Donohue



# Groundwater Modeling of Solvent Contamination Near City of Delavan Well No. 4

Sta-Rite Industries
Water Equipment Division
Delavan, Wisconsin

December 1983

Donohue & Associates, Inc.
Engineers & Architects

# Donohue

January 9, 1984

DONOHUE & ASSOCIATES, INC.

SHEBOYGAN OFFICE

Sta-Rite Industries, Inc.
777 East Wisconsin Avenue
Milwaukee, WI 53202

Attn: Mr. Jeffrey R. Cooke
Vice President and General Counsel

RECEIVED

SEP 13 1985

BUR. OF SOLID WASTE MGT.

Re: Groundwater Modeling Report
Sta-Rite Industries Water Equipment Division
Delavan, Wisconsin
Donohue Project No. 12894.002

Dear Mr. Cooke:

Attached is our final report of groundwater modeling of the solvent contamination near City of Delavan Well No. 4. Our report contains a description of the model, a discussion of site conditions and data used in the model, the result of our evaluation, and our conclusion and recommendations.

After your review of this report, we would be pleased to meet with you to discuss our findings. We appreciate the opportunity to work with you, Dick LaChapell, and his staff on this interesting project.

Very truly yours,

DONOHUE & ASSOCIATES, INC.

Michael L. Crosser

Michael L. Crosser
Project Manager

MLC/mb

cc: Dick LaChapell

attach: Groundwater Modeling Report

**Donohue & Associates, Inc.**
**4738 North 40th Street**
**Sheboygan, Wisconsin 53081**
**Engineers & Architects**
**414-458-8711**

# GROUNDWATER MODELING OF SOLVENT CONTAMINATION NEAR CITY OF DELAVAN WELL NO. 4

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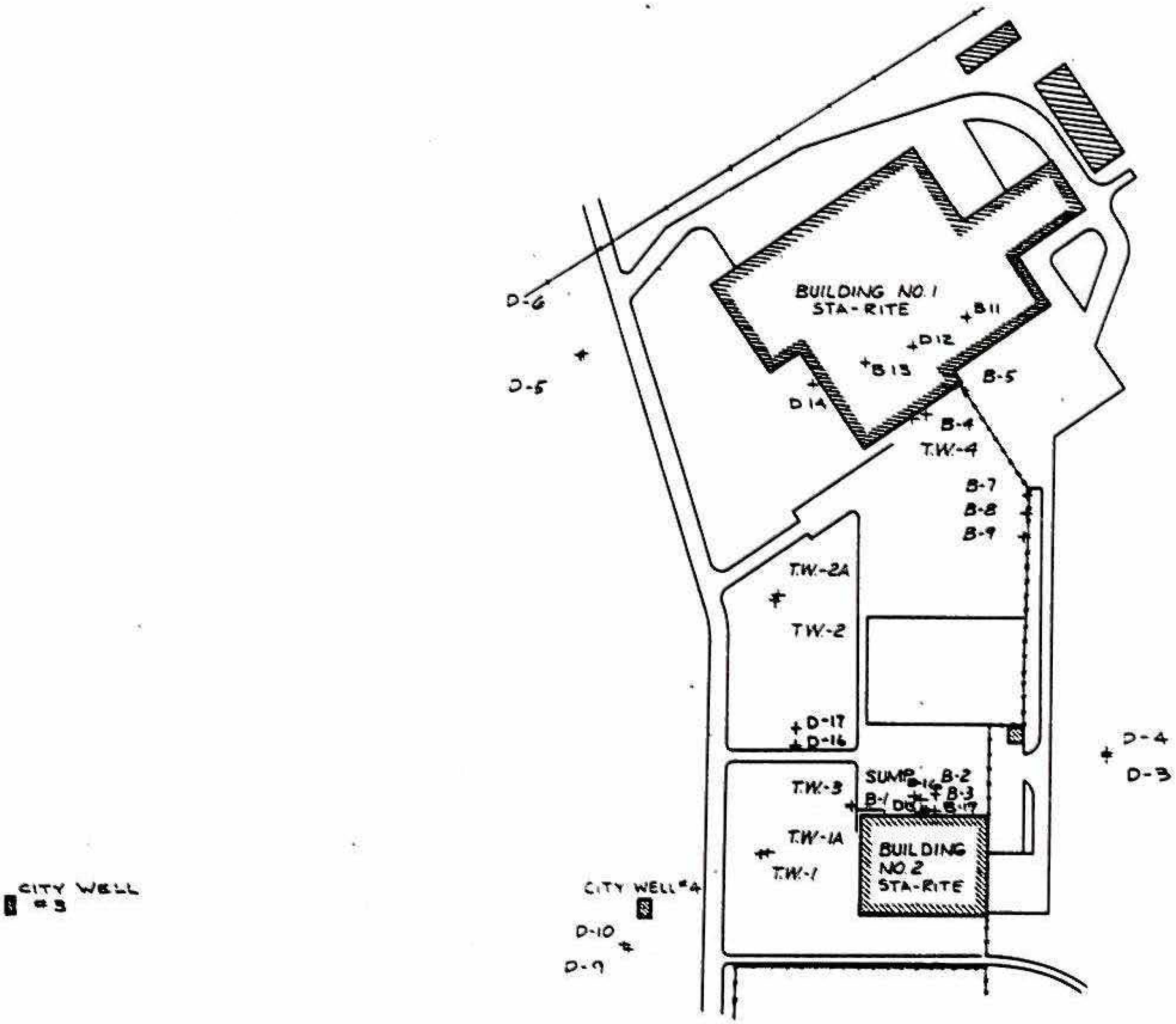
# GROUNDWATER MODELING OF CONTAMINANT MOVEMENT NEAR DELAVAN CITY WELL 4

## INTRODUCTION

Since late 1982, investigations of the chlorinated solvent contamination detected in City Well 4 in Delavan, Wisconsin, have been underway. The Wisconsin Department of Natural Resources (DNR) suspected that the Sta-Rite Industries Water Equipment Division facilities, located approximately 1,000 feet east of City Well 4, was the source of the solvent contamination. A site plan showing the location of the two Sta-Rite buildings (Plants 1 and 2) and City of Delavan Municipal Wells 3 and 4 is shown on Figure 1. The City retained Warzyn Engineering Company to investgiate. With the cooperation of Sta-Rite Industries, Warzyn Engineering obtained soil and groundwater samples on Sta-Rite property. The samples were obtained in areas of potential contamination as identified by Sta-Rite and in areas between the potentially contaminated areas and City Well 4. Warzyn issued a preliminary report of their findings on February 16, 1983, which indicated solvent contaminated water at the groundwater surface near the southeast wall of Plant 1 and soil and near-surface water contamination near the holding tank outside the north wall of Plant 2. Groundwater surface samples from wells between the identified contaminated areas and City Well 4 showed decreasing amounts of solvents as the distance from the identified contaminated areas near Plants 1 and 2 increased. Wells near the Sta-Rite property line showed little or no contamination.

In January 1983, Sta-Rite retained Donohue to conduct further evaluations. Donohue placed additional groundwater monitoring and sampling wells to obtain data covering greater areal and vertical distances and conducted a pumping test to determine aquifer characteristics. The goals of the work were to determine whether the identified areas of contamination near Plants 1 and 2 could contribute to the contamination of City Well 4 and to provide data for selecting remedial action if required. No definitive data were collected during the investigation that would indicate a direct path of migration from the contaminated areas on Sta-Rite property to City Well 4. However, there was strong indication that solvents in the groundwater in the vicinity of Plant 1 were moving off-site to the northwest, the direction of groundwater flow. The data and results were reported in May, 1983. Following evaluation of the results reported in May, 1983, Sta-Rite authorized additional investigations to determine groundwater and contaminant movement in the area and authorized removal of the sump tank and contaminated soils near the sump at Plant 2. The remedial actions were completed in December, 1983. Concurrent with the implementation of Plant 2 remedial actions and with the assistance of Thomas A. Prickett, Donohue modeled the groundwater flow system. The objectives of the program were to:

1. Model the area under investigation which includes the areas of identified contaminated groundwater on Sta-Rite property, and City Wells 3 and 4 using available data to determine the impact of potential contaminant sources on City water quality and the effect of remedial action at Plant 2. The available data include groundwater monitoring results from the wells shown on Figure 1 and the pump test data for City Well 4.

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N

0 100' 300'

FIGURE 1

2. Determine the variability in the characteristics of the hydrogeologic system and calibrate the model.

3. Verify the model by installing additional groundwater monitoring wells and analyzing groundwater samples.

4. Determine a pumping scheme to minimize contaminant movement to City Wells 3 and 4.

Figure 1 shows the location of all monitoring wells installed by Donohue and Warzyn.

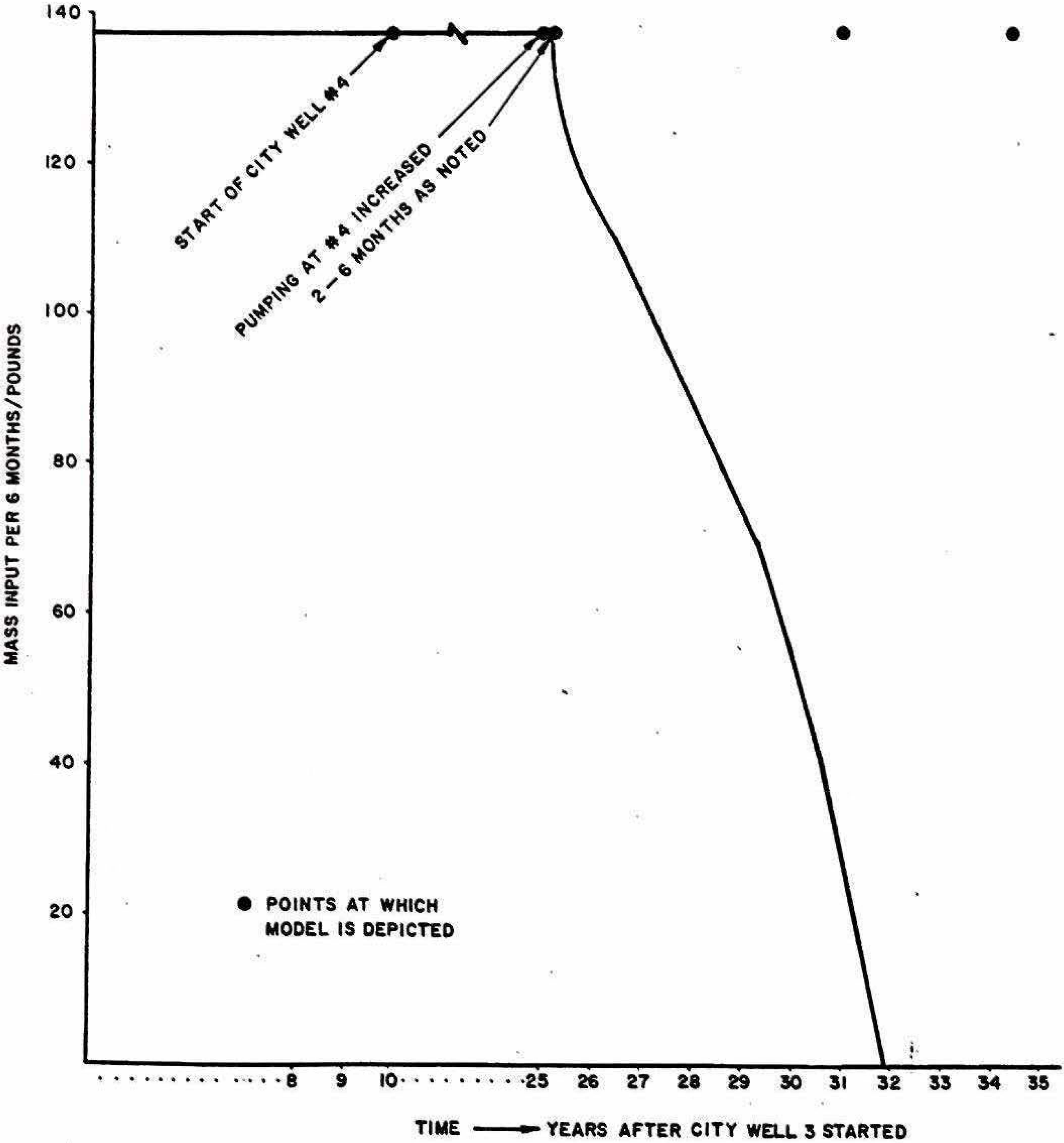
DESCRIPTION OF THE MODEL

A modified version of the "Random-Walk" solute transport model developed by Thomas A. Prickett, Thomas G. Naymik, and Carl G. Lonnquist was used to model the groundwater system. This computer model can simulate two-dimensional, non-steady/steady groundwater flow problems and aquifers under water table or artesian conditions. It covers time varying pumpage, effects of surface waters, and allows specification of chemical constituent concentrations (Prickett, 1981).

The random-walk technique is based on the concept that dispersion in porous media is a random process. A particle, representing the mass of a specific chemical constituent contained in a defined volume of water, moves through the modeled aquifer with two types of motion. One motion is with the main flow and the other is a random motion related to flow length and longitudinal and transverse dispersion. During modeling, enough particles are included so that their locations and densities are adequate to describe the concentration distribution of the dissolved constituent of interest (Prickett, 1981).

Model input parameters are needed which describe the movement of the groundwater. These parameters included transmissivity of the aquifer, storage coefficient, hydraulic conductivity, porosity, longitudinal and transverse dispersivity, pollutant retardation coefficient, and regional flow direction. In addition to basic aquifer parameter definition, possible sources of pollution and known locations of pumping wells were input to the model. The sources of the contamination were assumed to be the sump tank at Sta-Rite Plant 2, the road area southeast of Sta-Rite Plant 1, and an area beneath Sta-Rite Plant 1. Based upon a study of past records, we assigned City Well 3 a pumping duration of 25 years (since 1958) at a rate of 300,000 gpd. We also assumed that the introduction of contaminants to the aquifer started prior to the installation of City Well 4 (prior to 1968) and that City Well 4 has been pumping at a rate of 400,000 gpd up to the present time.

The model was run in half-year increments, with 100 particles representing 27,500 lbs of TCE (1 particle equals 275 lbs) added to the system each year until 1983. We assumed that following 1983, the amount of contamination reaching the aquifer decreased to zero in 6 years because of remedial actions and changes in solvent handling practices. Figure 2 shows the assigned rate

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## ASSUMED CONTAMINANT INPUT AMOUNT

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FIGURE 2

of loading of contaminants to the aquifer. The direction and length that each particle moved in response to the physical conditions, was then calculated by computer. A map was constructed showing the location of the particles after each half-year. The process was continued by moving and mapping the particles as the contaminant flowed in the system.

Calculations used to estimate the amount of solvent which was introduced to the aquifer from the sump at Plant 2 indicate an amount of 75 lbs/ day. The calculation assumes an annual use of 5,000 gallons per year and on-site disposal resulting in 2,500 gallons per year reaching the aquifer. This estimate represents worst case conditions. Concentrations currently found at City Well 4 are about 200µg/l. If City Well 4 is pumping at a rate of 0.4 MGD, the mass pumped is about 0.7 lbs/ day. To apply this to the model, only 1 particle would need to be captured by City Well 4 per year to represent the measured concentrations.

Monitoring wells placed at Plant 1 indicate significant groundwater contamination beneath the southeast portion of the building. There is also the potential for groundwater contamination resulting from a former disposal area located approximately 100 feet east of Borings 7, 8, and 9. We have not been able to estimate the amount of solvents introduced to the aquifer. In the model, 100 particles per year were added to the aquifer from Plant 1 sources.

## LIMITATIONS AND SOURCES OF ERROR

To avoid model misuse, it is important to know and understand the limitations and possible sources of error in modeling. All models are based on a set of simplifying assumptions; it is important to understand the field conditions as well as the assumptions that form the basis for the model.

To determine the appropriate model for this application, we considered the following factors: objectives of the modeling effort, the amount of available data and additional data to be collected, and the complexities of the problem. The main objective of the modeling effort was to determine a pumping scheme to minimize contaminant movement toward the well because the remedial action program for the Delavan City Well 4 had been determined prior to the start of the modeling effort. The emphasis on this modeling program was to aid in the development of a solution to the contaminant problem, rather than an extensive continuing effort on studying the problem. Therefore, to avoid extending a model beyond the calibration and verification data, we selected the two-dimensional model.

All models are limited and there are potential sources of error. The simplifying assumptions of the model must be considered to adequately determine how realistically the model portrays the actual system. In applying the two-dimensional model, we simplified actual site conditions as discussed below:

1. Use of a Two-Dimensional Model for a Three-Dimensional Problem. During analysis of the problem, it became apparent that there were significant vertical components to groundwater flow. These were caused by two main conditions: the anisotropy of the aquifer and the fact that City Well 4 only partially penetrated the aquifer. Although these affected groundwater flow, they do not appear to significantly affect

contaminant movement. The majority of contaminants were found at the water table with only minute quantities being found at depth in the aquifer.

2. Simplification of the Water Table. The model requires the input of the slope of the water table and flow direction which affect groundwater velocity. The assumption that the slope of the water table is constant over the area is fairly accurate. The water table map constructed by Donohue, April, 1983, does not indicate any significant changes in slope; however, flow directions do change. For the model, the flow direction was considered to be 60 degrees west of north, while the water table map shows 45 degrees or less. If an error results from this simplification, it would cause more movement of contaminants towards City Well 4 than may actually occur. Therefore, the assumption is conservative.

Application of this model involved three phases -- a data interpretation phase, a model calibration and verification phase, and a prediction phase. The data interpretation and calibration and verification phases consisted of the following:

1. Interpretation of all data collected concerning site conditions and a literature review to determine reasonable input parameters for the model, including aquifer characteristics, flow velocities, retardation, and dispersion characteristics.

2. Calibration of the contaminant transport model by adjusting dispersivities, retardation, and flow direction until the model simulated the observed conditions.

3. Verification of the model by installing additional groundwater monitoring wells and analyzing samples.

## SITE CONDITIONS

The aquifer from which City Wells 3 and 4 are withdrawing water is formed of unconsolidated glacial material. It consists of sand and gravel deposits. The saturated thickness of this material is approximately 120 feet beneath the site. This thickness includes all saturated, permeable, unconsolidated material from the land surface to the relatively impermeable, finer grained glacial drift beneath it.

The water table map in the vicinity of the Sta-Rite Industries and of Delavan in general shows the altitude of the water table dipping to the northwest. Most water in the area circulates through the unconsolidated material and shallow bedrock units and then discharges to the streams. It is known that the area around Delavan Lake acts as a recharge area for the shallow groundwater system, while Turtle Creek and Comus Lake would act as the local discharge area.

PUMP TEST DATA

A pump test was conducted on City Well 4 on March 18, 1983. The purpose of this pump test was to determine the aquifer characteristics (transmissivity and storativity) at the site. The aquifer characteristics could then be used to estimate the cone of influence of City Well 4. City Well 4 was pumped at 875 gpm for 8 hours; during the pump test MW9, MW10, TW1, TW1A, TW2, TW2A, and TW3 were monitored for drawdown. Upon completion of the pumping portion of the test, 1-hour recovery levels were also monitored in every well except TW2A. Time versus drawdown was plotted for each of the monitoring wells. For recovery well data, time versus residual drawdown was plotted on log-log paper. Drawdowns were then corrected for partial penetration effects from both the pumping well and observation wells and replotted on log-log paper.

To calculate aquifer characteristics, the time drawdown curves were matched with Theis type curves. Time drawdown curves were initially matched to delayed yield from storage curves as developed by Boulton and outlined in Lohman (1972); they were also compared to normal Theis type curves and partial penetration type curves. Transmissivity values range from a low of 80,000 gpd/foot calculated at MW10 to over 300,000 gpd/foot calculated at TW2. Storativity values vary between .001 and .01. Transmissivities and storativities were also calculated through curve matching of a plot of drawdown versus time/radius$^2$. The transmissivity found in this manner was 180,000 gallons per day per foot with a storativity of .001.

The overall transmissivity of the aquifer in the area is approximately 150,000 gpd/foot. Lower transmissivities are found near the pumping well, probably caused by inhomogenities in the unconsolidated materials. Transmissivities appear somewhat higher further away from City Well 4. They may appear higher than 150,000 gpd/foot because of leakage from the silty sands in the upper 30 feet of the formation or inhomogenities in the aquifer. In addition, the pump test may not have been of sufficient duration to determine all the effects caused by delayed yield from storage and partial penetration. The silty sand near the surface may also be affecting the short-term storativity values which were calculated as being indicative of a semi-confined aquifer. It is anticipated that the long-term storativity values would be about 0.1. It has also been determined that the aquifer is anisotropic. This means that the horizontal conductivity and vertical conductivity differ. Calculations determined while correcting for effects of partial penetration, indicate a horizontal conductivity approximately 30 to 40 times greater than the vertical conductivity. These differences in conductivities may be, in part, confining the contamination to the upper portion of the aquifer.

SUMMARY OF AQUIFER CHARACTERISTICS AND SOLVENT TRANSPORT VALUES

All models were run with the following values:

Transmissivity = 150,000 gpd/foot

Storage Coefficient = 0.1

Hydraulic Conductivity = 1,250 gpd/foot$^2$

Porosity =35 percent

Gradient = .004 feet/foot

Velocity = 1.9 feet/day in a direction 60 degrees west of north

In addition to these values, a longitudinal dispersion factor of 60, and a transverse dispersion factor of 15 were used based on observations in glacial and alluvial material (Anderson, 1979). A retardation factor was estimated based on results from literature describing movement of chlorinated solvents in the soil. The retardation factor is a function of the partition coefficient of the solvent between the soil and the aqueous phase. The partition coefficient is dependent on the amount of organic matter in the soil. Because the amount of organic matter in the soil at the groundwater table is very low, we selected a retardation factor of 1.0 (Roberts and Valocchi, 1981; Karickhoff et. al., 1979).

MODELING RESULTS

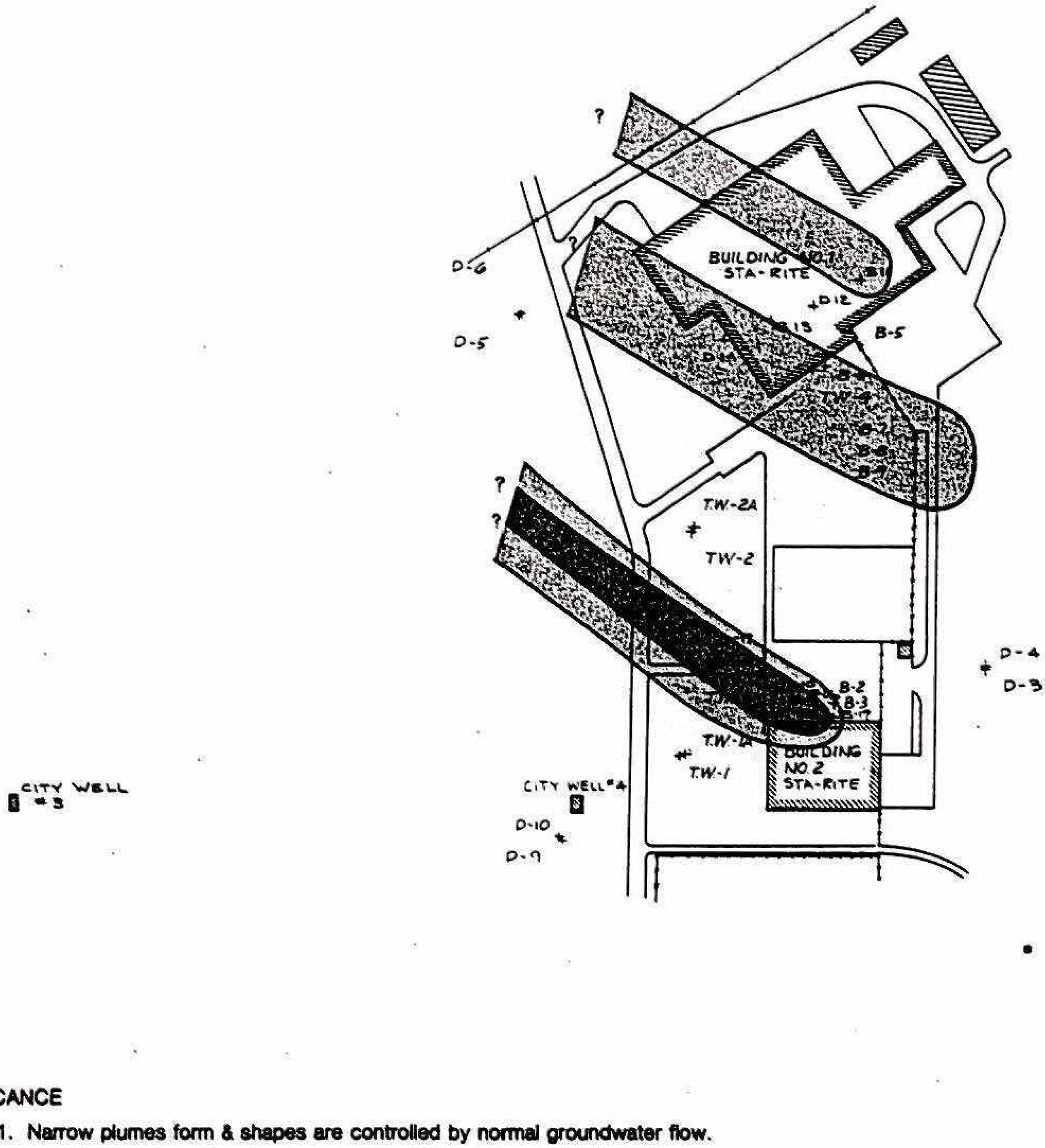
Conditions from 1958 to 1983

Figure 3 shows contaminant migration when City Well 3 is pumped regularly at 0.3 MGD and City Well 4 does not exist. The models for this period indicated that the dominant controlling factor of contaminant migration was the regional groundwater flow. Contamination remained confined to a relatively narrow path which moved to the northwest with the groundwater flow. The contaminant plumes become less distinct when City Well 4 is pumped at 0.4 MGD and City Well 3 at 0.3 MGD as dilution and dispersion of the contaminants occurs. The edge of the plume from Plant 2 is being pulled towards City Well 4. Contaminants did not enter City Wells 3; however, they did enter City Well 4 at an average rate of 275 lbs/year. This rate results in a concentration of 220 μg/l at a pumping rate of 0.4 MGD.

Predicted Conditions After 1983

Effect of Increasing the Pumping Rate of City Well 4 to 1.2 MGD for Two Months

The overall shape of the plumes remain fairly constant when City Well 4 has been pumping at maximum capacity for two months. Contaminant concentrations at City Well 4 remain near 200 μg/l; this is consistent with readings taken during increased pumping (Crispell-Snyder, oral communication). Contaminants are not moving towards City Well 3.




SIGNIFICANCE

1. Narrow plumes form & shapes are controlled by normal groundwater flow.

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0 100' 300'

FIGURE 3

### Effect of Resuming Normal Pumping Rate of 0.4 MGD from City Well 4 After Pumping at Maximum Capacity for Two Months

The remaining models assume that input of solvent to the aquifer decreases to zero over a six-year period due to remedial actions and changes in solvent handling procedures. Figure 4 shows the contaminant plumes approximately four years after normal pumping has been resumed. Contaminant input is decreasing. Relatively high concentrations are still found at the source, although the main portion of the plume is moving out of the area. City Well 4 starts to show decreasing concentrations while City Well 3 shows no contamination.

Figure 5 depicts the predicted plume three years after contaminant input has stopped and seven years after normal pumping has been resumed. The plumes are out of the area with only residual amounts left at the site. City Well 4 has concentrations below detection.

### Effect of Stopping the Pumping of City Well 4 Completely After Pumping at Maximum for Two Months

Figure 6 depicts the plumes approximately four years after City Well 4 is completely shut down. The plumes remain fairly distinct with the main portion of the plume moving out of the area. City Well 3 is not affected. Seven years after City Well 4 has been off, most contamination is out of the area (Figure 7). Small amounts of residual contamination may still be found.

### Effect of Continued Pumping of City Well 4 at the Maximum Rate

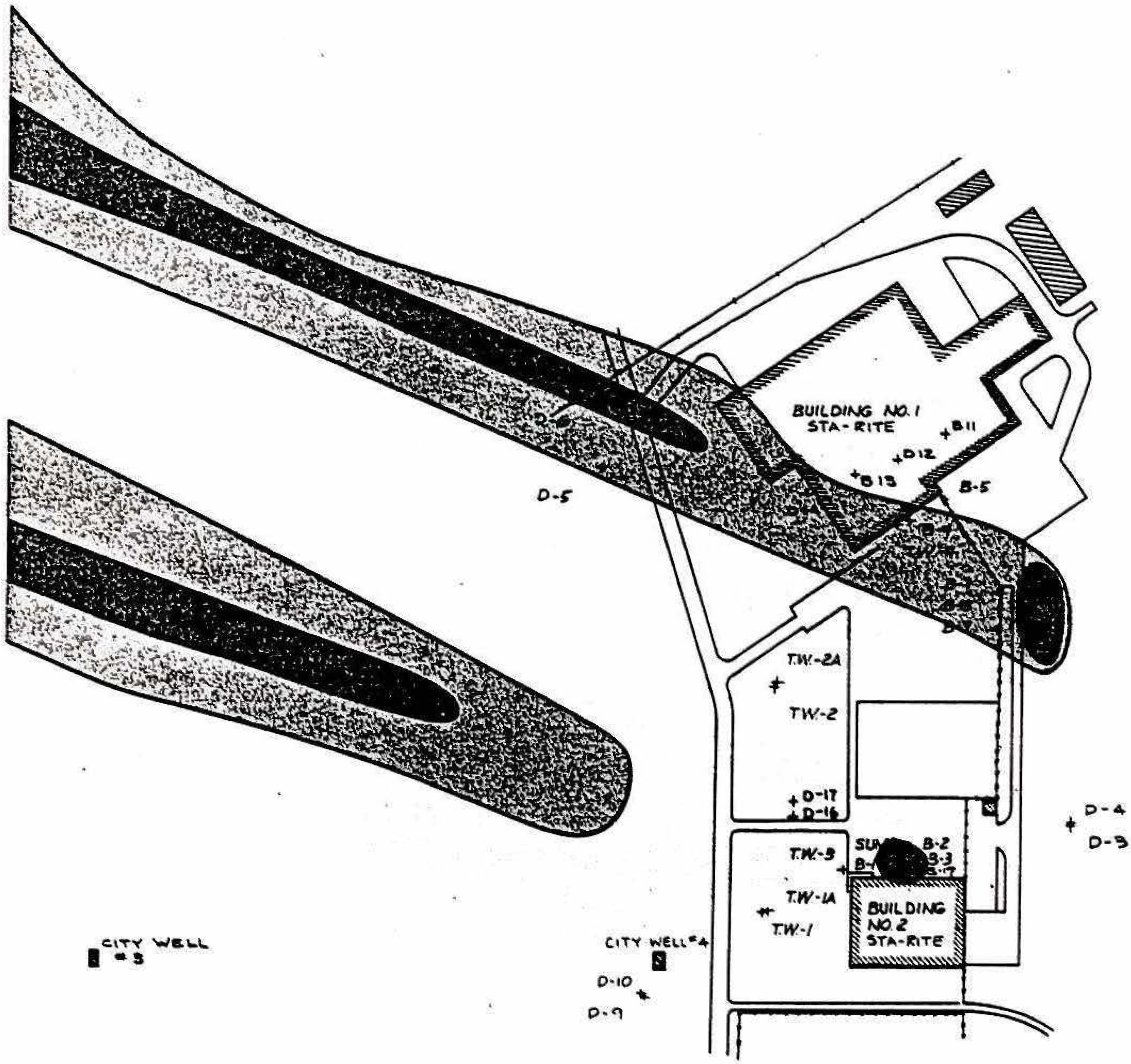
City Well 4 has a strong influence on the contaminant plume if it is continually pumped at a high rate. The plume is bent towards the well and contaminants enter from the upgradient side. Concentrations rise significantly in City Well 4 one to two years after pumping is increased. Once the plume is past City Well 4, it is again controlled by the regional groundwater flow.

Four years after increasing the pumping the main plume from Plant 2 is concentrated and smaller, moving towards City Well 4. The plumes in general become wider to the south. The main plume from Plant 1 moves out of the area. Concentrations are still higher than at present in City Well 4, although the amount in the aquifer is decreasing as City Well 4 captures the contamination.

Approximately seven years after increasing the pumping the main portion of the plume from Plant 1 is out of the area. Most contamination from Plant 2 is past City Well 4; however, pumping of City Well 4 retards the movement of the plume from Plant 2.

## MODEL VERIFICATION

Under City well pumping conditions in effect until 1983, the model predicts that the contaminant plume from Plant 2 would pass between monitoring wells installed prior to August 1983. To verify the prediction, Donohue installed additional wells to intercept the predicted plume (Donohue No. D-16 and D-17). Approximately 900μg/l of TCE was found in the groundwater near the surface of the groundwater table of the predicted location. No further verification efforts have been carried out.




SIGNIFICANCE

1. Concentration decreasing in City Well No. 4.
2. Main plumes located downgradient of City Well No. 4.
3. No contamination entering City Well No. 3.

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**NEAR CITY OF DELAVAN WELL NO. 4**
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WATER EQUIPMENT DIVISION
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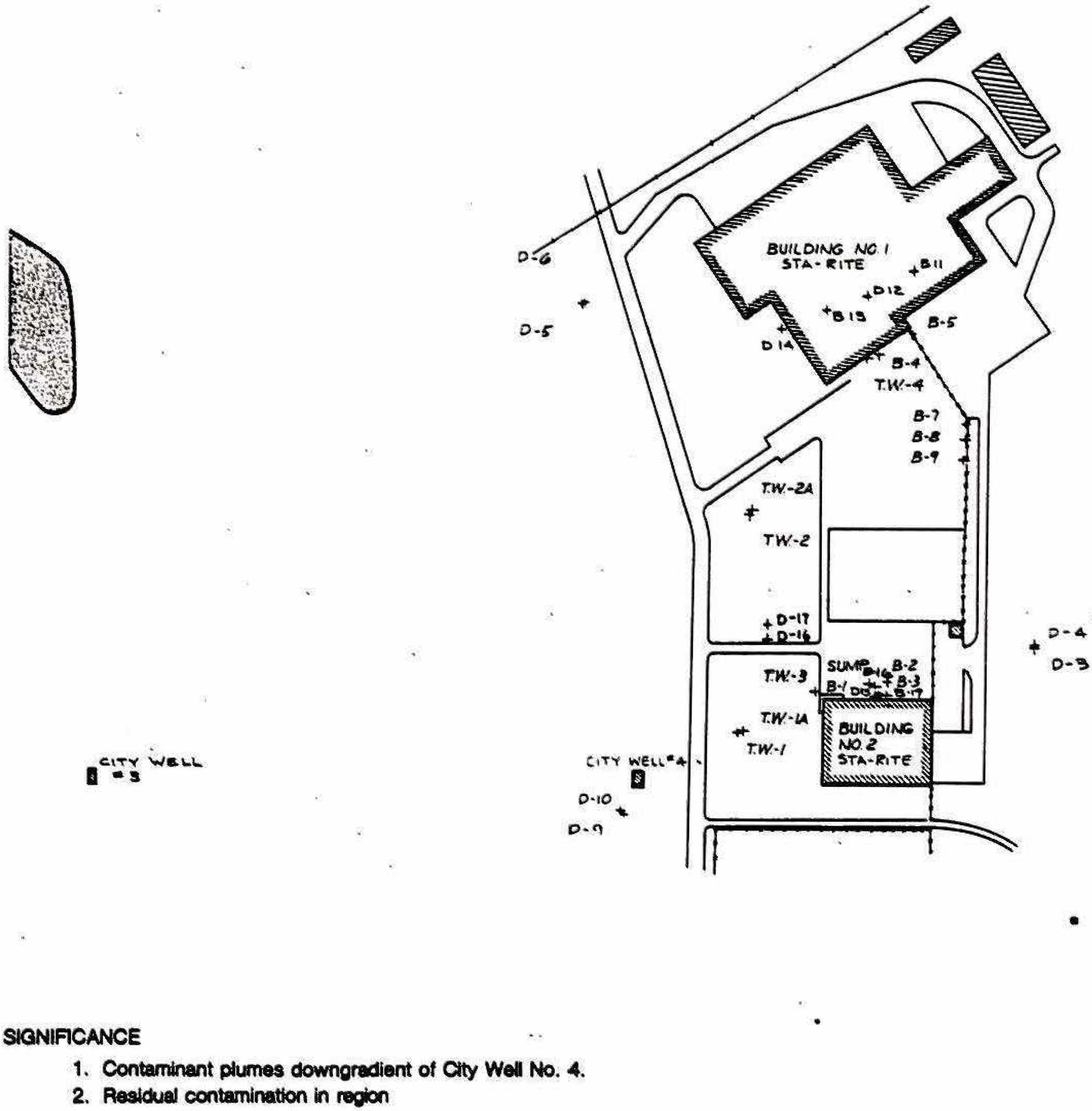
FIGURE 4




SIGNIFICANCE

1. Contaminant plumes downgradient of City Well No. 4.
2. Residual contamination in region

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NEAR CITY OF DELAVAN WELL NO. 4
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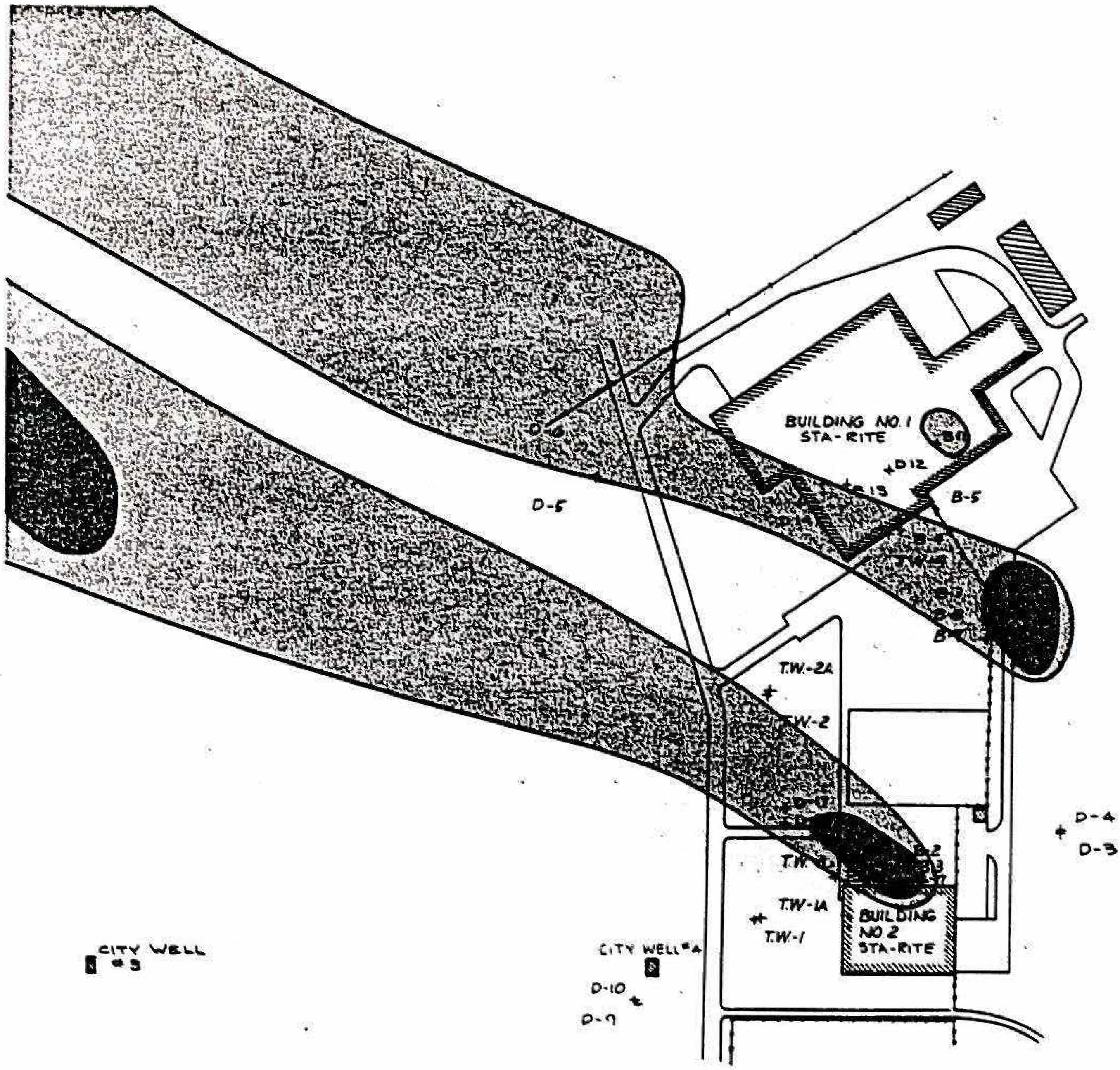
FIGURE 5




SIGNIFICANCE

1. Plume movement and shape controlled by groundwater flow.
2. Main plumes located downgradient of City Well No. 4.
3. No contamination entering City Well No. 3.

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NEAR CITY OF DELAVAN WELL NO. 4
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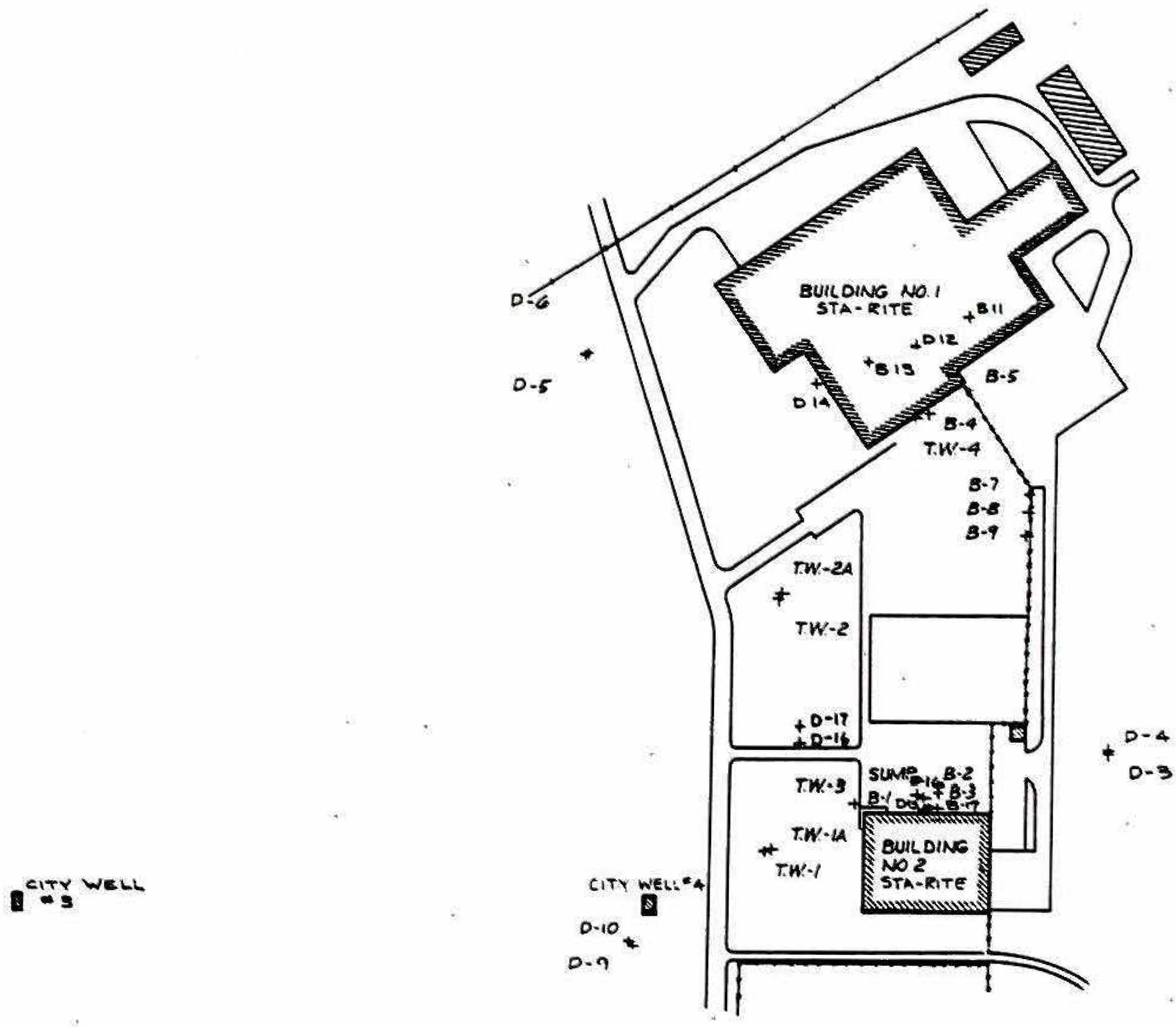
FIGURE 6




SIGNIFICANCE

1. Contaminant plumes downgradient of City Well No. 4.
2. Residual contamination in region

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0 100' 300'
FIGURE 7

CONCLUSIONS AND RECOMMENDATIONS

Groundwater modeling using identified contaminant sources indicate:

1. City Well 4 is on the edge of the solvent contaminant plume from Plant 2. The majority of the contamination moves downgradient, away from the wells.

2. Only a small portion of the contamination found near Plant 2 is moving into City Well 4. Contributions for non-point sources such as the ditch may constitute a portion of the amounts found in City Well 4, especially since we know there are still pockets of contamination in the soil. Contaminant movement into City Well 4 appears to be mainly controlled by dispersion into the aquifer. This would result in some variation in the amount which will be captured by City Well 4, but the amount should remain fairly constant for two to five years, then decrease in response to recent removal of the source material at Plant 2.

3. Contamination from Plant 1 is not affecting City Wells 4 or 3.

4. It is not reasonable to conclude that the concentration in City Well 3 is the result of contamination on Sta-Rite property.

5. To minimize contaminant movement toward City Well 4, the pumping rate should be maintained no greater than 0.4 MGD. This will allow contaminants to move with the groundwater flow. If City Well 4 is pumped at a rate greater than 0.4 MGD, a significant increase in concentration will occur at City Well 4 within one to two years after increased pumping. The pumping rate at City Well 3 should be maintained at a maximum of 0.3 MGD.

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