	0.7846E-04
1974 DEC 31	0.3466E-01	0.3512E-04
1975 DEC 31	0.6026E-01	0.3307E-04
1976 DEC 31	0.1053E+00	0.3167E-04
1977 DEC 31	0.4227E+00	0.8169E-04
1978 DEC 31	0.3774E+00	0.1091E-03
1979 DEC 31	0.1152E+00	0.3350E-03
1980 DEC 31	0.5737E+00	0.2834E-04
1981 DEC 31	0.4154E+00	0.4547E-03
1982 DEC 31	0.1084E+01	0.2240E-03
1983 DEC 31	0.3840E+00	0.2992E-03
1984 DEC 31	0.2912E+00	0.1435E-03
1985 DEC 31	0.7074E+00	0.1888E-04
1986 DEC 31	0.2726E+00	0.7226E-04

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

TOLUENE LOADING
(mg/l)

X (meters)	180.00	65.00
Y (meters)	17.00	65.00
Z (meters)	0.00	0.00
1964 DEC 31	0.2672E-06	0.1300E-07
1965 DEC 31	0.4516E-03	0.9310E-04
1966 DEC 31	0.1829E-01	0.4840E-02
1967 DEC 31	0.2285E+00	0.9041E-02
1968 DEC 31	0.3580E+00	0.1339E-01
1969 DEC 31	0.5976E+00	0.3254E-01
1970 DEC 31	0.2426E+00	0.4948E-01
1971 DEC 31	0.4062E+00	0.1035E-01
1972 DEC 31	0.2560E+00	0.6385E-01
1973 DEC 31	0.2271E+00	0.6576E-02
1974 DEC 31	0.6817E-01	0.4998E-02
1975 DEC 31	0.2371E+00	0.7329E-02
1976 DEC 31	0.5597E-01	0.5500E-02
1977 DEC 31	0.2289E+00	0.1873E-01
1978 DEC 31	0.1380E+00	0.1083E-01
1979 DEC 31	0.2459E+00	0.4626E-01
1980 DEC 31	0.8568E-01	0.1087E-01
1981 DEC 31	0.4813E-01	0.5389E-01
1982 DEC 31	0.1158E+00	0.4746E-01
1983 DEC 31	0.2741E+00	0.3320E-01
1984 DEC 31	0.1442E+00	0.1926E-01
1985 DEC 31	0.2219E+00	0.9039E-02
1986 DEC 31	0.1619E+00	0.6443E-02

```
PRZMAL INPUT FILE
GLEN WYNN LAGOONS - 1-1-1 TRICHLOROETHANE LOADING

         0       0       0       0       1
       7.9    1.68    0.30   43.72  110.00     0.19     0.19
0.0000  0.0000 0.1E-08
     92.00    7.50    0.01    0.18       2 1500.00
      73.8    15.2
         2
      36.0     0.0     0.0
     122.0    56.0     0.0
     1 164  311288
ALDBLD
YEAR
   2    ALDCSER
       10.10E+01       20.10E+01
```

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/l)

X (meters)		36.00	122.00
Y (meters)		0.00	56.00
Z (meters)		0.00	0.00
1964	DEC 31	0.7065E-05	0.7743E-07
1965	DEC 31	0.1365E-01	0.3683E-03
1966	DEC 31	0.9072E+00	0.1212E-01
1967	DEC 31	0.1133E+01	0.1426E+00
1968	DEC 31	0.5150E+00	0.2048E+00
1969	DEC 31	0.3014E+01	0.1898E+00
1970	DEC 31	0.6587E+00	0.9388E-01
1971	DEC 31	0.1293E+01	0.1369E+00
1972	DEC 31	0.6413E+00	0.1299E+00
1973	DEC 31	0.1131E+01	0.5058E-01
1974	DEC 31	0.1031E+00	0.4988E-01
1975	DEC 31	0.1820E+00	0.6919E-01
1976	DEC 31	0.2913E+00	0.1179E-01
1977	DEC 31	0.1000E+01	0.1744E-01
1978	DEC 31	0.6450E+00	0.5753E-01
1979	DEC 31	0.5042E+00	0.6660E-01
1980	DEC 31	0.4053E+01	0.1405E-01
1981	DEC 31	0.7473E+00	0.1721E+00
1982	DEC 31	0.2799E+01	0.8804E-01
1983	DEC 31	0.8842E+00	0.1432E+00
1984	DEC 31	0.6073E+00	0.2074E+00
1985	DEC 31	0.4215E+01	0.8731E-01
1986	DEC 31	0.1408E+01	0.7895E-01

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING (mg/l)

X (meters)		130.00	50.00
Y (meters)		15.00	35.00
Z (meters)		0.00	0.00
1964	DEC 31	0.3990E-06	0.9959E-07
1965	DEC 31	0.1086E-02	0.6377E-03
1966	DEC 31	0.4659E-01	0.7461E-01
1967	DEC 31	0.5453E+00	0.9815E-01
1968	DEC 31	0.7778E+00	0.5938E-01
1969	DEC 31	0.1070E+01	0.1497E+00
1970	DEC 31	0.4357E+00	0.2589E+00
1971	DEC 31	0.5104E+00	0.2135E+00
1972	DEC 31	0.3490E+00	0.4899E+00
1973	DEC 31	0.1739E+00	0.8877E-01
1974	DEC 31	0.1767E+00	0.5053E-01
1975	DEC 31	0.2196E+00	0.6221E-01
1976	DEC 31	0.4087E-01	0.9370E-01
1977	DEC 31	0.1330E+00	0.1955E+00
1978	DEC 31	0.2678E+00	0.9945E-01
1979	DEC 31	0.2838E+00	0.3046E+00
1980	DEC 31	0.5465E-01	0.2240E+00
1981	DEC 31	0.7924E+00	0.1154E+00
1982	DEC 31	0.2376E+00	0.2923E+00
1983	DEC 31	0.5784E+00	0.2377E+00
1984	DEC 31	0.7498E+00	0.1438E+00
1985	DEC 31	0.2586E+00	0.1618E+00
1986	DEC 31	0.3054E+00	0.1231E+00

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/1)

X (meters)	195.00	10.00
Y (meters)	5.00	35.00
Z (meters)	0.00	0.00
1964 DEC 31	0.3171E-06	0.7321E-07
1965 DEC 31	0.4689E-03	0.2948E-03
1966 DEC 31	0.2348E-01	0.2028E-01
1967 DEC 31	0.2009E+00	0.4058E-01
1968 DEC 31	0.2846E+00	0.1121E-01
1969 DEC 31	0.6585E+00	0.1092E+00
1970 DEC 31	0.2435E+00	0.2246E-01
1971 DEC 31	0.3225E+00	0.4270E-01
1972 DEC 31	0.2710E+00	0.5828E-01
1973 DEC 31	0.1695E+00	0.3280E-01
1974 DEC 31	0.7513E-01	0.7524E-02
1975 DEC 31	0.1189E+00	0.1380E-01
1976 DEC 31	0.4739E-01	0.1649E-01
1977 DEC 31	0.2530E+00	0.1198E-03
1978 DEC 31	0.1545E+00	0.4824E-01
1979 DEC 31	0.2671E+00	0.2498E-01
1980 DEC 31	0.9936E-01	0.1237E+00
1981 DEC 31	0.3834E-01	0.6570E-01
1982 DEC 31	0.1042E+00	0.5814E-01
1983 DEC 31	0.2347E+00	0.3588E-01
1984 DEC 31	0.1617E+00	0.6355E-01
1985 DEC 31	0.1493E+00	0.7139E-01
1986 DEC 31	0.1967E+00	0.1651E-01

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/l)

X (meters)	95.00	16.00
Y (meters)	45.00	57.00
Z (meters)	0.00	0.00
1964 DEC 31	0.9054E-07	0.6983E-08
1965 DEC 31	0.5638E-03	0.2049E-04
1966 DEC 31	0.3741E-01	0.2103E-02
1967 DEC 31	0.2181E+00	0.1669E-02
1968 DEC 31	0.1573E+00	0.6453E-04
1969 DEC 31	0.1432E+00	0.3797E-02
1970 DEC 31	0.2439E+00	0.1158E-02
1971 DEC 31	0.1271E+00	0.1256E-01
1972 DEC 31	0.3445E+00	0.1924E-02
1973 DEC 31	0.4300E-01	0.1857E-02
1974 DEC 31	0.6387E-01	0.2544E-03
1975 DEC 31	0.4759E-01	0.5336E-03
1976 DEC 31	0.3984E-01	0.2130E-02
1977 DEC 31	0.5914E-01	0.5706E-02
1978 DEC 31	0.9326E-01	0.1367E-02
1979 DEC 31	0.2597E+00	0.1452E-02
1980 DEC 31	0.5155E-01	0.1099E-01
1981 DEC 31	0.2479E+00	0.7413E-02
1982 DEC 31	0.2220E+00	0.1016E-02
1983 DEC 31	0.2314E+00	0.5254E-02
1984 DEC 31	0.3639E+00	0.3733E-02
1985 DEC 31	0.4621E-01	0.4947E-02
1986 DEC 31	0.8032E-01	0.3828E-02

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/l)

X (meters)		0.00	116.00
Y (meters)		0.00	97.00
Z (meters)		0.00	0.00
1964	DEC 31	0.6783E-05	0.4120E-08
1965	DEC 31	0.1259E-01	0.1758E-04
1966	DEC 31	0.7103E+00	0.7917E-03
1967	DEC 31	0.1050E+01	0.7206E-02
1968	DEC 31	0.4580E+00	0.1390E-01
1969	DEC 31	0.2843E+01	0.1212E-01
1970	DEC 31	0.2896E+00	0.3636E-02
1971	DEC 31	0.5937E+00	0.8687E-02
1972	DEC 31	0.5389E+00	0.7894E-02
1973	DEC 31	0.9656E+00	0.3080E-02
1974	DEC 31	0.5790E-01	0.3355E-02
1975	DEC 31	0.9806E-01	0.5522E-02
1976	DEC 31	0.1224E-01	0.4944E-03
1977	DEC 31	0.4509E+00	0.6943E-03
1978	DEC 31	0.5036E+00	0.2924E-02
1979	DEC 31	0.1397E+00	0.3274E-02
1980	DEC 31	0.3430E+01	0.1056E-02
1981	DEC 31	0.3773E+00	0.7414E-02
1982	DEC 31	0.2592E+01	0.2912E-02
1983	DEC 31	0.1615E+00	0.7386E-02
1984	DEC 31	0.3102E+00	0.1116E-01
1985	DEC 31	0.3719E+01	0.6576E-02
1986	DEC 31	0.1054E+01	0.5141E-02

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/l)

X (meters)	20.00	76.00
Y (meters)	17.00	112.00
Z (meters)	0.00	0.00
1964 DEC 31	0.2367E-05	0.2989E-09
1965 DEC 31	0.1672E-02	0.7511E-06
1966 DEC 31	0.1875E+00	0.1650E-04
1967 DEC 31	0.2182E+00	0.7892E-03
1968 DEC 31	0.1578E+00	0.8596E-04
1969 DEC 31	0.7905E+00	0.3017E-03
1970 DEC 31	0.2171E+00	0.3145E-03
1971 DEC 31	0.7501E+00	0.2497E-03
1972 DEC 31	0.3051E+00	0.3846E-03
1973 DEC 31	0.2949E+00	0.9828E-04
1974 DEC 31	0.3580E-01	0.2025E-04
1975 DEC 31	0.6178E-01	0.3253E-04
1976 DEC 31	0.8103E-01	0.2288E-04
1977 DEC 31	0.4373E+00	0.1049E-03
1978 DEC 31	0.3568E+00	0.8125E-04
1979 DEC 31	0.1194E+00	0.4135E-03
1980 DEC 31	0.5945E+00	0.3684E-04
1981 DEC 31	0.4283E+00	0.5243E-03
1982 DEC 31	0.1124E+01	0.2889E-03
1983 DEC 31	0.3672E+00	0.3768E-03
1984 DEC 31	0.3000E+00	0.1668E-03
1985 DEC 31	0.6689E+00	0.2465E-04
1986 DEC 31	0.2826E+00	0.5042E-04

GLEN WYNN LAGOONS - SAND SPRINGS, OKLAHOMA

1-1-1 TRICHLOROETHANE LOADING
(mg/l)

X (meters)	180.00	65.00
Y (meters)	17.00	65.00
Z (meters)	0.00	0.00
1964 DEC 31	0.3088E-06	0.4059E-08
1965 DEC 31	0.5374E-03	0.1080E-03
1966 DEC 31	0.1528E-01	0.5231E-02
1967 DEC 31	0.2658E+00	0.9747E-02
1968 DEC 31	0.4441E+00	0.1479E-01
1969 DEC 31	0.7752E+00	0.3148E-01
1970 DEC 31	0.2467E+00	0.5476E-01
1971 DEC 31	0.3686E+00	0.1181E-01
1972 DEC 31	0.2796E+00	0.6882E-01
1973 DEC 31	0.2189E+00	0.5759E-02
1974 DEC 31	0.1184E+00	0.5574E-02
1975 DEC 31	0.2693E+00	0.8132E-02
1976 DEC 31	0.5635E-01	0.6310E-02
1977 DEC 31	0.2206E+00	0.1662E-01
1978 DEC 31	0.1347E+00	0.1120E-01
1979 DEC 31	0.2473E+00	0.4463E-01
1980 DEC 31	0.9052E-01	0.1231E-01
1981 DEC 31	0.8753E-01	0.5813E-01
1982 DEC 31	0.1180E+00	0.5037E-01
1983 DEC 31	0.2607E+00	0.2595E-01
1984 DEC 31	0.1548E+00	0.1899E-01
1985 DEC 31	0.2746E+00	0.1023E-01
1986 DEC 31	0.1427E+00	0.7371E-02

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VITA

William S. Pinckney

Candidate for the Degree of

Master of Science

Thesis: A FIELD STUDY OF THE APPROPRIATENESS OF THE PRZM AQUIFER LINKAGE FOR MODELLING THE TRANSPORT OF INDUSTRIAL POLLUTANTS

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Biographical:

Personal Data: Born in Angleton, Texas, March 13,1953 the son of William P. and Betty J. Pinckney

Education: Received Bachelor of Science Degree in Communications from the University of Texas at Austin, Texas in May 1977; received Bachelor of Science Degree in Geology from the University of Texas at Austin, Texas in December 1981; completed requirements for the Master of Science Degree at Oklahoma State University in July 1991

Professional Experience: Geologist for Cottton Petroleum Corporation, Tulsa, Oklahoma, January 1982 to July 1986; Independent Consulting Geologist, Tulsa, Oklahoma July 1986 to June 1991

Professional Organizations: American Association of Petroleum Geologists (AAPG); National Water Well Association (NWWA); American Institute of Professional Geologists (AIPG)