Report of Hydrogeological Services
Slug Testing Results
Unocal Service Station 5353
Seattle, Washington

May 27, 1993

For

Unocal

GeoEngineers

File No. 0161-013-R69/052793

Geo Engineers

May 27, 1993

Geotechnical,
Geoenvironmental and
Geologic Services

Unocal
P.O. Box 76
Seattle, Washington 98111

Attention: Dr. Mark Brearley

We are submitting four copies of our "Report of Hydrogeological Services" for Unocal Service Station 5353 in Seattle, Washington. Contractual terms for our services are included in blanket contract number B1982F.

We appreciate the opportunity to be of continued service to Unocal. Please call if you have any questions regarding this report.

Yours very truly,

GeoEngineers, Inc.

Stephen C. Perrigo
Principal

NLP:SCP:cms
Document ID: 0161013.HGS

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REPORT OF HYDROGEOLOGICAL SERVICES
SLUG TESTING RESULTS
UNOCAL SERVICE STATION 5353
SEATTLE, WASHINGTON
FOR
UNOCAL

INTRODUCTION

This report summarizes the results of our slug testing conducted at the site of Unocal Service Station 5353 in February 1993. Service Station 5353 is located at 600 Westlake Avenue North, northeast of the intersection between Westlake Avenue and Mercer Street in Seattle, Washington. The property is identified as site number 008463 on Ecology's (Washington State Department of Ecology) UST (underground storage tank) list.

SITE HISTORY

The property owned by Unocal consists of the southern half of the city block bounded by West Mercer Street to the south, Westlake Avenue North to the west, Valley Street to the north and Terry Avenue North to the east. The Unocal property is occupied by Unocal Service Station 5353 (600 Westlake Avenue North) and a Denny's restaurant (601 Terry Avenue North) located east of the service station. The northern half of the city block is owned by the city of Seattle and is occupied by a boat sales facility and an auto shop.

The site is located in the SE¼ of the NE¼, and the NE¼ of the SE¼, of Section 30, Township 25 North, Range 4 East. The site location and the immediate vicinity are shown in Figure 1.

A release of about 80,000 gallons of leaded premium gasoline occurred at Unocal Service Station 5353 in 1980. Site characterization and remediation activities completed at the site between 1980 and 1981 included drilling 32 soil borings with monitoring wells and installation of a free product recovery system. Over 40,000 gallons of free product were recovered between 1980 and 1983.

A VES (vapor extraction system) was installed at the site in 1988 to mitigate combustible vapors in the soil beneath the site. The VES design, installation details and monitoring data obtained during VES operation are presented in the following reports: "Progress Report No. 1" dated July 12, 1988, "Interim Status Report" dated October 3, 1988 and "Progress Report No. 2" dated January 3, 1991. The VES continues in operation at the present time.

In October 1991, the city of Seattle requested that Unocal take steps to monitor combustible vapors in buildings, crawl spaces, vaults and other surface or near surface structures on the city's property where vapors could potentially accumulate. Vapor monitoring of the city property occupying the northern half of the city block bounded by Mercer Street, Terry Avenue, Fairview Street and Westlake Avenue was implemented by GeoEngineers in October 1991. The results of monitoring that occurred between October 1991 and July 1992 are presented in our "Report of GeoEnvironmental Services" dated December 2, 1992. The results of this monitoring indicated that hydrocarbon vapors were not accumulating in surface or near surface structures on the city property.

Eighteen additional monitoring wells were completed between October 1991 and February 1992 to evaluate the approximate extent of petroleum-related contamination in soil and ground water in the vicinity of the site. The results of this study are presented in our "Supplemental Report of Geoenvironmental Services" dated July 7, 1992. The locations of the monitoring wells installed between October 1991 and February 1992 are shown in Figure 1. The approximate extents of petroleum-related soil and ground water contamination as evaluated during this study are shown in Figures 2 and 3.

SCOPE OF WORK

The purpose of our most recent services was to estimate horizontal hydraulic conductivity at the site by performing slug tests in several monitoring wells. This information can be used in the future for remedial design. GeoEngineers' specific scope of services completed for this phase of the project is listed below.

1. Measure ground water levels and check for free (floating) product in ten monitoring wells. Calculate ground water elevations and evaluate the direction of ground water flow based on these measurements and our previous knowledge of the site.
2. Conduct rising-head slug tests in ten monitoring wells and monitor ground water elevations during the tests. Calculate the in-situ horizontal hydraulic conductivities at the locations of the ten monitoring wells based on the slug test data.

GROUND WATER ELEVATIONS

Ground water elevations at the locations of the ten monitoring wells in which slug tests were performed were measured on February 16 and 17, 1993, and are summarized in Table 1 and shown in Figure 1. Ground water table contours and approximate ground water flow direction based on the February 16 and 17 measurements are shown in Figure 1. The ground water table was encountered at depths ranging from approximately 9.0 to 11.3 feet below site grade. The approximate direction of ground water flow is toward the northeast. The direction of ground water flow based on our February 1993 measurements generally coincides with previous interpretations, with the exception of the apparent mounding of ground water in the vicinity of MW-35.

SLUG TESTING

PROCEDURES

Ten monitoring wells (MW-32A, MW-33, MW-34, MW-35, MW-37, MW-40, MW-42, MW-45, MW-48 and MW-49) were selected as locations for performing rising head slug tests. The monitoring wells were selected to obtain good areal distribution in known areas of subsurface petroleum-related contamination. The slug tests were completed on February 16 and 17, 1993.

Water levels were measured in the ten monitoring wells using an electric water level indicator before the slug tests were initiated.

After water levels were measured, slug tests were performed in each of the monitoring wells using the following procedure:

1. A pressure transducer was installed in the well, and was connected to an electronic data logger.
2. A slug of known volume (0.032 $feet^3$, 0.070 $feet^3$, or 0.092 $feet^3$) was lowered into the well. The ground water elevation was monitored until it had returned to about the elevation measured immediately before the test. This data is referred to as the falling head data.
3. The data logger was started and the slug was removed from the well.
4. The data logger recorded the water level in the well at predetermined intervals (once every 5 seconds for the first minute, once every 15 seconds for the next 3 minutes, and once per minute for the remainder of the test) as the water level rose after the slug was removed. This data is referred to as the rising head data.
5. The data logger was stopped after the change in the water level with respect to time became small.
6. The pressure transducer was removed from the well.

EVALUATION OF DATA

Hydraulic conductivities were calculated using the Bouwer and Rice method as presented in "Aquifer Testing, Design and Analysis of Pumping and Slug Tests," 1991, pages 307 - 315, by K. Dawson and D. Istok. Hydraulic conductivities were calculated using the following equations.

$$K=[r_c^2 \ln(R/r_w) \ln(H_o/H_T)] \ / \ [2(l-d)t]$$

$$\ln(R/r_w)=\{\{1.1/\ln(l/r_w)\}+\{A+B\ln[(m-l)/r_w]\}/\{(l-d)/r_w\}\}^{-1}$$

The terms used in these equations are defined in Figures 4 and 5. The equations are based on the following assumptions.

- The aquifer is bounded below by an aquiclude.
- All layers are horizontal and extend infinitely in the radial direction.
- The initial piezometric surface (before extraction) is horizontal and extends infinitely in the radial direction.

- The aquifer is homogeneous and isotropic.
- Ground water density and viscosity are constant.
- Ground water flow can be described by Darcy's Law.
- A volume of water, V, is extracted instantaneously at time $t=0$.
- Head losses through the well screen, filter material, and developed zone (if present) are negligible.
- The aquifer is incompressible.
- Change in the piezometric surface is small compared to the aquifer saturated thickness.

Based on our knowledge of the site, drilling methods, and drilling materials, we made the following site specific assumptions.

- The depth to the base of the aquifer (m) is approximately 60 feet.
- The radius of the borings (r_w) is approximately 5 inches (0.4167 feet), with the exception of MW-35, which has a radius of approximately 6 inches (0.5 feet).
- The filter pack material in the annular space between the monitoring well casings and the inside of the borings has a porosity (n) of approximately 0.3.

Plots of normalized drawdown (H_T/H_O) versus elapsed time for the rising head portion of the tests in the ten monitoring wells tested are shown in Figures 6 through 15. Best fit lines through the data were selected visually. Calculated horizontal hydraulic conductivities based on the rising head data are summarized in Table 1 and are shown in Figure 16. Hydraulic conductivities were not calculated for the falling head portions of the tests. The data obtained from the slug tests performed on MW-32A and MW-33 do not appear valid and hydraulic conductivities were not calculated for these wells.

Calculated values of horizontal hydraulic conductivity, based on the plots of normalized drawdown versus elapsed time and the two equations presented above, ranged from 4.1×10^{-4} feet per minute to 6.5×10^{-2} feet per minute. The mean horizontal hydraulic conductivity was 1.1×10^{-2} feet per minute, with a standard deviation of 2.2×10^{-2} feet per minute. If the maximum (MW-48) and minimum (MW-42) values are disregarded, the mean horizontal hydraulic conductivity is 4.3×10^{-3} feet per minute, with a standard deviation of 2.8×10^{-3} feet per minute. Both of these wells are located downgradient of the site. The calculated values of horizontal hydraulic conductivity generally correspond with published values for the soil types (silty sand and sandy silt) present at the site.

The information obtained during the slug tests performed on the site can be used to complete the initial steps for design of a ground water treatment system at the site if this becomes necessary at a future date.

LIMITATIONS

We have prepared this report for use by Unocal. This report may be made available to regulatory agencies and prospective buyers of the property. This report is not intended for use by others and the information contained herein is not applicable to other sites. Our interpretations of subsurface conditions are based on data from widely spaced wells at the site. It is always possible that conditions may be different in areas of the site that were not tested.

◆ ◇ ◆

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in this area at the time this report was prepared. No other conditions, express or implied, should be understood.

Respectfully submitted,

GeoEngineers, Inc.

Norman L. Puri
Environmental Engineer

Stephen C. Perrigo
Principal

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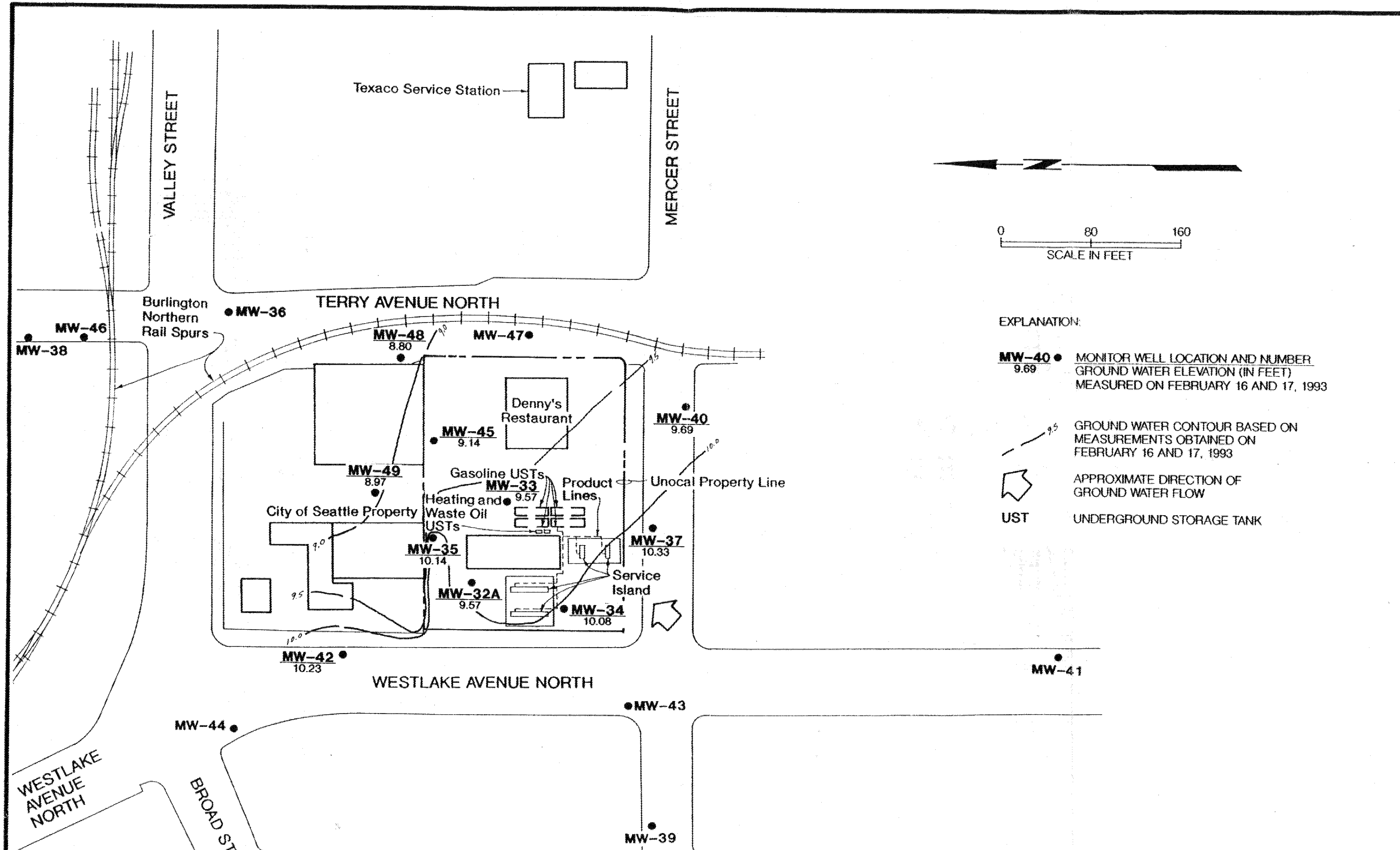
Document ID: 0161013.HGS

TABLE 1
CALCULATED HYDRAULIC CONDUCTIVITIES
SELECTED MONITORING WELLS

Monitoring Well Number	Ground Water Elevation (feet)	Hydraulic Conductivity K (feet/minute)
MW-32A	9.57	Not calculated
MW-33	9.57	Not calculated
MW-34	10.08	2.2×10^{-3}
MW-35	10.14	6.7×10^{-3}
MW-37	10.33	6.4×10^{-3}
MW-40	9.69	1.1×10^{-3}
MW-42	10.23	4.1×10^{-4}
MW-45	9.14	2.0×10^{-3}
MW-48	8.88	6.5×10^{-2}
MW-49	8.97	7.1×10^{-3}
Mean		1.1×10^{-2}
Standard Deviation		2.2×10^{-2}



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MONITORING WELL LOCATIONS AND GROUND WATER CONTOURS

FIGURE 1

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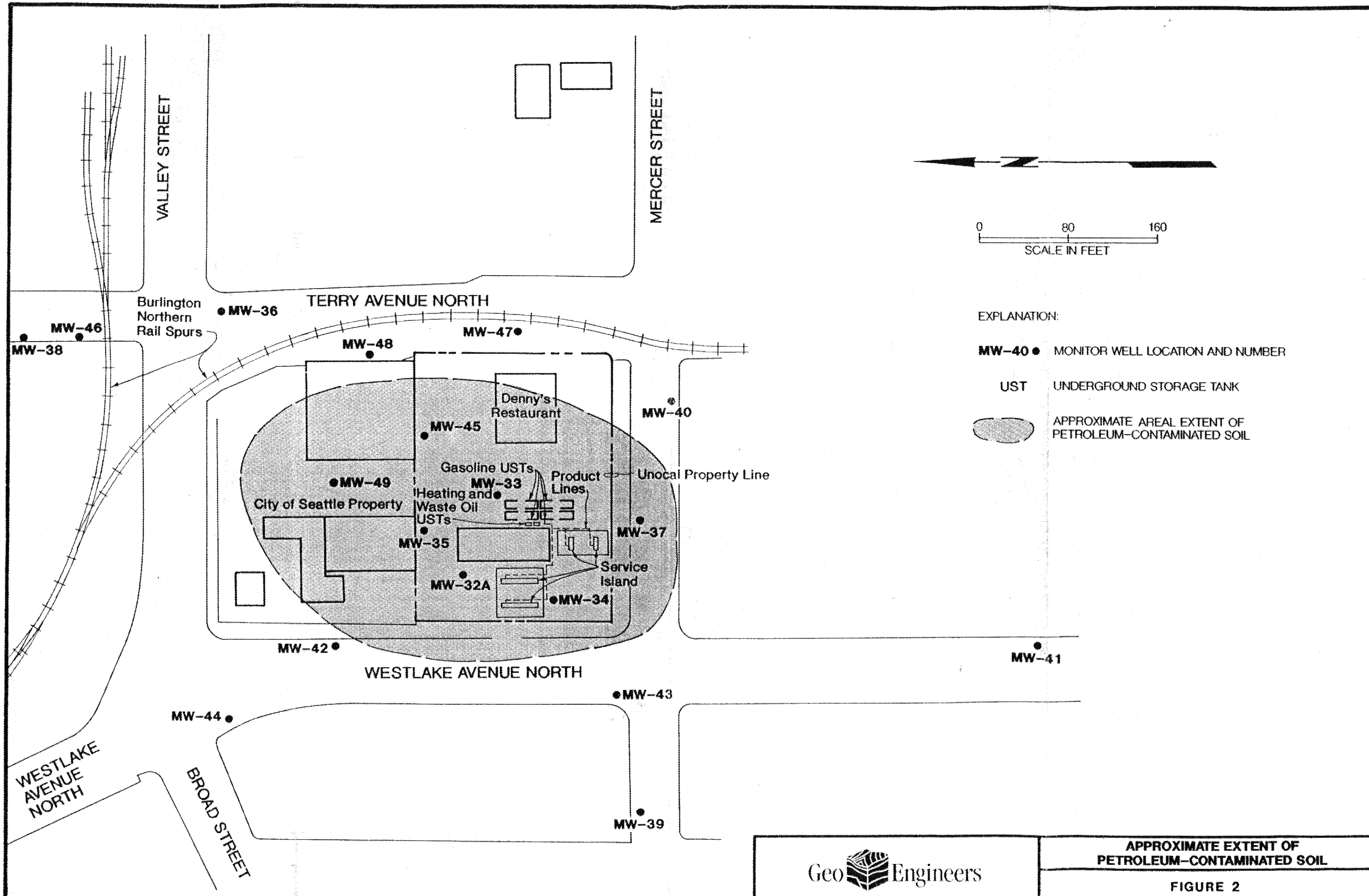
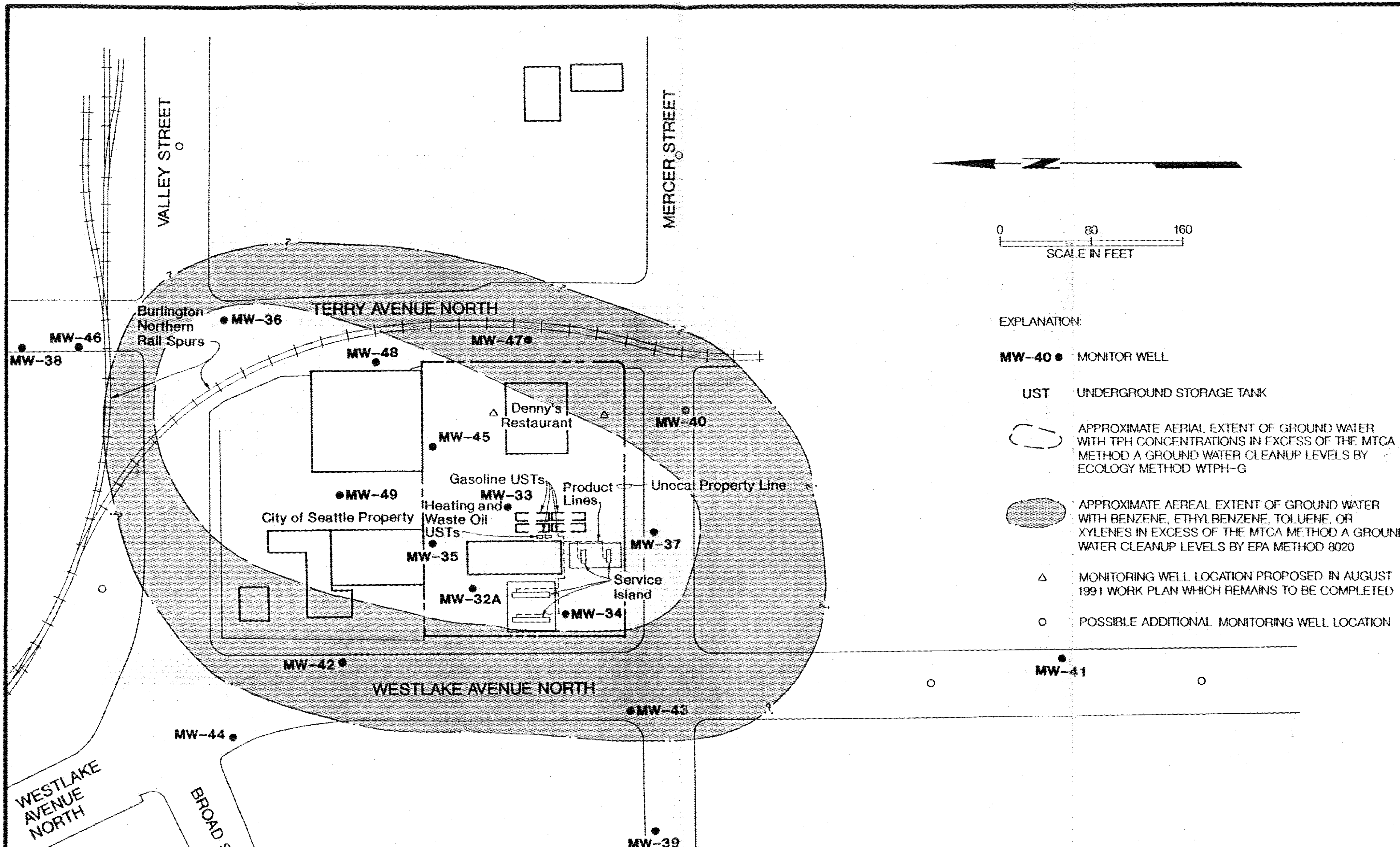


APPROXIMATE EXTENT OF PETROLEUM-CONTAMINATED SOIL

FIGURE 2



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APPROXIMATE AREAL EXTENT OF PETROLEUM-CONTAMINATED GROUND WATER

FIGURE 3

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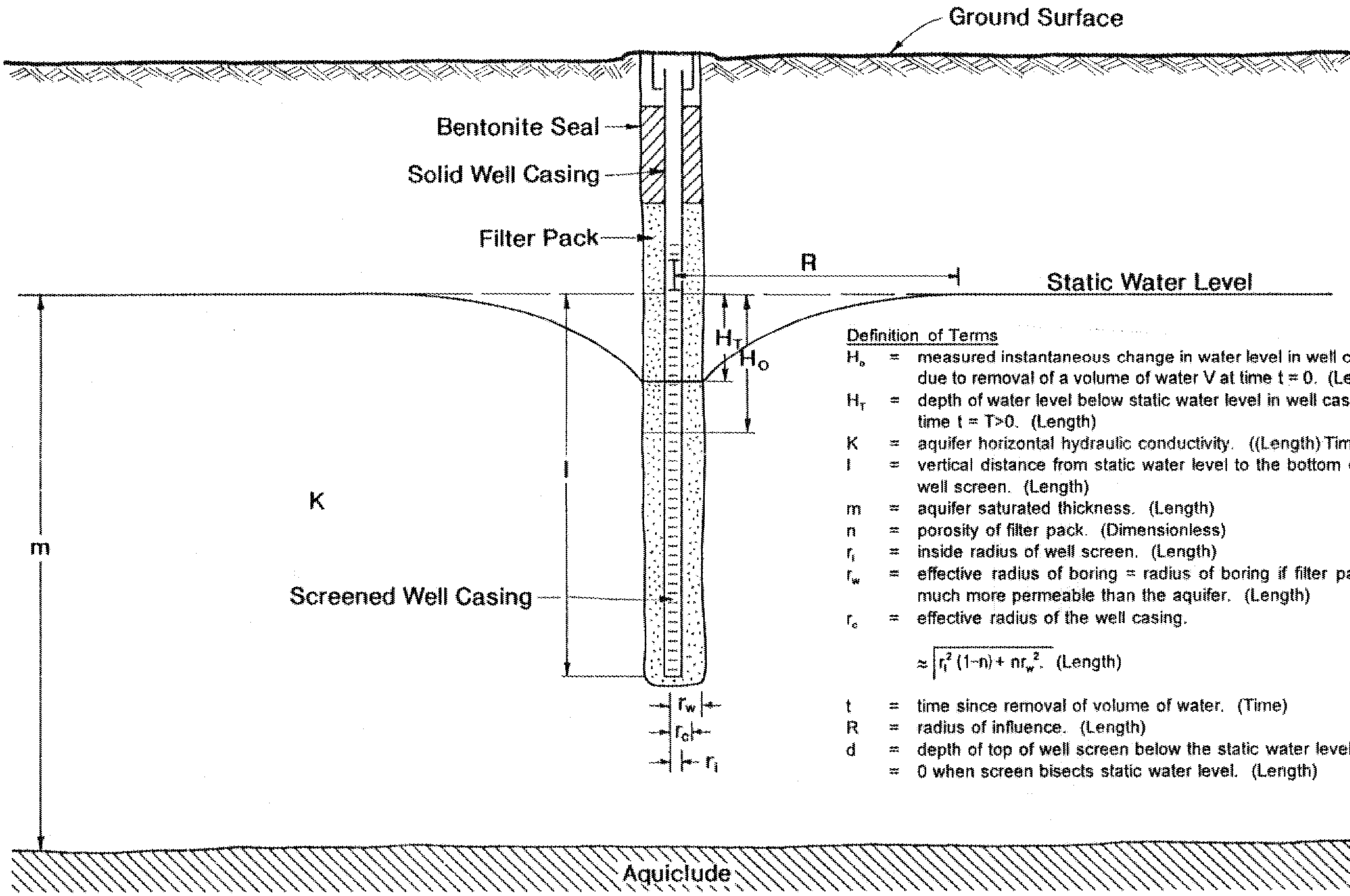

Definition of Terms

- H_o = measured instantaneous change in water level in well casing due to removal of a volume of water V at time t = 0. (Length)
- H_T = depth of water level below static water level in well casing at time t = T>0. (Length)
- K = aquifer horizontal hydraulic conductivity. ((Length) $Time^{-1}$)
- l = vertical distance from static water level to the bottom of the well screen. (Length)
- m = aquifer saturated thickness. (Length)
- n = porosity of filter pack. (Dimensionless)
- r_i = inside radius of well screen. (Length)
- r_w = effective radius of boring = radius of boring if filter pack is much more permeable than the aquifer. (Length)
- r_c = effective radius of the well casing.

  $\approx \sqrt{r_i^2 (1-n) + n r_w^2}$. (Length)
- t = time since removal of volume of water. (Time)
- R = radius of influence. (Length)
- d = depth of top of well screen below the static water level. = 0 when screen bisects static water level. (Length)

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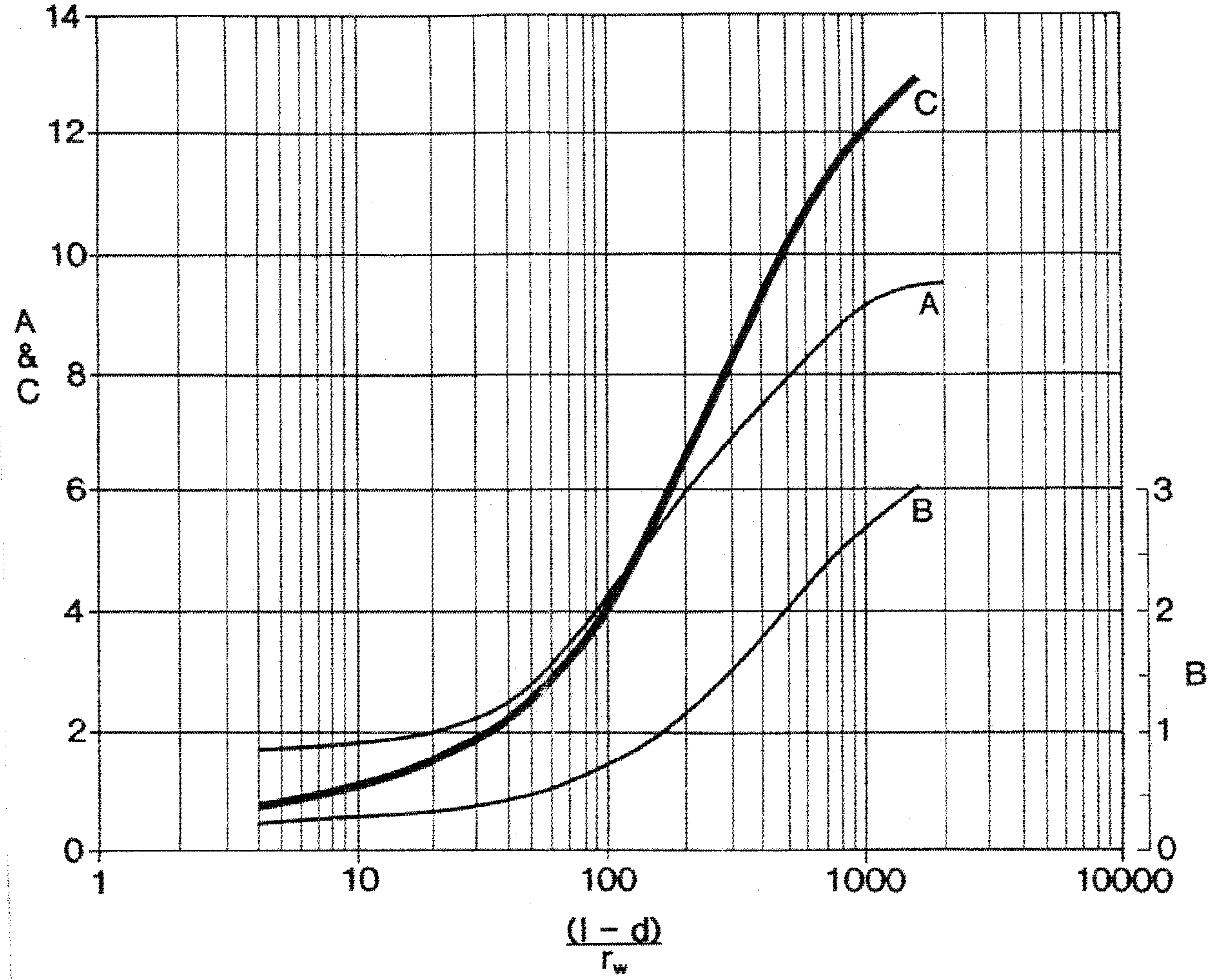
DEFINITION OF TERMS

FIGURE 4



Values of the coefficients A, B, and C for use in estimating the radius of influence, R (from Bouwer and Rice, 1976, p. 426)

Reference: "Aquifer Testing - Design and Analysis of Pumping and Slug Tests," 1991 Lewis Publishers, Inc. by Karen J. Dawson and Jonathan D. Istok

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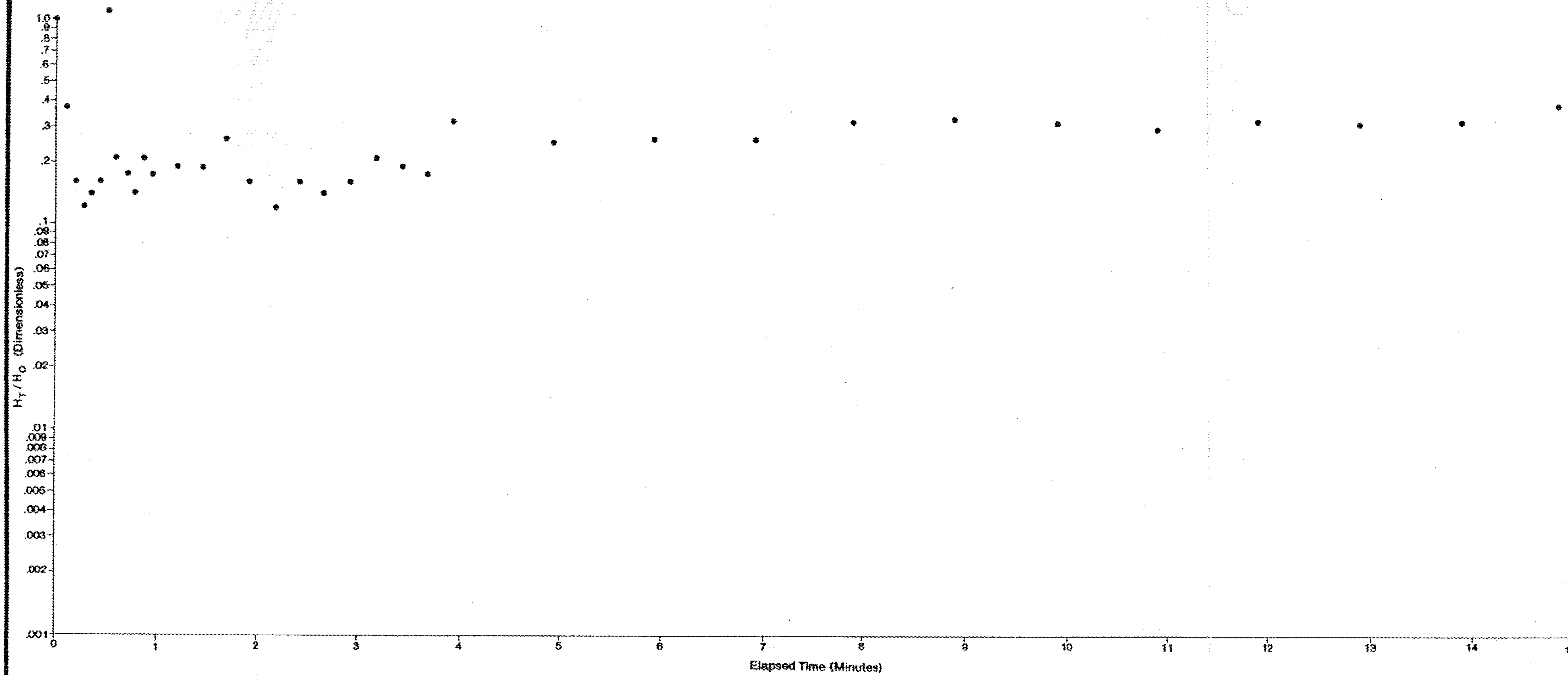
CONSTANT VALUES FOR BOUWER AND RICE EQUATIONS

FIGURE 5



EXPLANATION:
- FIELD DATA POINT

MW–32A

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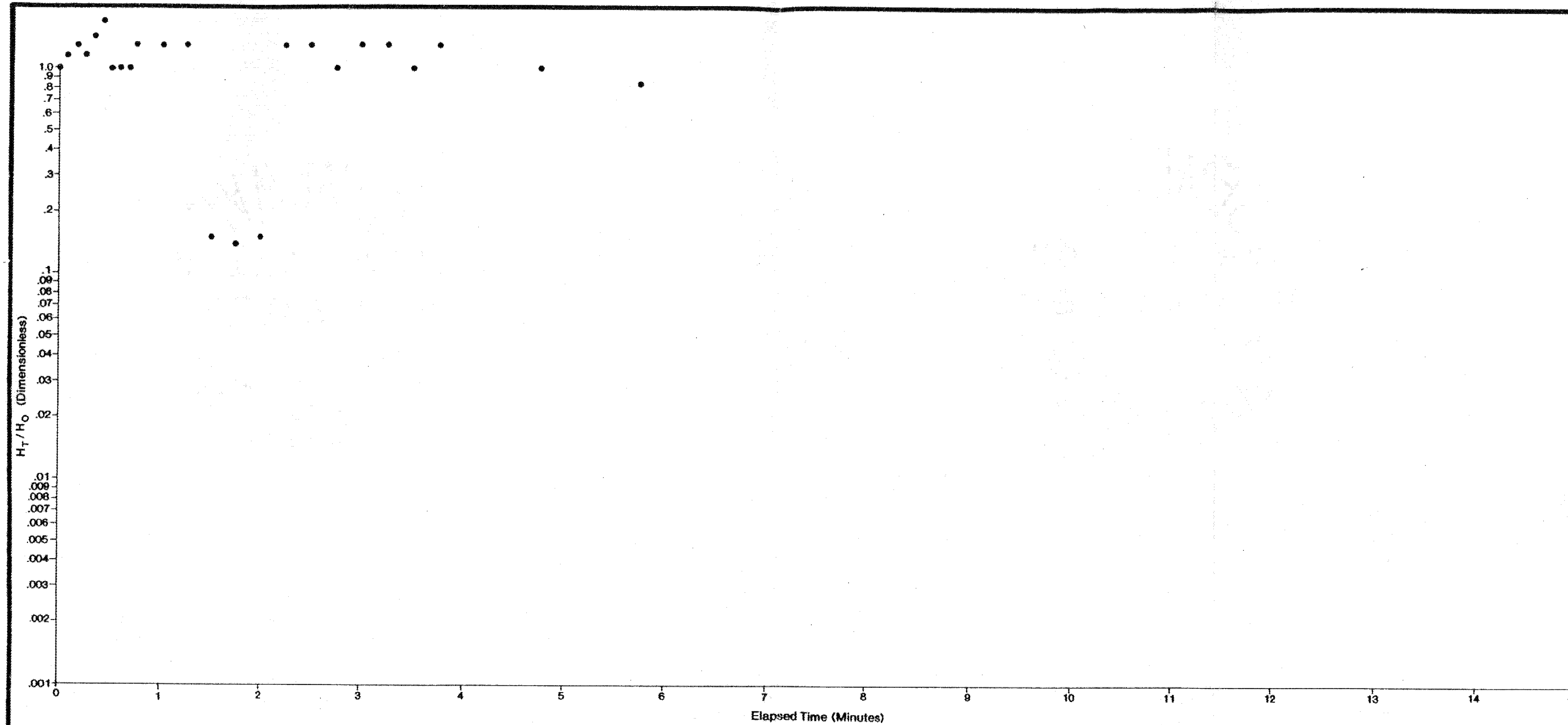
NORMALIZED DRAWDOWN H_T/H_0 (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 6



EXPLANATION:
• FIELD DATA POINT

MW–33

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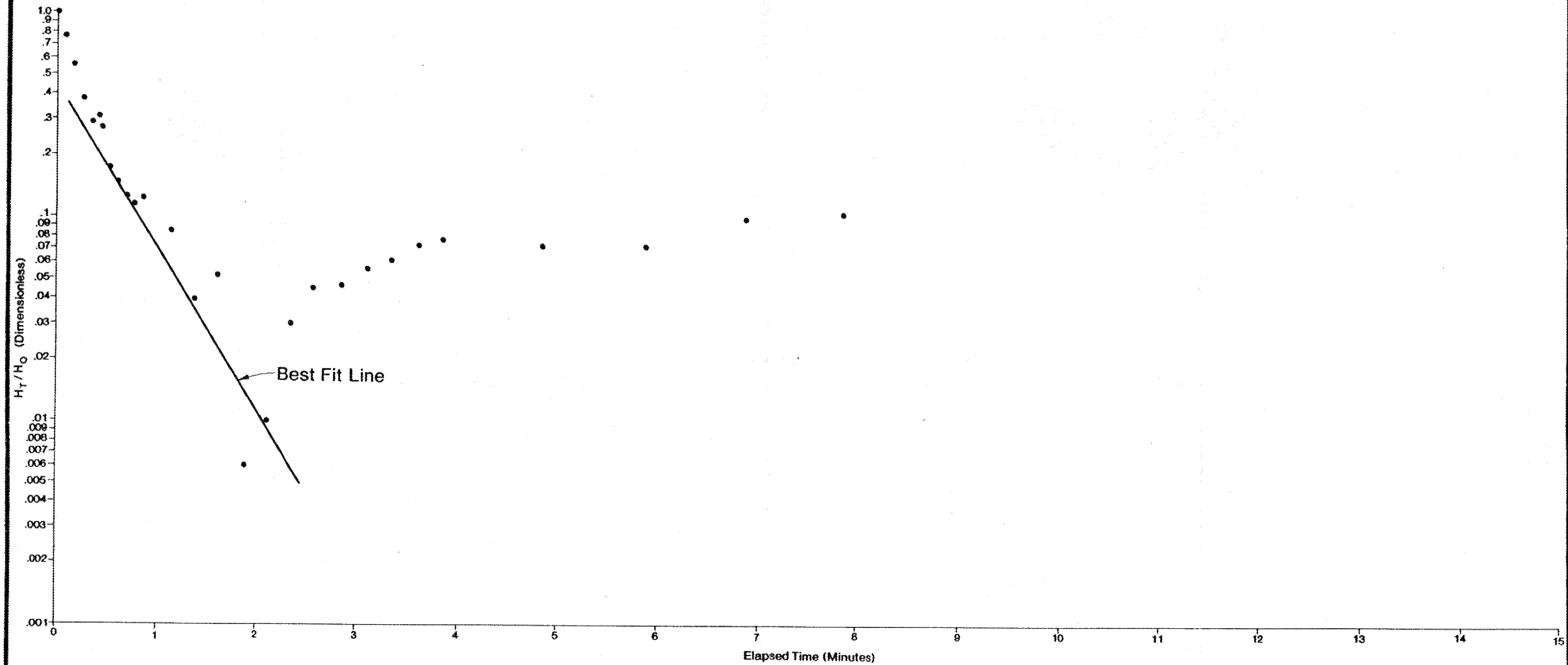
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 7



EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 1.1152 FEET AT T=0

r_i = 0.083 FEET

l = 12.16 FEET

m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW–34

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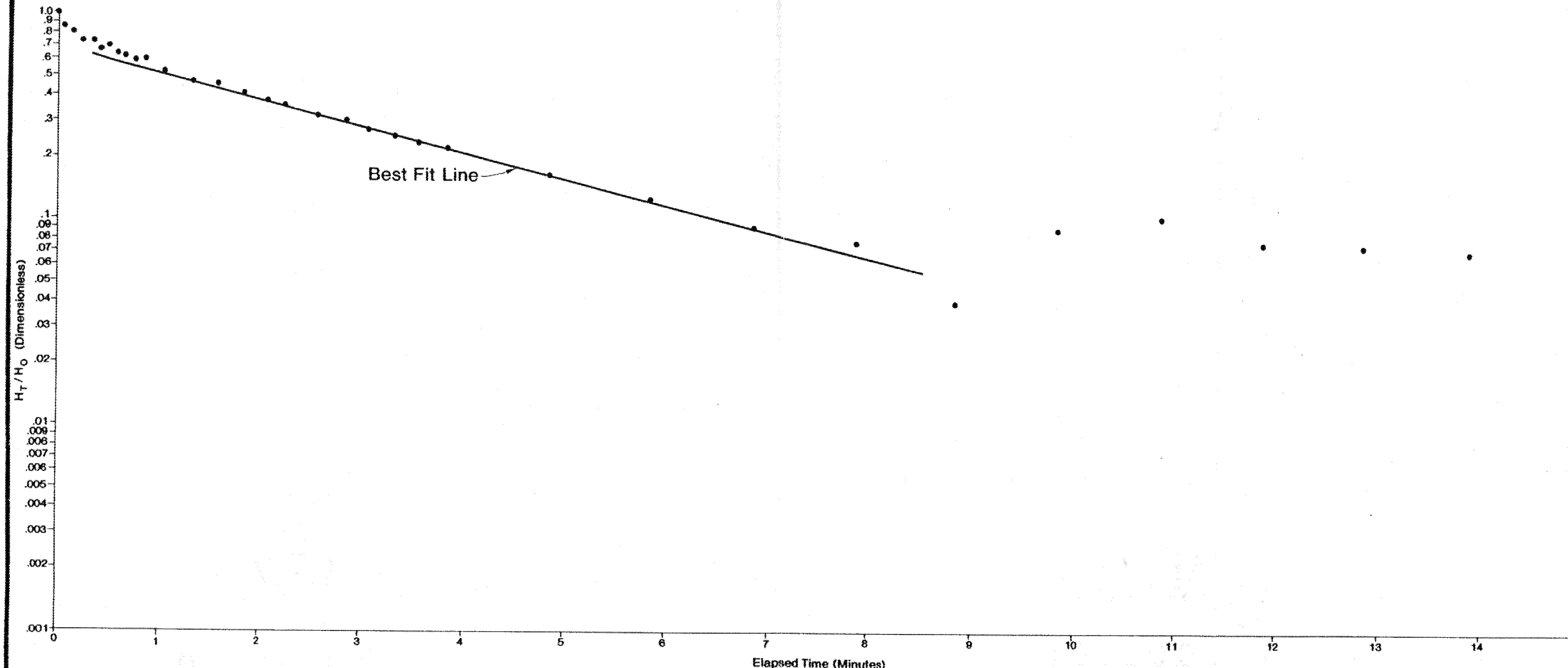
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 8



EXPLANATION:

- FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 0.6786 FEET
r_i = 0.167 FEET
l = 12.59 FEET
m = 60 FEET
r_w = 0.4167 FEET
n = 0.3 FEET

MW–35

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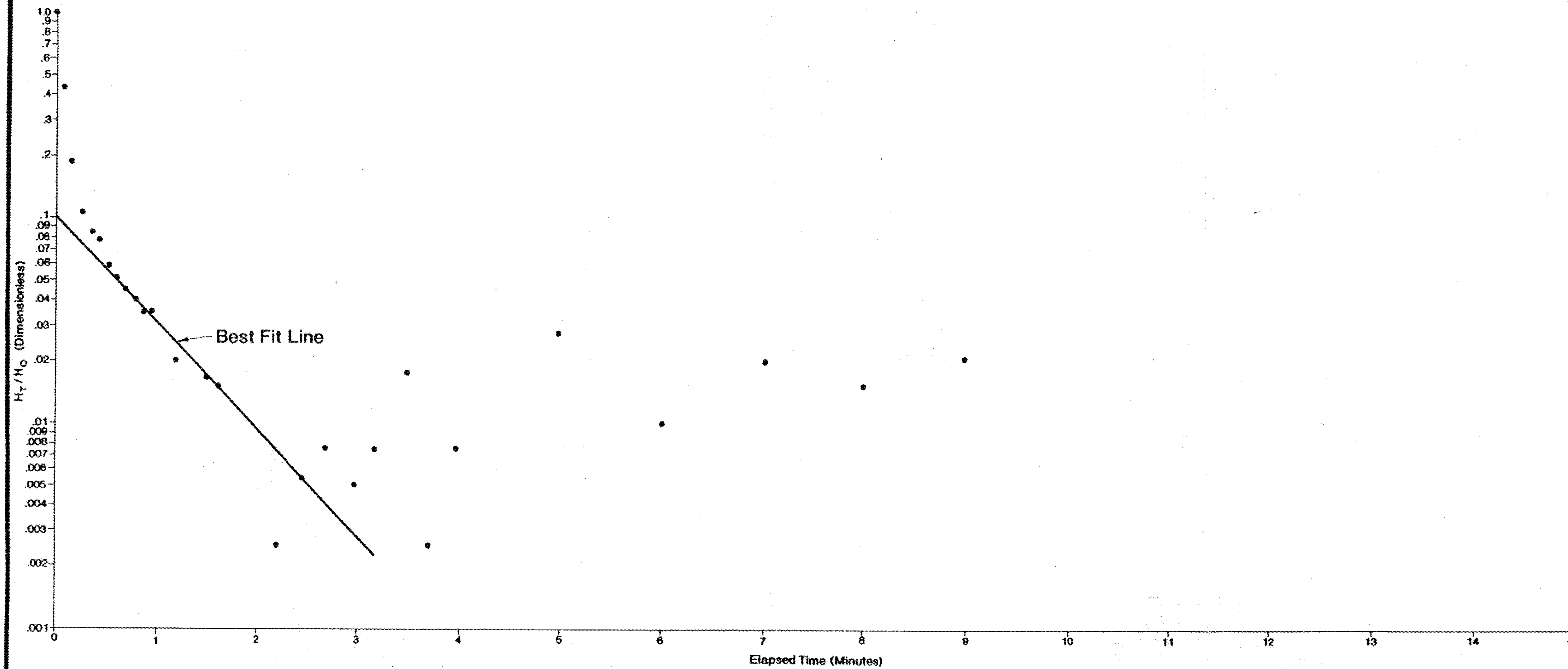
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 9



EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 1.4113 FEET

r_i = 0.083 FEET

l = 11.62 FEET

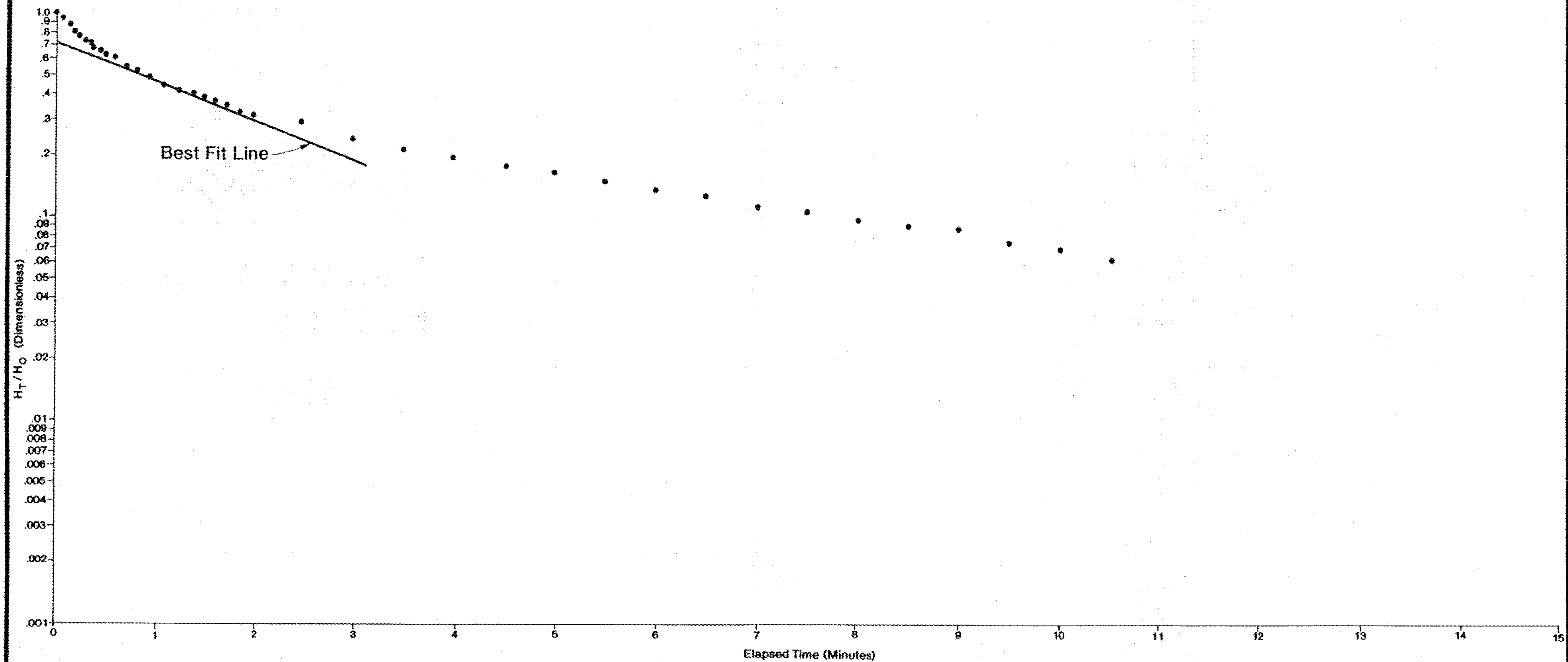
m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW−37

GeoEngineers	NORMALIZED DRAWDOWN H_T/H_0 (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)
	FIGURE 10



EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 1.6315 FEET

r_i = 0.083 FEET

l = 9.3 FEET

m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW-40

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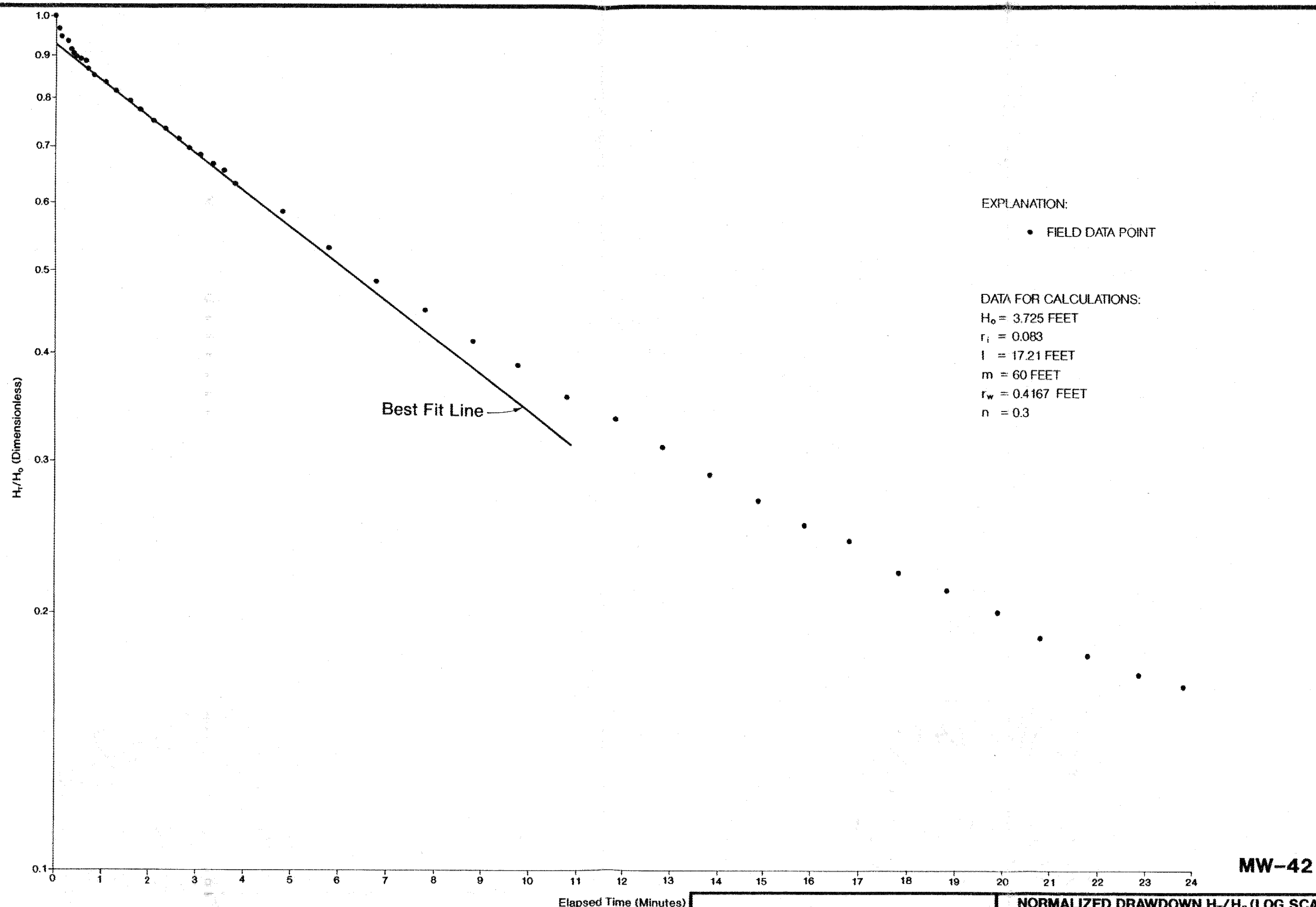
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 11



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NORMALIZED DRAWDOWN H_T/H_0 (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 12

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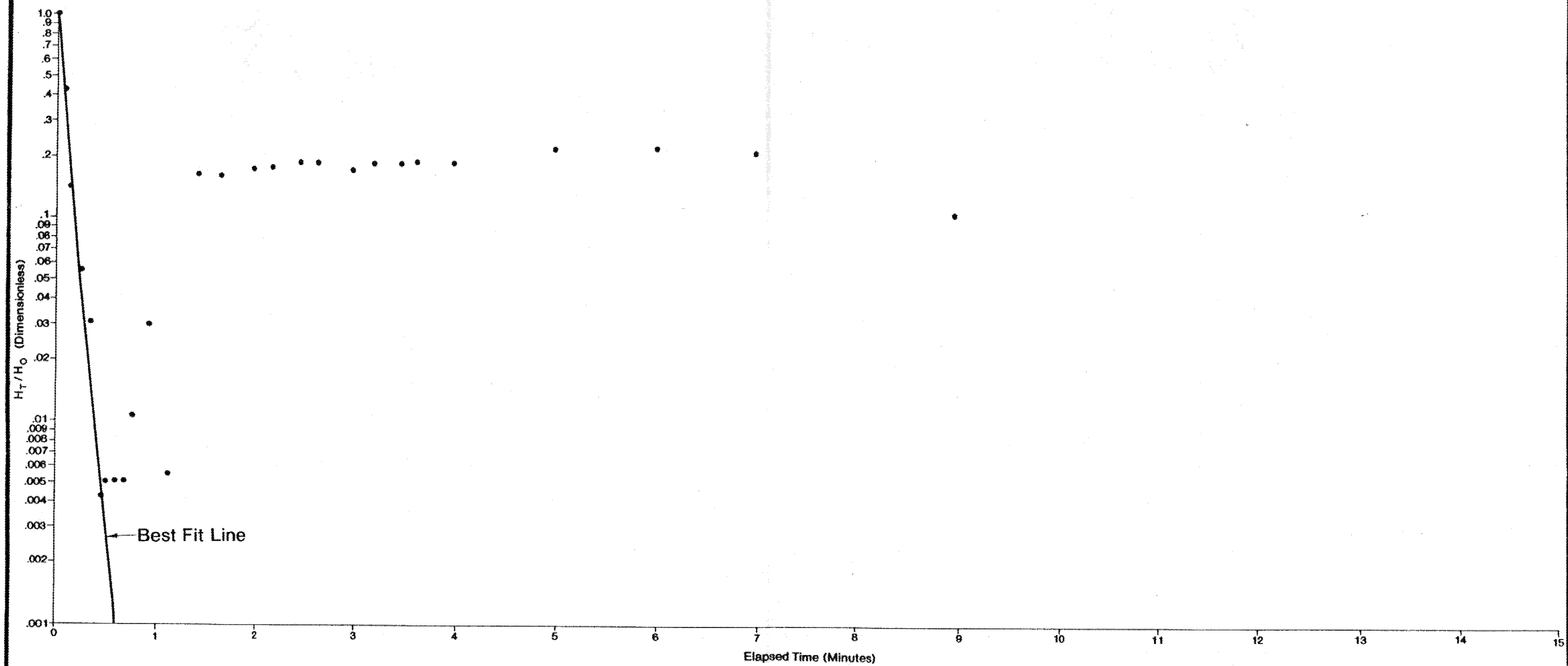

EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 0.6785 FEET

r_i = 0.083 FEET

l = 9.89 FEET

m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW-45

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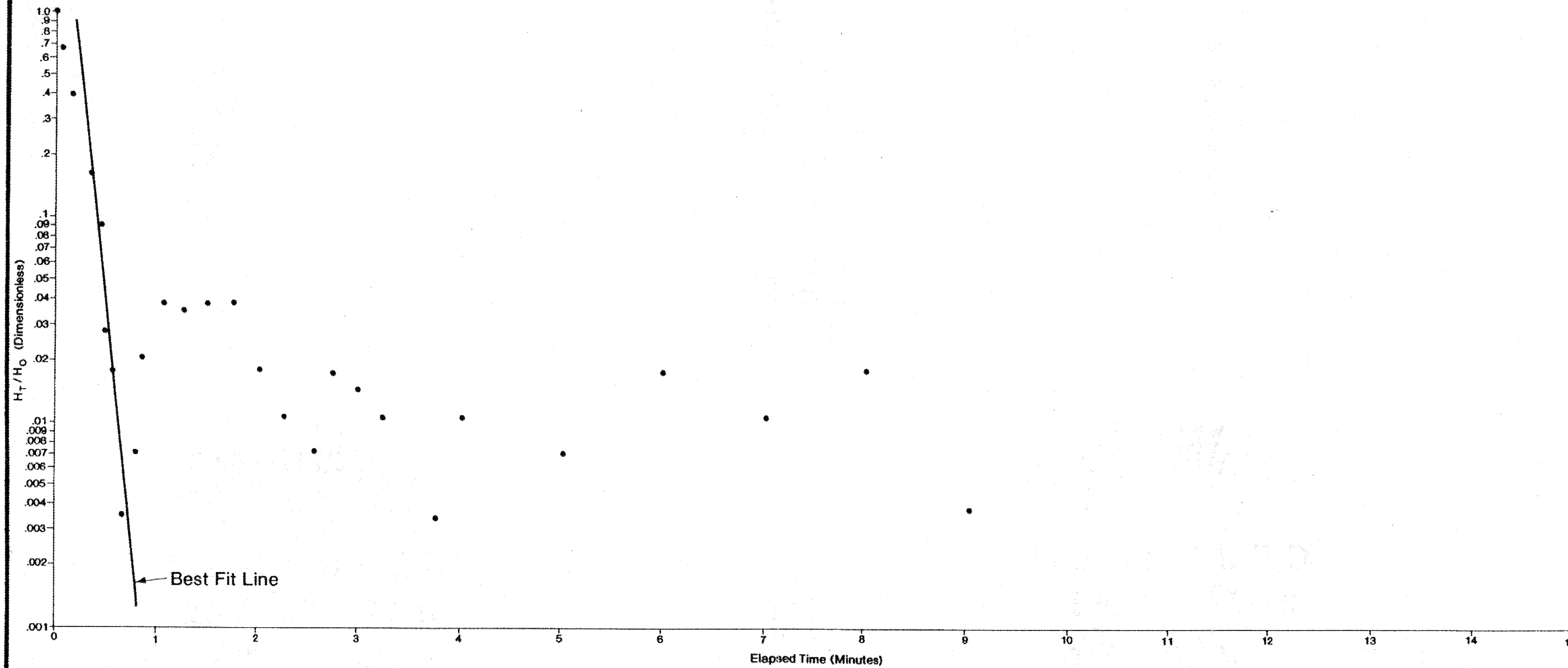
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 13



EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 1.0215 FEET

r_i = 0.083 FEET

l = 9.14 FEET

m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW–48

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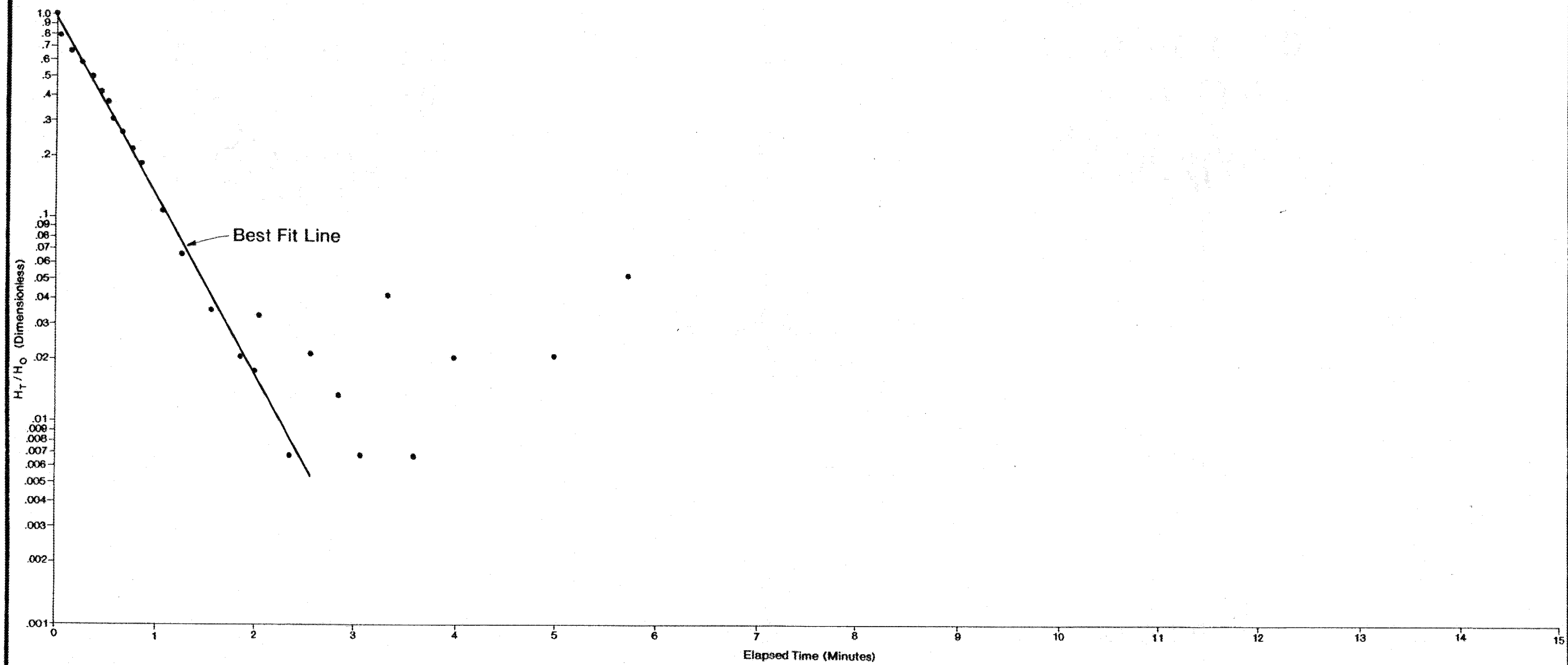
NORMALIZED DRAWDOWN H_T/H_0 (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 14



EXPLANATION:

• FIELD DATA POINT

DATA FOR CALCULATIONS:

H_o = 2.137 FEET

r_i = 0.083 FEET

l = 20.96 FEET

m = 60 FEET

r_w = 0.4167 FEET

n = 0.3 FEET

MW–49

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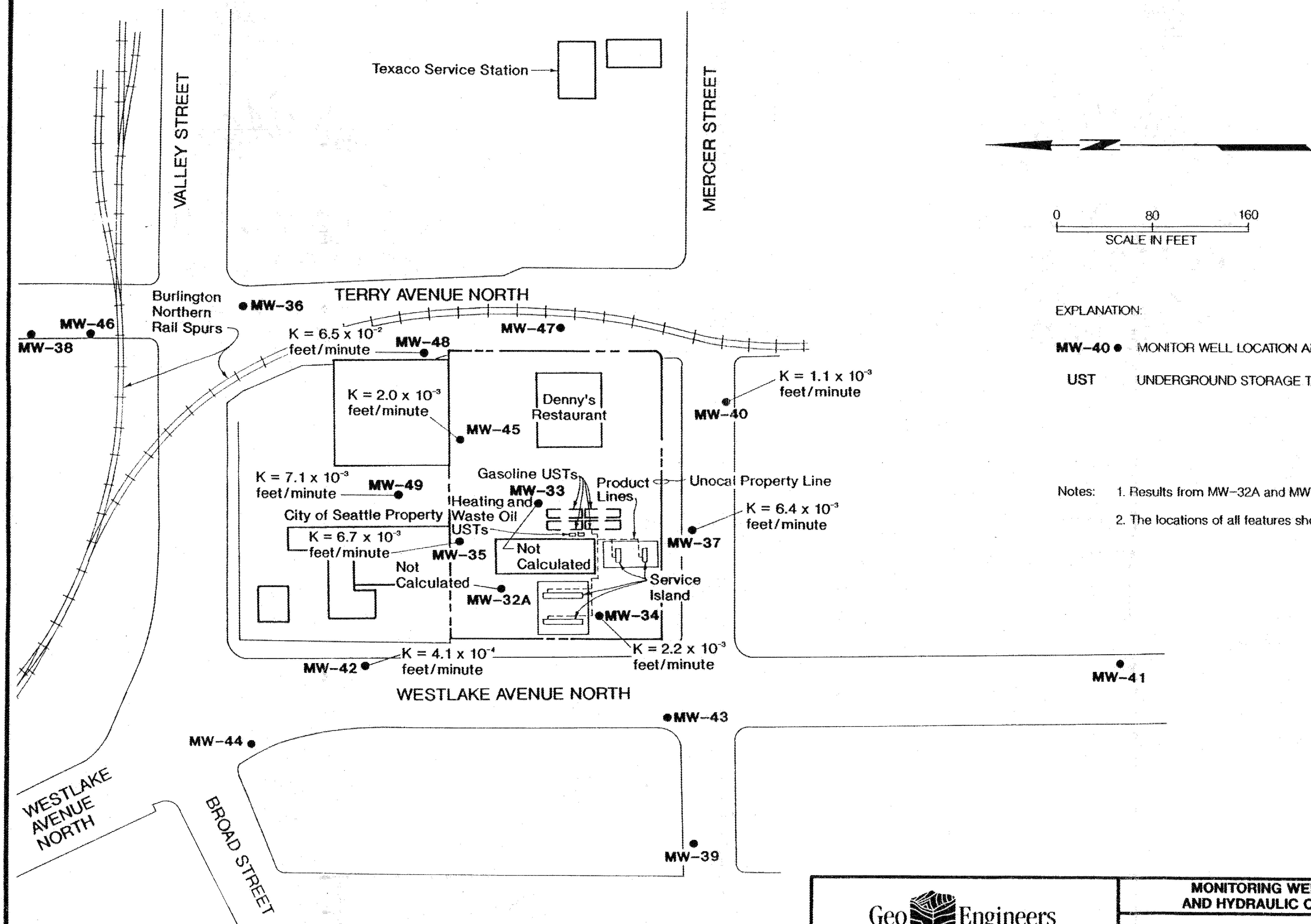
NORMALIZED DRAWDOWN H_T/H_O (LOG SCALE) VS. ELAPSED TIME (ARITHMETIC SCALE)

FIGURE 15



EXPLANATION:

MW-40 ● MONITOR WELL LOCATION AND NUMBER

UST UNDERGROUND STORAGE TANK

Notes:
1. Results from MW-32A and MW-33 were not calculated.
2. The locations of all features shown are approximate.

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MONITORING WELL LOCATIONS AND HYDRAULIC CONDUCTIVITIES

FIGURE 16

0161-013-B04 NLP:BDH 4/8/93