

**CITY OF WESTFIELD, MASSACHUSETTS
BOARD OF WATER COMMISSIONERS**

**DELINEATION OF WELL
PROTECTION ZONES**

MARCH 1989

DH Dufresne-Henry

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Engineering Disciplines
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Environmental
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Construction Management
Applied Science
Water Quality
Geologic
Hydrologic
Computer

March 1, 1989

City of Westfield
Board of Water Commissioners
City Hall
Westfield, MA 01085

Re: Well Protection Zones

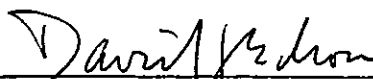
Gentlemen:

In accordance with our contract dated June 9, 1987 and as amended March 4, 1988, Dufresne-Henry is pleased to submit our revised well protection zone overlay map and accompanying report. The attached report is provided as a support document to the overlay map. The report describes in detail the philosophies and methodologies used to delineate the areas which need protection.

With regard to groundwater, the City is fortunate in two respects. Firstly, it is located over one of the largest and most productive aquifers in central and western Massachusetts. Secondly, City officials and citizens have recognized the need to protect this vital resource and have acted on that need. We have appreciated being of service to the City of Westfield and have enjoyed working with both the Board of Water Commissioners and the City's Aquifer Protection Committee on this project.

Very truly yours,

DUFRESNE-HENRY, INC.



David F. Edson, P.E.
Project Manager

DFE:ecb

CITY OF WESTFIELD, MASSACHUSETTS
BOARD OF WATER COMMISSIONERS

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WELL PROTECTION ZONES

March, 1989

Submitted by:
Dufresne-Henry, Inc.
Westford, Massachusetts

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1. Introduction

In 1987, Dufresne-Henry, Inc. was retained by the City of Westfield ("City") to determine, using accepted hydrogeologic and engineering methods, zones for protection for the City's eight public water supply wells. Previously, in 1985, the City had enacted a set of aquifer protection ordinances and had developed a zoning overlay map delineating protection zones. However, some within the City believed that the zones had not been determined using proper hydrogeologic and engineering methodology and were susceptible to potential challenges.

The first step in determining well protection zones was to select the methods and criteria upon which the zones would be based. In the Commonwealth of Massachusetts, the Department of Environmental Quality Engineering ("DEQE") has developed protection zone delineation criteria referred to as "Zone II". Zone II is the contributing area to a well (or wells) under the "most severe recharge and pumping conditions that can be realistically anticipated" which DEQE defines as 180 days of continuous well pumping with no recharge from precipitation. The Zone II criteria has been utilized to delineate the well protection zones shown on figure 1.

To economically determine well protection zones, groundwater flow computer modelling was performed using existing data. Considerable data regarding the aquifer was available from two primary sources. The City Engineering Department maintains excellent records regarding past test well drilling programs, production well installations and pumping tests. Considerable analysis was performed on this data to determine aquifer characteristics and hydraulic coefficients.

By good fortune, the United States Geologic Survey ("USGS") had recently completed an extensive hydrogeologic study of the Westfield area. Although the study has yet to be published, the USGS Boston office allowed us to review their raw data and preliminary groundwater resource atlas. If the City and USGS data were not available, the protection zone determination would have required extensive field work at a considerably greater project cost.

We wish to thank Mr. Leonard Phelon of the Water Department and Mr. Leonard Colson of the City Engineering Department for their willing assistance. Mr. Anthony Maevsky of USGS provided valuable assistance and opinions regarding the City's hydrogeology. We also wish to acknowledge the roles of Dr. Peter Shanahan and Ms. Jane Knott of our subconsultant, HydroAnalysis, Inc. Along with Mr. Gene Schragger, Dufresne-Henry staff hydrogeologist, Dr. Shanahan and Ms. Knott performed much of the technical work described in this report.

2. Hydrogeology of Westfield and Modelling Approach

Within the City of Westfield (and to the north and south) lies the largest aquifer in the Westfield and Farmington River basins. Referred to as the Barnes Aquifer, it is believed to be the preglacial course of the Connecticut River and, as such, is an extensive buried valley outwash deposit composed primarily of sand and gravel. Figure 2 shows the location of the preglacial Connecticut River along with the aquifer areas.

Figure 3 shows an idealized section of the aquifer in the vicinity of Pond Brook and Horse Pond (see approximate location on Fig. 2). As shown, the buried valley aquifer is underlain by a nearly continuous sheet of till which overlies bedrock composed primarily of New Haven Arkose, a sandstone formation. The maximum aquifer thickness is about 250 feet along the preglacial Connecticut River channel. The saturated thickness decreases toward the western and eastern edges of the aquifer and toward the south. Figure 4 shows a north-south aquifer cross-section along the preglacial channel based on City well records.

The City has developed six public water supply wells in the Barnes Aquifer. Well depths and pumping rates are as follows:



WESTFIELD



LEGEND





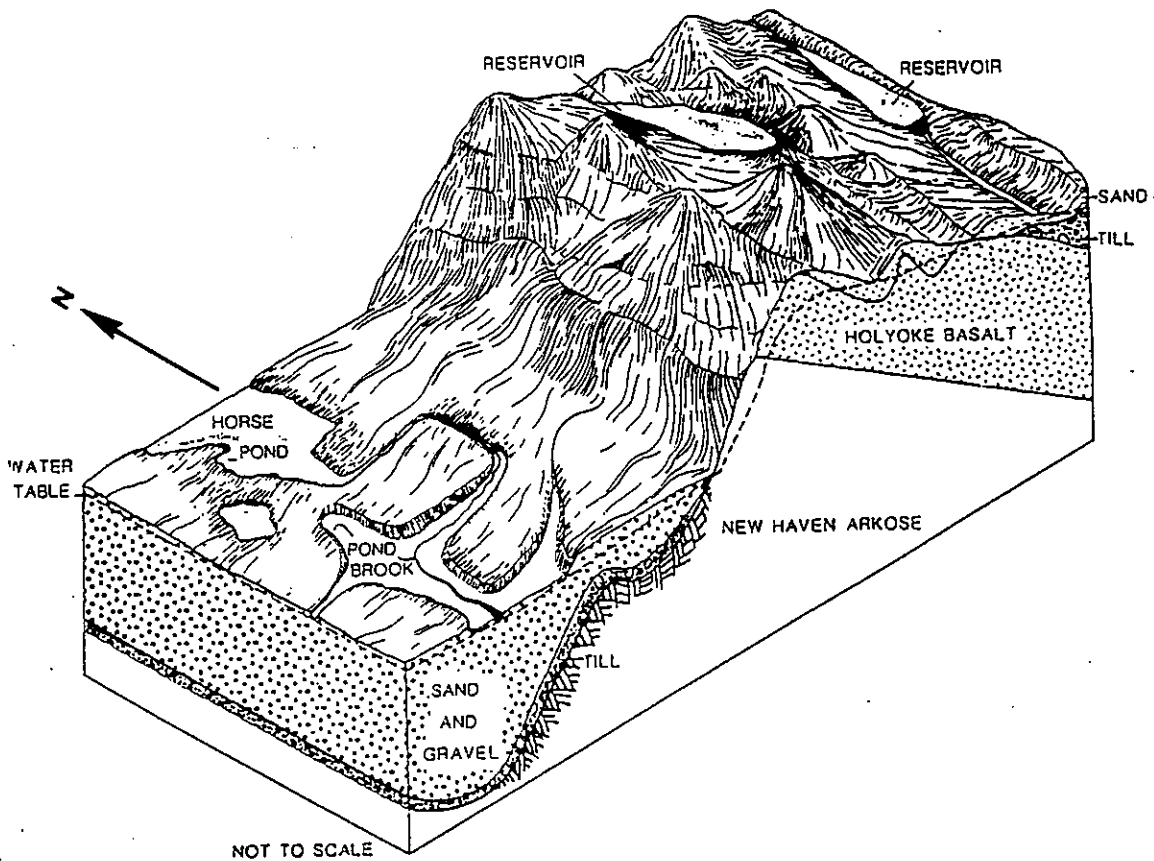
-  AQUIFER LOCATIONS
-  HIGH TRANSMISSIVITY AREA
-  PREGLACIAL CONNECTICUT RIVER
-  MODFLOW MODEL AREA

FIGURE 2

Client No.	917046	WESTFIELD WATER DEPARTMENT WELL LOCATION MAP		 Dufresne-Henry Inc.
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Date	MAR 89	WESTFIELD	MASSACHUSETTS	A



SOURCE : MAEVSKY, USGS

FIGURE 3

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Client No.	917046	WESTFIELD WATER DEPARTMENT IDEALIZED SECTION OF BARNES AQUIFER	 Dufresne-Henry Inc.
Proj. Mgr.	D.F.E.		
Date	MAR 89		
WESTFIELD		MASSACHUSETTS	A

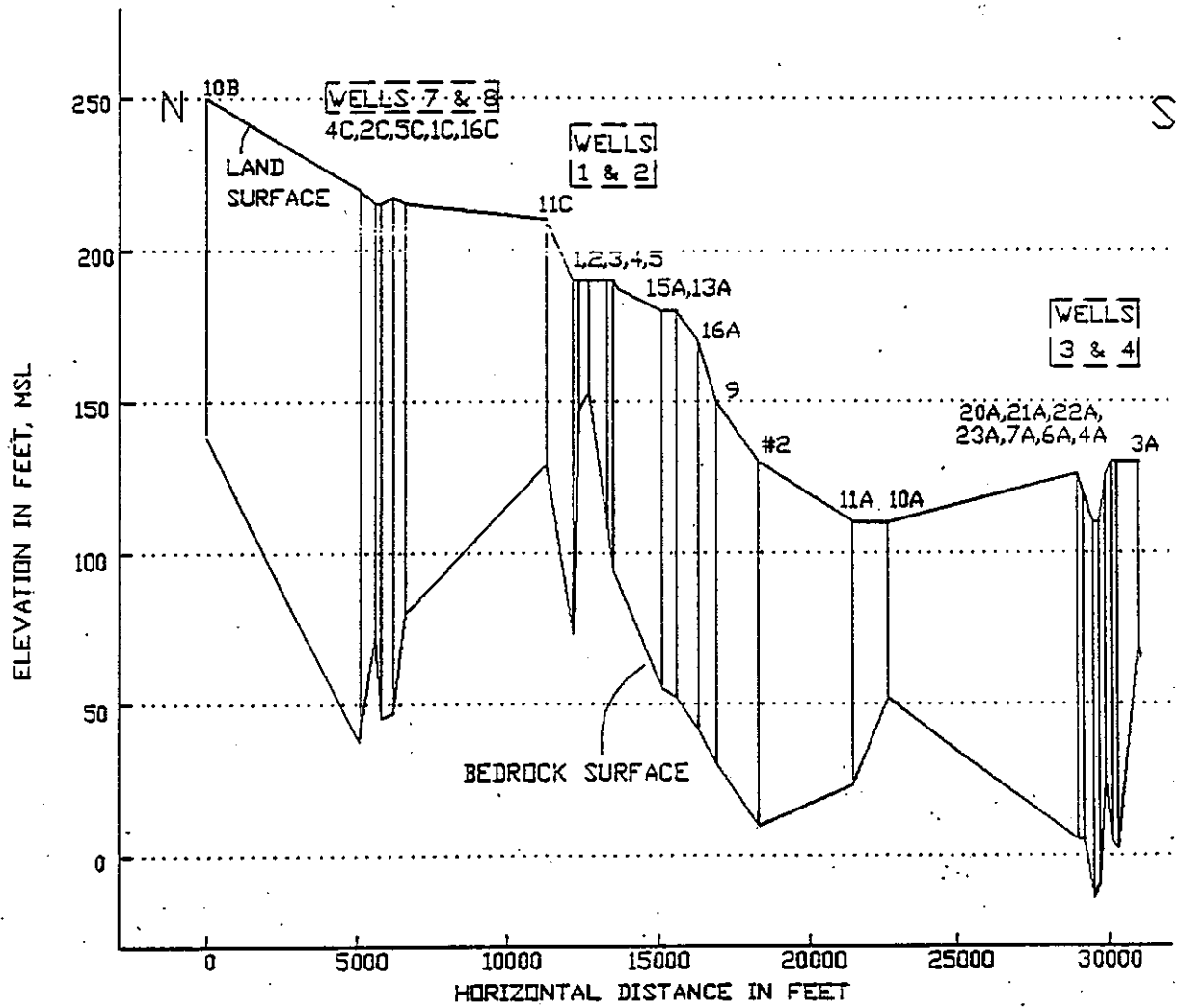



FIGURE 4

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Client No.	917046	WESTFIELD WATER DEPARTMENT		 Dufresne-Henry Inc.
Proj. Mgr.	D.F.E.	BARNES AQUIFER CROSS-SECTION		
Date	MAR 89	WESTFIELD	MASSACHUSETTS	
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<u>Well</u>	<u>Depth (ft)</u>	<u>Pumping Rate (gpm)</u>
1	117	1400
2	104	1400
3	126	1200
4	121	1600
7	171	1400
8	184	1400

These excellent well yields are indicative of the high aquifer transmissivities which were estimated to range between 10,000 ft²/day (75,000 gpd/ft) and 18,000 ft²/day (135,000 gpd/ft) at these wells.

In order to determine protection zones for the wells listed above, a computerized groundwater flow model encompassing the Barnes aquifer within Westfield was developed. Major factors incorporated in the model included:

- degree of stream-aquifer interaction under pumping conditions
- interferences between supply wells during pumping, and
- boundary effects from the sides of the buried valley.

The model is described in greater detail in Section 3.

Wells 5 and 6 are located in a much smaller and shallower outwash aquifer located along the Little River. Well 5 which is 72 feet deep, pumps at 250 gpm. Well 6 is 77 feet deep and pumps at 300 gpm. Aquifer transmissivity was estimated to be 1400 ft²/day (10,000 gpd/ft).

The modelling approach to determining protection zones for Wells 5 and 6 reflected the somewhat simpler hydrogeologic conditions. A capture-zone model, based on a widely used analytical approach, was applied which incorporated:

- effects of pumping both wells simultaneously, and
- induced recharge from the Little River

This model is described more fully in Section 4.

The modelling used to determine the well protection zones was well thought out and based upon sound hydrogeologic and engineering principles and methods. The aquifer parameters and coefficients used in the models were arrived at by an extensive analysis of prior field work data. The results are the well protection zones delineated in Figure 1.

3. Zones of Contribution to Wells 1,2,3,4,7 and 8

Zones of contribution to Wells 1,2,3,4,7 and 8 were determined by use of MODFLOW, a three-dimensional finite-difference groundwater flow model developed by USGS (McDonald and Harbaugh, 1984). The area modelled, shown on Figure 2, is approximately 14,000 feet in width and 32,00 feet in length. The north and south model boundaries were the City's limits. East-west boundaries were principally till (no-flow) boundaries representing the extent of the outwash deposits. The aquifer was modelled as a single layer, unconfined aquifer.

As shown on Figure 5, the model was discretized into 2,310 nodes - the intersections of 70 horizontal divisions and 33 vertical divisions. Node spacing varied from 400 to 900 feet horizontally and vertically. Each node was assigned values for initial groundwater head elevations, hydraulic conductivity, aquifer bottom elevation and storage coefficient. The model then solved for final groundwater head elevations. Preliminary zones of contribution were constructed normal to the resulting water table contours. Final zones of contribution were constructed by modifying the preliminary zones based on specific surficial geologic features indicated on USGS topographic quadrangles.

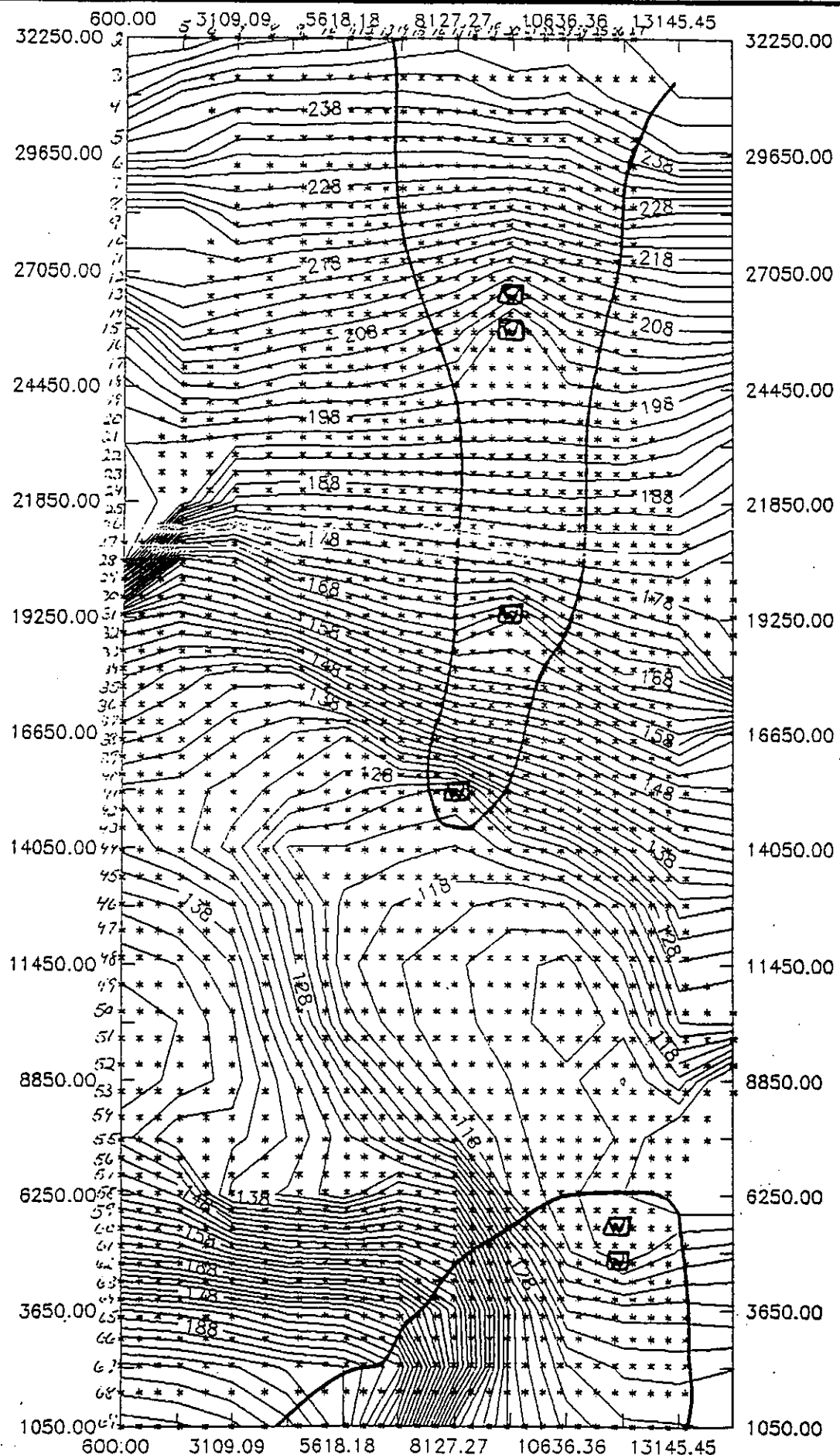



FIGURE 5

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Client No.	917046	WESTFIELD WATER DEPARTMENT			Dufresne-Henry Inc.
Proj. Mgr.	D.F.E.	MODFLOW GRAPHIC OUTPUT			
Date	MAR 89	WESTFIELD	MASSACHUSETTS		
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Rivers and streams were simulated as leaky boundaries to allow flow between them and the aquifer. The large lakes located in the stratified drift deposits (Buck Pond, Horse Pond, Pequot Pond and two unnamed ponds near the Route 90 interchange) were treated as constant head boundaries.

The lateral boundary on the eastern and western edges of the model and the southern boundary were treated as no-flow boundaries because they were generally parallel to flow lines. The northern model boundary was treated as a head-dependent (inflow) boundary to simulate flow from the groundwater divide located north of the City line.

Initially, the model was calibrated to static water table conditions by running the model to a steady-state condition with recharge from precipitation applied uniformly to each node at a rate of 25 inches per year. A close correlation was obtained between simulated and estimated water table elevations. This steady-state, non-pumping condition defined the pre-developed long-term average water table for the unconfined aquifer. To apply Zone II criteria and obtain protection zones, a transient pumping condition was then applied to the steady-state initial head condition which included:

- continuous pumping of Wells 1 (1400 gpm), 2 (1400 gpm), 3 (1200 gpm), 4 (1600 gpm), 7 (1400 gpm) and 8 (1400 gpm) for a period of 180 days
- no recharge from precipitation

Prior to the final results, sensitivity analyses were performed on the key input variables. All sensitivity runs were performed to steady-state conditions. These variables and sensitivity analyses are described as follows:

(a) areal recharge rate

The areal recharge rate used to obtain static head conditions of 25 inches per year was varied by factors of 0.5 and 1.5. According to USGS personnel, these values represented the expected range in average annual recharge rates to stratified-drift aquifers.

(b) hydraulic conductivity

Values of hydraulic conductivity were obtained from the draft USGS hydrologic atlas and from analyses of City pumping test and well log records. Based on the pumping tests and well logs, an average hydraulic conductivity of 132 ft/day (987 gpd/ft²) with a standard deviation of 56 ft/day was obtained. This value is

representative of a medium to highly transmissive sand and gravel and compared favorably to the USGS results. Sensitivity analyses were performed at plus and minus one and two standard deviations from the average. A hydraulic conductivity of 132 ft/day was uniformly utilized for the modelled aquifer.

(c) river parameters

The river boundaries in the model can act as sources of recharge (usually during pumping) or as sinks for groundwater discharge. Besides geometry and elevations, the key hydraulic input variable affecting stream/aquifer interaction is the ratio of streambed permeability (k') to streambed thickness (b'). Based upon personal communication with USGS personnel and some field information, this ratio may reasonably be expected to vary between 0.1 and 10. A value of 1.0 was used for all streams except the Westfield and Little Rivers which were modelled using a value of 0.1. Sensitivity analyses were performed by increasing the ratios by a factor of 10 and by setting all ratios to 0.1.

Once the initial steady-state conditions were obtained, nine separate sensitivity runs were performed as described in the following table:

Run	Model Parameter	Calibrated Value	New Value
S1	Recharge	25 in/yr	25 in/yr
S2	Recharge	25 in/yr	12.5 in/yr
S3	Recharge	25 in/yr	50 in/yr
S4	Hydraulic Conductivity	132 ft/day	20 ft/day
S5	Hydraulic Conductivity	132 ft/day	244 ft/day
S6	Hydraulic Conductivity	132 ft/day	76 ft/day
S7	Hydraulic Conductivity	132 ft/day	188 ft/day
S8	River k'/b'	1.0 & 0.1/day	10 & 1.0/day
S9	River k'/b'	1.0 & 0.1/day	0.1/day

The protection zones for Wells 1,2,3,4,7 and 8 shown on Figures 1 and 5 are the results of the analyses described above. They are based on DEQE Zone II criteria, existing data and accepted hydrogeologic analytic and modelling techniques.

The Zone II criteria is not the only basis used for establishing wellhead protection zones. For interest, groundwater times of travel were estimated for the protection zones. Average velocities of flow were approximated using the following equation:

$$V = (K/n) \times (h_1 - h_2)/L \quad \text{where}$$

V = average groundwater flow velocity (ft/day)
 K = hydraulic conductivity (ft/day)
 n = porosity (assumed as 27% for sand and gravel)
 (h₁ - h₂)/L = head gradient

The time of travel from the northern boundary (City line) to Wells 7 and 8 was estimated to be 5 to 6 years based on a velocity of 3.5 feet per day. Time of travel from the northern boundary to Well 1 was estimated to be 10 to 11 years and, to Well 2, 13 to 15 years.

The time of travel from the southeastern boundary to Wells 3 and 4 was estimated to be 7 years based on a groundwater velocity of 1.3 feet per day.

The aquifer times of travel can be used to plan groundwater monitoring programs and to estimate the likely impacts of upgradient contamination events. We note that contaminant times of travel are often slower than groundwater times of travel because of a variety of retardation effects.

4. Zones of Contribution to Wells 5 and 6

Westfield municipal supply Wells 5 and 6 are located in the western part of the city near Northwest Road (Figure 2). The wells are located in unconsolidated deposits several hundred feet south of the Little River. Flow of groundwater in these deposits is influenced by pumping at Wells 5 and 6, by induced recharge from the Little River, by the thickness and composition of the aquifer, and by the ground-water flow from land at higher elevations away from the river. The analysis reported here evaluated the zone of capture to these wells using an analytical approximation of the flow in the aquifer.

Wells 5 and 6 were installed in 1969 and are 72 feet and 77 feet in depth, respectively. Well 5 pumps at 250 gpm and Well 6 pumps at 300 gpm. Information on the hydrogeology in the vicinity of the site was available from test well and pump test records from the original installation of Wells 5 and 6, and from the USGS. These data characterized the hydraulic properties of the aquifer.

Wells 5 and 6 are located in sand and gravel deposits of the Little River flood plain. As mapped by the USGS, the wells are sited in a relatively small zone of high transmissivity bordering the river (Figure 6). Owing to this physical situation, a

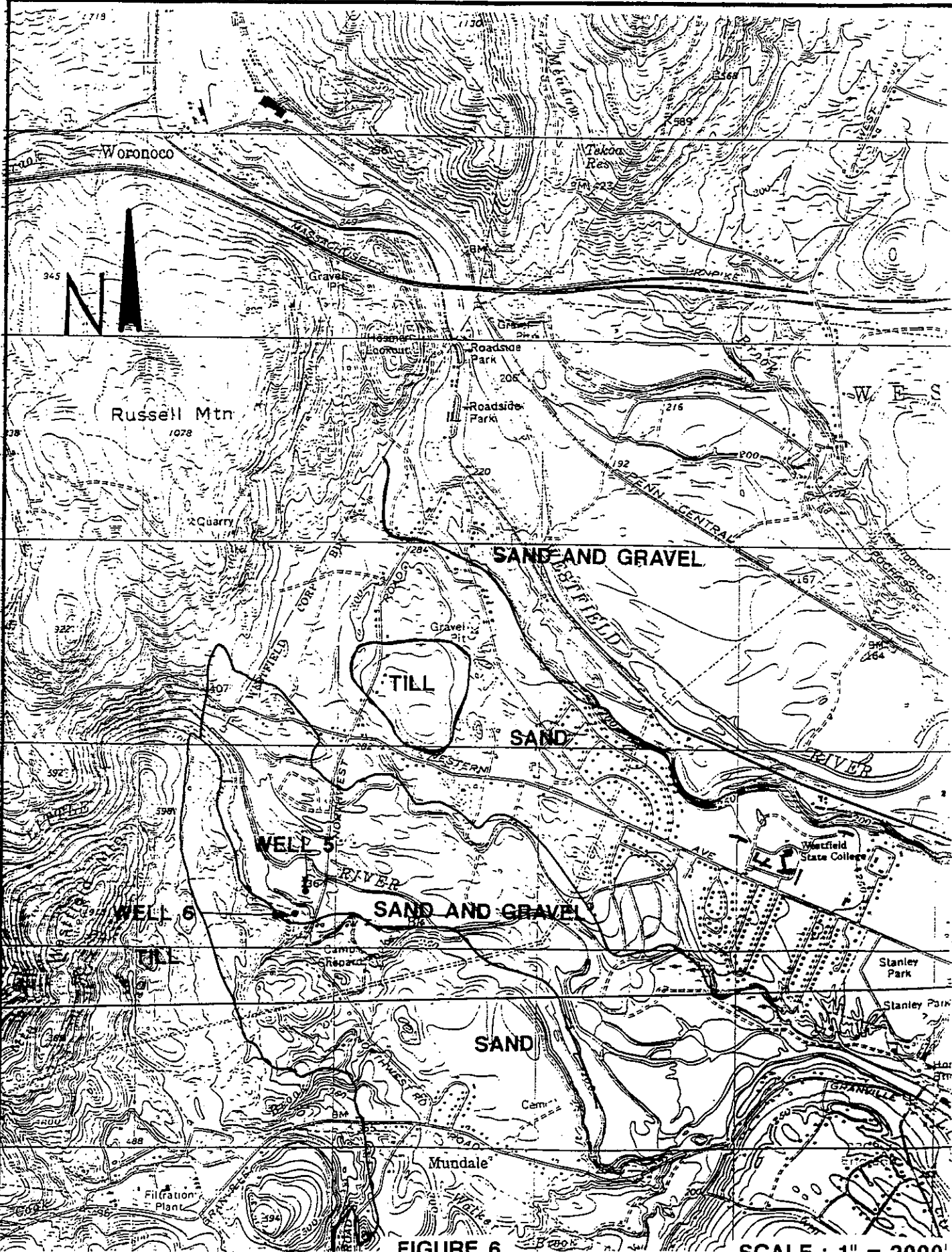


FIGURE 6

SCALE : 1" = 2000'

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WESTFIELD WATER DEPARTMENT
 AQUIFER NEAR WELLS 5 AND 6
 WESTFIELD MASSACHUSETTS

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Inc.

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substantial portion of the water withdrawn by Wells 5 and 6 is likely to come from induced infiltration from the Little River. The portion of the well withdrawal coming from the river is estimated to be approximately 85% after 180 days of pumping using mathematical relations included by Maevsky. This is consistent with pump tests at Well 5 which show the influence of a recharge boundary condition. This behavior indicated substantial induced recharge although not enough to completely supply the well.

The capture zone of Wells 5 and 6 was assessed using a groundwater flow model developed by HydroAnalysis, Inc. The model predicted the zone of capture of a pumping well in an idealized aquifer. The model is similar in principal to a widely-used analytical approach published by various authors including Lundy and Mahan (1972), Keely and Tsang (1983) and Javandel and Tsang (1986).

The conditions simulated by the capture-zone model include the following approximations and assumptions:

- o uniform, unidirectional regional groundwater flow towards the river from the south,
- o constant, uniform aquifer transmissivity, and
- o steady flow and pumping rates over time.

The effect of induced recharge from the Little River was included in the model through the method of images as described for example by Bear (1979, pp. 356-367).

The computer model required as input the aquifer transmissivity, the location and pumping rate of pumping wells, and the direction and gradient of flow in the aquifer in the absence of pumping at the wells. Conditions employed in this application of the model included:

- o an aquifer transmissivity of 10,000 gpd/ft (1400 ft²/day as a representative but somewhat conservative value from Maevsky, and
- o Wells 5 and 6 pumping at full capacity (250 gpm for Well 5, 300 gpm for Well 6).

Aquifer flow was inferred from the area topography and hydrogeologic deposits to flow from the southeast. The water-table gradient was unknown and was therefore tested over a range of possible values (0.01, 0.001, and 0.0001).

Results of the model simulation for the medium water table gradient (0.001) are shown in figure 7. The results show the flow lines that individual particles of water would trace as they flowed through the aquifer. Between any two lines, there is 12.5 gpm of groundwater flow according to the model results. The flow lines are a useful visual representation of the patterns of groundwater flow. They show that a substantial portion of the flow to the wells originates as recharge from the river. Additional flow comes from the regional flow which originates off the plot area to the southeast or north, flowing to the northwest in the direction of the groundwater gradient, and into the withdrawing groundwater wells. The results, however, are highly sensitive to the assumed water table gradient. With a steeper gradient of 0.01, relatively little flow at the wells comes from the river and proportionally more from the upland areas. With the shallow gradient of 0.0001, most of the water comes from the river.

The model results show that most of the water withdrawn at Wells 5 and 6 originates as induced infiltration from the Little River. The model also demonstrates a contributing upgradient area to the southeast of wells. The model results generally confirm the existing aquifer protection zone shown on the City's zoning overlay map. It is our recommendation that the existing protection zones for Wells 5 and 6 not be changed.

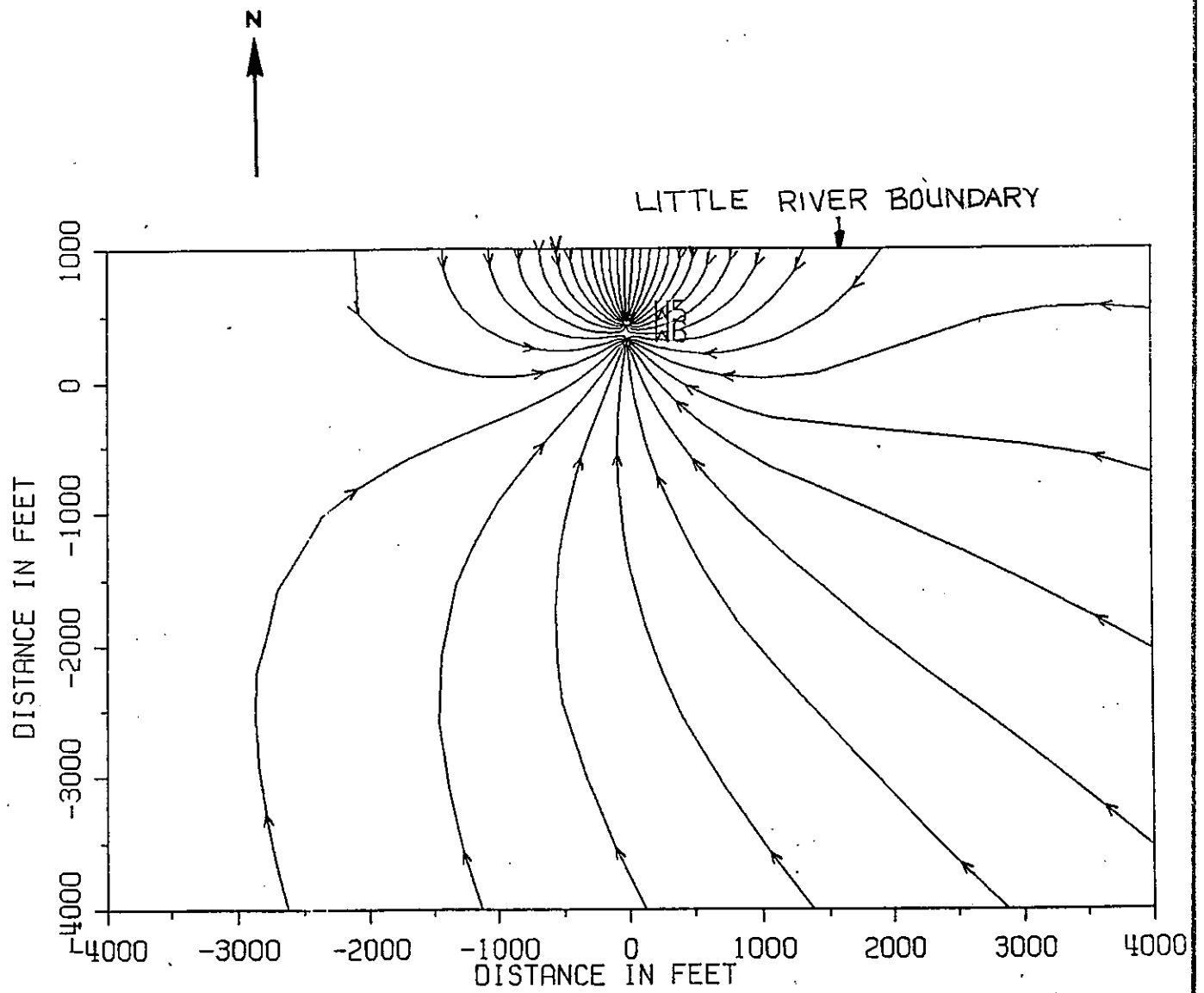


FIGURE 7

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Client No.	917046	WESTFIELD WATER DEPARTMENT CAPTURE ZONE MODEL OUTPUT	 Dufresne-Henry <small>Inc.</small>	
Proj. Mgr.	D.F.E.			
Date	MAR 89			
		WESTFIELD	MASSACHUSETTS	
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