INVESTIGATION OF SHALLOW HYDROGEOLOGY AT THE PLASTIFAX SITE, HARRISON COUNTY, MISSISSIPPI

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INTRODUCTION

On June 2, 1982, the Plastifax plant near Gulfport, Mississippi, was destroyed in a massive explosion resulting from an accident in an on-site manufacturing process which was believed to have occurred when employees were trying to formulate a chemical from diesel fuel, paraffin and nitric acid. One of the main products of the facility was chlorinated paraffin. The explosion was believed to have caused a release of hazardous chemicals to the environment which prompted an immediate investigation by State and Federal agencies.

The Plastifax plant site is located in Harrison County, Mississippi, on the north bank of the Bayou Bernard Industrial Canal. This site is approximately one mile east of the intersection of the U. S. Hwy 49 and Interstate 10. Industrial Seaway Road forms the northern boundary of the plant as it runs parallel to the bayou. This is an area of low topographic relief with elevations ranging from 25 feet above mean sea level about one-half mile north of the plant to less than 5 feet at the surface of Bayou Bernard. Average elevations at the plant itself range from 17 to 22 feet. The location is one of dense industrial development. The Chemfax plant is located on the western boundary of Plastifax and the Charter Oil Company terminal shares access to the bayou on the south boundary of the site.

Previous investigations of groundwater contamination consisted of drilling a series of shallow boreholes in and around the plant site for the purpose of collecting soil samples, installing a series of shallow piezometers for the purpose of monitoring water levels, and a network of five monitoring wells was designed for the purpose of collecting water samples from the shallowest aquifer in order to determine whether or not any contaminants were present in this zone. During the course of drilling these wells, the shallow subsurface material was described in driller's logs and a coefficient of permeability value of $2.0 * 10^{-7}$ cm/sec was obtained from a remolded sample collected from monitoring well MW-2. Water levels were measured occasionally in the piezometers and later in monitoring wells. (See Figure 1)

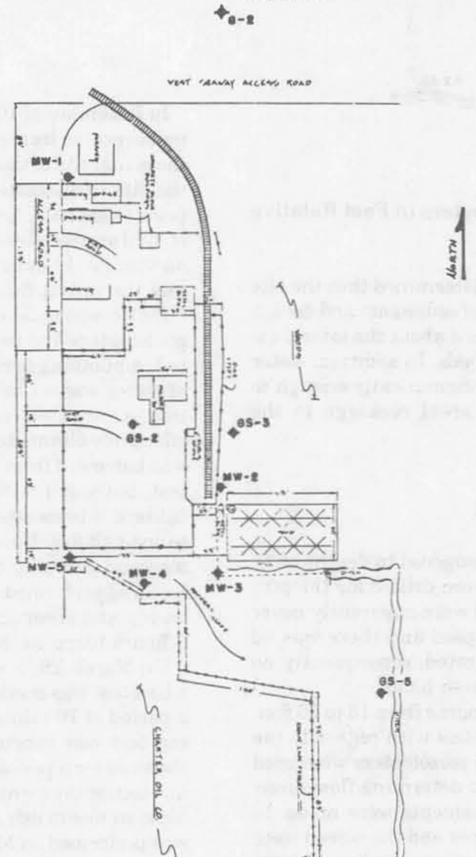

Figure 1: Location of Wells and Piezometers

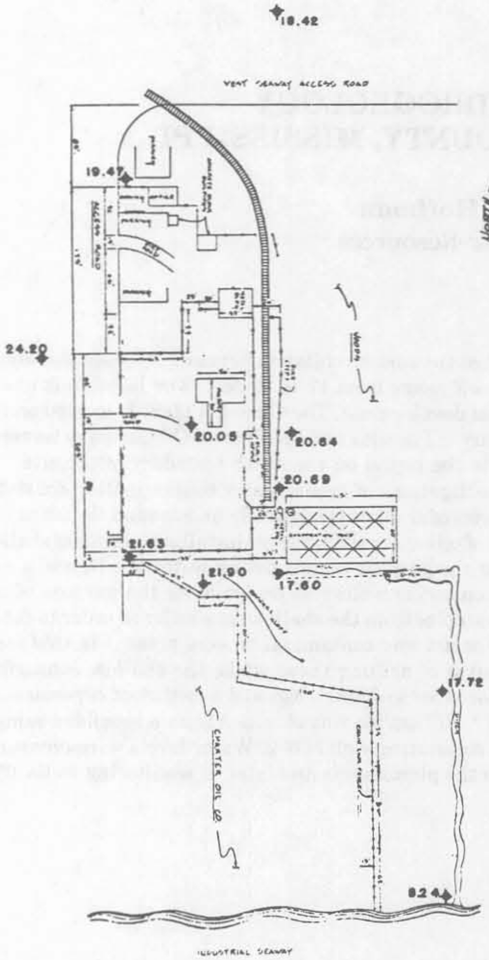

Figure 2: Elevations of Wells and Piezometers in Feet Relative to M.S.L.

After reviewing the existing data, it was determined that the site was underlain by a heterogeneous sequence of sediments and dredge and fill material and little could be determined about the lateral extent and continuity of the more permeable beds. In addition, water levels were not measured frequently and systematically enough to allow a reliable calculation of a rate of areal recharge to the shallowest aquifer.

PREVIOUS WORK

The records of five boreholes which were augered to depths of 17 to 23 feet were in the existing file. These were drilled for the purpose of collecting water and soil samples and were apparently never cased or plugged. Most of these holes collapsed and there was no detailed description of the materials penetrated, consequently no useful information could be gained from these holes.

Six piezometers were installed to depths ranging from 13 to 26 feet. Most of these holes were not described in detail with regard to the character of the materials penetrated. These piezometers were used occasionally to measure water levels and to determine flow directions but no systematic or frequent measurements were made. In the construction of these piezometers, the pipes and the screen were simply forced into the holes and the wells were not developed in any way. In addition, the diameter of these wells is too small to allow them to be easily pumped or bailed for the purpose of collecting samples or performing aquifer tests. No seals were placed around the casings to prevent the seepage of water from the surface through the boreholes around the outside of the casings. The principal value of these piezometers is to enhance the areal coverage available for water level measurements on the Plastifax site.

Five monitoring wells were installed at Plastifax for the primary purpose of permitting the collection of water samples to determine the presence of contaminants in the shallowest aquifer and the movement of any of these contaminants from the plant site. The driller's logs for these wells provide a good description of the units penetrated at each location. These wells are of sufficiently large diameter to allow them to be used for pumping tests; however, the wells probably should have been screened from the top of the saturated zone to the bottom of each well and there is some uncertainty regarding how extensively the wells were developed. An additional problem with these wells is that the upgradient well is not screened in the same sand as the four down-gradient wells since this sand apparently lenses out to the north beneath the plant site. A portion of a split-spoon sample collected from this shallow sand zone in MW-2 at a depth of 26.5 to 27.5 feet was remolded at a laboratory and a falling head test conducted on the sample resulted in a coefficient of permeability of $2.0 * 10^{-7}$ cm/sec. Such a remolded sample may not represent the true permeability of the aquifer as it behaves in situ. Freeze and Cherry (2), in their range of values of hydraulic conductivity, show that values of 10^{-7} cm/sec predominantly characterize unconsolidated deposits of marine clay and glacial till. It should be noted that the sample which was used to determine this value of the coefficient of permeability came from a zone which was supposed to be a sandy unit. These wells have provided additional points for measuring water levels in the shallow aquifer at the plant site, but prior to January of 1984, water level measurements were not taken in a systematic and frequent manner which could have provided useful hydrologic information concerning the site.

FIELD INVESTIGATION

In December of 1983, the plant site was visited to conduct a reconnaissance, to locate all wells and any existing boreholes, to inspect the actual site of the explosion and to use this information in planning the site investigation. The first problem which had to be resolved prior to starting field work was to obtain accurate measurements of land surface elevations at each of the eleven wells and piezometers on the site. In January, 1984, these measurements were completed and the initial field work was conducted. (See Figure 2)

Static water level measurements were taken on all wells and piezometers and two pumping tests and one slug test were attempted. A pumping test on MW-4 was attempted but less than 8 gallons of water was withdrawn from this well when the pump broke suction. A very slow rate of recovery was subsequently observed which effectively eliminated this well for use in pumping tests. A transducer was borrowed from the U.S.G.S. to measure water levels during this test, but this limited the results in that this device could only be calibrated to measure water levels with one tenth of a millivolt equal to one-half foot. Because of these problems, it became imperative that a second pumping test should be done on this well. Finally, a slug test was performed on MW-5 by injecting 2 gallons of water into the casing and observing the well's recovery for a period of more than 3 hours using an electric tape.

On March 29, a series of static water levels were measured and a bail test was conducted on MW-2 with recovery being observed for a period of 70 minutes, using an electric tape. On April 4, a pumping test was conducted on MW-2 for one hour and recovery was observed for a period of 175 minutes. Measurements were made using an electric tape which eliminated the problem associated with those measurements using the transducer. On April 5, a similar pump test was performed on MW-2 for a period of 54 minutes and recovery was observed for 340 minutes. On April 6, a similar pump test was performed on MW-5 for a period of 45 minutes and no recovery was observed. In each of these tests measurements were made using an electric tape and the pump was lowered into the well in the evening of the day prior to each pumping test and left in the well overnight to allow the static water levels to stabilize.

ANALYSIS OF DATA

The water level measurements taken on January 26 were adjusted relative to mean sea level and a potentiometric map based upon these measurements was produced by contouring water levels at one-foot intervals on the plant site. A similar map was made using the water level measurements of March 29.

Pump test and recovery data was generally analyzed using the method suggested by Strausberg (4) for mini-rate pumping tests on aquifers of low permeability. This method utilized a calculated residual drawdown to correct for the effects of dewatering of the aquifer during pumping. In performing these calculations, the saturated thickness of the aquifer was assumed to extend from the top of the zone of saturation to the bottom of the screened interval for each well.

Slug and bail tests conducted on MW-2 and MW-5 were analyzed by the method of Hvorslev (3), which is applicable for a point piezometer. This method was selected over that of Cooper (1) because the latter's usefulness is restricted only to confined aquifers. Hvorslev's method may be used to determine in situ hydraulic conductivity values from point piezometers that may be open over a short interval at their base whereas the other method requires that they be screened over the entire saturated thickness of the aquifer. The Hvorslev analysis assumes that the aquifer is homogeneous, isotropic and infinite in extent. It also assumes that both soil and water are incompressible. It must be acknowledged that slug and bail tests yield reliable data only for that point location at which the test was conducted and the results of such tests must be applied with caution over large areas.

RESULTS AND INTERPRETATION

Geology

The driller's logs of monitoring wells and available descriptions of some of the piezometer holes show that the Plastifax site is underlain by rather a heterogeneous assemblage of deposits. The upper 5 to 10 feet of material encountered in most holes is primarily sandy silt, silty clay and stiff gray clay with some predominantly silty sand or clay beds present. Clay deposits were encountered in every hole and appear to underlie the entire plant site at shallow depths. In the down-gradient monitoring wells (MW-2 through MW-5) a sandy lens of material was encountered at depths in the range of 20 to 35 feet below land surface. This sandy zone varies in thickness and clay and silt content from well to well across the plant site along this line of down-gradient wells. This unit does not persist laterally beneath the plant site as it is not encountered at all in MW-1. The shallowest saturated sand encountered in MW-1 was at a depth of 50 to 60 feet below land surface.

This data suggests that the thickness, lateral extent and permeability of the shallow deposits underlying the Plastifax site is highly variable and would be difficult to predict with any degree of certainty from one location to another across the site. The only feature which appears to be consistent is the presence of the clay beneath the immediate surficial material and overlying the water-bearing sandy and silty deposits across the entire site.

Water Level Mapping

The results of interpretative mapping of the potentiometric surface of the shallow aquifer beneath the Plastifax site reveal that the primary direction of flow is to the south toward Bayou Bernard which is probably a discharge area for at least a portion of the fluid in this aquifer. This configuration of the potentiometric surface is just as one might expect in such a case; however, on the site of the manufacturing area itself an interesting feature is present in both sets of water level measurements. The water level in G-2 was higher than those levels to the south as one would expect, but the water levels in G-3 and GS-3 were consistently the highest of any observed. This seems to indicate that flow in the manufacturing area of the plant site is converging beneath the area of the plant itself and subsequently is moving southward toward the bayou. If this is indeed the case then there is no flow from the plant site in any direction other than to the bayou. This may mean that any contamination detected in water samples from this part of the site could have moved laterally from some adjacent source. These observed water levels must be treated with some caution since both G-3 and GS-3 have no seals around the outside of the casing which would prevent water from seeping downward through the boreholes from the surface and thereby creating localized "mounding" effects around each piezometer. There is no evidence that in fact this is what is happening, but it cannot be ruled out at this point. (See Figures 3 and 4)

Aquifer Parameters

Tests of MW-2 consisted of pumping and recovery observations and a bail test. Analysis of these tests yielded the following coefficients of permeability:

(1) Pump Test	$P = 1.3 * 10^{-5}$ cm/sec
(2) Corrected Recovery	$P = 1.6 * 10^{-5}$ cm/sec
(3) Bail Test	$P = 1.4 * 10^{-4}$ cm/sec

Tests of MW-5 consisted of two pumping tests with one recovery and a slug test which gave the following results:

(1) Pump Test 1	$P = 1.7 * 10^{-5}$ cm/sec
(2) Corrected Recovery	$P = 1.4 * 10^{-5}$ cm/sec
(3) Pump Test 2	$P = 1.6 * 10^{-5}$ cm/sec
(4) Slug Test	$P = 4.2 * 10^{-5}$ cm/sec

Tests on MW-1 consisted of two pumping tests and two recovery observations which gave the following results:

(1) Pump Test 1	$P = 9.2 * 10^{-4}$ cm/sec
(2) Recovery 1	$P = 1.1 * 10^{-3}$ cm/sec
(3) Pump Test 2	$P = 1.9 * 10^{-3}$ cm/sec
(4) Recovery 2	$P = 1.8 * 10^{-3}$ cm/sec

The results of the analysis of the recovery data are probably the most accurate and usable of this set of data, although all of the results fall into the same range of values. The reasons for suggested use of the recovery data are that it is not subject to the surges of the pump and other problems associated with maintaining the constant discharge in the pumping tests, nor is it confined to application as point data as in the case of the results of slug and bail tests.

Based upon the field work and analysis of data, the value of $2.0 * 10^{-7}$ cm/sec for the coefficient of permeability obtained from laboratory analysis of a remolded sample appears too low for the shallow water-bearing sandy material encountered in the down-gradient monitoring wells. The results of this study suggest a value of approximately $1.5 * 10^{-5}$ cm/sec which is more typical of silty sand deposits. The deeper sand encountered in MW-1 yielded an approximate coefficient of permeability of $1.8 * 10^{-3}$ cm/sec which is representative of cleaner sand deposits. The water level measurements observed in MW-1 and the shallower wells and piezometers are consistent to indicate that there is a good hydraulic connection existing between the shallow, less permeable material and the deeper more permeable sand deposits.

Travel Time Calculations

These calculations are for the flow of water in the shallow saturated zone beneath the Plastifax site from the approximate location of piezometer GS-2 to Bayou Bernard. There are assumed to be no retardation effects acting upon contaminants and the calculation is thus strictly applicable to the flow of groundwater in a macroscopic sense.

The following equation was used to calculate travel time:

$$\bar{v} = \frac{K}{n}\frac{dh}{dl}$$

where,

$\bar{v}$:	Average linear velocity	(L/T)
K:	Hydraulic conductivity or coefficient of permeability	(L/T)
n:	Porosity	(%)
$\frac{dh}{dl}$	:Hydraulic gradient	(Dimensionless)

Average linear velocity is not representative of the velocity of water particles moving through the pore spaces of an aquifer. In the microscopic sense, velocities will be greater than $\bar{v}$ since the water particles must travel along irregular paths which are longer than the linearized flow path which average velocity represents.

An average porosity value of 35% was selected for this aquifer which is an average value representative of silty and sandy unconsolidated deposits.

A hydraulic gradient of 0.02 was calculated from the location of piezometer GS-2 to the most southerly water level contour near the bayou on each of the potentiometric maps.

By using the equation with these values and an average coefficient of permeability of 1.5 * 10^{-5} cm/sec, the average linear velocity for flow in the shallow aquifer in which the down-gradient monitoring wells are screened is 27 cm/year or 0.89 ft/year. This is a much higher rate of flow for this zone than would be obtained from the laboratory permeability which yields $\bar{v}$ = 0.36 cm/year or 0.012 ft/year.

Calculations of average linear velocity for flow in the lower sand unit in which MW-1 is screened yield values of $\bar{v}$ = 3244 cm/year or 106 ft/year.

Assuming a direct flow path from GS-2 which is located approximately at ground zero of the explosion to Bayou Bernard, a distance of 520 feet was used to calculate the time of travel in the aquifer assuming that all flow is horizontal. The following results were obtained from this calculation for travel time from the position of GS-2 to the bayou.

(1) Shallow sandy material in down-gradient wells
520 ft/ 0.89 ft/year = 584 years

(2) Deeper sand in MW-1
520 ft/ 106 ft/ year = 5 years

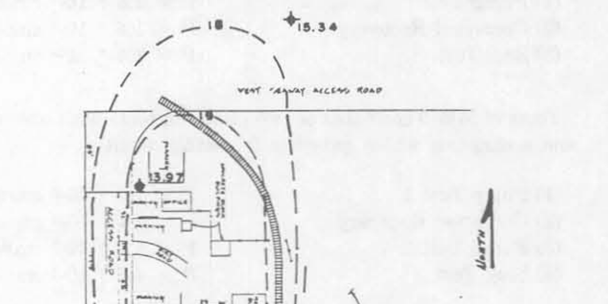

Figure 3: Piezometric Map of Shallowest Aquifer on 1/26/84. (Contour Interval = 1 ft.)

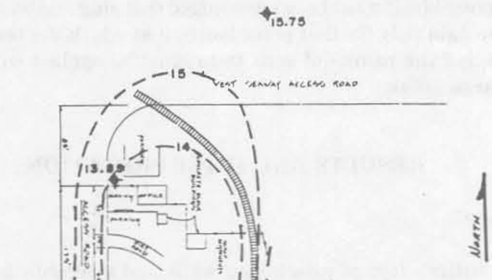

Figure 4: Piezometric Map of Shallowest Aquifer on 3/29/94. (Contour Interval = 1 ft.)

(3) Shallow sandy material in down-gradient wells (using laboratory permeability)
520 ft/ 0.012 ft/year = 43,000 years

The previous calculations are applicable only in the case of bulk flow. The following calculations take into account the effects of longitudinal and transverse dispersion upon a hypothetical contaminant. This assumes that the contaminant has been introduced into the flow system as an instantaneous slug originating at some point source. The mass of contaminant is then carried away by transport in a steady-state, uniform flow field moving in the x - direction within a homogeneous, isotropic medium.

The concentration distribution of the contaminant mass at time, t, is given by Baetsle (1) in the following equation:

$$C(x,y,z,t) = [C_oV_o/(8(\pi\ t)^{3/2}\ (D_xD_yD_z)^{1/2})]$$
$$EXP\ [-X^2/4D_xt - Y^2/4D_yt - Z^2/4D_zt]$$

where,

C_o:	Initial Concentration
V_o:	Initial Volume
D_x,D_y,D_z:	Coefficients of dispersion in the x,y,z directions
X,Y,Z:	Distances in the x,y,z directions from the center of gravity of the contaminant mass

$X = x - \bar{v}t$
$D_x = a_1\bar{v}$
$D_y = a_t\bar{v}$
$D_z = a_t\bar{v}$

where,
a_1: Longitudinal dispersivity
a_t: Transverse dispersivity

The values used in these calculations are shown in the following table.

t(yrs)	$V_o(ft^3)$	a_1(ft)	a_t(ft)	x(ft)	y(ft)	z(ft)
100	100	100	30	520	60	10
	200					
300	300					
	400					
500	500					

The dispersivity values, a_1 and a_t, were obtained from calculations of the results of numerical transport models (method of characteristics) against actual observations of groundwater solute transport by Evenson and Dettinger (3).

A time of approximately 300 years is required for an allowable relative concentration of $8 * 10^{-7}$ to reach Bayou Bernard assuming an initial volume of contaminant of 100 cubic feet in the shallowest aquifer beneath the plant site.

The results obtained from this calculation of concentration distribution utilizing a series of initial volumes over a range of time intervals are shown in Figure 5.

There is no evidence that groundwater contamination has actually occurred at the Plastifax site; therefore, all of these calculations are strictly based upon a hypothetical instance of contamination.

CONCLUSIONS

The data gathered in this study suggests that there is little danger of contamination of underground drinking water sources from hazardous materials spread over the site in the explosion itself. This is because the very shallowest water-bearing deposits at the site are of low permeability and the area seems to be underlain by a relatively persistent clay unit which overlies the water-bearing zones. The most likely means by which contaminants could have reached the bayou under natural circumstances would be from surface runoff.

Due to the nature of the shallow subsurface deposits encountered and described in the wells drilled at Plastifax, it appears most likely that contaminants could have reached the saturated zone mainly by being introduced through some type of artificial penetration such as a borehole or well.

The primary concern at this point is that contaminants which might be present from whatever source in the shallow, low permeability zone of saturation may reach the deeper, more highly permeable materials in which MW-1 is screened. The probability of this occurring seems to be quite limited because of the presence of so much clay and other fine-grained deposits underlying the site.

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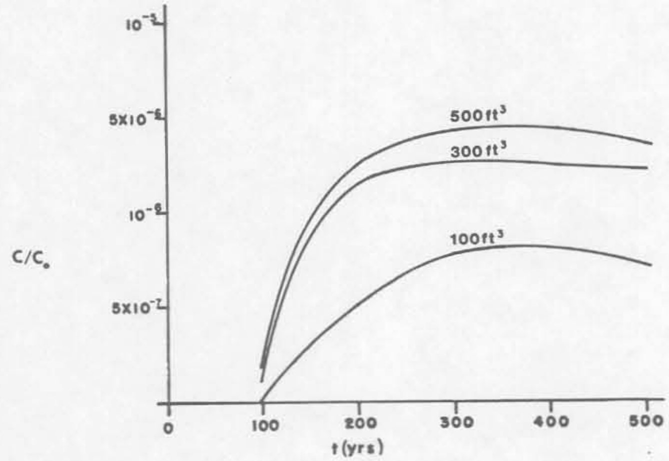

Figure 5: Plot of Calculated Relative Concentration Distributions