Applied GeoSystems, Inc. 3315 Almaden Expressway, Suite 34, San Jose, CA 95118 (408) 264-7723

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REPORT OF
PUMPING AND RECOVERY TEST RESULTS
at
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

AGS 60025.04

Prepared for
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TABLE OF CONTENTS

TABLES

PLATES

APPENDICES

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REPORT OF PUMPING AND RECOVERY TEST RESULTS at ARCO Station 374 6407 Telegraph Avenue Oakland, California

INTRODUCTION

This Report summarizes work previously performed by RESNA\Applied GeoSystems (AGS) and others, and describes the tasks performed and results of a pumping and recovery test conducted to evaluate remediation of shallow ground water at the subject site. This report also includes summaries of field procedures used during this investigation, findings, interpretation of the data, and conclusions. ARCO Products Company (ARCO) requested that AGS perform an aquifer pump test and recovery test to evaluate the general aquifer characteristics at the site and to investigate possible use of former underground storage-tank pit wells W-1 and W-2 for future recovery and remediation of gasoline hydrocarbons in the ground water. Work performed for this investigation included performing an initial step draw-down test, a constant discharge pump test and recovery test at the site.

SITE DESCRIPTION AND BACKGROUND

ARCO Station 374 is located at the northwestern corner of the intersection of Telegraph and Alcatraz Avenues in Oakland, California. The location is shown on Plate 1, Site Vicinity Map. Pertinent site features include two service islands, a station building, new underground gasoline-storage tanks (USTs) in a pit in the northeastern part of the site, and the former gasoline USTs pit located in the southwestern part of the site. Pertinent site features are shown on Plate 2, Generalized Site Plan. Numerous small commercial businesses and residential apartments are located along Telegraph and Alcatraz Avenues. Residential apartment buildings are located west and north of the site. A vacant lot, formerly a gasoline service station, is located at the southeastern corner of the intersection. The surface topography in the area is relatively flat, sloping very gently to the southeast.

REGIONAL AND LOCAL HYDROGEOLOGY

ARCO Station 374 is located west of the East Bay Hills at an elevation of approximately 160 feet above mean sea level. This area lies within the Berkeley Alluvial Plain, which is a subarea of the East Bay Alluvial Plain. Soils in this area are mapped as older alluvium that consists of a heterogeneous mixture of poorly consolidated to unconsolidated clay, silt, sand, and gravel units (Helley, 1979). The sediments were derived mainly from the hills to the east and southeast and represent successive coalescing alluvial fans deposited during the Pleistocene epoch.

The sediments found beneath the East Bay Alluvial Plain are believed to be about 200 feet thick in the Berkeley area and are the major ground water source in the region. Water-yielding capabilities are highly variable. Generally, high yields come only from wells that extend through several of the sand and gravel beds. Ground water in the East Bay Plain occurs predominantly under confined conditions and tends to flow toward the San Francisco Bay to the west and southwest (Hickenbottom and Muir, 1988).

PREVIOUS WORK

Subsurface Investigations

AGS (June 15, 1988) performed a limited environmental site assessment at the site after the detection of a vapor/vent line leak in the unleaded system during annual tank testing at the site, in February 1988, and the filing of an Underground Storage Tank Unauthorized Release (Leak) Report with the Alameda County Public Health Service by Brown and Caldwell in April 1988. The results of this investigation indicated total petroleum hydrocarbons as gasoline (TPHg) concentrations ranging from 48 to 930 parts per million (ppm) in samples from four borings near the underground gasoline storage tanks. These laboratory results are summarized in Table 1. Ground water was encountered at approximately 10 feet in the borings. A water sample from boring B-1, obtained through the hollow stem augers, contained one inch of floating product. Product sheen was observed on water samples from borings B-2 and B-4.

On June 7 through June 10, 1988, the four underground gasoline-storage tanks were removed from the site (AGS, August 1, 1988). No holes were observed in the removed tanks; however, some of the tar coating had dissolved around the fill ports of the tanks. Laboratory analyses of soil samples collected on June 7, 9, and 10, 1988 from the native soil beneath each end of each tank indicated TPHg concentrations ranging from less than 100 ppm to 1,097 ppm. Excavation was extended to remove impacted soil north of tank T4; a soil sample collected after this excavation indicated a TPHg concentration of 795 ppm. Locations of these samples are shown on Plate 2, and results of laboratory analyses of the samples are shown in Table 1. Ground water was observed seeping into the northwestern portion of the tank pit at a depth of approximately 12 feet. Analysis of a composite soil sample collected from the new tank pit excavation in the northeastern portion of the site indicted no concentrations of TPHg above 2 ppm. Observation wells W-1 and W-2 were installed in the former underground storage tank pit; observation wells W-3 and W-4 were installed in the new underground storage tank pit. Subjective analyses of the water from these wells indicated the presence of sheen in wells W-1 and W-2 in the former tank pit. Soil removed from the former tank excavation was disposed at a Class I Landfill, or aerated until acceptable TPHg concentrations were detected by laboratory analysis and disposed at a local landfill, by ARCO's contractor.

AGS prepared a work plan for a supplemental environmental investigation to evaluate the extent of gasoline hydrocarbon impact at the site (AGS, September 11, 1988). The proposed work included drilling three soil borings and installing ground-water monitoring wells in each boring. One monitoring well required an encroachment permit, which delayed further drilling until July 1989.

A water sample from well W-4 located in the new tank pit was collected and analyzed for TPHg and benzene, toluene, ethylbenzene, and total xylenes (BTEX) in December 1988 (AGS, January 5, 1989). TPHg and BTEX were not detected at concentrations above the detection limits (Table 2).

After obtaining an encroachment permit from the City of Oakland and slight modifications to the work plan mentioned above, four soil borings (B-1 through B-4) were drilled and four 4-inch diameter ground-water monitoring wells (MW-1 through MW-4, respectively) were installed in the borings to delineate further the extent of gasoline-impacted soil and ground water (AGS, March 27, 1991). One boring/monitoring well (B-3/MW-3) was located offsite in the inferred downgradient direction. Boring/monitoring well locations are shown on Plate 2, Generalized Site Plan. Ground water was encountered in the boreholes at depths between 12 and 17 feet below ground surface. Concentrations of TPHg in the soils from the borings ranged from nondetectable to 60 ppm. Results of laboratory analyses of selected soil samples from borings B-1/MW-1 through B-4/MW-4 are shown in Table 1. The extent of gasoline hydrocarbons in soil was not evaluated. Soils encountered in the borings consisted primarily of silty clay with some sand and gravel. A sandy gravel lens was found in boring B-4 at depths of 13 to 22 feet below ground surface underlain by silty clay. A graphic representation of the earth materials encountered in the borings is shown on Plate 3, Geologic Cross Sections. The locations of cross sections A-A' and B-B' are shown on Plate 2, Generalized Site Plan.

Ground-water Monitoring

In July 1989, ground-water monitoring wells MW-1 through MW-4 were developed and sampled as part of the investigation. Laboratory analytical results of ground-water samples and the results of ground-water gradient evaluation revealed that the ground water collected from onsite monitoring wells MW-2 (upgradient of the former underground gasoline-storage tanks), MW-4 (immediately downgradient of the former underground gasoline-storage tanks), and MW-3 (offsite, downgradient of the former underground gasoline storage tanks) contained elevated levels of gasoline hydrocarbons. Concentrations of TPHg in July, 1989 ranged from 33 parts per billion (ppb) in MW-1 to 8,200 ppb in MW-4. Some sheen and emulsion was observed in well MW-4 and some emulsion was observed in the offsite well MW-3. Quarterly monitoring was initiated in 1989. Laboratory analytical results for ground water samples are presented in Table 2, Cumulative Results of Laboratory Analyses of Ground-Water Samples. In February 1991, TPHg levels ranged from nondetectable in MW-1 to 5,200 ppb in MW-4. Benzene exceeded Maximum Contaminant Levels (MCL's) in MW-2, MW-3, and MW-4. And toluene exceeded the Recommended Action level in MW-4. Ground-water flow direction is toward the south/southwest.

Water samples submitted for mineral analysis indicated that the native water is of relatively low quality, with mineral concentrations of chloride, manganese, and total dissolved solids exceeding the MCL established for secondary drinking water supplies established by Title 40 of the Code of Federal Regulations, Section 143 and Title 22, Section 64445.1 of the California Administrative Code. Mineral analysis results for ground-water samples are shown in Table 3, Results of General Mineral Analysis: Ground Water.

Well Search

A search of the California State Department of Water Resources (DWR) records of known wells within a 1-mile radius of the site was performed during the limited subsurface environmental investigation performed by AGS (March 27, 1991). Twelve wells were identified. Three of the wells are located within a 1/2-mile radius of the site in the general downgradient ground-water flow direction of the site (south/southwest). Four downgradient wells are located within 1 mile of the site, but greater than 1/2 mile. None are known to be domestic supply wells. Of the seven wells located downgradient of the site, three wells are used for ground-water monitoring, two for cathodic protection, and one well is an industrial supply well used to provide water to a coin-operated laundry business located approximately one mile from the site at 5702-B Adeline Street, Oakland, California. The purpose of well # 5 installed in 1935 is unknown. The well locations relative to the site are shown on Plate 4, Well Location Map, and well specifics are shown on Table 4, Wells Within One Mile of ARCO Station 374.

Records Search

A records search was conducted at the RWQCB regarding a former gasoline service station located across from the site in the upgradient ground-water flow direction (AGS, March 27, 1991). A report by AquaScience Engineers of Walnut Creek, California (May 27, 1986) describes the removal and condition of three underground gasoline-storage tanks and one underground waste-oil storage tank that were removed from that site in March 1986. The 550-gallon waste-oil tank and one 5,000-gallon gasoline-storage tank were reported to have holes in them. Each tank pit was found to contain water with floating product residue. Contaminated water was reportedly removed and contaminated soil excavated and aerated. No additional subsurface environmental investigation was conducted to assess the possible impact on ground-water downgradient from that site, which is located upgradient from ARCO Station 374.

Drawdown Test

A single-well drawdown test was conducted on well MW-1 to assess the recharge capability of the first encountered water-bearing zone (AGS, March 27, 1991). Analysis of the test data indicated the rate of recharge in the uppermost water-bearing zone beneath the site to be approximately 0.09 gpm. A more detailed aquifer test was performed by AGS on April 25, 1991. Data obtained from this test is also included in this report.

AQUIFER CHARACTERIZATION

Step-Drawdown Test

A step-drawdown test was performed on well W-2 (located in the backfill) on April 11, 1991 to determine the optimum pumping rate at which to perform the constant discharge test. Water levels in the two wells in the backfill (W-1 and W-2) dropped steadily and uniformly. It was concluded that the best approach was to pump at a maximum rate that the pump/discharge system was capable of as a way of dewatering the gravel backfill. The discharge rate was determined using both a flow meter and a calibrated five gallon bucket with a stopwatch. Nearby monitoring well MW-4 showed a significant decline in water level which continued even after the cessation of pumpage.

Ground-Water Gradient and Flow Direction

Immediately prior to beginning the pump test, AGS personnel measured initial water levels. Water level measurements were obtained using an electric depth sounder. Depth to water (DTW) levels in the pumping well (W-2) and in the observation wells (W-1 and MW-1 through MW-4) were measured for the purposes of determining the hydraulic gradient and ground-water flow direction during the day of the pump test. Ground-water elevation and DTW data are reported in Table 5. The gradient was 0.029 ft/ft and is shown on Plate 5, Ground-Water Gradient Map, April 25, 1991. The ground-water flow direction has consistently been southwestward. Appropriate field procedures followed during the pump and recovery test are described in Appendix B.

Pumping and Recovery Tests

A 10.5-hour pump test and 20-hour recovery test were conducted on April 25 and 26, 1991. Well W-2 was used as the pumping well and wells W-1, MW-1, MW-2, MW-3, and MW-4 were used as observation wells. Data obtained from this pumping test permits the determination of the sustainable pumping rate from the pumping well and an estimate of the hydraulic conductivity and storativity of the aquifer. The information is also used to determine the zone of capture of the extraction well. A submersible pump was utilized for the test and the pumping rate was adjusted by a valve. The discharge rate was determined with the use of a flow meter. Well W-2 was chosen as the well to be pumped because of its completion within the gravel backfill of the former underground tank excavation. It is located in an area of elevated TPHg concentrations in ground water. Pumping continued (approximately 10.5 hours) until four feet of the gravel backfill had been dewatered. Data readings were first noted every 30 minutes during the early portion of the test. After 12 hours, this time interval was increased to once every hour. Well W-2 was pumped at a rate of 9.0 gallons per minute (gpm) for the first 10.5 hours of the test. This was followed by a recovery test approximately 20 hours in length. During the recovery test the water levels in the backfill rose but water levels in the aquifer continued to fall as water drained into the cone of depression created in the backfill. Refer to Appendix B for additional data on pump test procedures.

Test Results

The two wells completed in the backfill (W-1 and W-2) do not show typical drawdown curves; these are typically linear on a semi-logarithmic plot (Appendix B, Plates B-1 and B-2). Instead, the arithmetic plot shows a linear relationship as though a container were being emptied. This linear response reflects the very high hydraulic conductivity and large storage coefficient of the gravel backfill, as well as the limited extent of the backfill material. An estimate of the hydraulic conductivity of the gravel backfill was made by comparing the differences in saturated aquifer thickness at the end of pumping in wells W-2 and W-1, located 13.5 feet apart. Using the Thiem (1906) equation for an unconfined aquifer which assumes steady-state conditions, the hydraulic conductivity of the gravel backfill calculates out as 2,780 feet per day (ft/d). Although the field conditions do not meet either the assumption of steady-state conditions or an infinite aquifer, the value obtained should be of the correct order of magnitude. The water level in the backfill, at a pumping rate of approximately 9 gpm, falls at an average rate of 0.34 ft/hr. The rise in water level in the backfill during recovery is approximately 0.011 ft/hr. This indicates that the rate of inflow from the aquifer to the tank backfill is approximately 0.29 gpm (see Appendix B for detailed calculations and Plates B-7 through B-12 for graphs of the recovery test data). Based on this, it is clear that the aquifer must be several orders of magnitude less permeable than the gravel backfill.

The three distant observation wells (MW-1, MW-2, and MW-3) showed no response to pumping during the 10.5 hour pump test, and in fact showed a slight rise in the water level (Plates B-3 through B-5). Monitoring well MW-4 located approximately 10 feet from the gravel backfill, showed a rapid and significant decline in water level (Plate B-6). Again, the usual straight-line, semi-logarithmic plot was not observed, because of the atypical nature of the pump test configuration. The drop in water level appears quite linear on an arithmetic plot. An estimate of the hydraulic conductivity of the aquifer can be made using Darcy's Law and assuming the aquifer is draining more or less uniformly into the backfill from all sides. For an excavation 20 feet by 30 feet in plan view and an initial saturated thickness of approximately 6.7 feet the area cross-sectional (A) to flow is 670 square feet (ft^2) (see Appendix B for calculations). For a water level difference (dh) of 2.3 feet towards the end of pumping over a distance (dl) of 10 feet, and a discharge (Q) from the aquifer of 0.29 gpm (56 ft^3/d), the hydraulic conductivity (K) is estimated as 0.37 ft/d. This value is consistent with the observation that the hydraulic conductivity of the aquifer must be several orders of magnitude less than that of the gravel backfill.

Computer Simulation

Because of the uncertainties involved in the analysis of the field data, computer simulation of the field pumping was performed to test the validity of the results obtained above. The U.S. Geological Survey model, MODFLOW (MacDonald and Harbaugh, 1984) was chosen to simulate the response to pumping observed during the field test and to predict the effects of pumping for a prolonged period.

The pumping test was simulated by pumping at 9 gpm (1,730 ft^3/d) for 10.5 hours followed by a period 18 hours long in which no pumping occurred. A number of different values for hydraulic conductivity and storativity were tried. The ones which provided the best fit to the field data were:

Hydraulic Conductivity Gravel Backfill: 2,000 ft/d
Specific Yield Gravel Backfill: 0.28
Hydraulic Conductivity Aquifer: 0.2 ft/d
Specific Yield Aquifer: 0.01

The hydraulic conductivity values are close to the values obtained above from the field data. The specific yield values were those which gave the closest fit to the observed water level change. The aquifer was treated as homogeneous and isotropic to simplify the computer simulation, although the soil boring/well logs indicate it is heterogeneous. Plate B-13 shows the finite difference grid, and Plate B-14 shows the site flow gradient map for the computer simulation.

Comparison of Field and Computer Results

A comparison between the manually obtained field data and the simulated water level changes are shown on Plates B-15 through 20. The agreement is very good for the gravel backfill, and reasonably good for MW-4 and MW-2. The simulated drawdown at the end of 10.5 hours of pumping is shown on Plate B-21. This agrees well with that observed in the field. Once a reasonably good match had been achieved to the field data, the model was run in a predictive mode. Well W-2 was pumped at 9.0 gpm for 10.5 hours followed by pumping at various rates for 100 days. The maximum pumping rate that the well could sustain during that time period without running dry was 0.24 gpm. This agrees well with the estimated recharge from the aquifer above of 0.29 gpm. The head distribution at the end of the 100 days of pumping is shown on Plate B-22.

DISCUSSION & CONCLUSIONS

The yield of well W-2, which has been proposed for the extraction well, is relatively low. There is good agreement between the recharge to the backfill (0.29 gpm) and the sustainable pumping rate determined from modeling (0.24 gpm) for a 100 day time period. The utilization of the gravel backfill as a collection sump may be a good solution to increase the yield of this aquifer, beyond what could be achieved by a well without large drawdowns. It can be assumed that well W-3 may possess a similar yield and sustainable pumping rate.

Zone of Capture Calculation

The zone of capture for well W-2 in the excavation backfill is drawn onto the head contours on Plate B-22. The zone is sufficiently large to capture the high concentration portion of the plume, but will not capture portions of the plume which have migrated off-site in the down-gradient direction.

Ground-Water Extraction System

The subsurface conditions surrounding monitoring well W-2 may create difficulties for a ground-water extraction system. The presence of monitoring well W-2 in the permeable gravel backfill during the pump and recovery test made it difficult to achieve steady-state drawdown conditions. Ground-water modeling was utilized to simulate different pumping rates with chosen aquifer parameters. The maximum sustainable pumping rate as determined from modeling is 0.24 gpm. This is considered to be a relatively low yield.

Using the gravel backfill as a collection sump may enhance the yield of the aquifer. The zone of capture effected by W-2 will capture the high concentration of the plume, but will neglect the off-site portions in the down-gradient direction. Thus, because of the limited capture area predicted down-gradient of the site and possible TPHg migration offsite, it would be most effective to place a ground-water extraction well offsite adjacent to existing ground-water monitoring well MW-3 for the purpose of controlling offsite migration of petroleum hydrocarbons in the ground water.

PROJECT STAFF

Ms. Joan E. Tiernan, Ph.D., a Registered Civil Engineer (C.E. 044600) is in overall charge of this project. Mr. Greg Barclay, General Manager, provided supervision of field and office operations of the project. Ms. June Oberdorfer, Ph.D., Professor in Hydrology at San Jose State University, provided field supervision and performed calculations and modeling of acquired data. Mr. Joel Coffman, Assistant Project Geologist, is responsible for the day-to-day field and office operations of the project. AGS employs a staff of geologists and technicians who assisted with the project.

LIMITATIONS

This report was prepared in accordance with generally accepted standards of environmental geological practice in California at the time this investigation was performed. This assessment was conducted solely for the purpose of evaluating environmental conditions of the soil and ground water with respect to gasoline-related hydrocarbons at the site. No soil engineering or geotechnical references are implied or should be inferred. Evaluation of the geologic conditions at the site for the purpose of this assessment is made from a limited number of observation points. Subsurface conditions may vary away from the data points available. Additional work, including further subsurface investigation, can reduce the inherent uncertainties associated with this type of assessment.

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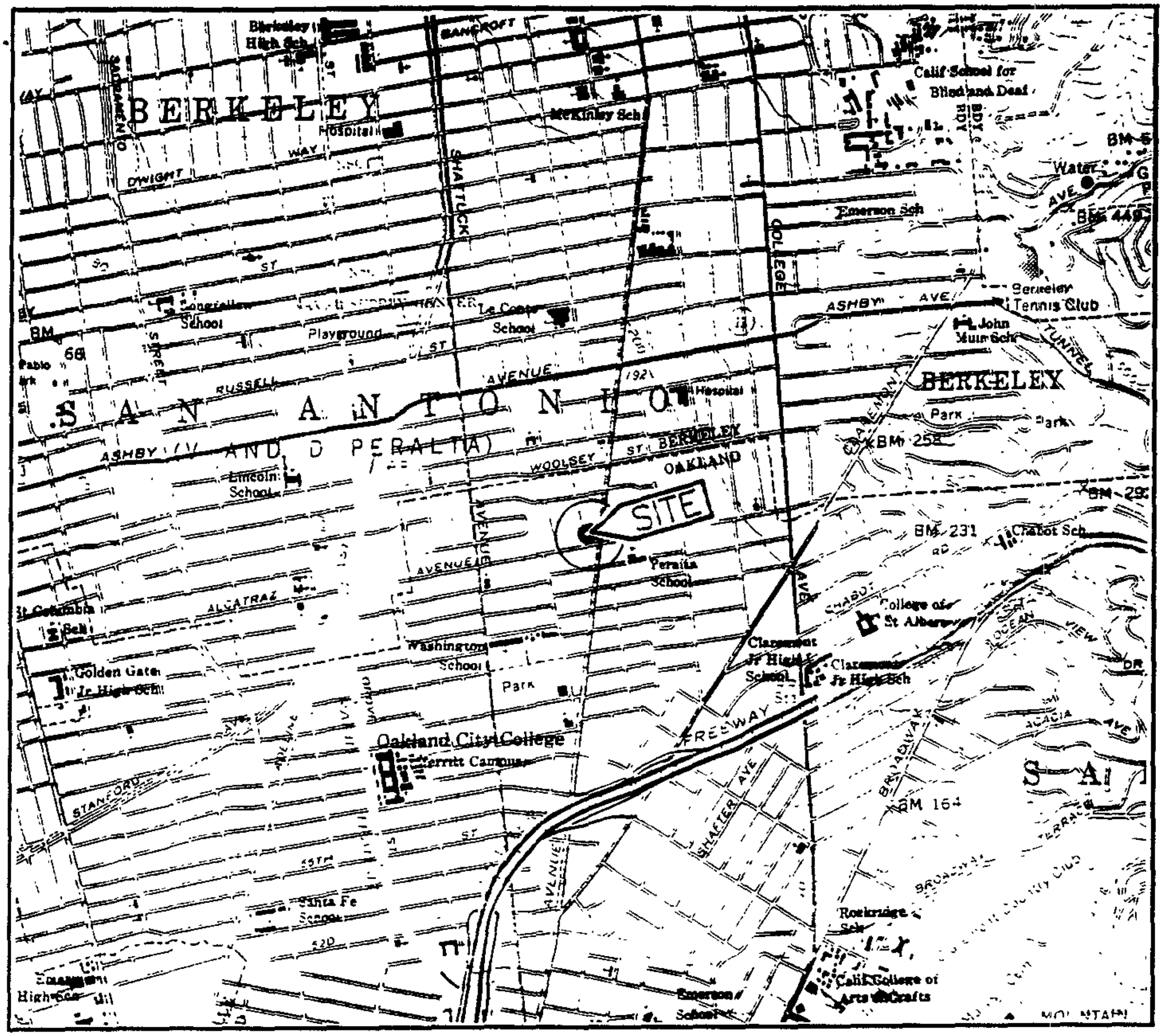

Source: U.S. Geological Survey
7.5-Minute Quadrangles
Oakland West/East
California.
Photorevised 1980

N

Approximate Scale

2000 1000 0 2000 4000

feet

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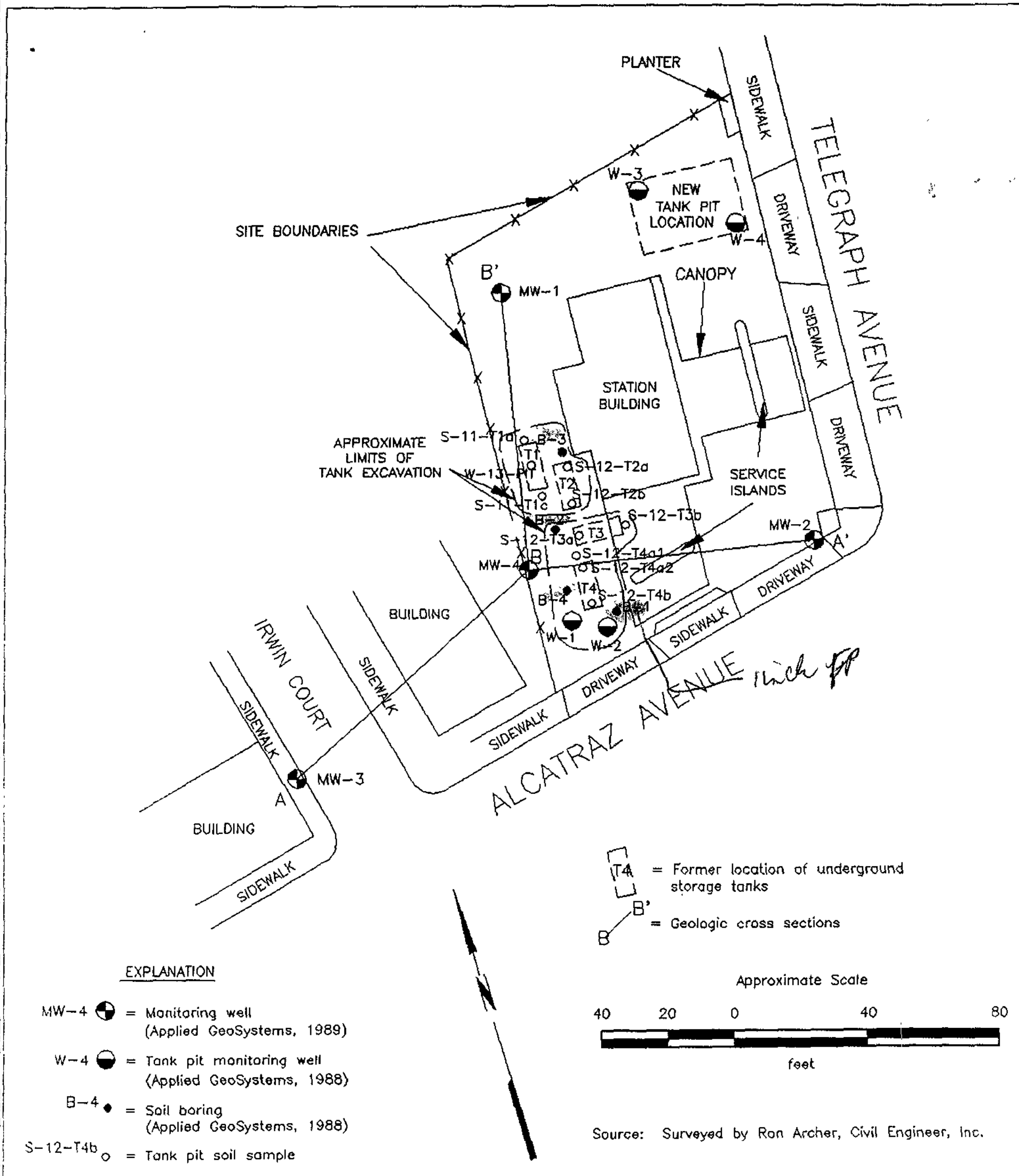
PROJECT 60025-4

SITE VICINITY MAP
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

PLATE

1



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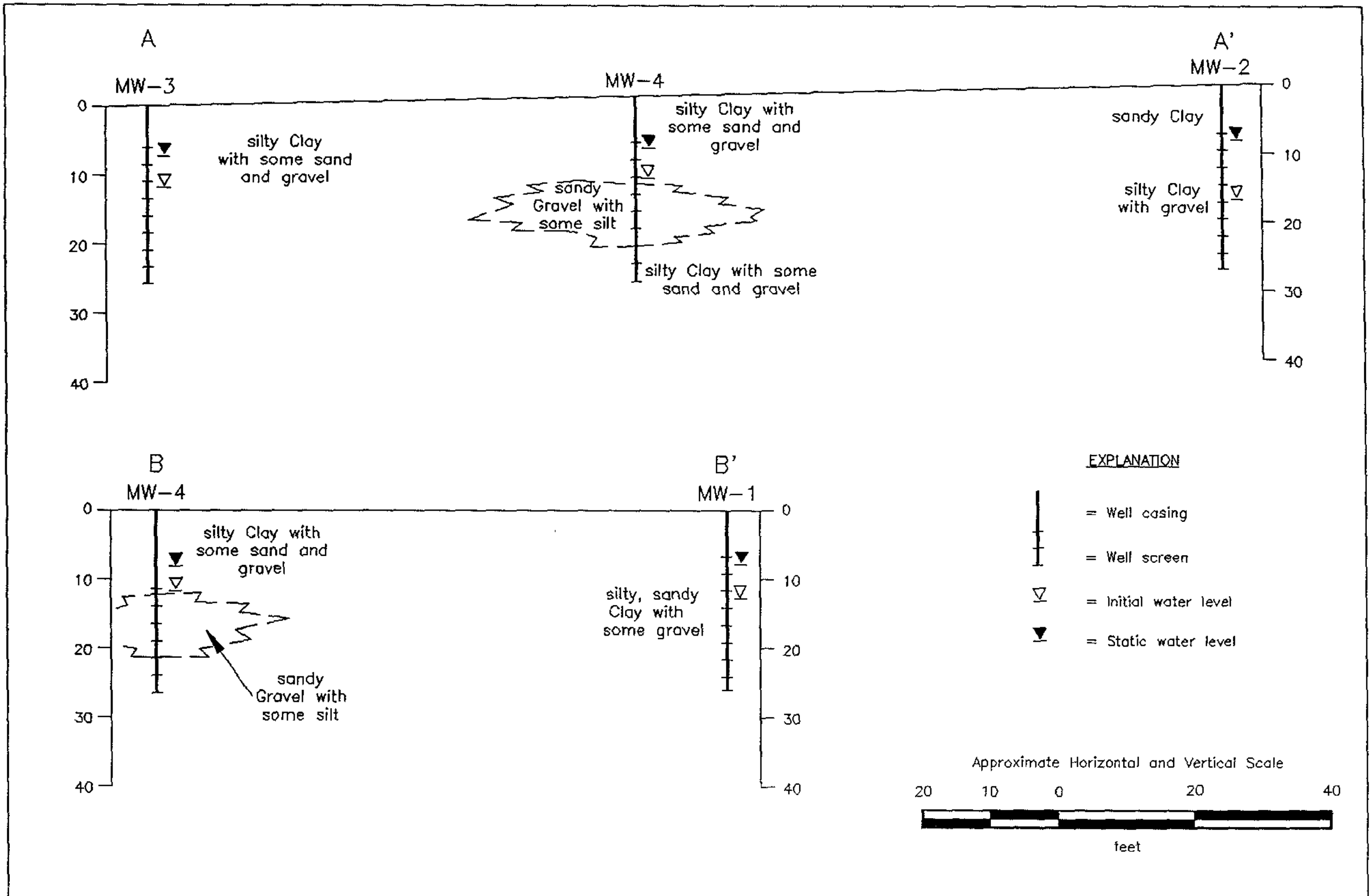
GENERALIZED SITE PLAN
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

PLATE 2



PLATE

3

GEOLOGIC CROSS SECTIONS A-A' AND B-B'
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

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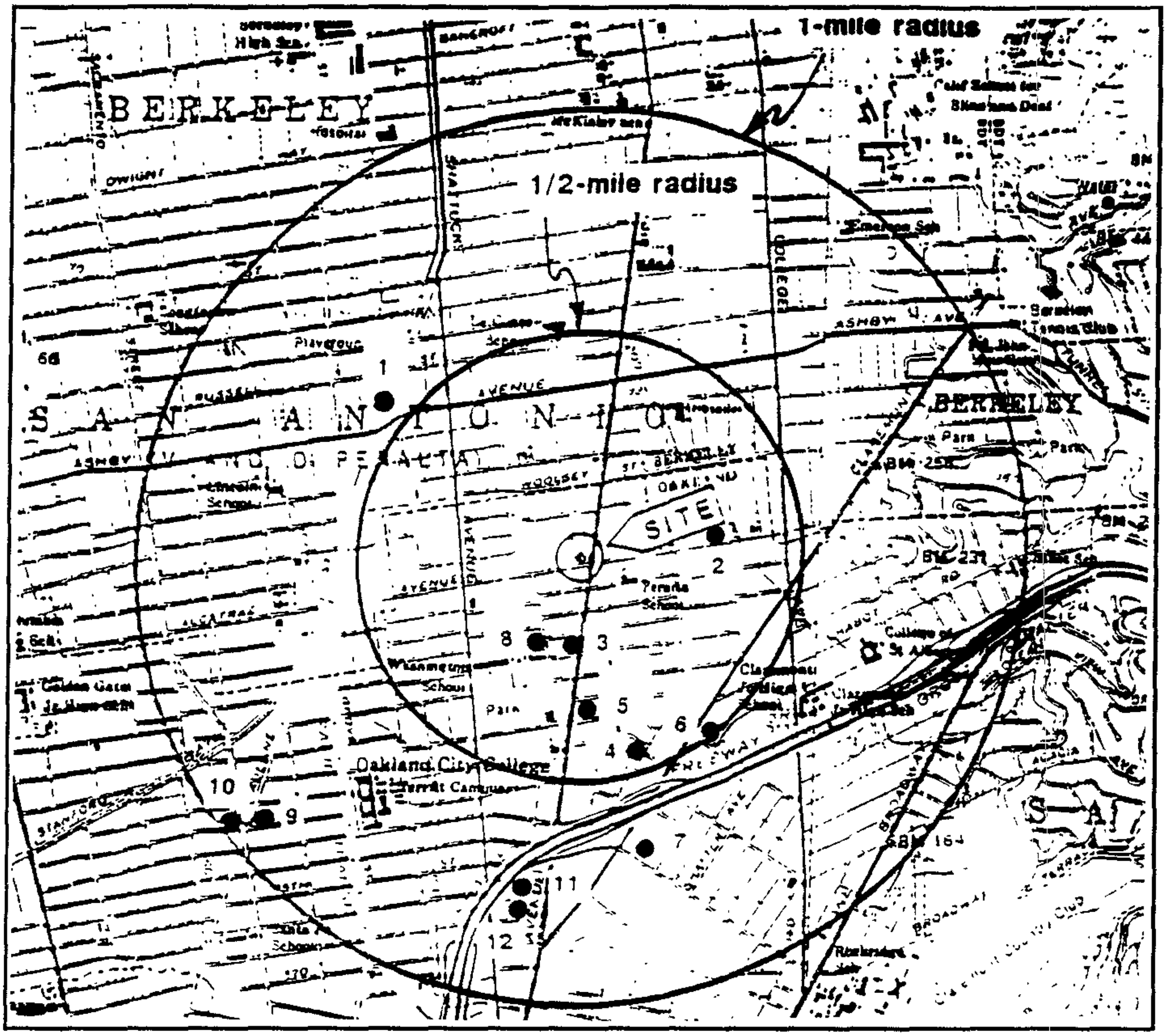

Source: U.S. Geological Survey
7.5-Minute Quadrangles
Oakland West/East
California.
Photorevised 1980

● = Well locations

(See Table 4 for well information)

N

Approximate Scale

2000 1000 0 2000 4000

feet

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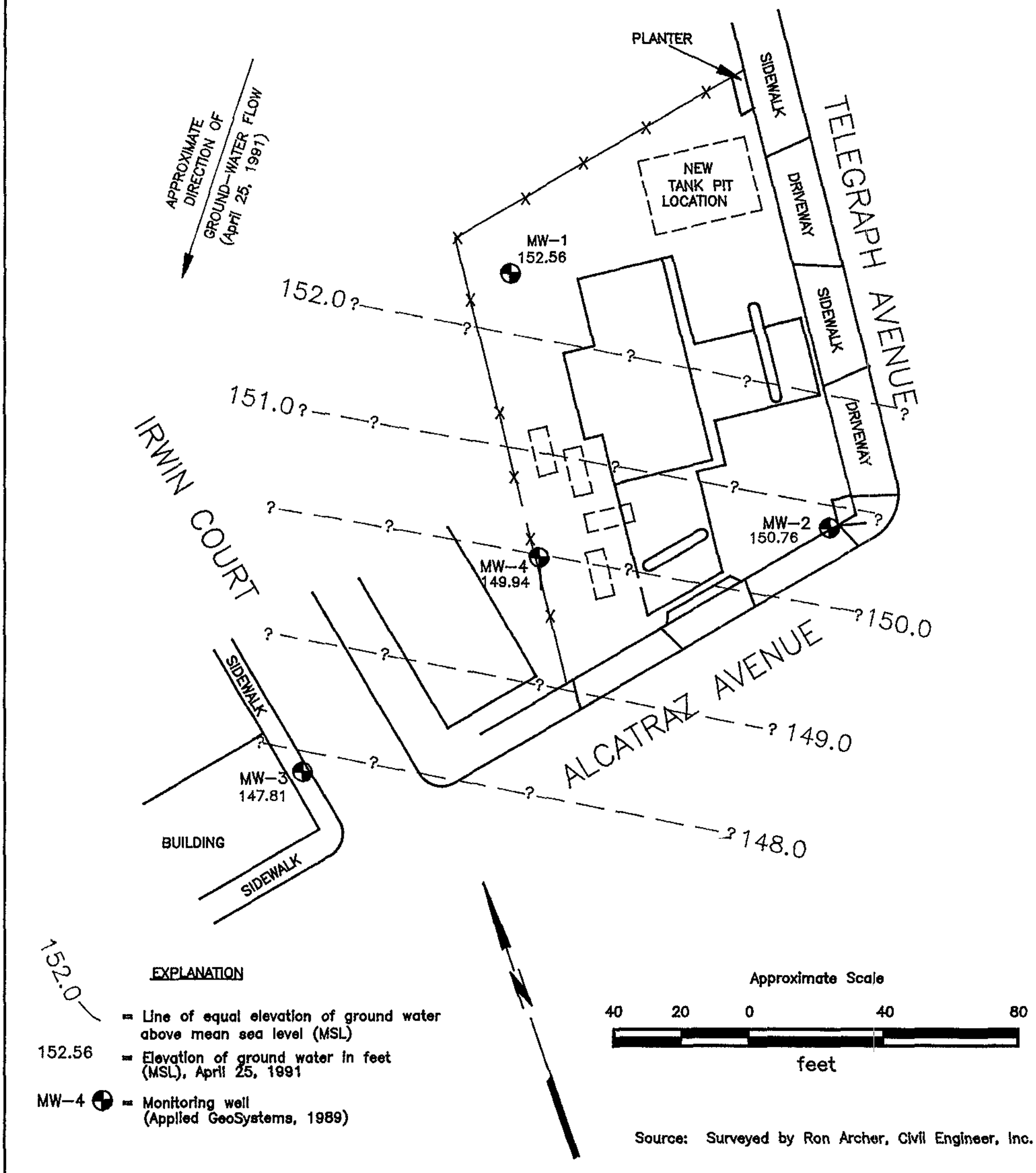
WELL LOCATION MAP
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

PLATE

4



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GROUND-WATER GRADIENT MAP
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

PLATE

5

TABLE 1
CUMULATIVE ANALYTICAL RESULTS OF SOIL SAMPLES
ARCO Station 374
6407 Telegraph Avenue
Oakland, California

Sample Number	TPHg	Benzene	Toluene	Ethyl-benzene	Total Xylenes
July 1989					
S-3.5-B1/MW-1	<2	<0.05	<0.05	<0.05	<0.05
S-8.5-B1/MW-1	60	0.66	2.9	0.99	5.2
S-3.5-B2/MW-2	<2	<0.05	<0.05	<0.05	<0.05
S-13.5-B2/MW-2	<2	<0.05	<0.05	<0.05	<0.05
S-18.5-B2/MW-2	<2	<0.05	<0.05	<0.05	<0.05
S-3.5-B3/MW-3	<2	<0.05	<0.05	<0.05	<0.05
S-3.5-B4/MW-4	<2	<0.05	<0.05	<0.05	<0.05
S-13.5-B4/MW-4	<2	<0.05	<0.05	<0.05	<0.05
S-18.5-B4/MW-4	<2	<0.05	<0.05	<0.05	<0.05
S-0731-B4 (1a,b,c,d)*	21	<0.05	<0.05	<0.05	0.37
June 1988					
S-11-T1A	399	14.7	20.0	20.5	91.9
S-11-T1B	8	2.57	0.74	0.39	2.75
S-12-T2A	4	0.35	0.10	0.38	0.70
S-12-T2B	75	0.91	1.77	3.61	11.92
S-12-T3A	4	2.54	0.13	<0.05	0.13
S-12-T3B	<2	<0.05	<0.05	<0.05	<0.05
S-12-T4A	1,097	16.3	34.5	81.6	188.2
S-12-T4A2**	795	23.1	24.9	67.1	130.9
S-12-T4B	3	0.76	<0.05	<0.05	<0.05
S-13-PIT	3.6	0.738	0.038	0.154	0.566
June 15, 1988 report					
S-05-B1	165	NA	NA	NA	NA
S-10-B1	48	NA	NA	NA	NA
S-05-B2	260	NA	NA	NA	NA
S-8.5-B2	60	NA	NA	NA	NA
S-05-B3	64	NA	NA	NA	NA
S-09-B3	62	NA	NA	NA	NA
S-05-B4	389	NA	NA	NA	NA
S-8.5-B4	930	NA	NA	NA	NA

Results are in parts per million (ppm).
TPHg: Total petroleum hydrocarbons as gasoline.
<: Below the reporting limits of the analytical method.
*: Signifies composite sampel following aeration.
**: Resample of area near sample T4A following additional excavation.
NA: Not analyzed.

Sample designations:

S-13.3-B4 — Boring number; Sample depth in feet; Soil sample

S-12-T4B — Tank number and location; Sample depth in feet; Soil sample

TABLE 2
CUMULATIVE RESULTS OF LABORATORY ANALYSES OF GROUND-WATER SAMPLES
ARCO Service Station 374
Oakland, California

Date/Well	TPHg	TPHd	B	T	E	X	TOG
W-4							
12/21/88	<20	NA	<0.50	<0.50	<0.50	<0.50	NA
MW-1							
07/21/89	33	NA	0.77	1.6	1.5	5.0	NA
08/30/89	<20	NA	<0.50	<0.50	<0.50	<0.50	NA
10/04/89	<20	NA	<0.50	<0.50	<0.50	<0.50	NA
01/10/90	<20	NA	<0.50	<0.50	<0.50	<0.50	NA
08/07/90	<20	NA	<0.50	<0.50	<0.50	<0.50	NA
12/06/90	<50	NA	3.6	2.7	0.6	5.8	NA
02/20/91	<50	NA	<0.50	<0.50	<0.50	<0.50	NA
MW-2							
07/21/89	4200	NA	280	210	38	24	NA
08/30/89	4200	NA	160	260	45	240	NA
10/04/89	4300	NA	860	300	29	330	NA
01/10/90	8000	NA	890	710	120	760	NA
08/07/90	6000	NA	880	76	25	80	NA
12/06/90	1600	NA	330	69	18	63	NA
02/20/91	1300	NA	160	46	13	48	NA
MW-3							
07/21/89	430	NA	9	4.8	<0.50	50	NA
08/30/89	1200	NA	85	46	8.4	55	NA
10/04/89	7000	NA	580	900	120	670	NA
01/10/90	940	NA	130	59	21	73	NA
08/07/90	2300	NA	180	64	59	120	NA
12/06/90	460	350	52	55	14	39	NA
02/20/91	470	<100	36	30	9.3	31	NA
MW-4							
07/21/89	8700	NA	720	360	120	640	NA
08/30/89	7300	NA	630	220	72	320	NA
10/04/89	21000	NA	2300	1300	280	1300	NA
01/10/90	4300	NA	470	250	63	430	NA
08/07/90	69000	28000	8700	4200	540	4600	<5000
12/06/90	NA	NA	NA	NA	NA	NA	NA
02/20/91	5200	<100	690	200	95	580	<5000

MW-4	HALOGENATED VOLATILE ORGANICS (EPA Method 601/8010)
07/31/90	Nondetectable for thirty one compounds tested (<1 ppb)

Results in micrograms per liter (ug/L) = parts per billion (ppb). NA: Not analyzed
TPHg: Total petroleum hydrocarbons as gasoline by EPA method 5030/8015.
TPHd: Total petroleum hydrocarbons as diesel by EPA method 3510/8015.
{B: Benzene, T: Toluene, E: Ethylbenzene, X: Total Xylene isomers} by EPA method 8020/602.
TOG: Total oil and grease measured by Standard Method 503A/E.
<: Less than laboratory detection limits

TABLE 3
RESULTS OF GENERAL MINERAL ANALYSIS: GROUND WATER
ARCO Station 374
6074 Telegraph Avenue
Oakland, California
(October 4, 1990)

Constituent	MW-1	MCL
Chloride	+330	250 Rec 500 Up 600 St
Copper	<0.5	1.0
Iron	0.23	0.3
Manganese	+0.061	0.05
Sulfate	120	250 Rec 500 Up 600 St
Total Dissolved Solids	+1,000	250 Rec
Zinc	0.011	5.0

Results and values in parts per millions (ppm) with the exception of Specific Conductance (micro-mhos/cm or micro-siemens/cm).
MCL: Maximum Contamination Level for Secondary Drinking Water Standards established by Title 40 of the Code of Federal Regulation Section 143 and Title 22 Section 64445.1 of the California Administrative Code.
Rec: Recommended value.
Up: Upper value.
St: Value for short term use only.
+: Constituent in ground water which exceeds established MCL.

TABLE 4
WELLS WITHIN ONE MILE OF THE SUBJECT SITE
ARCO Station 374
6074 Telegraph Avenue
Oakland, California

Well ID	Well Location	Owner	Year Drilled	Recorded Use
1	3215 Adeline	R. Harkon	1981	Domestic?
2	4801 Oakport	PG&E	1974	Cathodic
3	6125 Telegraph	ARCO	1986	Monitoring
4	Martin & Herman	PG&E	1974	Cathodic
5	5976 Telegraph	Creamery	1935	NA
6	Forest & Claremont	NA	NA	NA
7	Clifton & Claremont	PG&E	1975	Cathodic
8	62nd & Racine	PG&E	1977	Cathodic
9	5702 Adeline	A. Santos	1977	Industrial
10	Market & 57th	PG&E	1974	Cathodic
11	51st & Telegraph	Pacific Rim	1988	Monitoring
12	51st & Telegraph	Kaldveer Ass.	1988	Monitoring

Source: California Department of Water Resources.
NA: Information not available.

TABLE 5
CUMULATIVE GROUND-WATER MONITORING DATA
ARCO Station 374
Oakland, California
(Page 1 of 2)

Date Well Measured	Well Elevation	Depth to Water	Water Elevation	Product
MW-1				
07/20/89		8.04	151.40	None
08/30/89		8.47	150.97	None
10/04/89		8.50	150.94	None
01/10/90		6.74	152.70	None
08/07/90	159.44	6.87	152.57	None
12/06/90		7.35	152.09	None
12/19/90		7.22	152.22	None
01/29/91		8.28	151.16	None
02/20/91		7.98	151.46	None
04/25/91		6.89	152.55	NM
MW-2				
07/20/89		8.15	150.31	None
08/30/89		8.42	150.04	None
10/04/89		8.40	150.06	None
01/10/90		6.12	152.34	None
08/07/90	158.46	6.35	152.11	Odor
12/06/90		7.15	151.31	Odor
12/19/90		7.38	151.08	Odor
01/29/91		8.41	150.05	Odor
02/20/91		8.26	150.20	Odor
04/25/91		7.70	150.76	NM
MW-3				
07/20/89		7.58	146.60	None
08/30/89		8.00	146.18	None
10/04/89		7.73	146.45	Emulsion
01/10/90		7.78	146.40	Odor
08/07/90	154.18	7.66	146.52	Odor
12/06/90		7.75	146.43	Odor
12/19/90		7.58	146.60	Odor
01/29/91		7.60	146.58	Odor
02/20/91		7.51	146.67	Odor
04/25/91		6.37	147.81	NM

See notes on Page 2 of 2

TABLE 5
CUMULATIVE GROUND-WATER MONITORING DATA
ARCO Station 374
Oakland, California
(Page 2 of 2)

Date Well Measured	Well Elevation	Depth to Water	Water Elevation	Product
MW-4				
07/20/89		8.09	148.99	None
08/30/89		8.45	148.63	Sheen
10/04/89		8.57	148.51	Sheen/Emulsion
01/10/90		7.26	149.82	Odor
08/07/90	157.08	6.87	150.21	Odor
12/06/90		8.02*	149.06*	Product Sheen
12/19/90		7.69	149.39	Odor
01/29/91		8.39	148.69	Odor/Sheen
02/20/91		8.16	148.92	Odor
04/25/91		7.14	149.94	NM

Elevations and DTW measured in feet.
* = Floating Product.
NM = Not Measured

APPENDIX A

FIELD PROTOCOL

FIELD PROTOCOL

The following presents Applied GeoSystems' protocol for a typical site investigation involving gasoline hydrocarbon-impacted soil and/or ground water.

Site Safety Plan

The Site Safety Plan describes the safety requirements for the evaluation of gasoline hydrocarbons in soil, ground-water, and the vadose-zone at the site. The site Safety Plan is applicable to personnel of Applied GeoSystems and its subcontractors. Applied GeoSystems personnel and subcontractors of Applied GeoSystems scheduled to perform the work at the site are be briefed on the contents of the Site Safety Plan before work begins. A copy of the Site Safety Plan is available for reference by appropriate parties during the work. A site Safety Officer is assigned to the project.

Soil Excavation

Permits are acquired prior to the commencement of work at the site. Excavated soil is evaluated using a field calibrated (using isobutylene) Thermo-Environmental Instruments Model 580 Organic Vapor Meter (OVM). This evaluation is done upon arrival of the soil at the ground surface in the excavator bucket by removing the top portion of soil from the bucket, and then placing the intake probe of the OVM against the surface of the soil in the bucket. Field instruments such as the OVM are useful for measuring relative concentrations of vapor content, but cannot be used to measure levels of hydrocarbons with the accuracy of laboratory analysis. Samples are taken from the soil in the bucket by driving laboratory-cleaned brass sleeves into the soil. The samples are sealed in the sleeves using aluminum foil, plastic caps, and aluminized duct tape; labeled; and promptly placed in iced storage. If field subjective analyses suggest the presence of hydrocarbons in the soil, additional excavation and soil sampling is performed, using similar methods. If ground water is encountered in the excavation, ground water samples are collected from the excavation using a clean Teflon® bailer. The ground water samples are collected as described below under "Ground-Water Sampling". Stockpiled soil is placed on plastic and covered with plastic, and remains the responsibility of the client. The excavation is backfilled or fenced prior to departure from the site.

Sampling of Stockpiled Soil

One composite soil sample is collected for each 50 cubic yards of stockpiled soil, and for each individual stockpile composed of less than 50 cubic yards. Composite soil samples are obtained by first evaluating relatively high, average, and low areas of hydrocarbon concentration by digging approximately one to two feet into the stockpile and placing the intake probe of a field calibrated OVM against the surface of the soil; and then collecting one sample from the "high" reading area, and three samples from the "average" areas. Samples are collected by removing the top one to two feet of soil, then driving laboratory-cleaned brass sleeves into the soil. The samples are sealed in the sleeves using aluminum foil, plastic caps, and aluminized duct tape; labeled; and promptly placed in iced storage for transport to the laboratory, where compositing will be performed.

Soil Borings

Prior to the drilling of borings and construction of monitoring wells, permits are acquired from the appropriate regulatory agency. In addition to the above-mentioned permits, encroachment permits from the City or State are acquired if drilling of borings offsite in the City or State streets is necessary. Copies of the permits are included in the appendix of the project report. Prior to drilling, Underground Services Alert is notified of our intent to drill, and known underground utility lines and structures are approximately marked.

The borings are drilled by a truck-mounted drill rig equipped with 8- or 10-inch-diameter, hollow-stem augers. The augers are steam-cleaned prior to drilling each boring to minimize the possibility of cross-contamination. After drilling the borings, monitoring wells are constructed in the borings, or neat-cement grout with bentonite is used to backfill the borings to the ground surface.

Borings for ground-water monitoring wells are drilled to a depth of no more than 20 feet below the depth at which a saturated zone is first encountered, or a short distance into a stratum beneath the saturated zone which is of sufficient moisture and consistency to be judged as a perching layer by the field geologist, whichever is shallower. Drilling into a deeper aquifer below the shallowest aquifer can begin only after a conductor casing is properly installed and allowed to set, to seal the shallow aquifer.

Drill Cuttings

Drill cuttings subjectively evaluated as having hydrocarbon contamination at levels greater than 100 parts per million (ppm) are separated from those subjectively evaluated as having hydrocarbon contamination levels less than 100 ppm. Evaluation is based either on subjective evidence of soil discoloration, or on measurements made using a field calibrated OVM. Readings are taken by placing a soil sample into a ziplock type plastic bag and allowing volatilization to occur. The intake probe of the OVM is then inserted into the headspace created in the plastic bag immediately after opening it. The drill cuttings from the borings are placed in labeled 55-gallon drums approved by the Department of Transportation; or on plastic at the site, and covered with plastic. The cuttings remain the responsibility of the client.

Soil Sampling in Borings

Soil samples are collected at no greater than 5-foot intervals from the ground surface to the total depth of the borings. The soil samples are collected by advancing the boring to a point immediately above the sampling depth, and then driving a California-modified, split-spoon sampler containing brass sleeves through the hollow center of the auger into the soil. The sampler and brass sleeves are laboratory-cleaned, steam-cleaned, or washed thoroughly with Alconox® and water, prior to each use. The sampler is driven with a standard 140-pound hammer repeatedly dropped 30 inches. The number of blows to drive the sampler each successive six inches are counted and recorded to evaluate the relative consistency of the soil.

The samples selected for laboratory analysis are removed from the sampler and quickly sealed in their brass sleeves with aluminum soil, plastic caps, and aluminized duct tape. The samples are then be labeled, promptly placed in iced storage, and delivered to a laboratory certified by the State of California to perform the analyses requested.

One of the samples in brass sleeves not selected for laboratory analysis at each sampling interval is tested in the field using an OVM that is field calibrated at the beginning of each day it is used. This testing is performed by inserting the intake probe of the OVM into the headspace created in the plastic bag containing the soil sample as described in the Drill Cuttings section above. The OVM readings are presented in Logs of Borings included in the project report.

Logging of Borings

A geologist is present to log the soil cuttings and samples using the Unified Soil Classification System. Samples not selected for chemical analysis, and the soil in the sampler shoe, are extruded in the field for inspection. Logs include texture, color, moisture, plasticity, consistency, blow counts, and any other characteristics noted. Logs also include subjective evidence for the presence of hydrocarbons, such as soil staining, noticeable or obvious product odor, and OVM readings.

Monitoring Well Construction

Monitoring wells are constructed in selected borings using clean 2- or 4-inch-diameter, thread-jointed, Schedule 40 polyvinyl chloride (PVC) casing. No chemical cements, glues, or solvents are used in well construction. Each casing bottom is sealed with a threaded end-plug, and each casing top with a locking plug. The screened portions of the wells are constructed of machine-slotted PVC casing with 0.020-inch-wide (typical) slots for initial site wells. Slot size for subsequent wells may be based on sieve analysis and/or well development data. The screened sections in ground-water monitoring wells are placed to allow monitoring during seasonal fluctuations of ground-water levels.

The annular space of each well is backfilled with No. 2 by 12 sand, or similar sorted sand, to approximately two feet above the top of the screened casing for initial site wells. The sand pack grain size for subsequent wells may be based on sieve analysis and/or well development data. A 1- to 2-foot-thick bentonite plug is placed above the sand as a seal against cement entering the filter pack. The remaining annulus is then backfilled with a slurry of water, neat cement, and bentonite to approximately one foot below the ground surface.

An aluminum utility box with a PVC apron is placed over each wellhead and set in concrete placed flush with the surrounding ground surface. Each wellhead cover has a seal to protect the monitoring well against surface-water infiltration and requires a special wrench to open. The design discourages vandalism and reduces the possibility of accidental disturbance of the well.

Ground-Water Monitoring Well Development

The monitoring wells are developed by bailing or over-pumping and surge-block techniques. The wells are either bailed or pumped, allowed to recharge, and bailed or pumped again until the water removed from the wells is determined to be clear. Turbidity measurements (in NTUs) are recorded during well development and are used in evaluating well development. The development method used, initial turbidity measurement, volume of water removed, final turbidity measurement, and other pertinent field data and observations are included in reports. The wells are allowed to equilibrate for at least 48 hours after development prior to sampling. Water generated by well development will be stored in 17E Department of Transportation (DOT) 55-gallon drums on site and will remain the responsibility of the client.

Ground-Water Sampling

The static water level in each well is measured to the nearest 0.01-foot using a Solinst® electric water-level sounder or oil/water interface probe (if the wells contain floating product) cleaned with Alconox® and water before use in each well. The liquid in the onsite wells is examined for visual evidence of hydrocarbons by gently lowering approximately half the length of a Teflon® bailer (cleaned with Alconox® and water) past the air/water interface. The sample is then retrieved and inspected for floating product, sheen, emulsion, color, and clarity. The thickness of floating product detected is recorded to the nearest 1/8-inch.

Wells which do not contain floating product are purged using a submersible pump. The pump, cables, and hoses are cleaned with Alconox® and water prior to use in each well. The wells are purged until withdrawal is of sufficient duration to result in stabilized pH, temperature, and electrical conductivity of the water, as measured using portable meters calibrated to a standard buffer and conductivity standard. If the well becomes dewatered, the water level is allowed to recover to at least 80 percent of the initial water level. Prior to the collection of each ground water sample, the Teflon® bailer is cleaned with Alconox® and rinsed with tap water and deionized water, and the latex gloves worn by the sampler changed. Hydrochloric acid is added to the sample vials as a preservative (when applicable). A sample method blank is collected by pouring distilled water into the bailer and then into sample vials. A sample of the formation water is then collected from the surface of the water in each of the wells using the Teflon® bailer. The water samples are then gently poured into laboratory-cleaned, 40-milliliter (ml) glass vials, 500 ml plastic bottles or 1-liter glass bottles (as required for specific laboratory analysis) and sealed with Teflon®-lined caps, and inspected for air bubbles to check for headspace, which would allow volatilization to occur. The samples are then labeled and promptly placed in iced storage. A field log of well evacuation procedures and parameter monitoring is maintained. Water generated by the purging of wells is stored in 17E DOT 55-gallon drums onsite and remains the responsibility of the client.

Vadose-Zone Sampling

Vapor readings are made with a field calibrated OVM, which has a lower detection limit of 0.1 ppm. Prior to purging each vadose-zone monitoring well, an initial reading is taken inside the well by connecting the tubing of the OVM to a tight fitting at the top of the well. Each vadose-zone monitoring well is then purged for approximately 60 seconds using an electric vacuum pump connected to the tight fitting. Ambient readings of the air at the site are taken with the OVM after each well is purged. The OVM is then connected to the well fitting, and the reading recorded. The well is then again purged for approximately 30 seconds, and again measured using the OVM. These purging and measuring procedures are repeated until two consecutive OVM readings are within ten percent of each other.

Sample Labeling and Handling

Sample containers are labeled in the field with the job number, sample location and depth, and date, and promptly placed in iced storage for transport to the laboratory. A Chain of Custody Record is initiated by the field geologist and updated throughout handling of the samples, and accompanies the samples to a laboratory certified by the State of California for the analyses requested. Samples are transported to the laboratory promptly to help ensure that recommended sample holding times are not exceeded. Samples are properly disposed of after their useful life has expired.

Aquifer Testing

Bailer Test

The initial water level is measured in the test well, and water bailed from the test well using a Teflon® bailer and cable cleaned with Alconox® and water. Pressure transducers are used to measure water levels in the test well during drawdown and partial recovery phases, over a minimum period of approximately one to two hours. The bailing rate for the designated test well is recorded.

Pumping Test

The initial water levels in wells to be used during the test are measured prior to commencement of pumping. The flow rate of the pump is adjusted to the desired pumping rate, and water levels allowed to recover to initial levels. Pumping then begins, and the starting time of pumping is recorded. Drawdowns in observation wells are recorded at intervals throughout pumping using pressure transducers. Evacuated water is stored in a storage tank at the site and remains the responsibility of the client. After the pump is shut off, recovery measurements are taken in the wells until recovery is at least 80 percent of the initial water level. Barometric pressure and tidal information are collected for the time interval of the pumping test to allow screening of possible effects of atmospheric pressure and tidal fluctuations on the ground water levels.

APPENDIX B

PUMP TEST METHODS & RESULTS

PUMP TEST METHODS & RESULTS

Local Hydraulic Gradient. The magnitude of the hydraulic gradient as determined from water level data for the day of the test is approximately 2.9×10^{-2}. The direction of flow is to the south-southwest. This observed pattern is consistent with previously determined water levels. A ground water elevation map for the day of the pump test is provided in on Plate 5.

Well Development. It was presumed that the well had not been developed, however, as it was constructed in conjunction with the emplacement of the gravel backfill, development was not deemed necessary. The well completion was not a limiting factor in the amount of water which could be pumped.

Step-Drawdown Test. A step-drawdown test was performed on April 11, 1991 to determine the optimum pumping rate at which to perform the constant discharge test. It was observed that the water levels in the two wells in the backfill (W-1 and W-2) dropped very uniformly, as if a container were being emptied. It was concluded that the best approach would be to pump water out at the maximum rate that the pump/discharge system was capable of as a way of dewatering the gravel backfill. Nearby monitoring well MW-4 showed a significant decline in water level which continued even after the cessation of pumpage.

Floating Product and Discharge Disposal. No floating product was encountered in the course of the test. The discharge water was contained in a 6,500 gallon Baker tank.

Methods. The well was pumped using a submersible pump. The pumping rate was the maximum possible, approximately 9 gpm, with the pump and discharge configuration. The discharge rate was determined using both a flow meter and a calibrated five gallon bucket with a stopwatch for the step-drawdown test and with the flowmeter for the constant discharge test. Initial water level measurements were obtained for all wells before the start of pumping. Water level measurements were obtained using an electric depth sounder. Water levels were measured at 30 minute intervals during the early portion of the test. After twelve hours, this time interval was increased to water level measurements once every hour. Water levels were also recorded every five minutes with an In-Situ Hermit datalogger attached to pressure transducers in five of the wells. Because of its distance from the site, no pressure transducer was used in well MW-3. After pumping for 636 minutes, the pump was turned off and recovery data were obtained for 20 hours.

Results. Well W-2 was pumped at a rate of 9.0 gpm (= 1730 ft^3/d) for the first 10.5 hours of the test. The drawdown in the pumping well reached approximately 4 feet at the same time that the Baker tank filled. Although the Baker tank was supposed to hold 6,500 gallons, the total discharge as determined from the totalizer on the flowmeter and from multiplying the discharge rate times the time is closer to 5,500 gallons. There was good agreement between the bucket method and the flowmeter method for determining discharge which supports the fact that the total volume pumped was most likely closer to 5,500 gallons than to 6,500 gallons.

There was reasonably good agreement between the datalogger water level change values and those measured by hand for three of the pressure transducers (MW-2, W-1, and W-2). Water level change as measured by the pressure transducer for MW-1 was only about one third of that measured manually. This may be a function of the small water level changes (around 0.11 feet of drawdown measured manually) observed by both methods, although small water level changes were reasonably accurately recorded by the pressure transducer in MW-2. Values obtained by the pressure transducer for MW-4 were about 14% less than those measured by hand. Datalogger data for pumping drawdown as a function of time are given for the pumping well on Plate B-1. The figure contains both a semi-logarithmic and an arithmetic plot. Data for the five observation wells are presented on Plates B-2 through B-6. Recovery data for the six wells at the site are given on Plates B-7 through B-12. Data in the plots are from the data logger for all wells except MW-3, for which manual measurements are plotted.

The two wells completed in the backfill (W-1 and W-2) do not show typical drawdown curves; these are typically linear on a semi-logarithmic plot. Rather water levels drop in a linear manner with time on the arithmetic plot, as if a container were being evacuated. This linear response reflects the very high hydraulic conductivity and large storage coefficient of the gravel backfill, as well as the limited extent of the backfill material. A very rough estimate of the hydraulic conductivity of the gravel backfill can be made by comparing the differences in saturated aquifer thickness at the end of pumping in wells W-2 and W-1, located 13.5 feet apart. Using the Thiem (1906) equation for an unconfined aquifer, which assumes steady-state conditions:

$$K = \frac{Q \ \ln(r_2/r_1)}{\pi \ (h_2^2 - h_1^2)}$$

where Q = discharge
r_2 = distance to W-1
r_1 = radius of W-2
h_2 = saturated thickness in W-1
h_1 = saturated thickness in W-2

$$K = \frac{1730 \text{ ft}^3/\text{d} \ \ln(13.5 \text{ ft}/ 0.17 \text{ ft})}{3.14 \quad (2.50^2 - 2.32^2)}$$

$$= 2{,}780 \text{ ft/d}$$

Clearly, the field conditions meet neither the assumption of steady-state conditions nor of an infinite aquifer, but the value obtained should be of the correct order of magnitude. This value is within the range of reasonable hydraulic conductivity values for gravel. The water level in the backfill, at a pumping rate of 9.0 gpm, falls at an average rate of 0.34 ft/hr. The rise in water level in the backfill during recovery is approximately 0.011 ft/hr. This indicates that the rate of inflow from the aquifer to the tank backfill is approximately:

$$[(0.011 \text{ ft/hr})/(0.34 \text{ ft/hr})] \times 9.0 \text{ gpm} = 0.29 \text{ gpm}$$

Based on this, it is clear that the aquifer must be several orders of magnitude less permeable than the gravel backfill.

The three more distant observation wells (MW-1, MW-2, and MW-3) showed no response to pumping during the first 10.5 hours of the test, rather they seemed to indicated a slow rise in water levels. MW-4, however, located at a close but undetermined distance (on the order of 10 feet) from the gravel backfill, did show a rapid and significant decline in water level. Again, the usual straight-line, semi-logarithmic plot was not observed, because of the atypicalness of the pump test configuration. The drop in water level appears quite linear on an arithmetic plot. A very rough estimate of the hydraulic conductivity of the aquifer can be made using Darcy's Law and assuming the aquifer is draining more or less uniformly into the backfill from all sides. For an excavation 20 feet by 30 feet in plan view and an initial saturated thickness of approximately 6.7 feet the area cross-sectional (A) to flow is:

$$A = (20 \text{ ft} \times 2 \text{ sides} \times 6.7 \text{ ft}) + (30 \text{ ft} \times 2 \text{ sides} \times 6.7 \text{ ft})$$
$$= 670 \text{ ft}^2$$

For a water level difference (dh) of 2.3 feet towards the end of pumping over a distance (dl) of 10 feet, and a discharge (Q) from the aquifer of 0.29 gpm (56 ft^3/d), the hydraulic conductivity (K) is estimated as:

$$K = Q/(A\ dh/dl) = 58 \text{ ft}^3/\text{d} \ / \ [670 \text{ ft}^2 \times (2.3 \text{ ft}/10 \text{ ft})]$$
$$= 0.37 \text{ ft/d}$$

This value is consistent with the observation that the hydraulic conductivity of the aquifer must be several orders of magnitude less than that of the gravel backfill.

All three distant observation wells in the aquifer began to show a response to the draining of the backfill shortly after the cessation of pumping. Again, the response curves form better straight lines on an arithmetic plot than on a semi-logarithmic plot, making them not amenable to the standard means of interpretation.

Modeling. Because of the uncertainties involved in the analysis of the field data, computer simulation of the field pumping was performed to test the validity of the results obtained above. The U.S. Geological Survey model, MODFLOW (MacDonald and Harbaugh, 1984) was chosen to simulate the response to pumping observed during the field test and to predict the effects of pumping for a prolonged period.

The central portion of the finite difference grid is shown on Plate B-13. The grid extends 1050 feet in each direction beyond the area shown to establish appropriate boundary conditions. The eastern and western boundaries are no-flow boundaries (representing flow lines) and the northern and southern boundaries are constant head boundaries, set so that they reproduce the gradient observed prior to the start of pumping on April 25, 1991. The constant head at the northern boundary was 176.3 feet and at the southern boundary was 123.3 feet. These values provided a good reproduction (Plate B-14) of the water levels observed in the four monitoring wells on that date. The simulated values vary by 0.2 feet or less from the observed values. The bottom of the aquifer is located at 143 feet elevation for the gravel backfill and at a depth of 15 feet below the water table for the aquifer. The first value is based upon the depths of the two gravel pack monitoring wells which are assumed to fully penetrate the backfill. The second value is estimated from the geologic logs, although the bottom of the aquifer is not clearly defined.

The pumping test was simulated by pumping at 9.0 gpm (1,730 ft^3/d) for 10.5 hours followed by a period 18 hours long in which no pumping occurred. A number of different values for hydraulic conductivity and storativity were tried. The ones which provided the best fit to the field data were:

Hydraulic Conductivity Gravel Backfill: 2,000 ft/d
Specific Yield Gravel Backfill: 0.28
Hydraulic Conductivity Aquifer: 0.2 ft/d
Specific Yield Aquifer: 0.01

The hydraulic conductivity values are close to the values obtained above from the field data. The specific yield values were those which gave the closest fit to the observed water level change. The aquifer was treated as homogeneous and isotropic for simplicity's sake, although well logs indicate it is heterogeneous.

A comparison between the manually obtained field data and the simulated water level changes are shown on Plates B-15 through 20. The agreement is very good for the gravel backfill, and reasonably good for MW-4 and MW-2. The model did not indicate as great a water level drop for MW-1 and MW-3 as that observed. This may be due to heterogeneities in the field, particularly in short-term specific yield, which were not taken into account in the modeling. The simulated drawdown at the end of 10.5 hours of pumping is shown on Plate B-21. This agrees well with that observed in the field.

Once a reasonably good match had been achieved to the field data, the model was run in a predictive mode. Well W-2 was pumped at 9.0 gpm for 10.5 hours followed by pumping at various rates for 100 days. The maximum pumping rate that the well could sustain during that time period without running dry was 0.24 gpm. This agrees well with the estimated recharge from the aquifer above of 0.29 gpm. The head distribution at the end of the 100 days of pumping is shown on Plate B-22.

Discussion. Because of the difficulty in analyzing the field data due to the non-typical extraction from the gravel backfill, the values obtained for hydraulic conductivity from the field data and for hydraulic conductivity and storativity from the model calibration can only by viewed as approximations. Particularly uncertain is the value for specific yield for the aquifer. The storage coefficient can vary both with space and with time during pumping, reflecting variations in the way water is released from storage in the porous medium. The poor calibration to the well response at the more distant monitoring wells indicates that, at least for short-term response, the storage coefficient is less than the value of 0.01 obtained in the modeling.

The yield of well W-2, which has been proposed for the extraction well, is relatively low. There is good agreement between the recharge to the backfill (0.29 gpm) and the sustainable pumping rate determined from modeling (0.24 gpm) for a 100 day time period. The utilization of the gravel backfill as a collection sump appears to be a good solution to increase the yield of this aquifer, beyond what could be achieved by a well without large drawdowns.

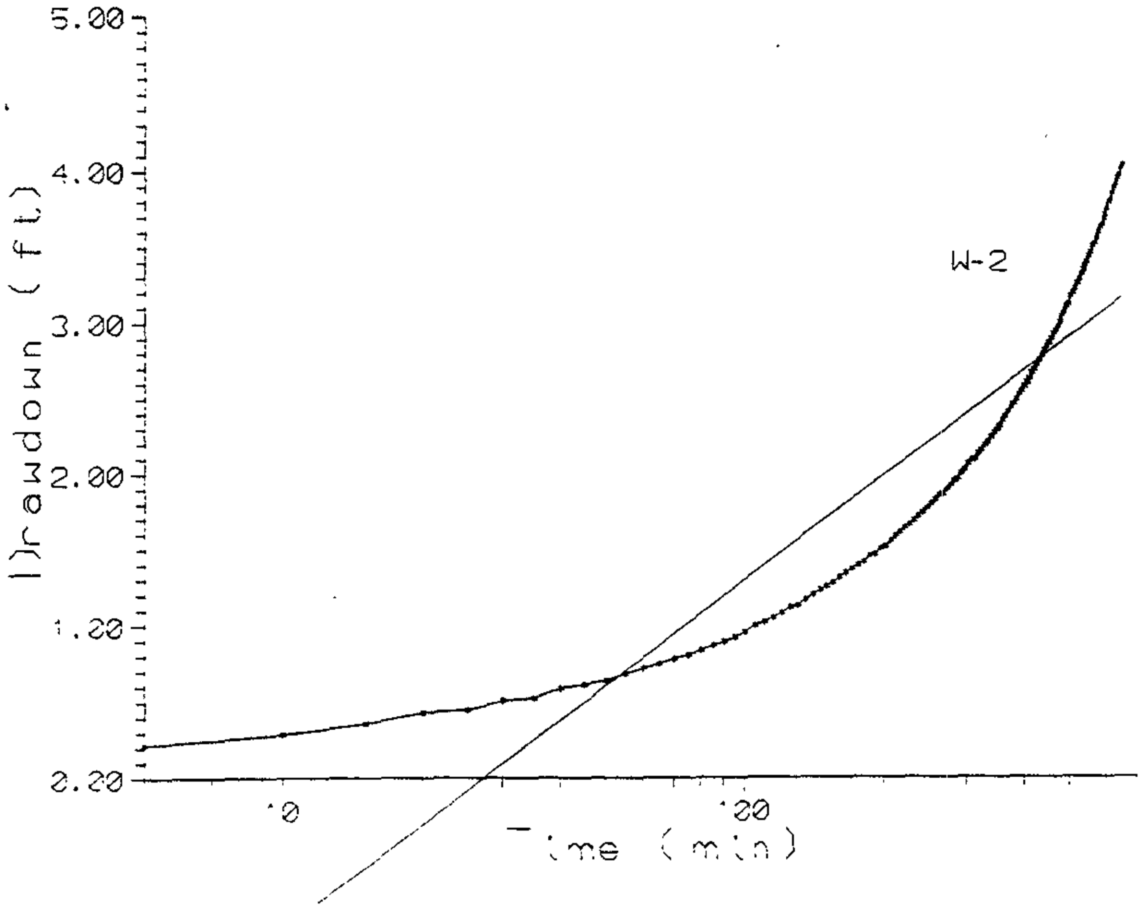
Zone of Capture Calculation. The zone of capture for well W-2 in the excavation backfill is drawn onto the head contours on Plate B-22. The zone is sufficiently large to capture the high concentration portion of the plume, but will not capture portions of the plume which have migrated off-site in the down-gradient direction.

References.

MacDonald, M. G., and A. W. Harbaugh, 1984. A Modular Three-Dimensional Finite-Difference Ground-water Flow Model, U. S. Geological Survey.

Thiem, G., 1906. Hydrologische Methoden. Leipzig: Gebhardt.

Arco #374 Pump Test (4/25/91)



Arco #374 Pump Test (4/25/91)

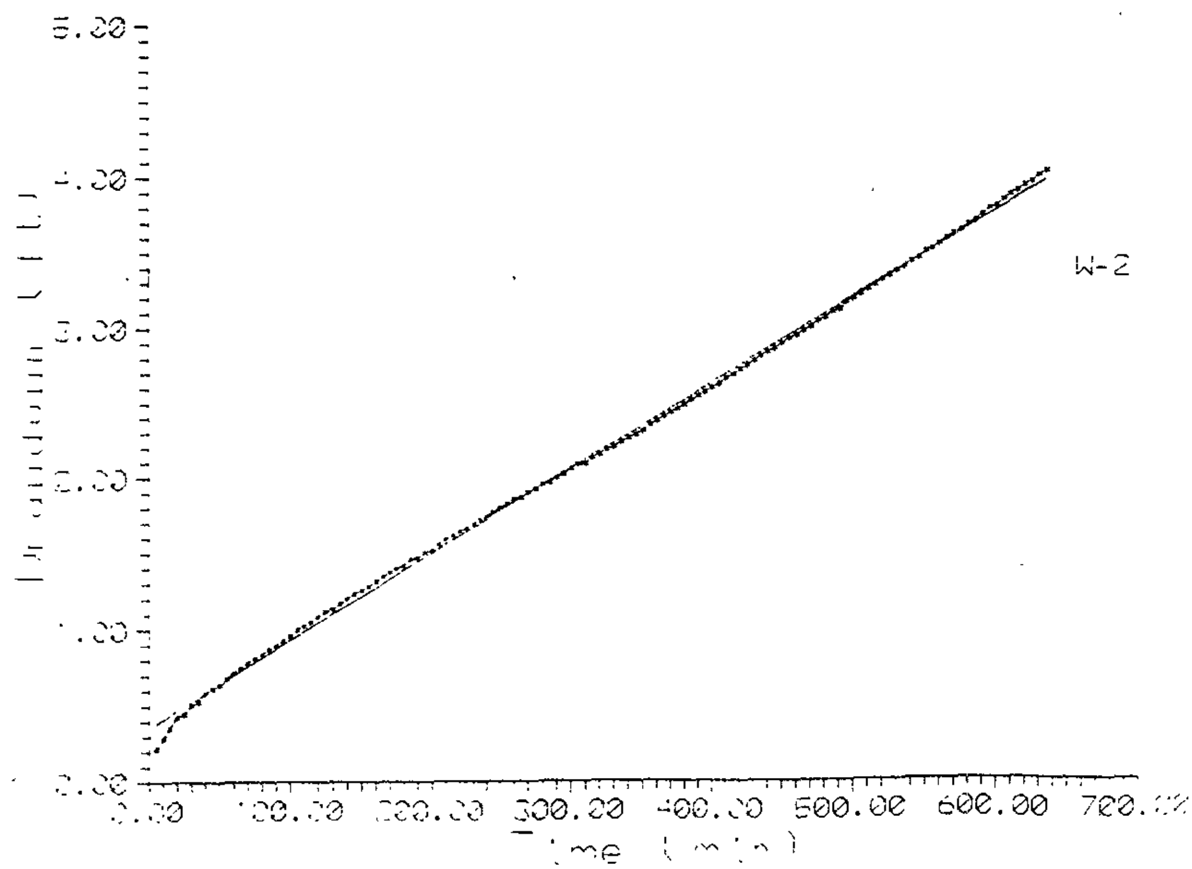
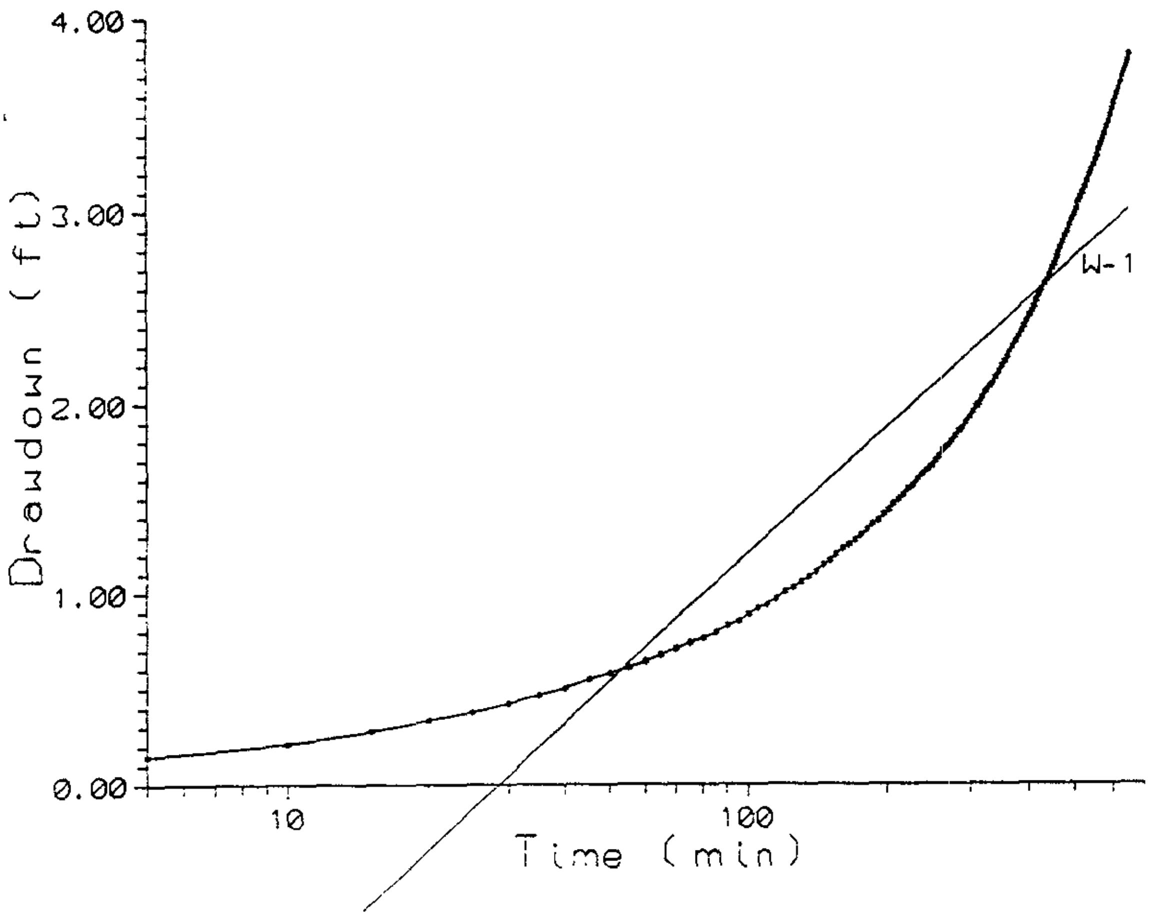


PLATE B-1

Arco #374 Pump Test (4/25/91)



Arco #374 Pump Test (4/25/91)

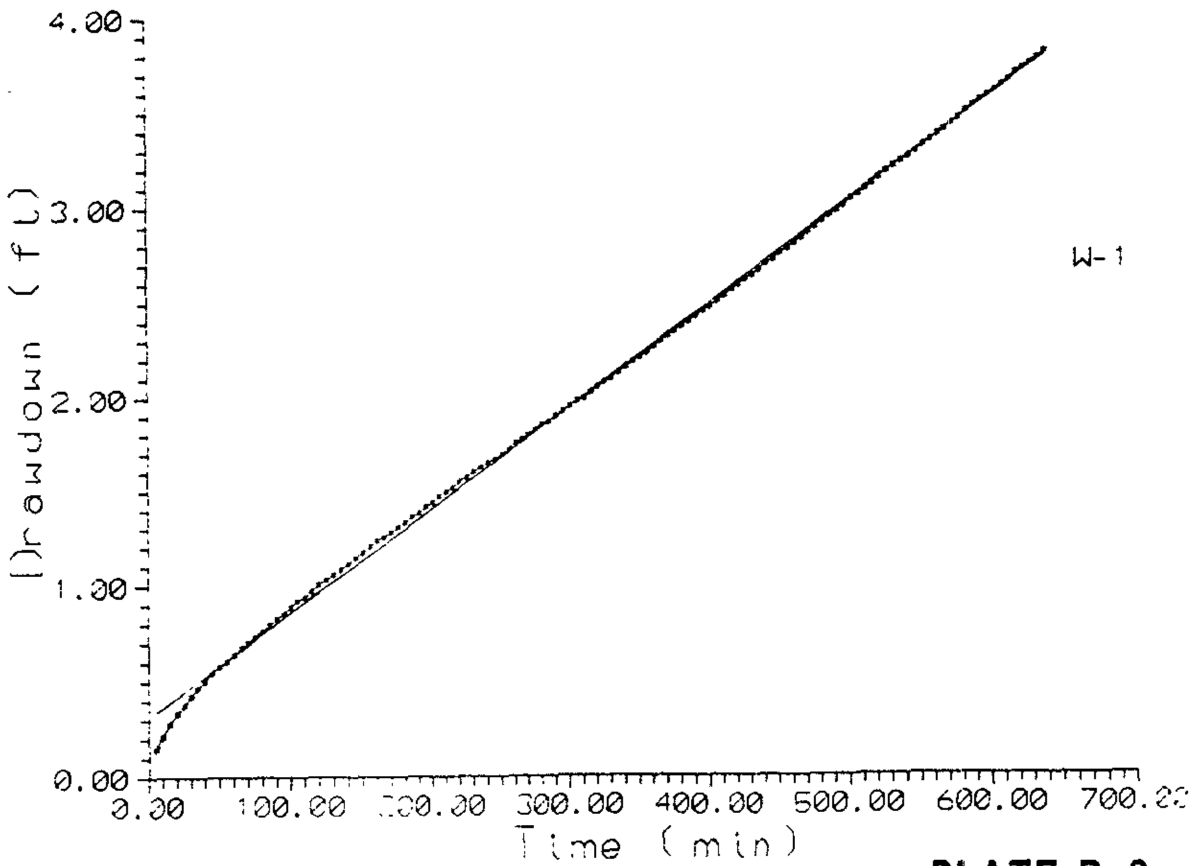
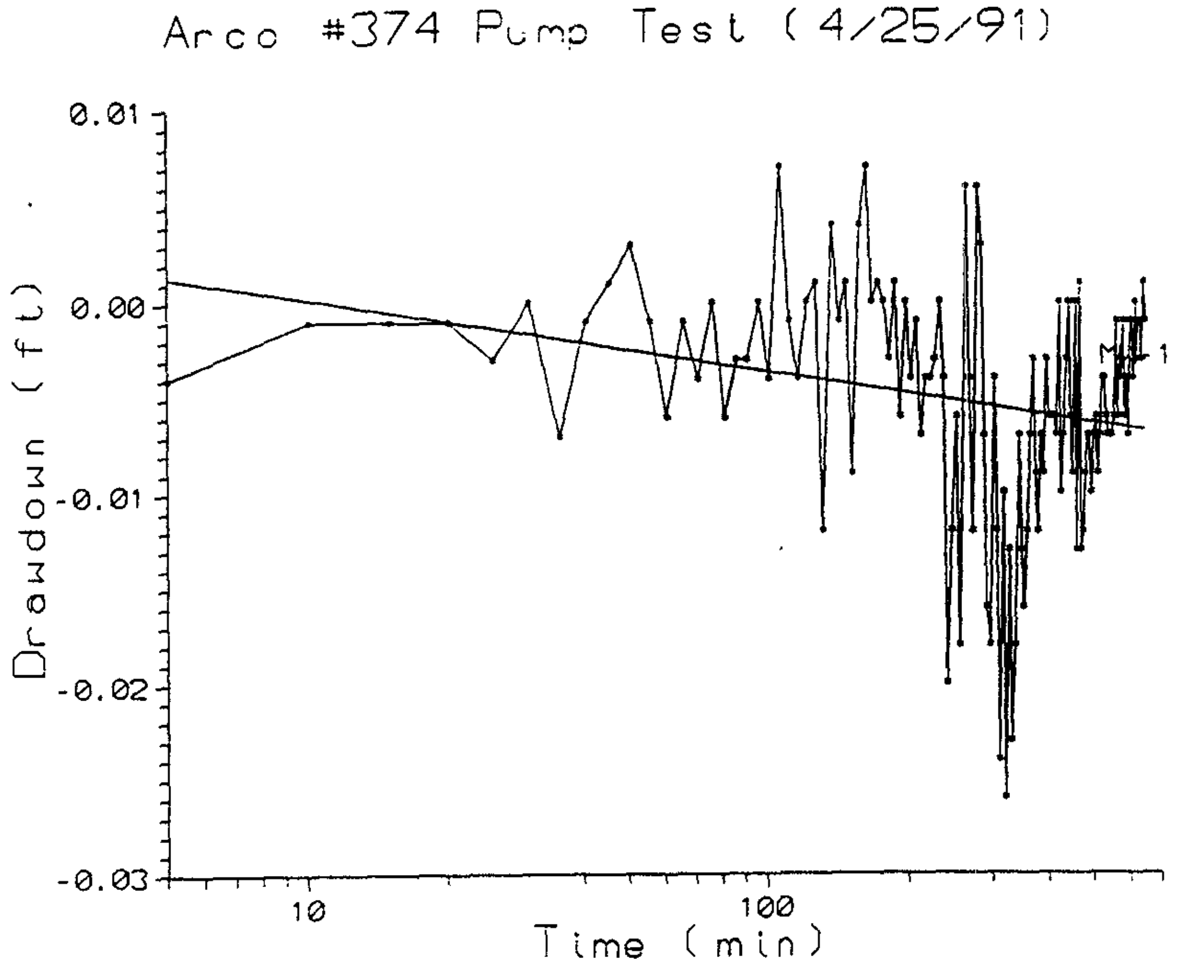
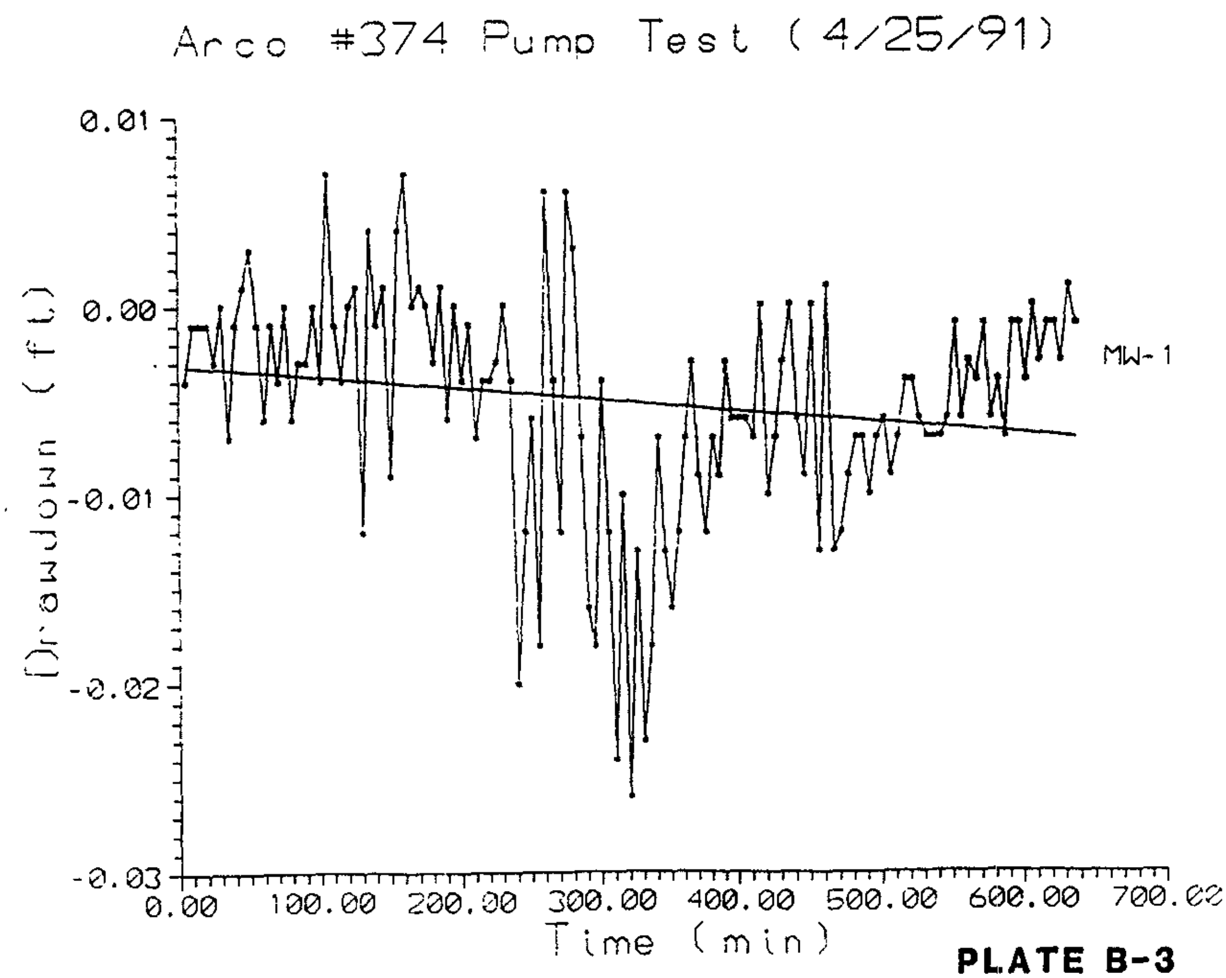


PLATE B-2

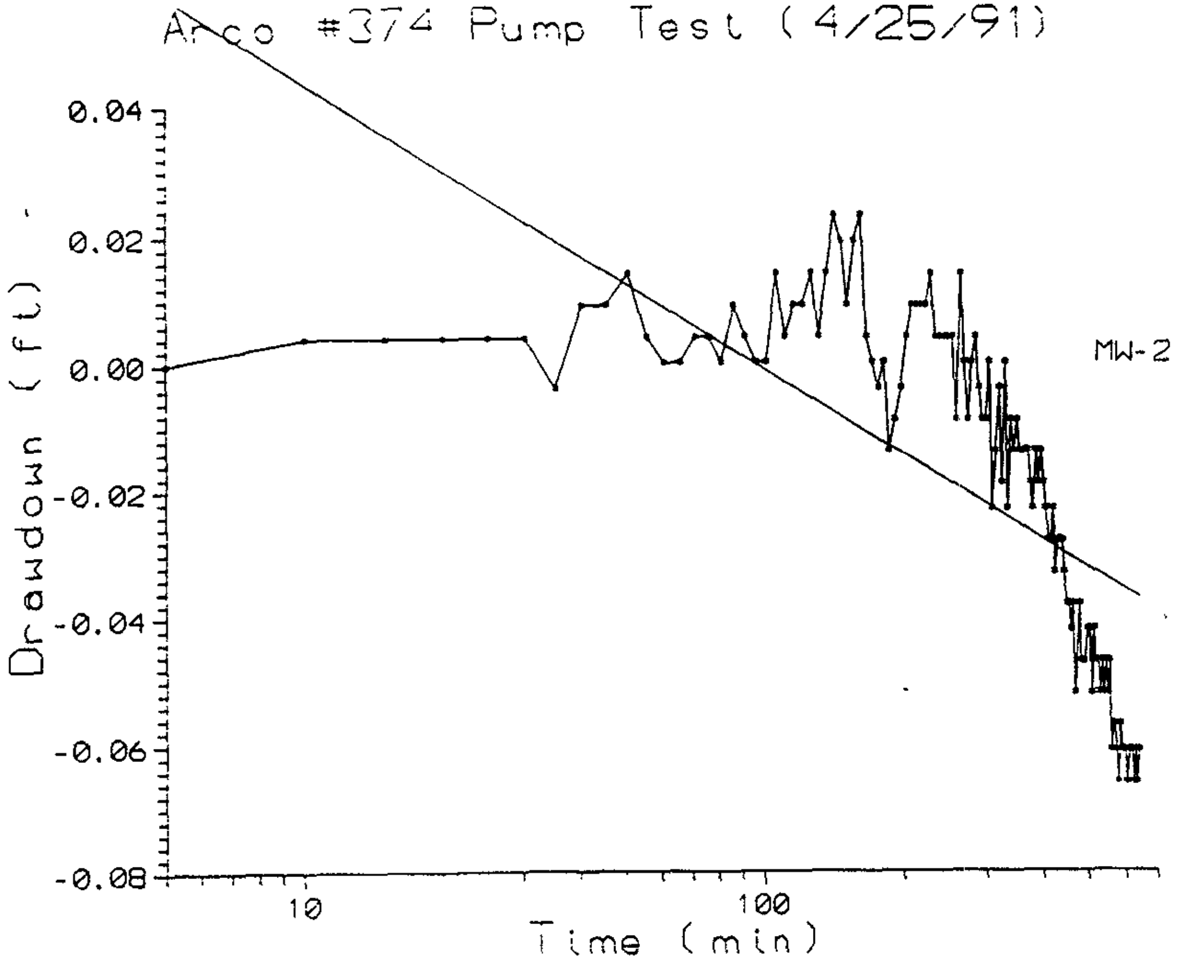


Arco #374 Pump Test (4/25/91)
0.01
0.00
-0.01
-0.02
-0.03
Drawdown (ft)
10
100
Time (min)
MW-1



Arco #374 Pump Test (4/25/91)
0.01
0.00
-0.01
-0.02
-0.03
Drawdown (ft)
0.00
100.00
200.00
300.00
400.00
500.00
600.00
Time (min)
MW-1

PLATE B-3


Arco #374 Pump Test (4/25/91)
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
Drawdown (ft)
MW-2
10
100
Time (min)

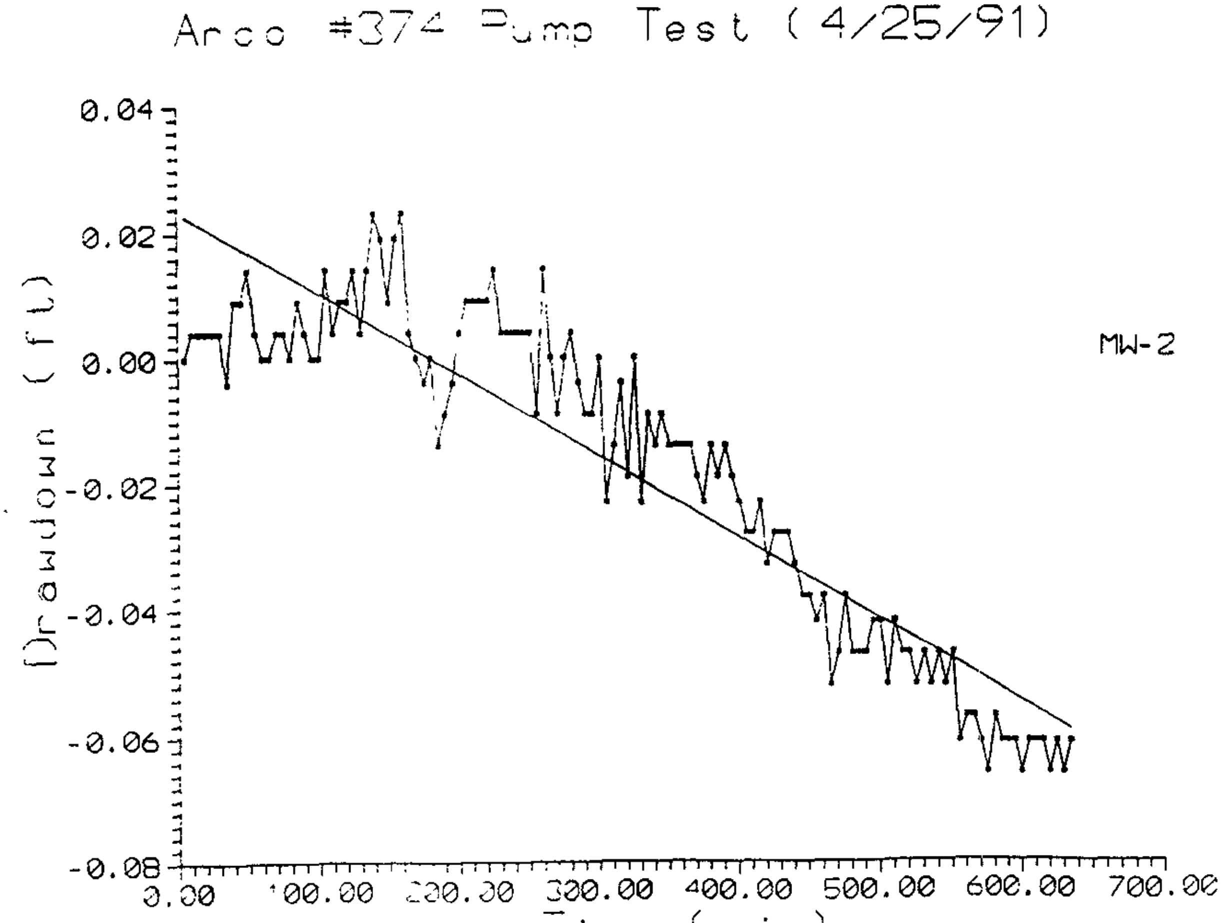
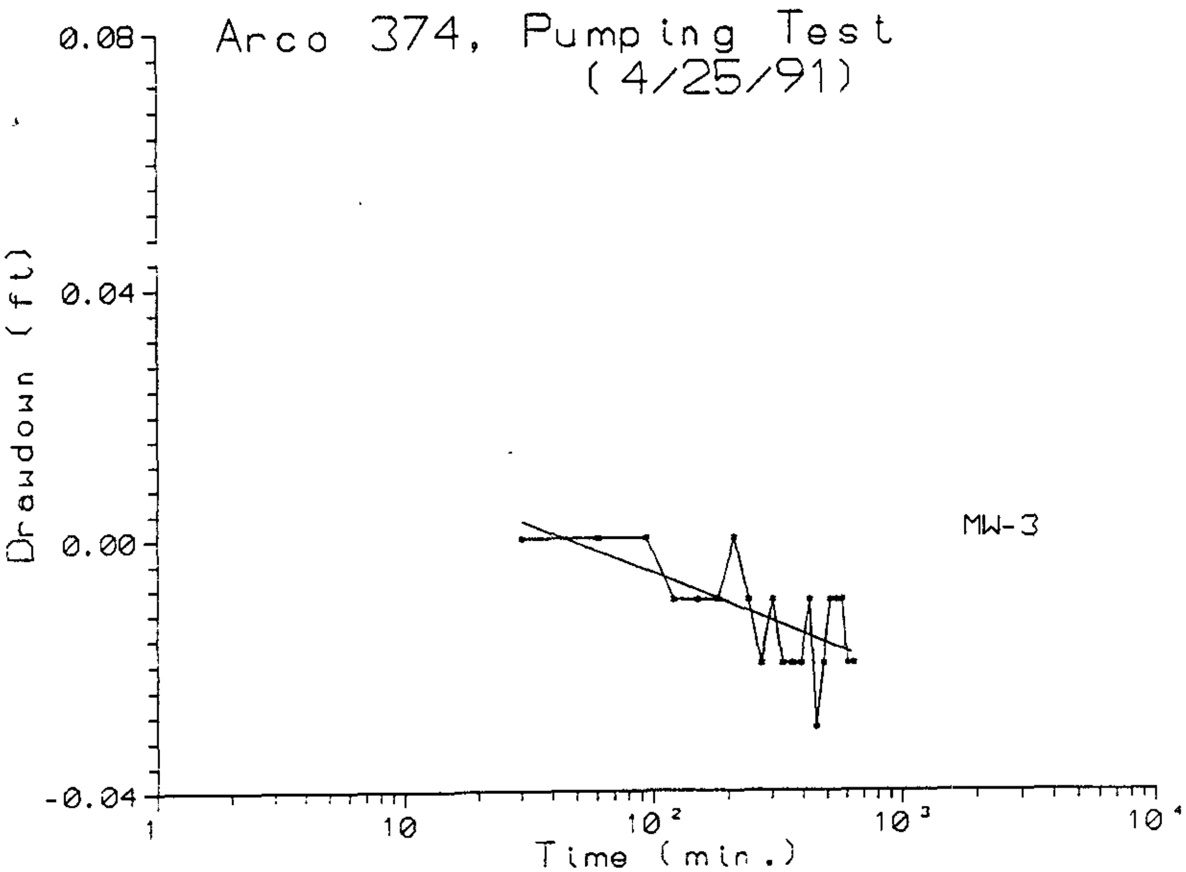

Arco #374 Pump Test (4/25/91)
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
Drawdown (ft)
MW-2
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
Time (min)

PLATE B-4


Arco 374, Pumping Test
(4/25/91)
0.08
0.04
0.00
-0.04
Drawdown (ft)
MW-3
1
10
10²
10³
10⁴
Time (min.)

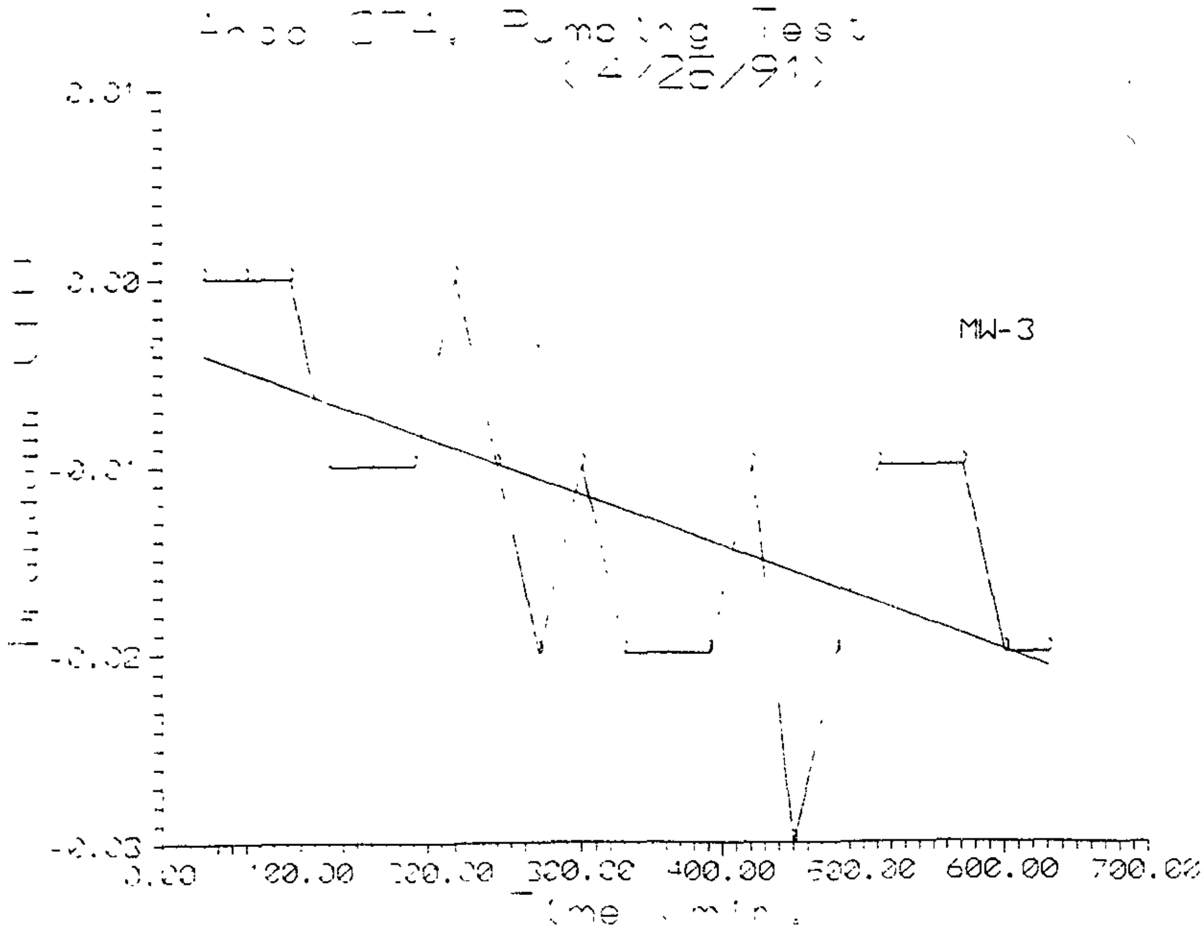
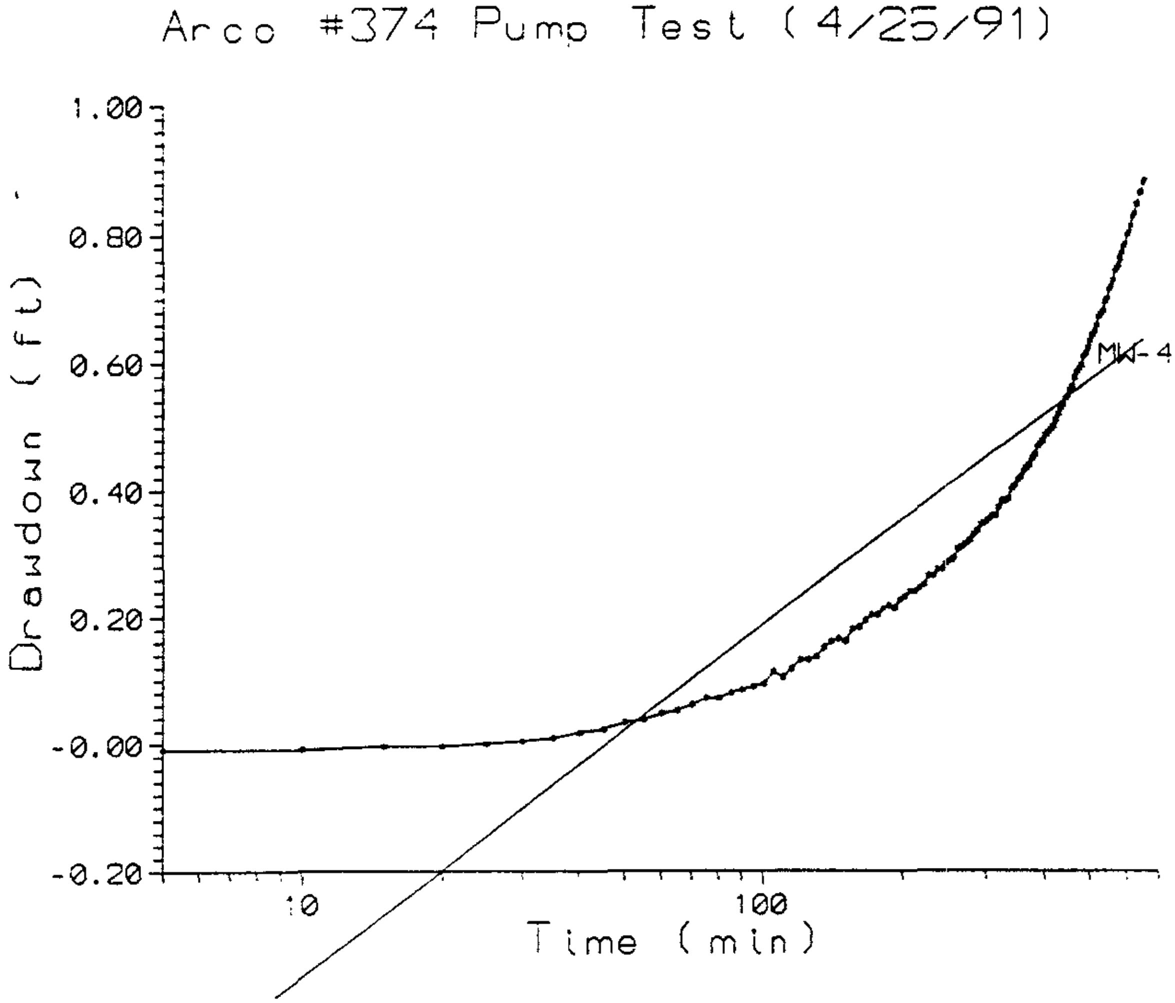

MW-3
100.00
200.00
300.00
400.00
500.00
600.00
700.00

PLATE B-5


Arco #374 Pump Test (4/25/91)
Drawdown (ft)
1.00
0.80
0.60
0.40
0.20
-0.00
-0.20
MW-4
10
100
Time (min)

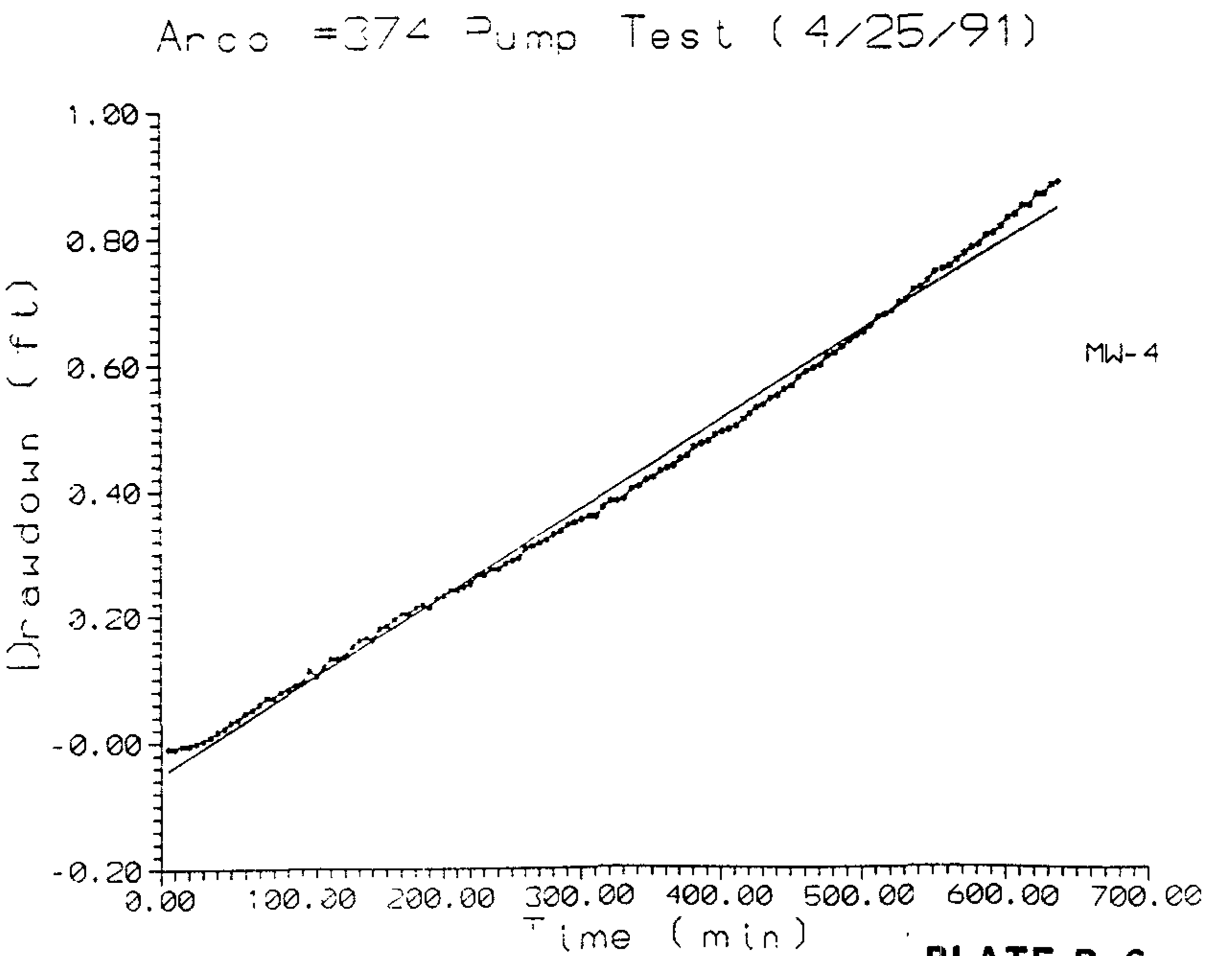
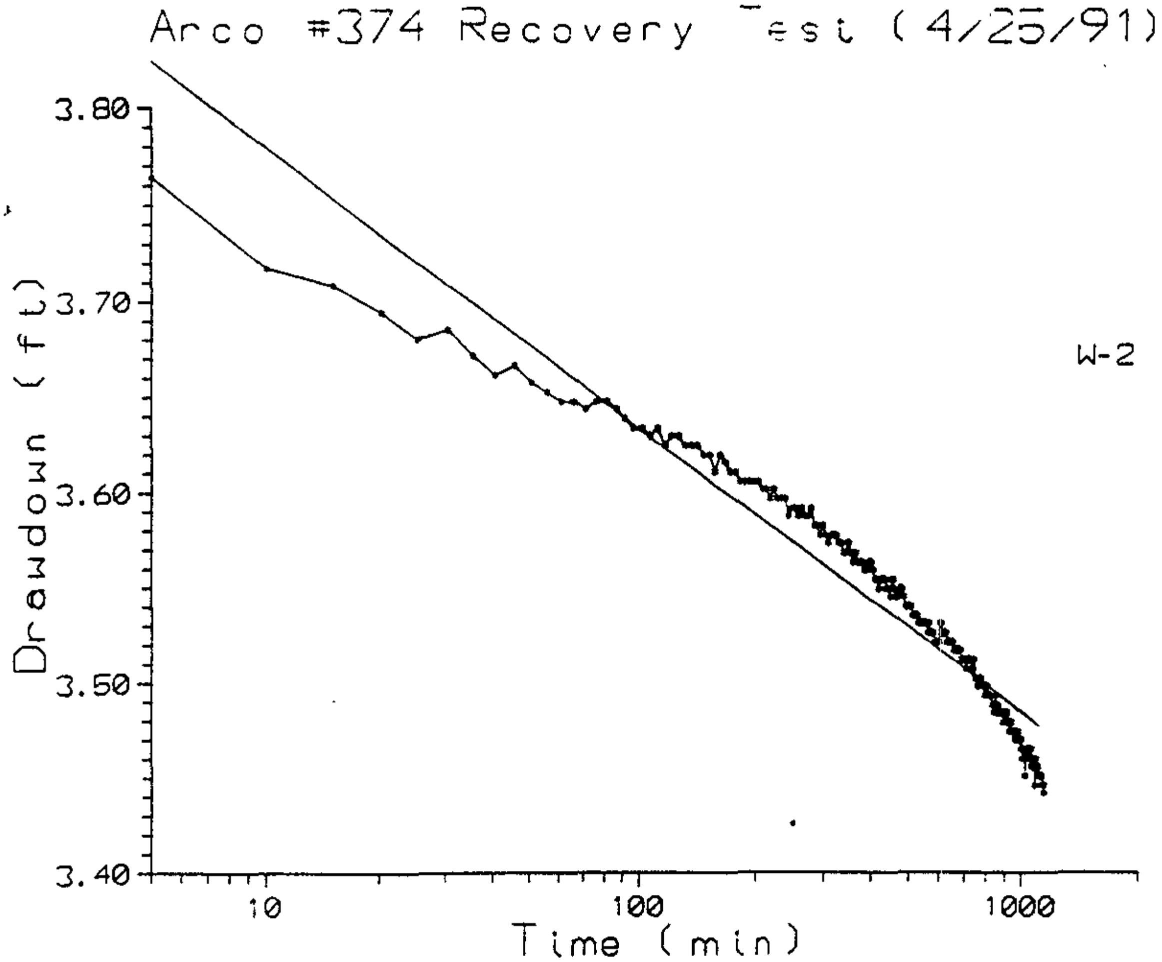
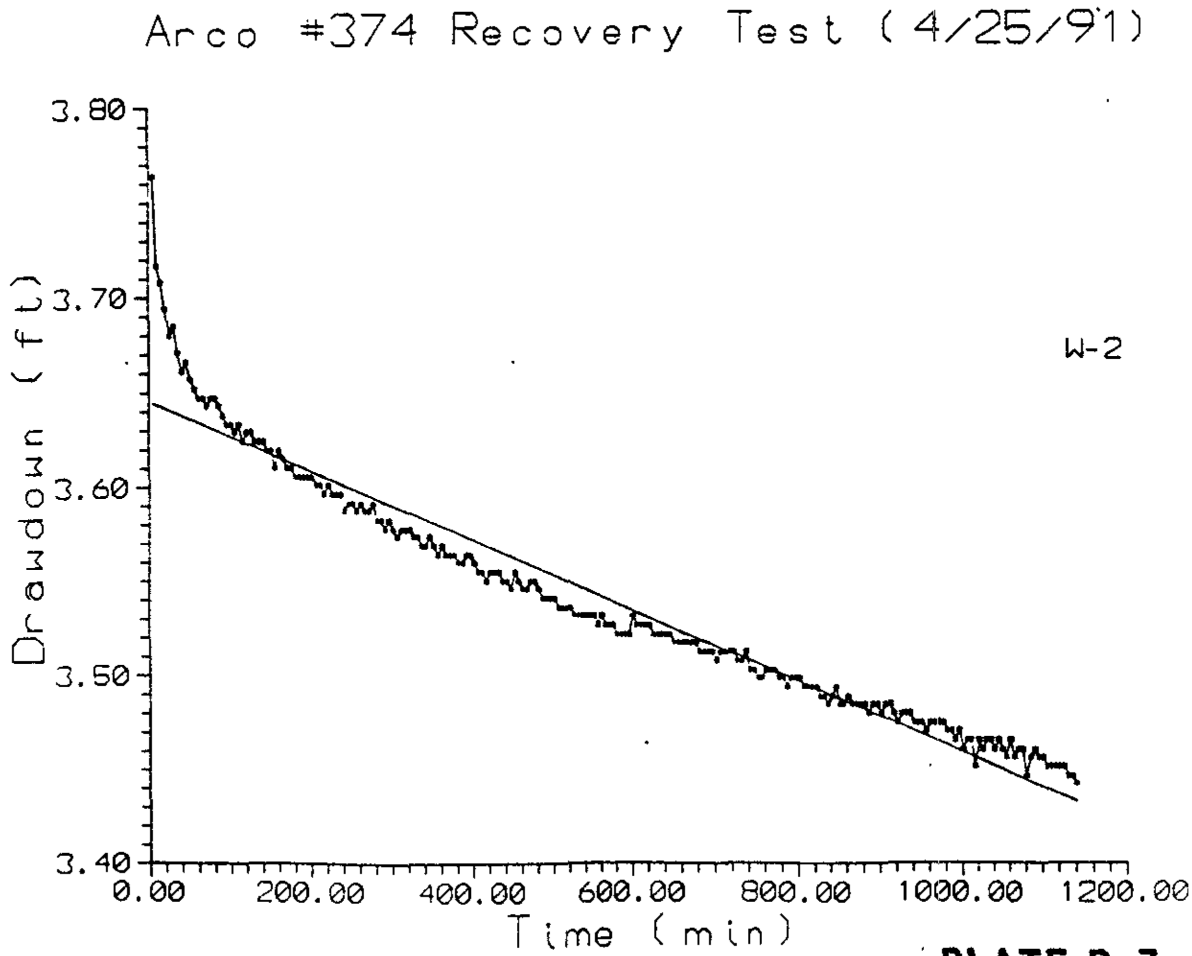

Arco #374 Pump Test (4/25/91)
Drawdown (ft)
1.00
0.80
0.60
0.40
0.20
-0.00
-0.20
MW-4
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
Time (min)

PLATE B-6



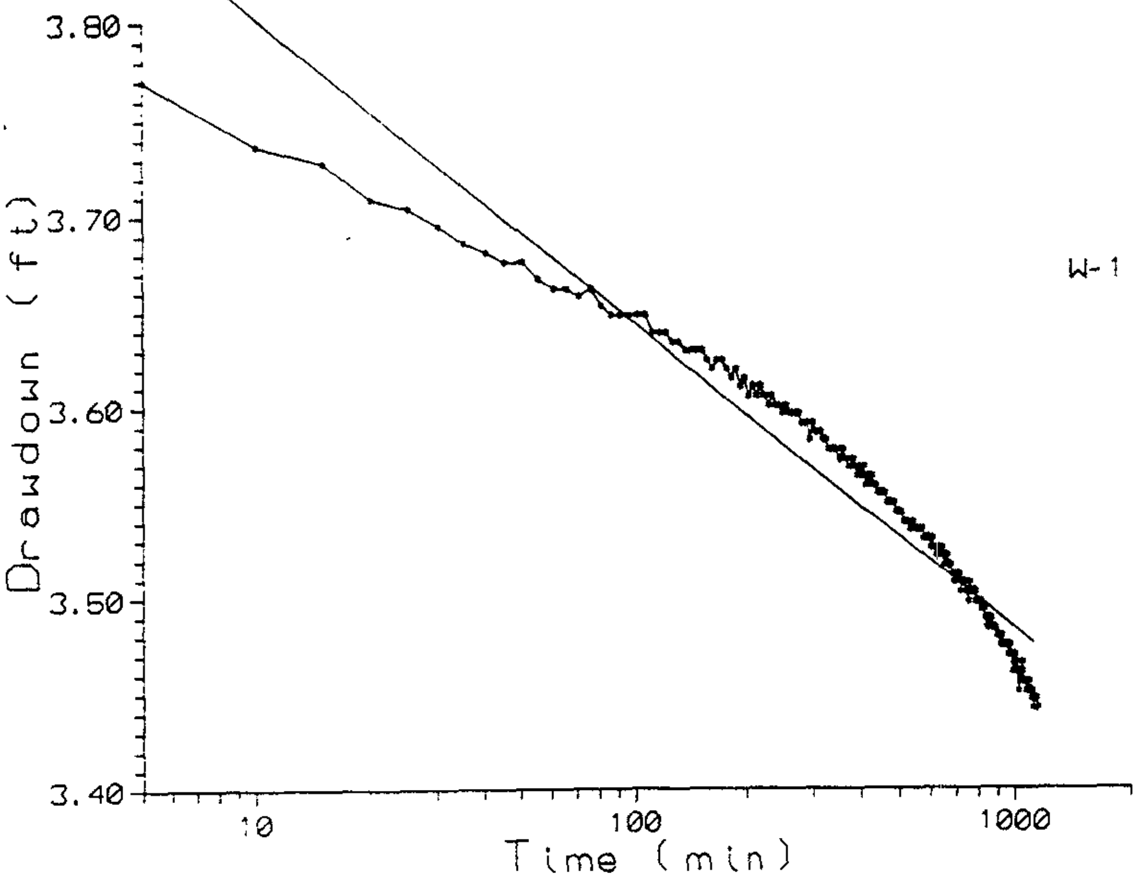
Arco #374 Recovery Test (4/25/91)
3.80
3.70
3.60
3.50
3.40
Drawdown (ft)
W-2
10
100
1000
Time (min)



Arco #374 Recovery Test (4/25/91)
3.80
3.70
3.60
3.50
3.40
Drawdown (ft)
W-2
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
Time (min)

PLATE B-7

Arco #374 Recovery Test (4/25/91)



Arco #374 Recovery Test (4/25/91)

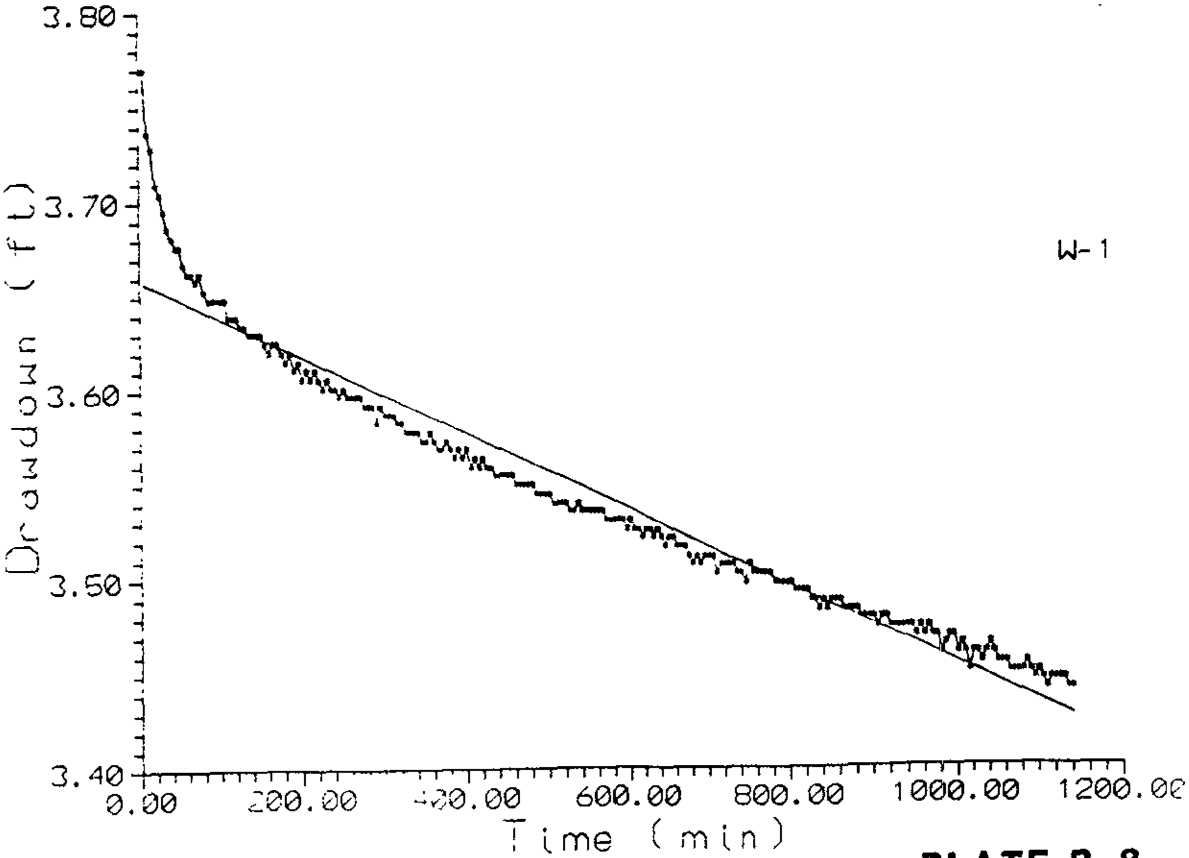
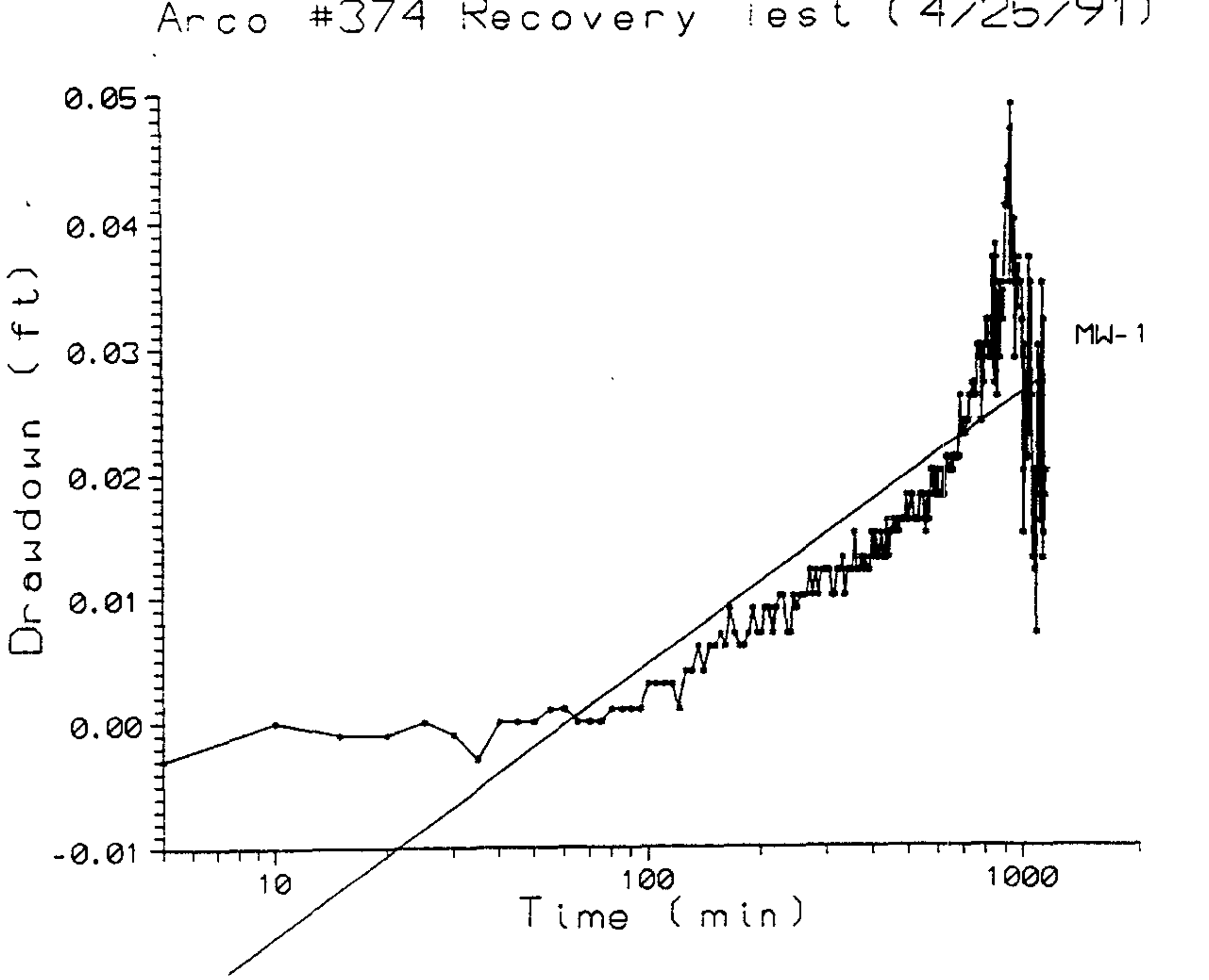
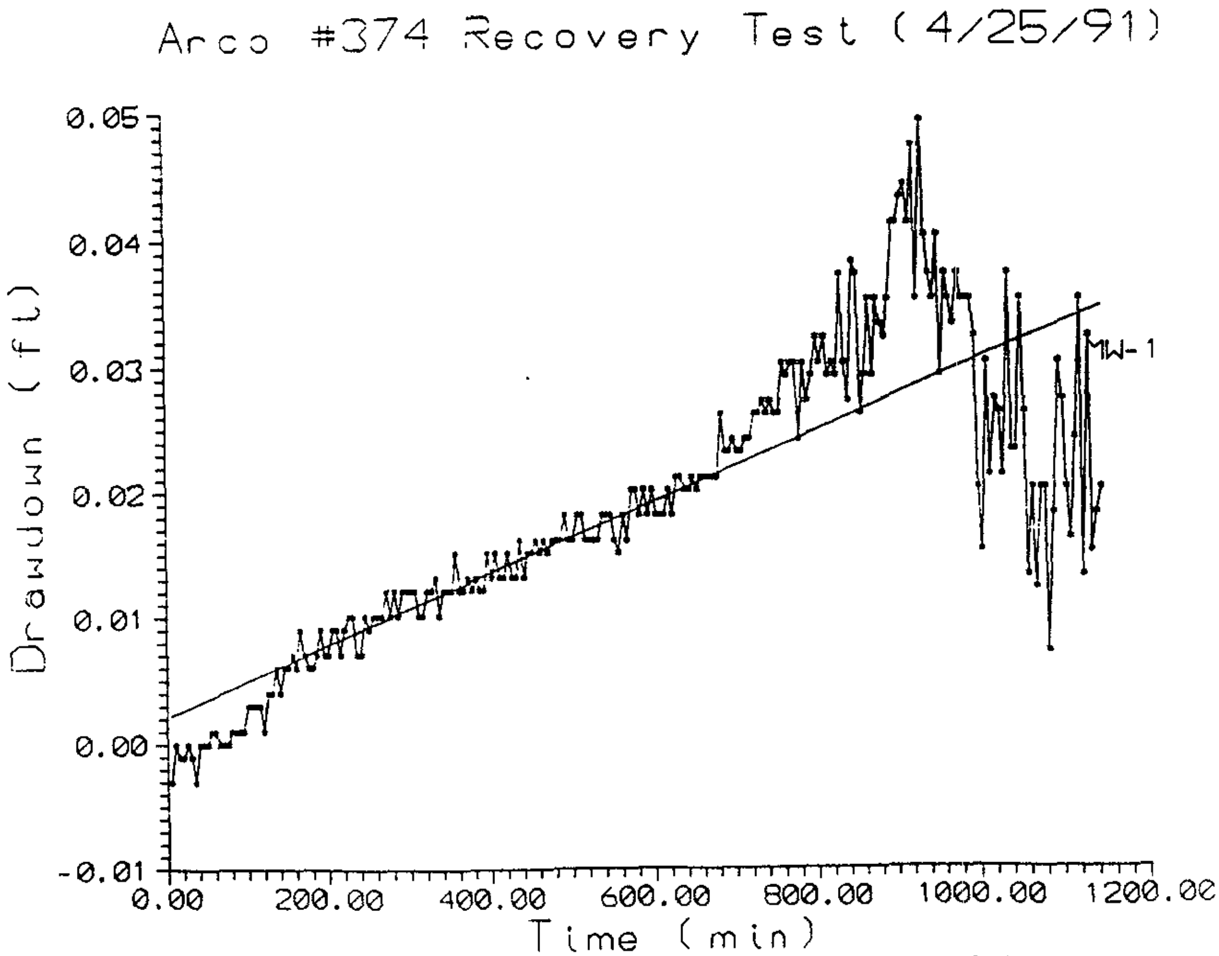


PLATE B-8

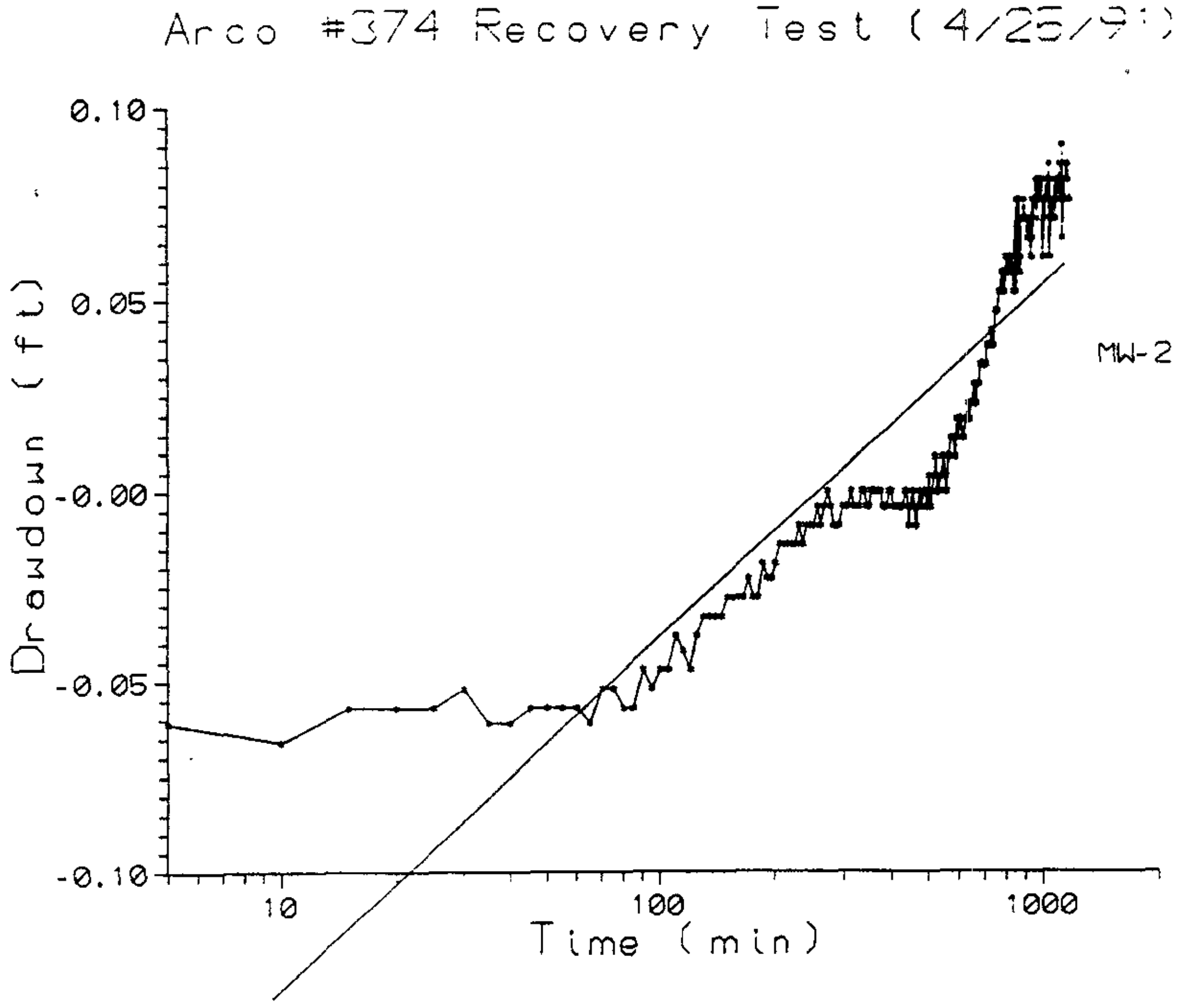


Arco #374 Recovery Test (4/25/91)
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
Drawdown (ft)
10
100
1000
Time (min)
MW-1



Arco #374 Recovery Test (4/25/91)
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
Drawdown (ft)
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
Time (min)
MW-1

PLATE B-9


Arco #374 Recovery Test (4/25/91)
0.10
0.05
-0.00
-0.05
-0.10
Drawdown (ft)
10
100
1000
Time (min)
MW-2

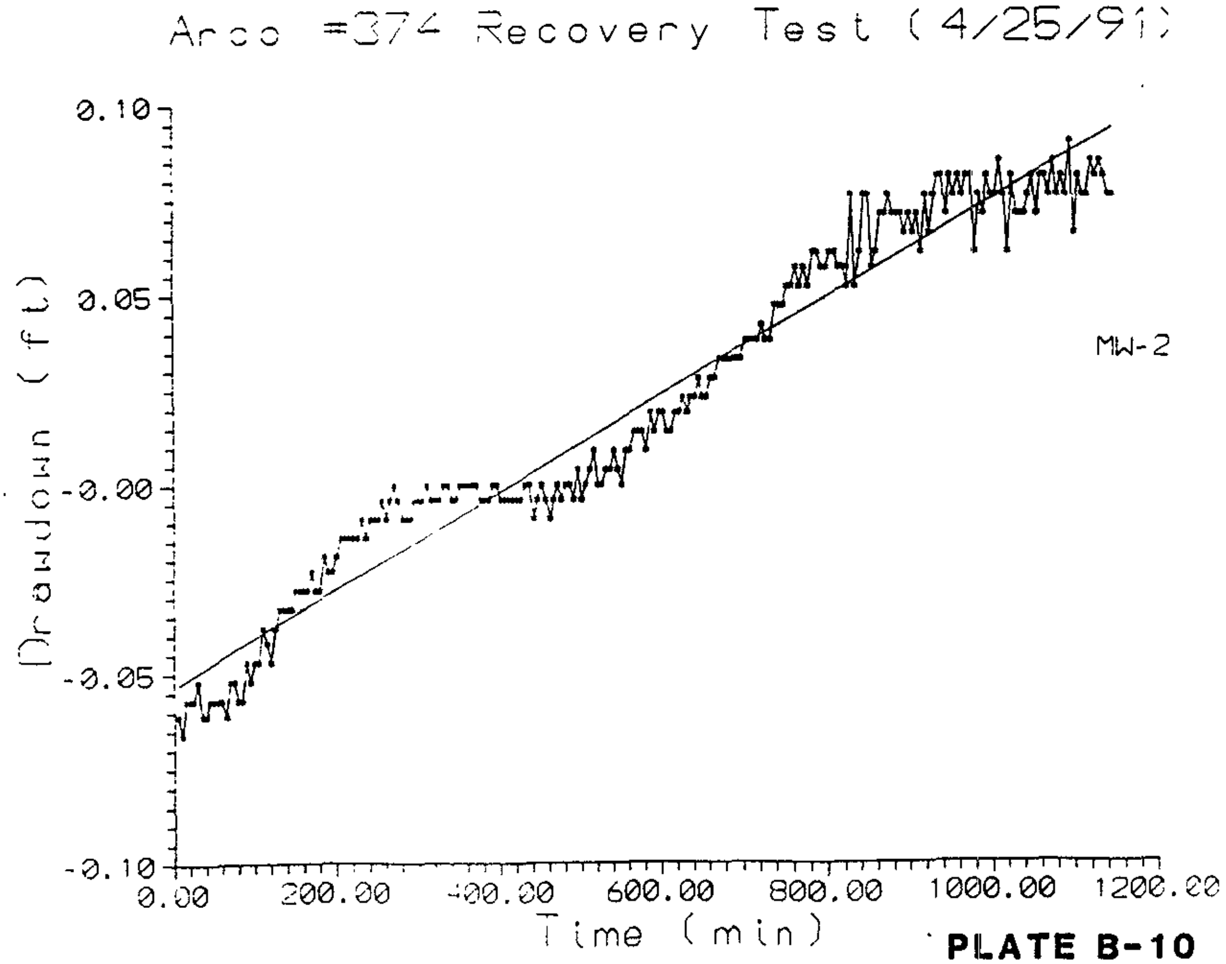
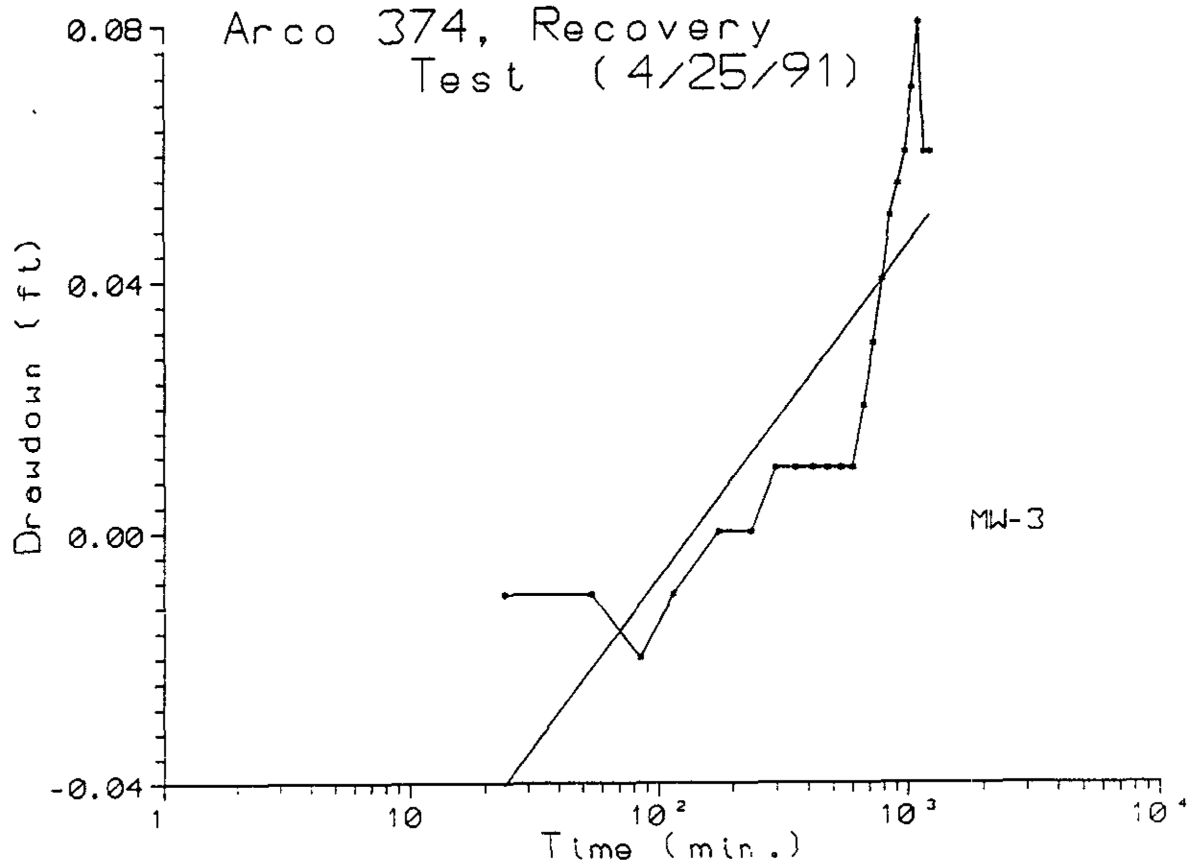

Arco #374 Recovery Test (4/25/91)
0.10
0.05
-0.00
-0.05
-0.10
Drawdown (ft)
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
Time (min)
MW-2

PLATE B-10


Arco 374, Recovery
Test (4/25/91)
0.08
0.04
0.00
-0.04
Drawdown (ft)
1
10
10²
10³
10⁴
Time (min.)
MW-3

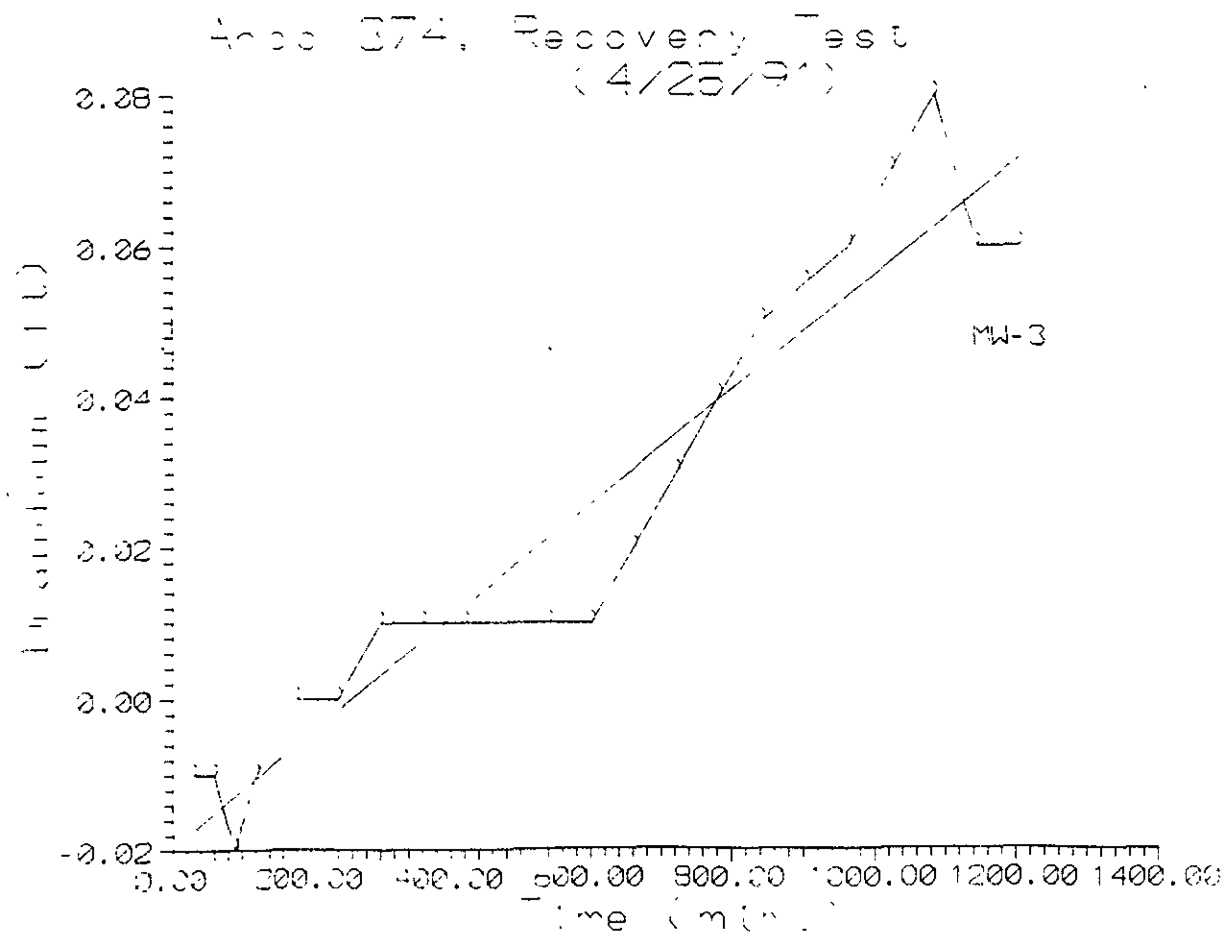
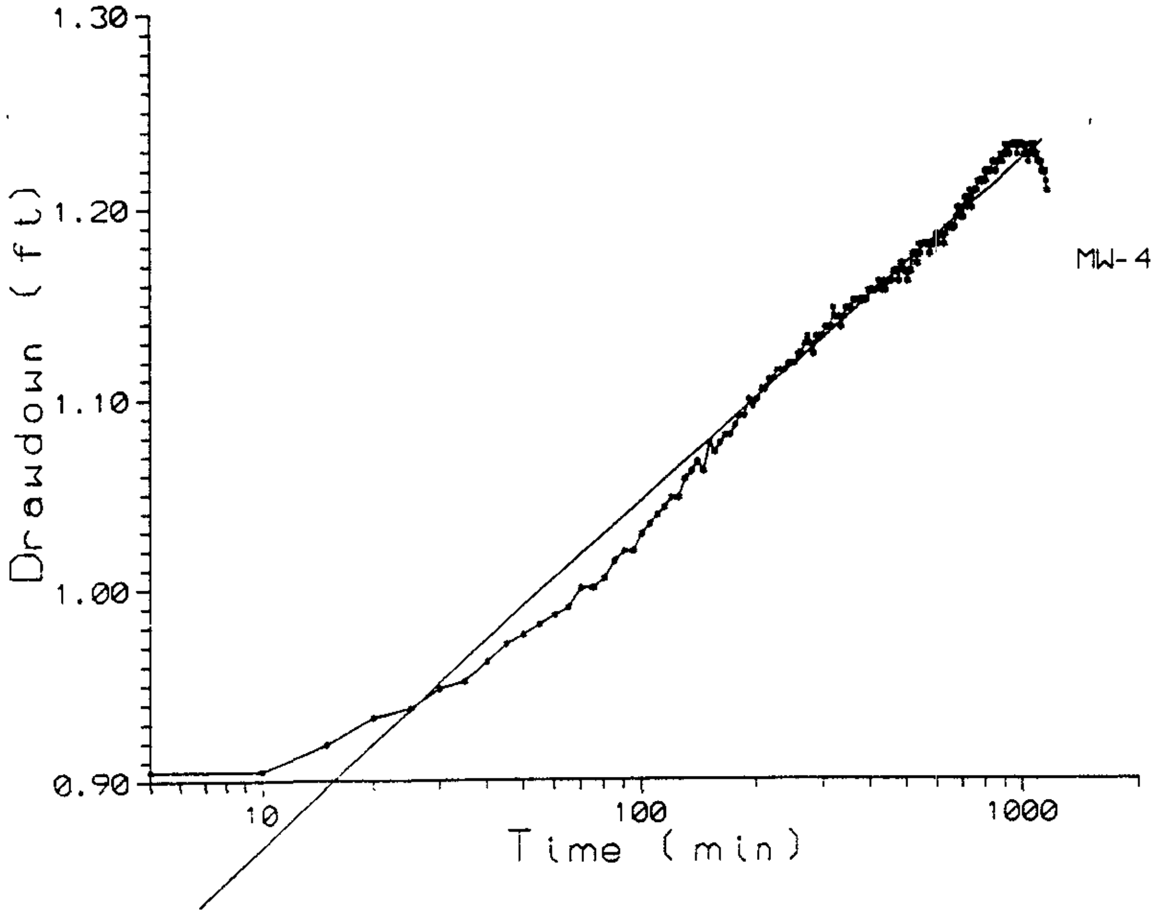

MW-3
0.08
0.06
0.04
0.02
0.00
-0.02
200.00
400.00
800.00
1200.00
1400.00

PLATE B-11

Arco =374 Recovery Test (4/25/91)



Arco =374 Recovery Test (4/25/91)

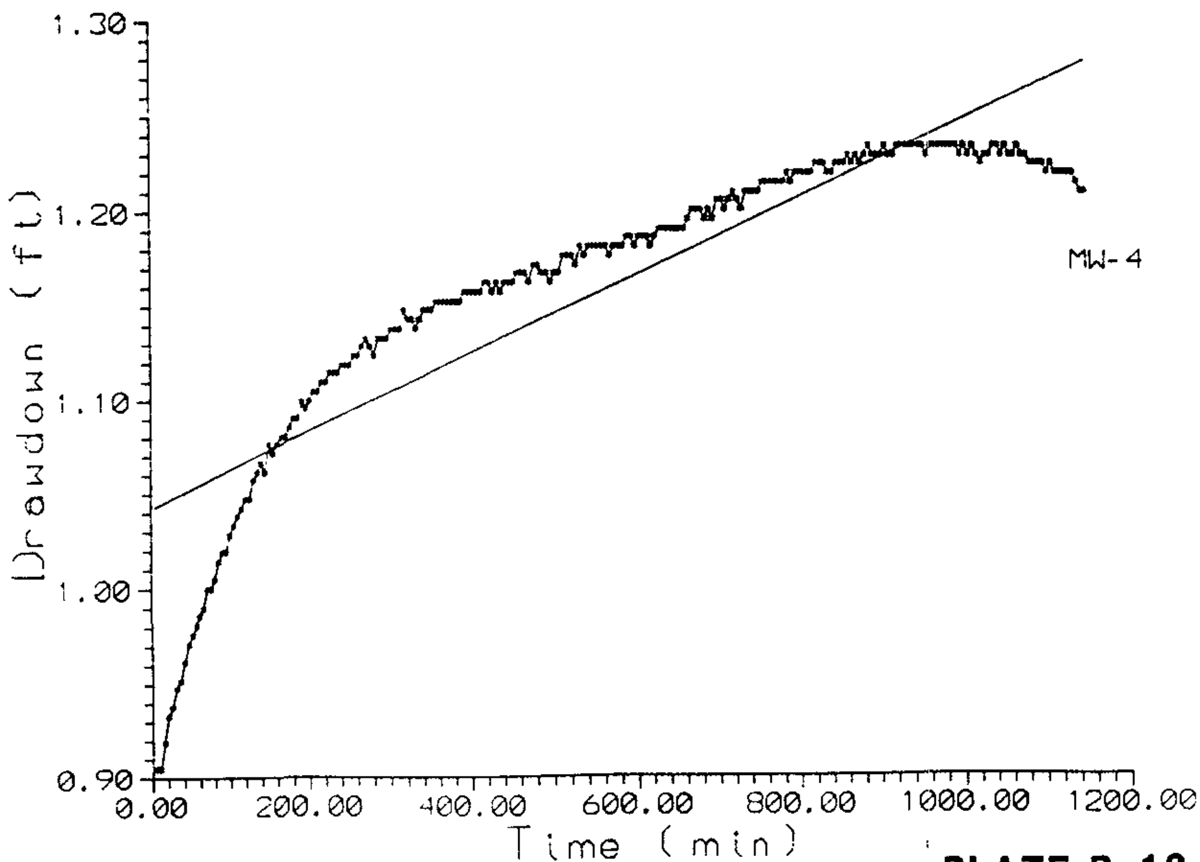
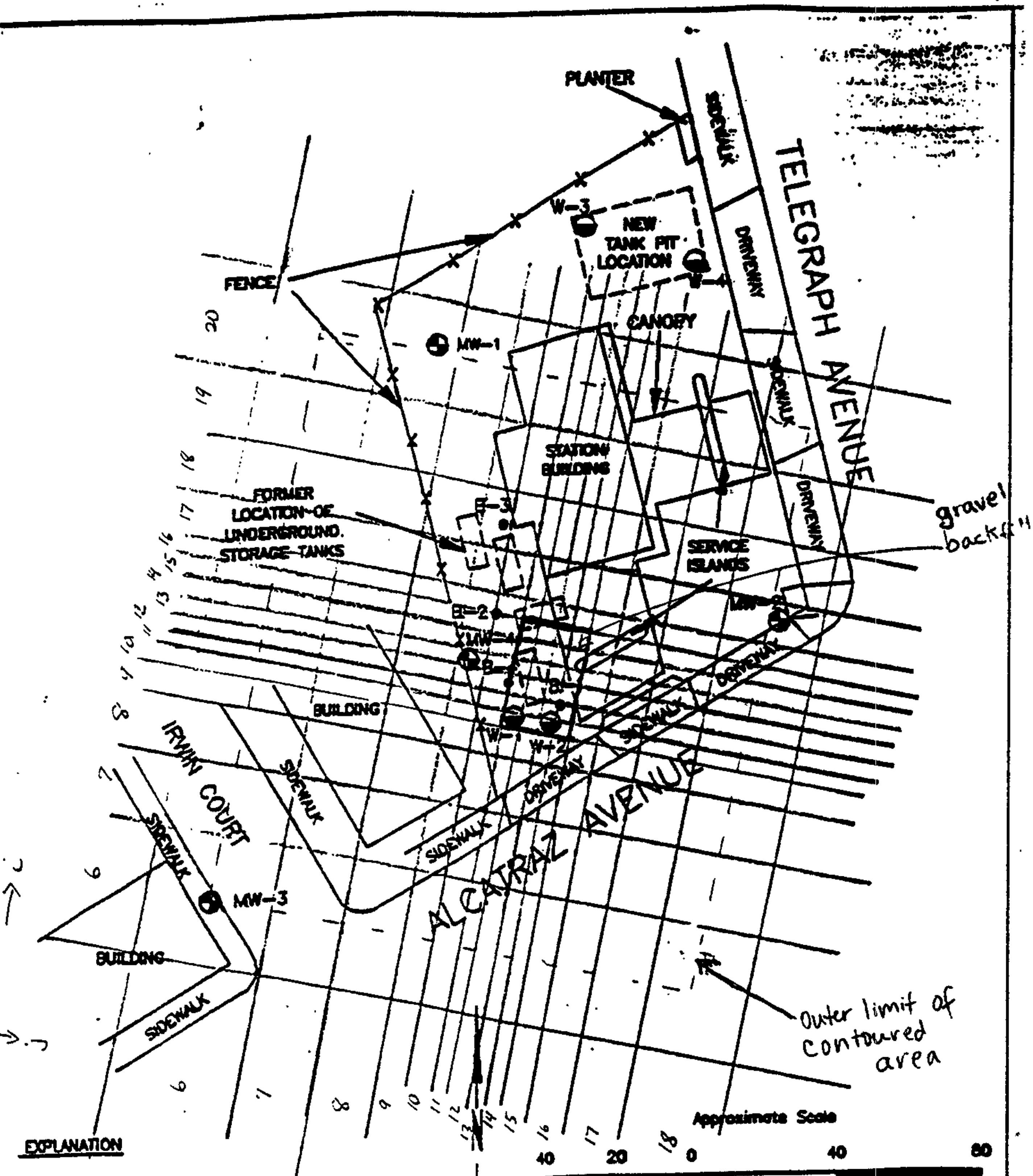


PLATE B-12



EXPLANATION

W-4 = Monitoring well installed by (Applied GeoSystems, 1989)

W-4 = Tank pit monitoring well installed by (Applied GeoSystems, 1988)

B-4 = Soil boring (Applied GeoSystems, 1988)

Source: Surveyed by Ron Archer, Civil Engineer, Inc.

PLATE B-13

Arco #374, Regional Flow

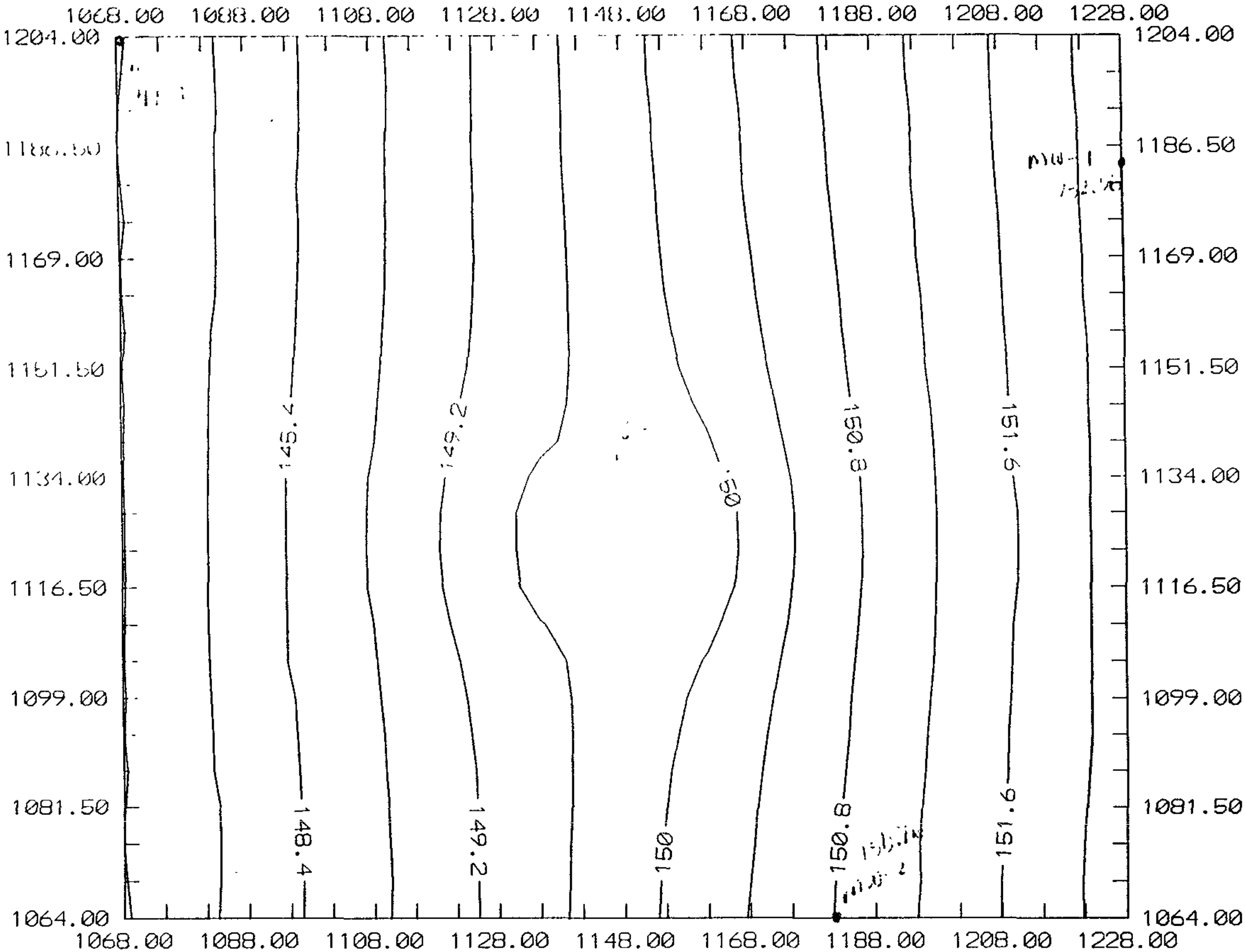


PLATE B-14

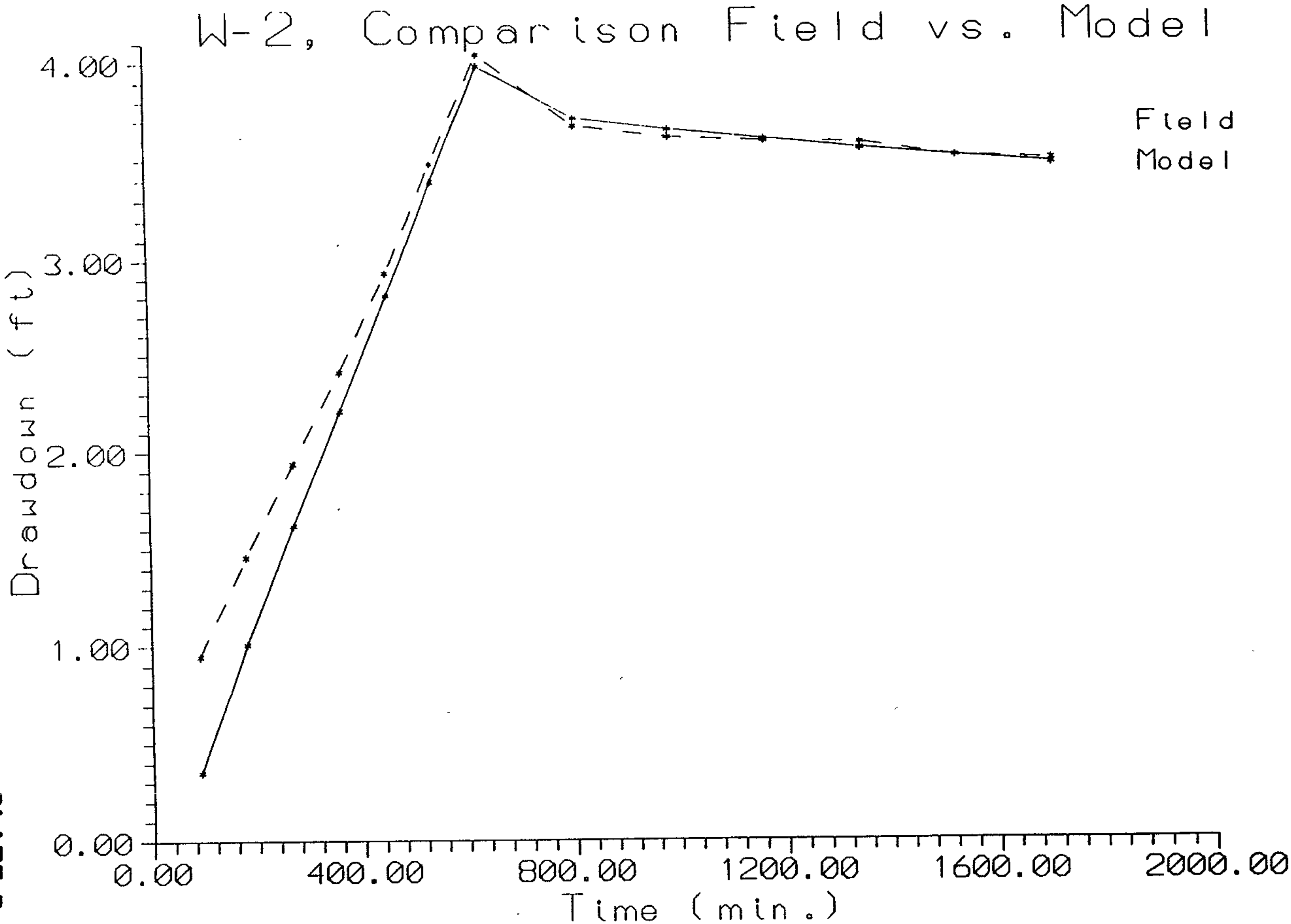

W-2, Comparison Field vs. Model
Field
Model
Drawdown (ft)
4.00
3.00
2.00
1.00
0.00
0.00
400.00
800.00
1200.00
1600.00
2000.00
Time (min.)

PLATE B-15

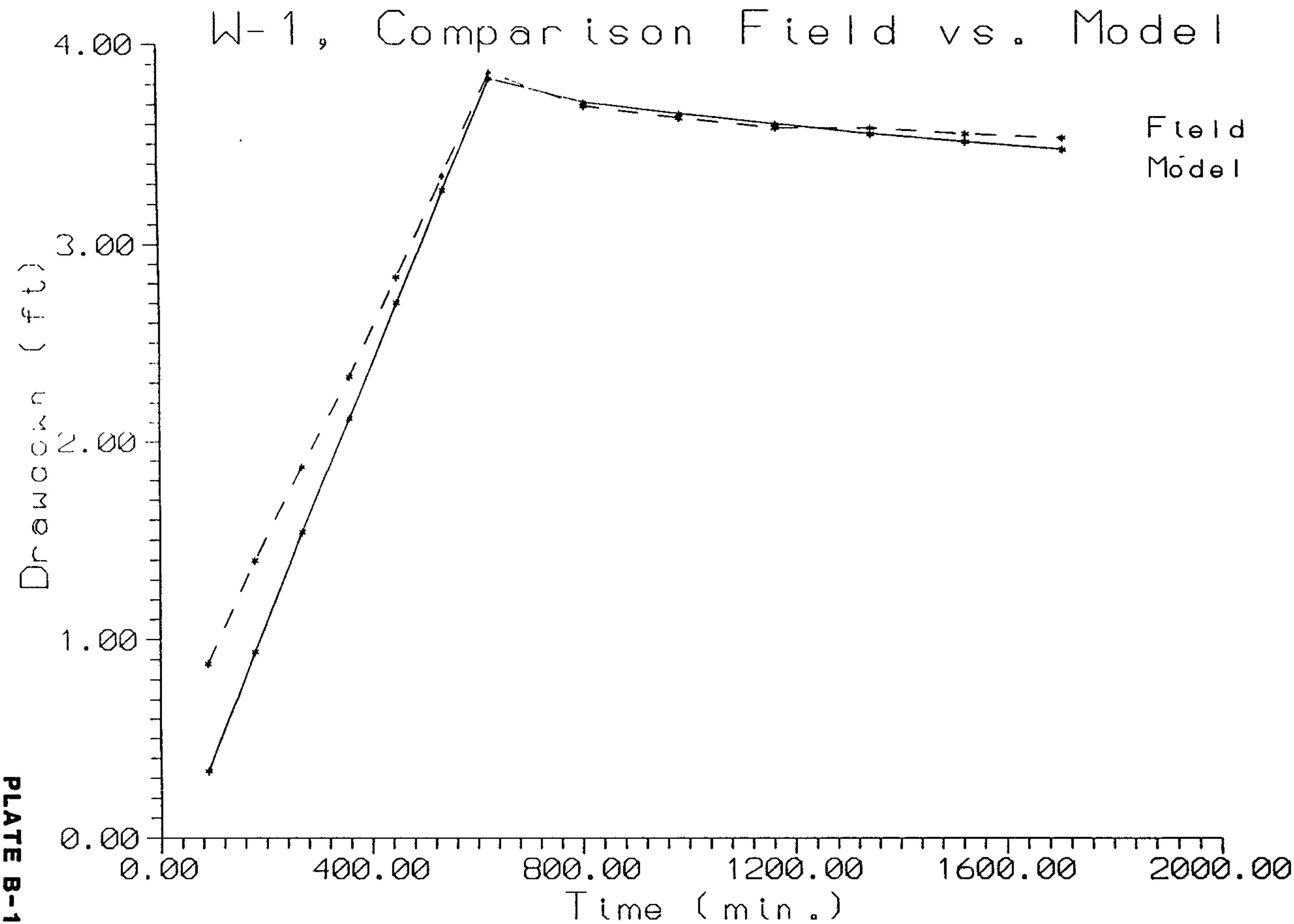

W-1, Comparison Field vs. Model
Field
Model
Drawdown (ft)
Time (min.)
0.00
1.00
2.00
3.00
4.00
0.00
400.00
800.00
1200.00
1600.00
2000.00

PLATE B-16

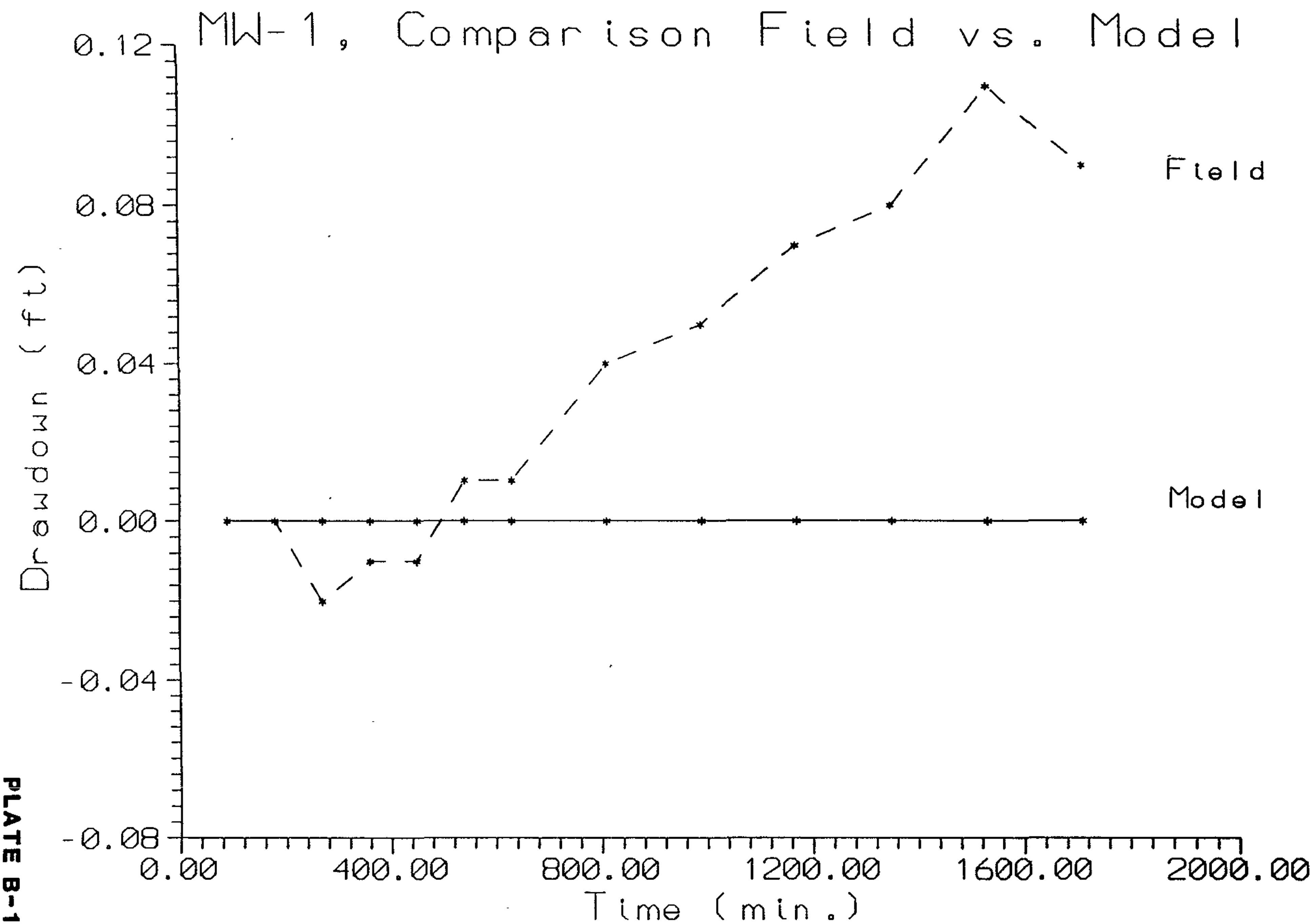

MW-1, Comparison Field vs. Model
0.12
0.08
0.04
0.00
-0.04
-0.08
Drawdown (ft)
Field
Model
0.00
400.00
800.00
1200.00
1600.00
2000.00
Time (min.)

PLATE B-17

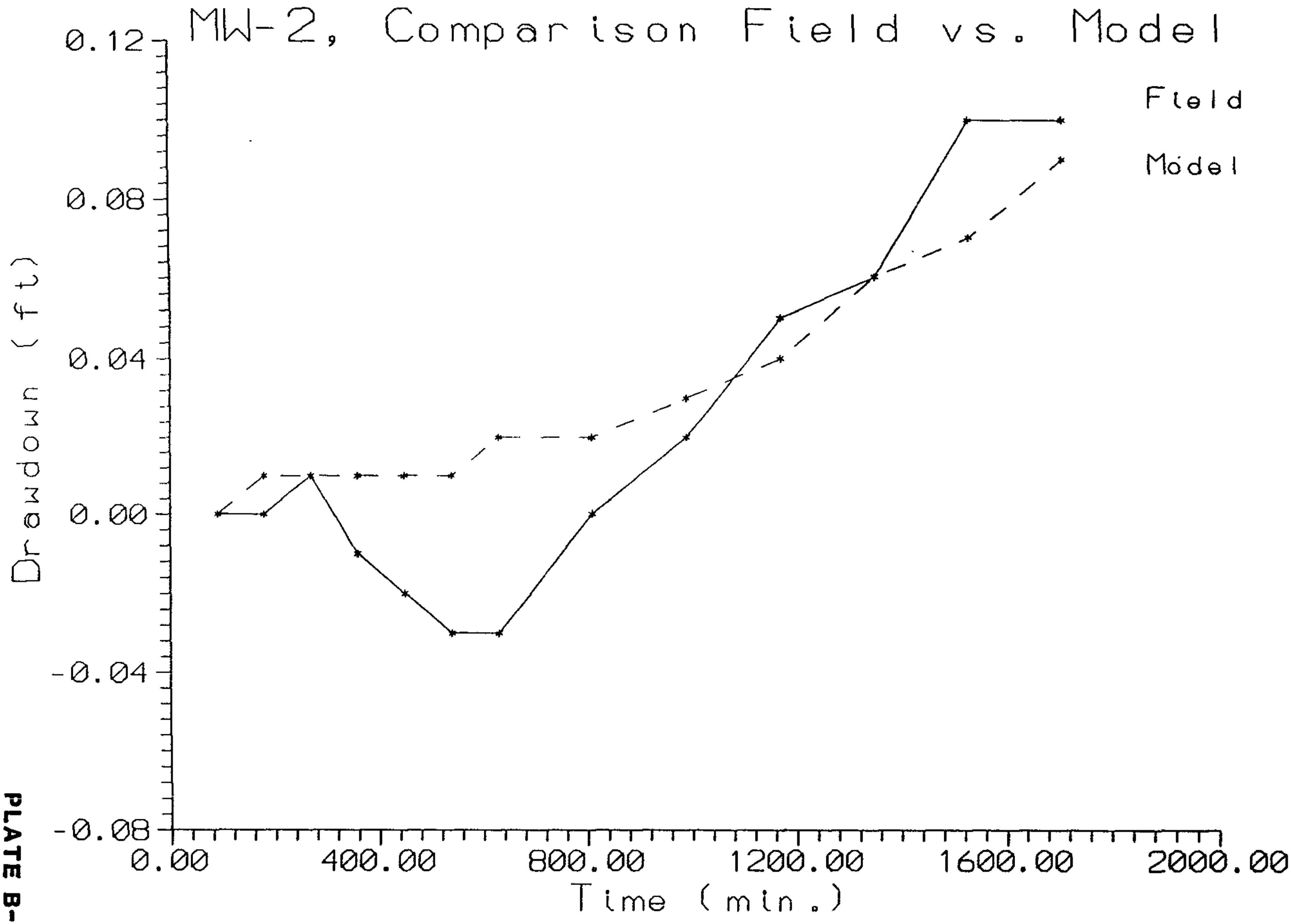

MW-2, Comparison Field vs. Model
Field
Model
Drawdown (ft)
0.12
0.08
0.04
0.00
-0.04
-0.08
0.00
400.00
800.00
1200.00
1600.00
2000.00
Time (min.)

PLATE B-18

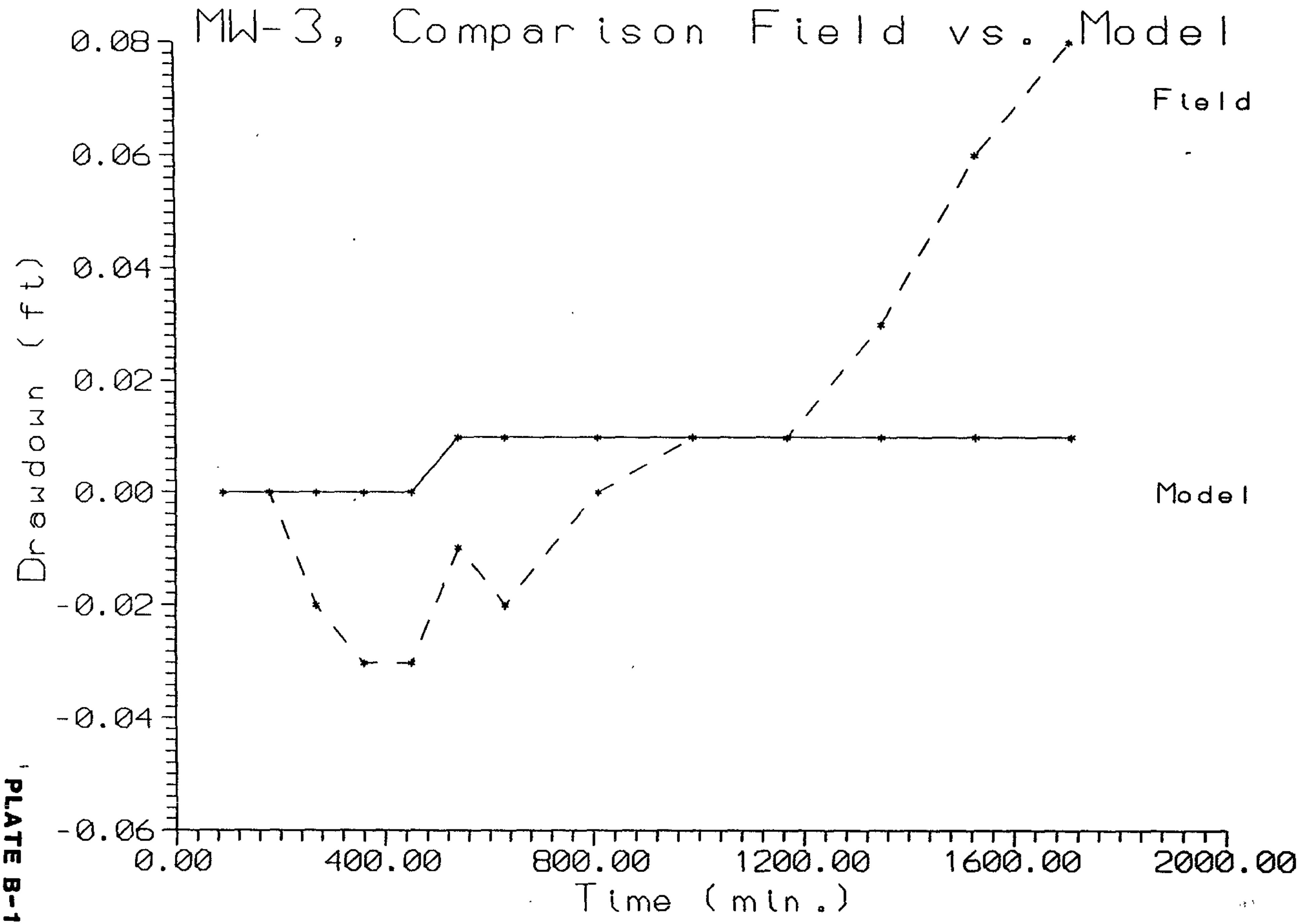

MW-3, Comparison Field vs. Model
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
Drawdown (ft)
0.00
400.00
800.00
1200.00
1600.00
2000.00
Time (min.)
Field
Model

PLATE B-19

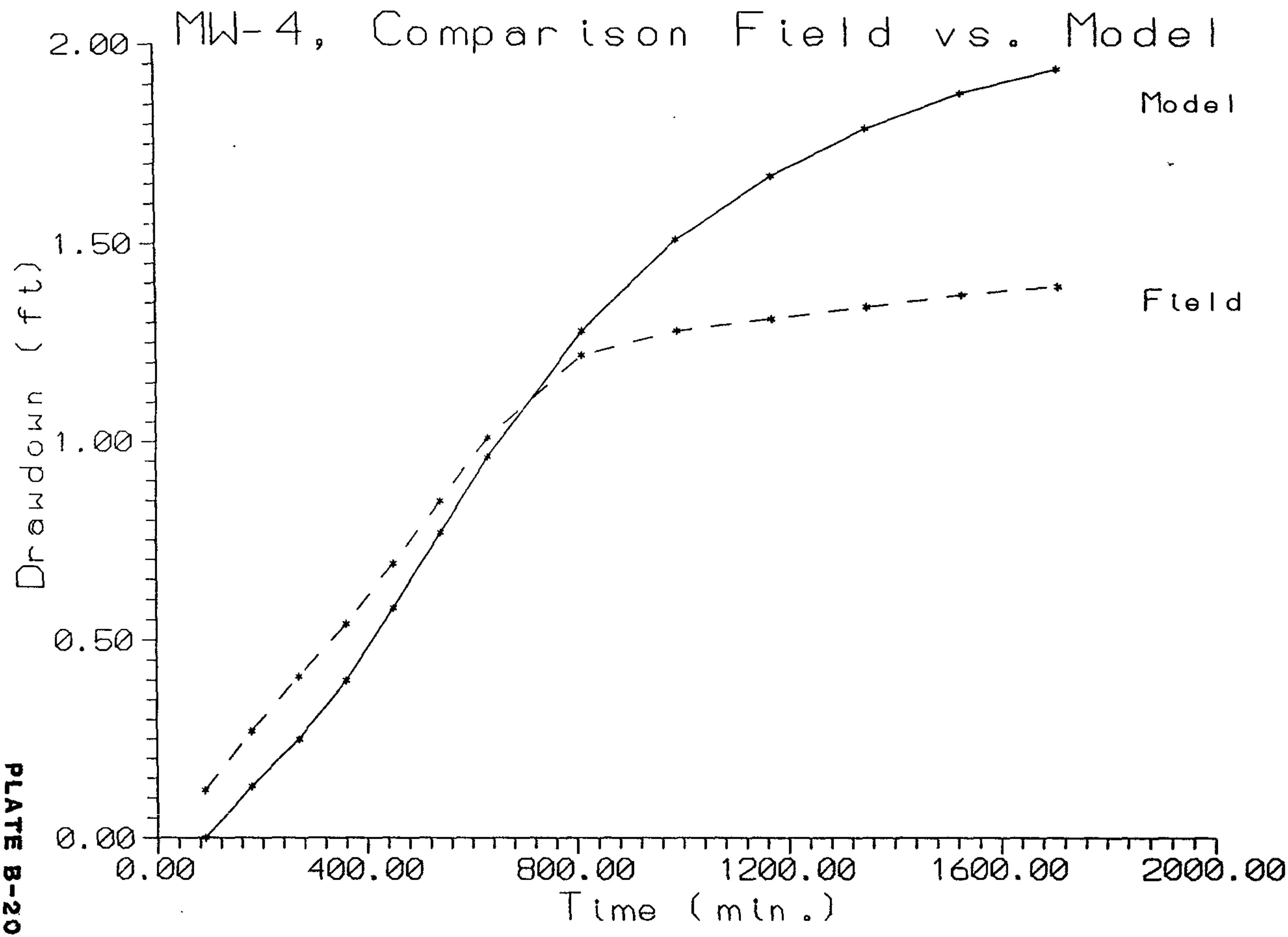

MW-4, Comparison Field vs. Model
Model
Field
Drawdown (ft)
Time (min.)
2.00
1.50
1.00
0.50
0.00
0.00
400.00
800.00
1200.00
1600.00
2000.00

PLATE B-20

Arco #3/4, Simulated Head, End of Pumping

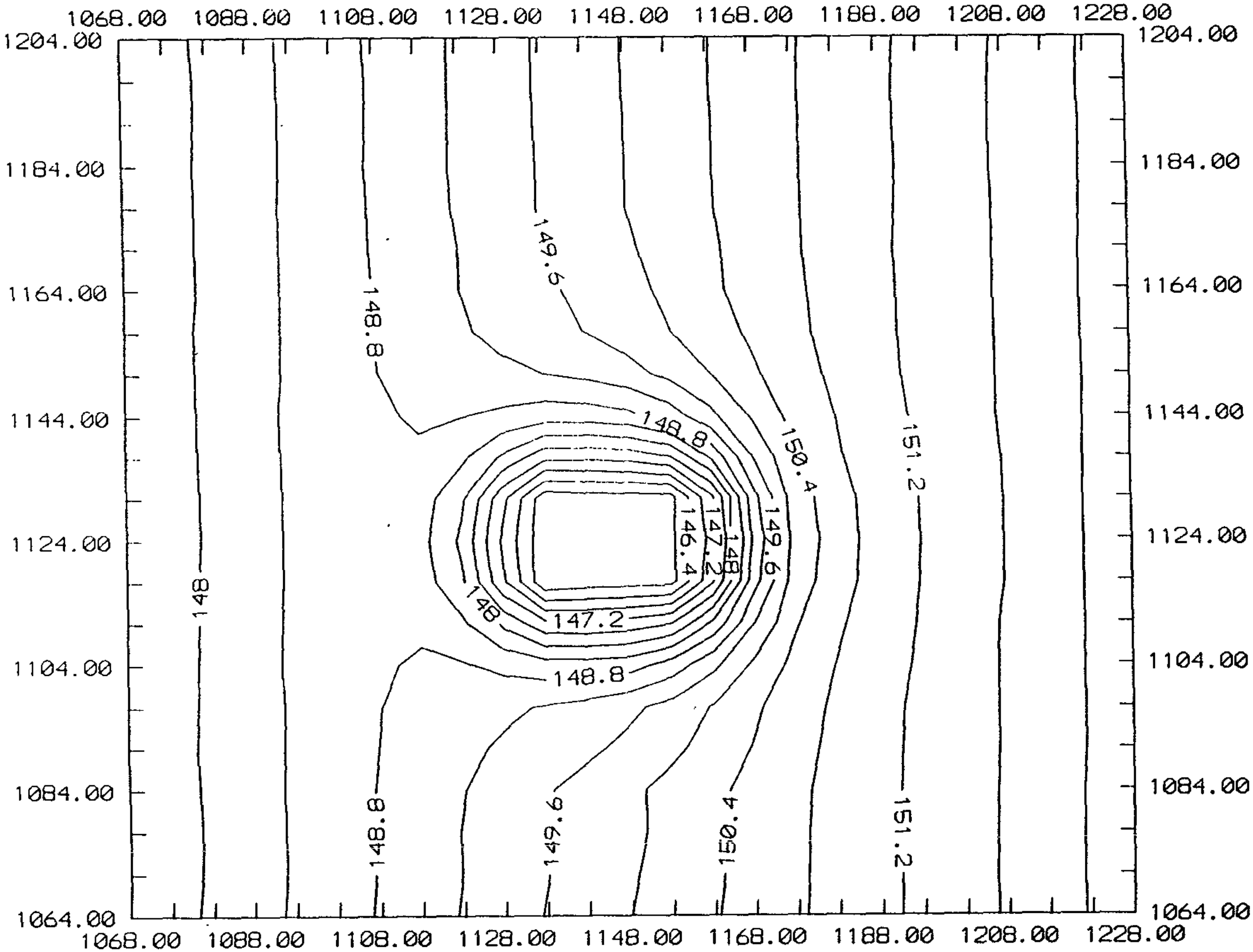


PLATE B-21

Arco #374, Head After 100 Days at Q = 0.24 gpm

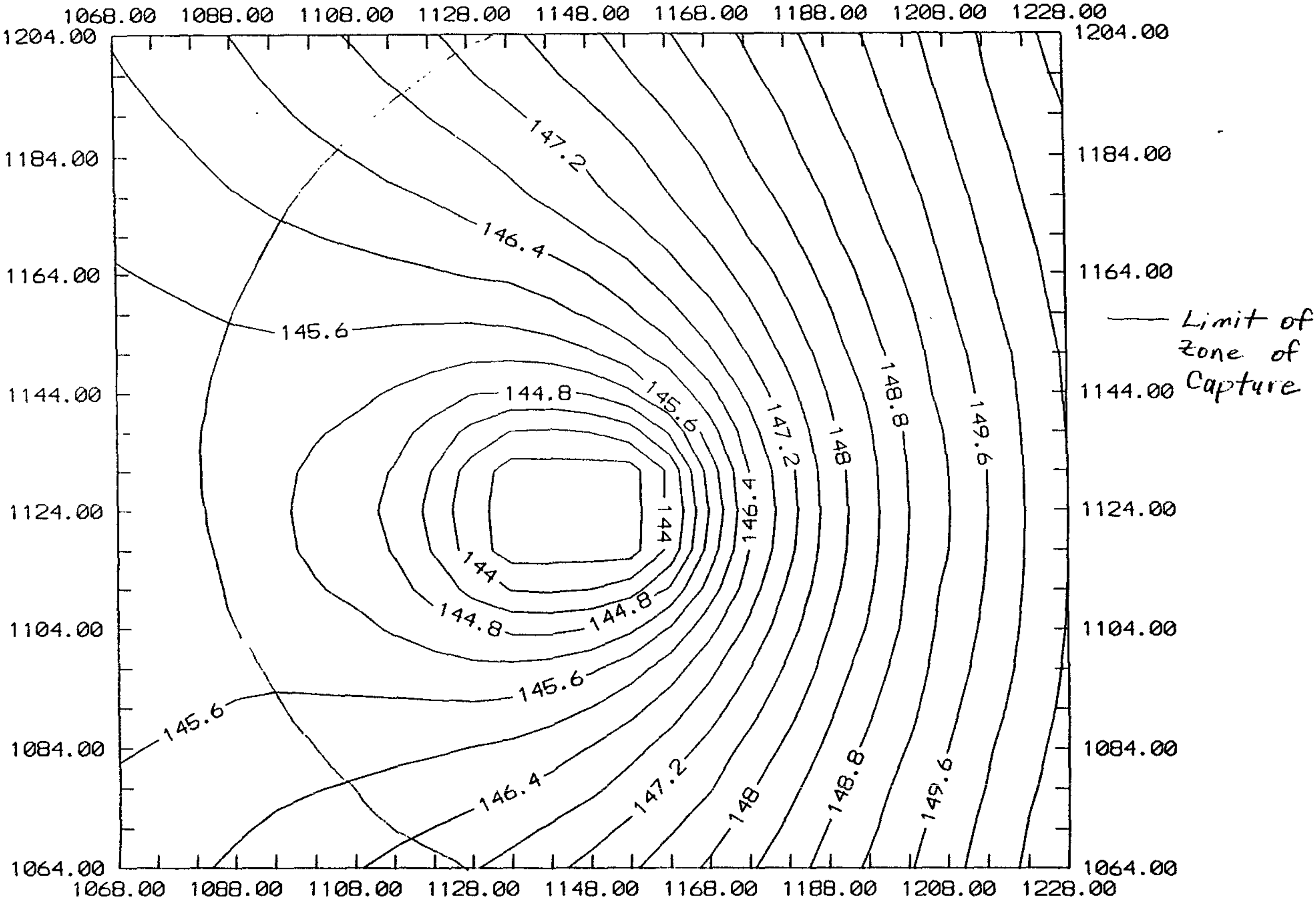


PLATE B-22

Applied GeoSystems

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San Jose, California 95118
(408) 264-7723 FAX (408) 264-2435

TRANSMITTAL

TO: MR. LARRY SETO
ACHCSA
DEPARTMENT OF ENVIRONMENTAL HEALTH
80 SWAN WAY, ROOM 200
OAKLAND, CA. 94621

DATE: 7/31/91
PROJECT NUMBER: 60025.04
SUBJECT: PUMPING TEST REPORT

FROM: JOEL COFFMAN
TITLE: PROJECT GEOLOGIST

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