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SECTION TITLE:
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CONTRACT NO. DE-AC05-86OR21548

COMPLETION REPORT FOR THE PILOT PUMPING TEST FOR THE GROUNDWATER OPERABLE UNIT AT THE WELDON SPRING SITE

WELDON SPRING SITE REMEDIAL ACTION PROJECT
WELDON SPRING, MISSOURI

OCTOBER 1998 **REV. 0**

U.S. Department of Energy
Oak Ridge Operations Office
Weldon Spring Site Remedial Action Project

Prepared by MK-Ferguson Company and Jacobs Engineering Group

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NOVEMBER 16, 1998

U. S. Department of Energy
Weldon Spring Site
Remedial Action Project
ATTN: Mr. Stephen H. McCracken
Project Manager
7295 Highway 94 South
St. Charles, MO 63304

SUBJECT: Contract No. DE-AC05-86OR21548
PILOT-PUMPING TEST PERFORMED IN SUPPORT OF THE GROUNDWATER OPERABLE UNIT

Dear Mr. McCracken:

Attached please find the completion report for the subject test. This test provided a better understanding of the hydrogeologic conditions in the area of TCE impact. It is evident that the stratigraphy and structure of the weathered Burlington-Keokuk Limestone in the area of impact have significant influence on the movement of groundwater in the shallow aquifer. A general conclusion from this study is that the shallow aquifer in the area of the TCE impact is more transmissive than previously suggested indicating that the removal of groundwater though the use of vertical wells is possible.

This report should be forwarded to Argonne National Laboratory for use in the evaluation of in situ and ex situ treatment alternatives being considered for the Proposed Plan.

If you have any questions or comments regarding this study, please contact Rebecca Cato at extension 3507.

Sincerely,

Douglas E. Steffen
Project Director

DES/bc/lac

Attachment as stated

cc: Pamela Thompson

MORRISON KNUDSEN CORPORATION Environmental/Government Group Weldon Spring Site Remedial Action Project Contract No. DE-AC05-86OR21548	
	Rev. No. 0
PLAN TITLE: Completion Report for the Pilot Pumping Test for the Groundwater Operable Unit at the Weldon Spring Site	

APPROVALS

Groundwater Operable Unit Coordinator	10/27/98 Date
Data Administration Manager	10/28/98 Date
Engineering Manager	11/3/98 Date
Project Quality Manager	11/03/98 Date
Deputy Project Director	11/4/98 Date

DOE/OR/21548-757

Weldon Spring Site Remedial Action Project

Completion Report for the Pilot Pumping Test for the Groundwater Operable Unit at the Weldon Spring Site

Revision 0

October 1998

Prepared by

MK-FERGUSON COMPANY
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for the

U.S. DEPARTMENT OF ENERGY
Oak Ridge Operations Office
Under Contract DE-AC05-86OR21548

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1. INTRODUCTION

The U.S. Department of Energy (DOE) is conducting an evaluation to determine the appropriate response action to address groundwater contamination at the Weldon Spring Chemical Plant. The groundwater operable unit (GWOU) at the chemical plant is one of four operable units being evaluated by the DOE under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) process as part of the Weldon Spring Site Remedial Action Project.

The chlorinated solvent trichloroethylene (also known as trichloroethene or TCE) has been detected in the shallow aquifer at the chemical plant and at the adjacent Weldon Spring Training Area (WSTA). This area exhibits TCE contamination in monitoring wells at concentrations ranging from 0.5 µg/l to 1,300 µg/l. A concentration of 9,000 µg/l was measured in a sample taken from MW-2038 in 1996. Samples collected previously and subsequently have not duplicated this result. The regulatory maximum contaminant limit (MCL) for TCE in groundwater is 5 µg/l, as outlined in 40 CFR 141.

The DOE proposed and carried out a pilot pumping test program following a review of the *Feasibility Study for the Groundwater Operable Unit* (Ref. 1) by representatives of the U.S. Environmental Protection Agency (EPA) and State of Missouri Department of Natural Resources (MDNR). This report documents the activities performed during the program and provides analysis of the test results. These activities were outlined in the *Pilot Pumping Test for the Groundwater Operable Unit at the Weldon Spring Site* (Ref. 2).

1.1 Purpose

The primary objectives of the pumping test program, as outlined in the pumping test plan (Ref. 2), were to:

- Determine the aquifer responses to groundwater withdrawal in the area of TCE contamination. No previous data of this type existed for this part of the site.
- Provide data, such as aquifer parameters, which are necessary to evaluate potential groundwater remediation techniques.
- Obtain groundwater samples to further delineate the distribution of TCE in groundwater.

The objectives given above were accomplished during this program. Aquifer characteristics obtained from the pumping tests will be utilized in the evaluation of the practicality and effectiveness of techniques considered for remediation of TCE in groundwater.

1.2 Scope

The scope of the pilot pumping test involved numerous tasks that were both interdependent and challenging. Thus, tasks were arranged sequentially to utilize information gathered during one task and apply it to a subsequent task. The elements of the field program involved the following (in general chronological order):

- Locate, drill, and install a pumping well.
- Perform a step drawdown test with recovery (to estimate the maximum sustainable well yield).
- Perform a short-term constant rate pumping test with recovery (to estimate the area of influence around the well and aid in locating observation wells).
- Drill and install observation wells.
- Perform a long-term constant-rate pumping test with recovery.

The last item was the culmination of the field program and the most critical element. The pumping phase of the multiple well test was designed to last at least 10 days. This phase actually lasted 18 days. It was extended to properly evaluate aquifer boundary conditions. The recovery phase of this test ended on September 11, 1998.

1.3 Background

The focus of the groundwater operable unit is the shallow aquifer situated in the Burlington-Keokuk Limestone, the uppermost bedrock unit. The formation has two zones; the upper, weathered unit and the lower, unweathered unit. The weathered Burlington-Keokuk Limestone is identified by physical properties of the rock attributable to weathering such as alteration, color (staining), fracturing, solution features, and secondary mineralization. The unit includes a subunit, which exhibits a noticeably higher degree of weathering, known as the strongly weathered subunit.

Impacted groundwater at the chemical plant occurs primarily within the weathered Burlington-Keokuk. In bedrock lows, groundwater sometimes occurs within the overburden in the residuum unit, which is an unconsolidated erosional remnant of the underlying limestone bedrock. The hydraulic conductivity is generally highest in wells completed in the bedrock lows. This fact helped determine the location of the pumping well and observation wells installed during this program.

2. WELL DRILLING AND INSTALLATION

Drilling and well installation for the pumping test well and observation wells commenced on May 18, 1998, and was completed on July 10, 1998. A large diameter pumping well and four smaller observation wells were drilled, installed, and developed during this time period.

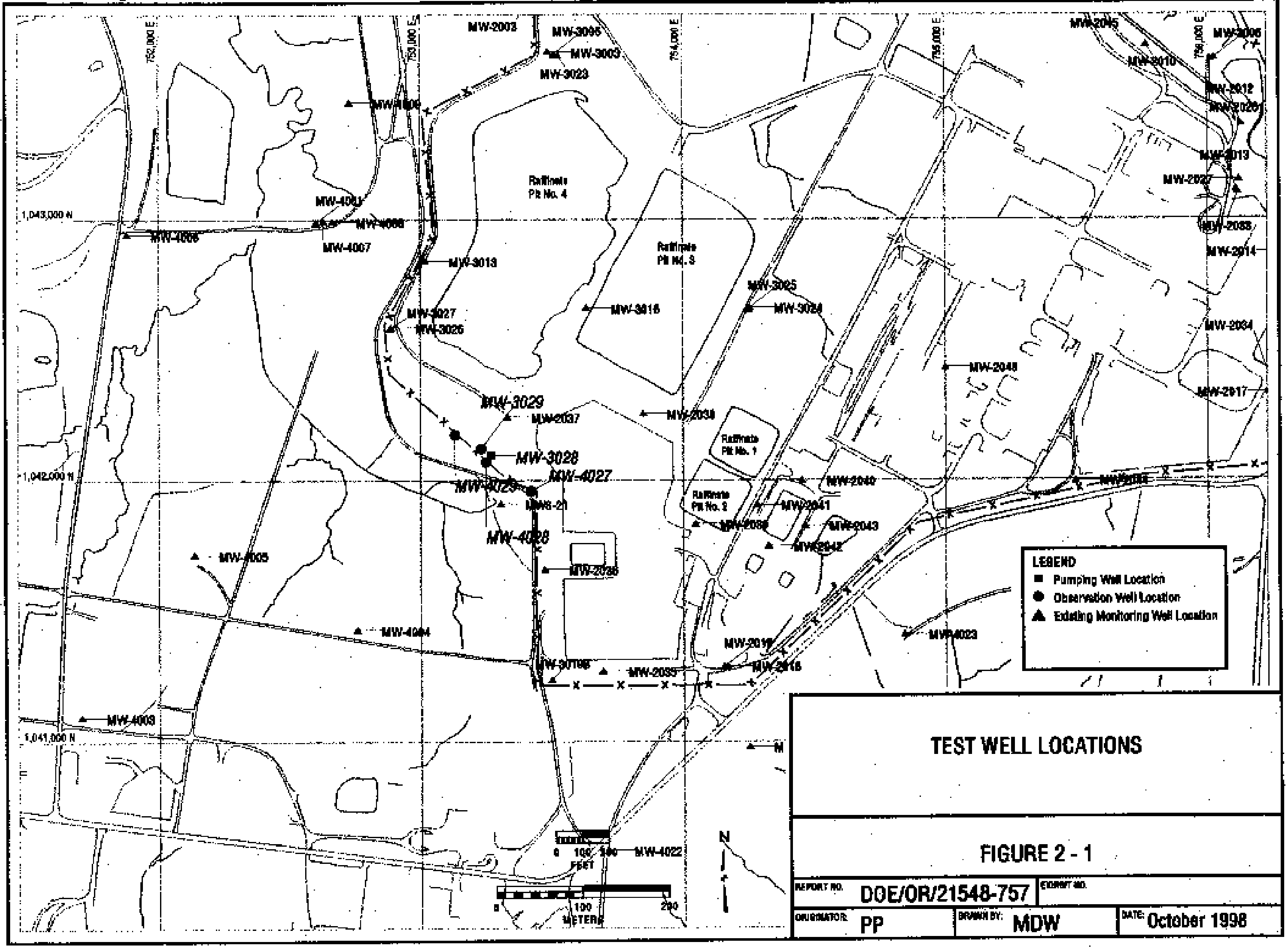
2.1 Location Selection

The location for the pumping well was selected using previous hydrogeologic and groundwater sampling data collected at the site. First, historical groundwater data were reviewed to determine the apparent lateral distribution of trichloroethylene (TCE) and to see if any migration pattern was observable. From the data, it appears that the initial migration direction of TCE follows the hydraulic gradient from the raffinate pits to the south. Next, the most current top of bedrock data were reviewed to determine if structural control of groundwater flow and contaminant migration was evident. From previous drilling and hydrologic testing, it has been determined that the linear bedrock low areas (paleochannels) generally show increased permeability and could preferentially direct groundwater flow along these features. The bedrock map showed a potential for structural control on groundwater flow from the area south of the raffinate pits along a broad bedrock low oriented to the southwest that turns northwest. The location of the pumping well intended to take advantage of this feature and ideally intersect a transmissive flow zone.

2.2 Pumping Well

The pumping well (MW-3028) was located to intersect a projection of this bedrock low into an area south of the raffinate pits and to be proximate to monitoring wells exhibiting TCE contamination, namely MW-2037 and MWS-21. Figure 2-1 shows the location of the pumping well. The well was drilled with a truck-mounted CME-750 drill rig. Hollow stem augers with an inside diameter (ID) of 10-1/4 in. and outside diameter (OD) of 14-3/4 in. were used to drill through the overburden materials. Auger cutting samples were continuously collected and described according to Procedure ES&H 4.4.7, *Soil, Rock Core, and Rock Chip Borehole Logging and Storage*.

Once bedrock was encountered (as indicated by auger refusal), the drilling method was changed to NQ wireline coring. Before coring, a 3-in. ID, steel casing was placed through the augers and drilled into the rock a few feet to facilitate circulation of drilling water and cuttings directly up and out of the borehole into a portable "mud tank" located at the surface. A 10-ft solid core barrel was utilized to retrieve rock samples. Upon completion of a core run (the length of the run varied), the core barrel was brought to the surface through the drill pipe, where the



TEST WELL LOCATIONS

FIGURE 2 - 1

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ORIGINATOR: PP	DRAWN BY: MDW	DATE: October 1998

core was extracted from the barrel, placed in a wooden core box, and then logged in accordance with Procedure ES&H 4.4.7. Computer-generated borehole logs documenting soil and rock encountered during the drilling of the pumping well are provided in Appendix A.

After reaching the base of the weathered Burlington-Keokuk Limestone, the bedrock portion of the well was reamed to 10 in. using a Schraam air-rotary drill rig fitted with a down-hole hammer bit. An auxiliary compressor furnished the additional air velocity needed to move drill cuttings up and out of the large diameter borehole. Reaming was performed to provide the required hole diameter for placement of annulus material around the 6-in. diameter well screen and casing.

2.3 Observation Wells

The observation wells were drilled relatively close to the pumping well to provide a means to monitor the response of the shallow aquifer to pumping. The following four observation wells were drilled and installed as part of this program:

- MW-3029: Located 47 ft. northwest of the pumping well.
- MW-4028: Located 32 ft southwest of the pumping well.
- MW-4029: Located 161 ft northwest of the pumping well.
- MW-4027: Located 204 ft southeast of the pumping well.

The first observation well drilled (MW-4027), was initially drilled as a possible alternate location for the pumping well. The packer test results from the pumping well showed only moderate hydraulic conductivity (high 10^{-4} cm/sec range) so the MW-3028 borehole was left cased and the drill rig was moved to the MW-4027 location. Packer tests during drilling at this location showed even lower hydraulic conductivity results than did the original pumping well location. To finalize the pumping well location, a 2-in. polyvinyl chloride (PVC) screen and riser were installed in each of the two boreholes. They were then briefly developed using a surge block within the screen zone. The boreholes were subsequently pumped using a 2-in. submersible pump to determine which well could sustain the higher yield. The borehole at the MW-3028 location maintained a higher pumping rate than the boring at the MW-4027 location; therefore, this location was reamed and completed as the pumping well.

The locations of the remaining observation wells were finalized based on both their proximity to and direction from the pumping well. Wells MW-4028 and MW-3029 were each drilled relatively close to the pumping well (32 ft and 47 ft, respectively) while MW-4029 was drilled 161 ft to the northwest along the fence line. This direction is approximately 90° from a line projected from the pumping well to MW-2037 and almost the same distance. Using both wells for observation allows a comparison of drawdown along two orthogonal axes to assess horizontal anisotropy in the aquifer.

The observation wells were drilled using the same equipment and methods as the pumping well except that the holes were reamed to 6 in. instead of 10 in. to accommodate a 2-in. diameter well screen and casing. All but one of the observation wells (MW-4027) were drilled and completed through the full thickness of the weathered Burlington-Keokuk Limestone hydrostratigraphic unit. The pumping test plan called for all but one of the observation wells to be screened for only 10 ft across the potentiometric surface. After installing MW-4027 and reviewing additional aquifer test data analysis methods, the decision was made to fully penetrate and screen the weathered unit in the remainder of the observation wells. Soil and core samples were collected and described on borehole logs in an identical fashion to the pumping well. The logs can be found in Appendix A.

2.4 Constant Head Hydraulic Conductivity (Packer) Testing

During the drilling of the pumping well and MW-4027, the bedrock was pressure tested (packer tested) using methods described in the *Groundwater Manual* (Ref. 3) at approximately 10-ft intervals throughout the length of the boring. Because of schedule constraints and a determination that the testing was not critical to the successful completion of the program, packer testing was discontinued for subsequent observation wells.

At the completion of a core run, the inner core barrel was removed and the hole was flushed with water to remove drill cuttings. The drilling pipe and outer core barrel were then pulled out of the borehole. A single packer assembly was installed in the borehole through the casing and inflated at the top of the test interval. The open hole below was then pressurized by pumping water directly into the boring through a water pipe extending through the packer. Test pressure and flow rates were measured with a pressure gauge and water meter, respectively. Four packer tests were performed in MW-3028 and three were conducted in MW-4027. Results from the packer testing are presented in Section 4.

2.5 Well Completion and Development

Final well screen placement was determined in the field for each well depending on the measured static water level. The goal was to fully screen the weathered unit of the Burlington-Keokuk Limestone (except for MW-4027) and position the screen across the static water surface allowing enough screen to accommodate seasonal variation in the water level. At the completion of reaming the borehole to the desired depth in each well, the Schraam air-rotary rig was moved off the hole and the CME drilling rig was moved back on to place the well. A well string consisting of the following materials was installed in the boreholes: schedule 40 PVC slotted well screen with threaded bottom cap and PVC blank riser casing with threaded top cap; (observation wells had 2-in. screen and casing versus 6-in. for the pumping well). Also, the pumping well screen type differed from the observation wells in that it was continuous-slotted (0.020-in. slot) versus machine-cut (0.010-in. slot). Annulus materials were then placed through the augers as follows: (1) 10/20 Colorado Silica® sand pack to approximately 2 ft to 3 ft above the screen top; (2) Peltonite® 3/8-in. bentonite pellet seal (hydrated with potable water) to 3 ft to 5 ft above the top of sand pack; and (3) Grout-Well® high solids bentonite grout to approximately 3-ft below ground surface. Table 2-1 summarizes the well construction data for wells installed during this program. As-built well construction diagrams are provided in Appendix A.

Table 2-1 Test Well Construction Data

Well Number	Missouri State Plane Coordinates (NAD 83)		Ground Elev. (ft) (MSL)	Top of Casing Elev. (ft)	Filter Pack Interval[1]	Screened Interval[1]	Total Well Depth[(a)]
	Northing (ft)	Easting (ft)					
MW-3028	1042096.61	753269.49	649.20	651.92	34.2-61.0	37.0-57.0	61.0
MW-3029	1042123.34	753231.36	649.49	653.48	35.7-61.0	38.5-58.5	61.0
MW-4027	1041959.59	753421.25	644.74	647.77	29.5-43.2	32.0-42.0	43.2
MW-4028	1042071.69	753249.08	646.71	650.35	32.0-57.0	34.5-54.5	57.0
MW-4029	1042175.97	753129.19	648.32	651.28	32.5-58.0	36.0-56.0	58.0

(a) Interval or depth measured in feet below ground surface.
Note: Well MW-3028 is completed with 6-in. Schedule 40 PVC riser and screen (0.020-in. continuous slot). Observation wells completed with 2-in. Schedule 40 PVC riser and screen (0.010-in. machine-cut slot).

Each well was developed by the drilling subcontractor after a minimum of 24 hours had elapsed after annulus grout placement. Development was accomplished by initially surging the well with a surge block attached to the drill rig's wireline (pumping well) or a hand-held PVC unit (observation wells). This was generally performed for 10 minutes by moving the surge block up and down in the screened zone to adequately force water back and forth from the formation into the well through the well screen and sand pack. This surging action cleans out fine sand and fines around the well, develops the sand pack, and breaks down any "skin" on the borehole wall caused by the drilling process. Once the first surging was completed, the well was pumped using a 2-in. (4-in. in the case of the pumping well) submersible pump until free of turbidity. The well was then surged again for a similar period. It was again pumped until free from turbidity. During development, physical parameters (temperature, conductivity, and pH) were measured and recorded for the well. Each of these measurements was allowed to stabilize according to Procedure ES&H 4.4.8, *Monitoring Well Installation and Development*, before accepting the well as fully developed. Minimum well volumes were significantly exceeded for all the wells during development. Well development forms were completed according to Procedure ES&H 4.4.8 and are included in Appendix A.

The wells were completed at the surface by imbedding a 6-in. (10-in. for the pumping well) locking protective casing in a 6-in. thick, 36-in. diameter surface concrete pad. Continuous placement of concrete from the top of the well annulus grout (generally 3 ft below ground surface) to approximately 6-in. above ground surface was performed to provide protection against frost heaving. Four 4-in. diameter, 6-ft long, concrete-filled pipe bollards were also placed approximately 4 ft from the well casing to protect the well from vehicular/construction traffic. The bollards and the protective casing were painted yellow to enhance visibility. All wells were surveyed for location and elevation (ground surface and well casing top) which are provided in Table 4-2 and on the borehole logs (Appendix A). All protective casings were locked upon completion.

3. AQUIFER TESTING

3.1 Field Logistics and Equipment

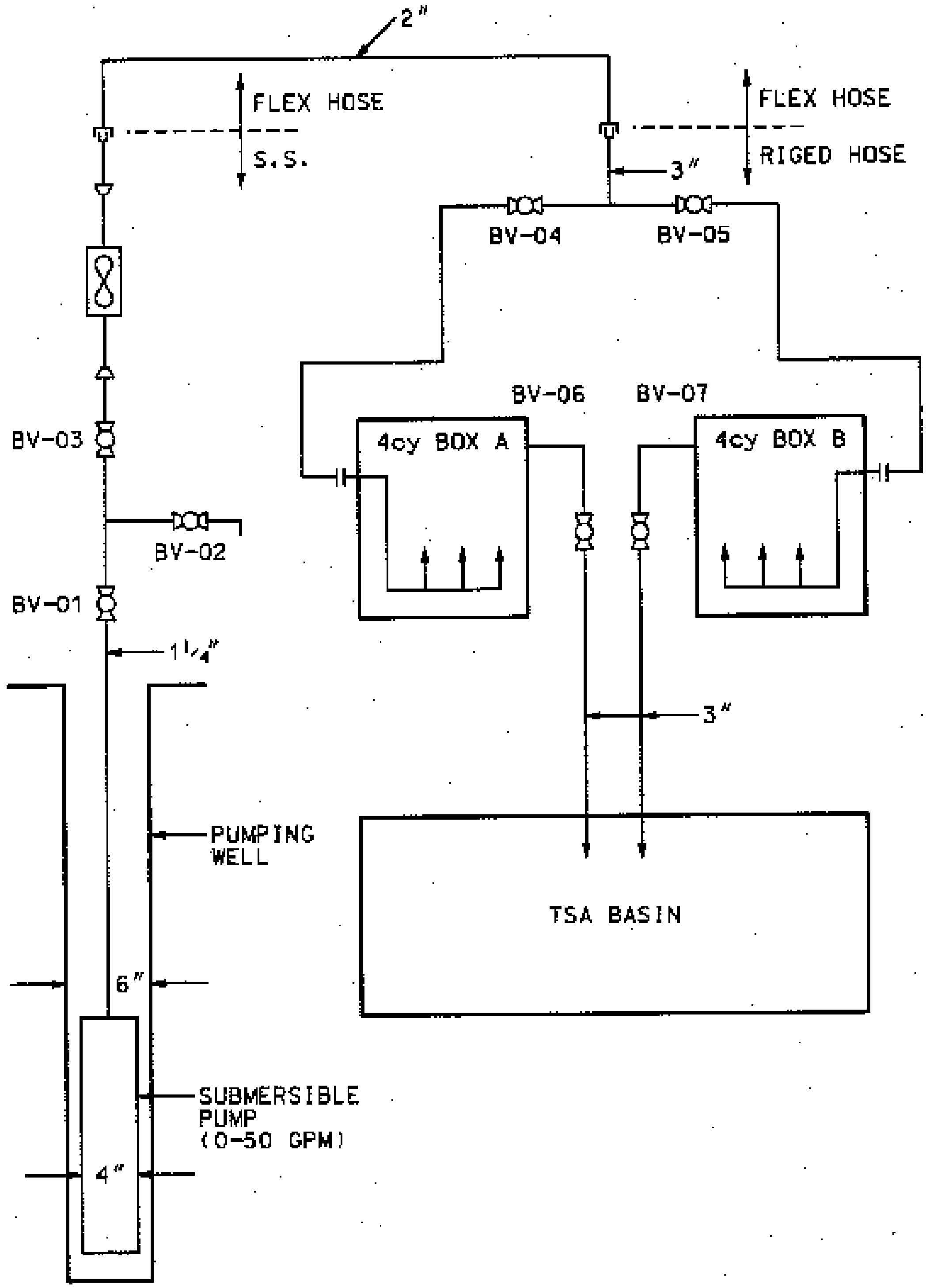
The general layout for the pumping test consisted of a submersible pump that discharged the pumped groundwater approximately 800 ft to an inline activated carbon treatment system. The treated water was then delivered into a lined surface impoundment located at the temporary storage area (TSA).

A Grundfos Redi-Flo 4®, Variable Performance Pump (Model 25E3 pump end, 2.0 HP motor) was used to extract groundwater from the pumping well. This electric submersible pump was constructed of 304 stainless steel and teflon components. The capacity of the pump ranged from 0 to 50 gallons per minute (gpm). The pump was installed in the pumping well at a depth of 58 ft below the ground surface.

A discharge line, constructed of 304 braided stainless steel, was connected to the pump end. This line was 1.25 in. in diameter and 100 ft in length. A series of ball valves were installed at the end of the discharge line for the purposes of controlling flow and diverting water through a sample collection port. All piping, including the sample ports, was constructed of 304 stainless steel.

A totalizing water meter (Carlon™) was installed after the sample collection port to calculate the flow rate and to record the total volume of water extracted in gallons during the pumping test. Flow rate measurements (in gallons per minute) were recorded at least hourly during each test. The water then continued through a 2-in. general rubber hose and was delivered to an inline activated carbon treatment system at the TSA (Boxes A and B on Figure 3-1). The treated water discharged to a lined surface impoundment. A sample collection port was installed on the discharge line of the treatment system immediately downstream of the carbon treatment unit. The entire pumping test system is illustrated in Figure 3-1.

Water level measurements collected throughout the pumping test were obtained using electronic water level sounding meters (Solinst® Model 101, P2) and pressure transducers (In Situ® 15 and 20 psi) connected to electronic data loggers (In Situ Hermit® 1000C, 2 channel).



NOT TO SCALE

PUMP TEST CONFIGURATION

FIGURE 3-1

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3.2 Water Level Monitoring

Pressure transducers and electronic data loggers were used to measure changes in water levels in selected observation locations as the tests proceeded. Pressure transducers recorded water levels at the production well (MW-3028) and monitoring locations MW-3029, MW-2036, MW-2037, MW-4027, MW-4028, MW-4029, and MWS-021. Transducers were secured and zeroed in these wells and the electronic data loggers were set to record water level drawdown during each test. The data loggers were programmed to record water levels in logarithmic time intervals at locations MW-3028, MW-3029, MW-4028 and MW-4029. Linear time intervals were recorded at the remaining locations.

Water levels were monitored at several outlying monitoring wells where the potential for drawdown was unknown. These were measured with manual static water level meters for groundwater level changes during and after the long-term, multiple well aquifer pumping test. Locations continuously measured during pumping events were MW-2036, MW-2038, and MW-3027. At the conclusion of long-term test, additional locations were included for water level monitoring during the recovery period due to the unanticipated large area of influence. These locations included MW-2035, MW-2039, MW-3003, MW-3006, MW-3019, MW-3023, MW-3024, MW-3025, MW-4001, MW-4004 through MW-4010, and MWS-004.

3.3 Step-Drawdown Test

The step-drawdown test was conducted on June 19, 1998. This test was performed to determine an optimal pumping rate for subsequent tests. Prior to initiating the step-drawdown test, the groundwater levels were measured and recorded in the pumping well and in monitoring wells MW-2036, MW-2037, MW-2038, MW-3026, MW-3027 and MWS-021 to provide preliminary information regarding hydraulic communication between these locations and the test production well.

Prior to starting the pumping test, the pump and associated discharge line equipment were tested and the pump was calibrated to produce 6.3 gpm for the first test step. Due to an electrical problem, the pump could not adequately sustain this low rate, and the rate was increased to 10.6 gpm after 28 minutes of pumping. The duration of the second step was 2 hours after which the pumping rate was increased to 15.5 gpm. This rate was sustained for 4 hours. The fourth and final step consisted of pumping the well at a rate of 23 gpm for 6 hours after which aquifer recovery recordings were initiated.

3.4 Short Term Constant Discharge Test

The short term, constant discharge pump test consisted of pumping the production well at an optimum rate, as determined from the step-drawdown test and monitoring water level decline in the production well and nearby monitoring wells listed in the previous section. Pressure transducers and electronic data loggers were used to monitor water level changes in the wells.

The selected pumping rate was 31 gpm and the test was conducted on July 1, 1998. The data loggers were programmed to begin recording data simultaneously with the pump startup. The well was pumped at the constant rate for a period of approximately 14 hours. Pumping rates were checked every 15 minutes during the first 2 hours of the test, then hourly for the remainder of the test.

Upon completion of pumping, the water level in the well continued to be measured and recorded until the groundwater level recovered. Approximately 99% recovery was achieved within 12 days.

3.5 Long Term Constant Discharge Test

The long term test began following completion of four new observation wells (MW-3029, MW-4027, MW-4028, and MW-4029) that were utilized to measure drawdown responses to constant discharge from the production well. Water levels from the observation wells were measured following well completion and development, and pressure transducers were placed in the production well and each observation well when it was determined that groundwater had reached equilibrium. The pump was set to discharge at a rate of 10.7 gpm based on the results of the single well tests. The pumping was started on July 13, 1998, with electronic loggers set to collect water level readings in logarithmic time at the pumping well, and observation wells MW-3029, MW-4028, and MW-4029. Electronic loggers were set in linear time to record data in linear time in MW-4027, MWS-021, MW-2036, and MW-2037. A barometric pressure transducer was placed near MW-2037 to record atmospheric pressure changes which occurred during the testing period.

The discharge rate was checked at 10-minute intervals for the first 2 hours of the test. Thereafter, the production rate was checked hourly. The production well was pumped for approximately 18 days when it was determined that sufficient data had been collected. The pump was shut down on July 31, 1998. The data loggers were set to continue to collect water level readings in the production well and observation wells to record the aquifer recovery. It was determined that adequate recovery had been reached on September 11, 1998, for the purposes of this program. Water level data will be collected periodically to determine when complete recovery is attained.

A summary of the drawdown from pumping and total recovery for each well is provided in Table 3-1. Total drawdown at each location was measured during the final hour of the long-term test. Due to the unanticipated large area of influence, 17 additional wells were added to the water level monitoring program. Four of these additional wells indicated conclusive evidence of drawdown due to pumping from MW-3028.

Table 3-1 Summary of Groundwater Level Changes During the Long Term Constant Discharge Test

Monitoring Location	Pre-Pumping Depth to Water (ft., TOC)	Depth to Water After Pumping (ft., TOC)	Drawdown from Pumping (ft.)	Depth to Water after 3-Week Recovery (ft.)	Total Recovery (ft) % Recovery[a]
MW-2035	—	54.74	—	54.80	N.C.
MW-2036	46.78	48.70	1.92	48.43	0.27 ft./ 14%
MW-2037	47.96	51.78	3.82	49.14	2.64 ft./ 69%
MW-2038	55.52	56.58	1.06	56.55	0.03 ft. / 3%
MW-2039	—[b]	52.73	—	52.97	N.C.
MW-3003	—	48.23	—	48.33	N.C.
MW-3019	—	55.88	—	55.77*	0.11 ft.
MW-3023	—	46.51	—	46.65	N.C.
MW-3024	—	47.89	—	46.49	1.40 ft
MW-3025	—	38.44	—	38.23	0.21 ft
MW-3026	—	39.70	—	39.74	N.C.
MW-3027	37.93	38.45	0.52	38.68	N.C.
MW-3028	41.00	47.77	6.77	42.20	5.57 ft. / 82%
MW-3029	42.54	47.06	4.52	43.75	3.31 ft. / 73%
MW-4001	—	20.09	—	19.99	0.10 ft.
MW-4004	—	40.84	—	41.04	N.C.
MW-4005	—	46.65	—	46.75	N.C.
MW-4006	—	20.12	—	20.08	N.C.
MW-4007	—	28.06	—	28.06	N.C.
MW-4008	—	39.74	—	39.84	N.C.
MW-4009	—	31.81	—	32.02	N.C.
MW-4010	—	41.56	—	41.87	N.C.
MW-4027	36.80	40.60	3.80	38.59	2.01 ft. / 53%
MW-4028	39.40	43.45	4.05	41.18	2.27 ft. / 56%
MW-4029	40.34	43.66	3.32	42.17	1.49 ft. / 45%
MWS-004	—	21.02	—	21.10	N.C.
MWS-021	30.79	33.27	2.48	32.56	0.71 ft. / 29%

(a) Recovery calculated from data obtained on September 11, 1998.
(b) Pre-pumping data not collected since expected radius of influence was assumed not to reach these locations
N.C.: No conclusive evidence of pumping influence on water level
* This location measurement was 10 days after pumping.

4. HYDROGEOLGIC DATA ANALYSIS

4.1 Bedrock Stratigraphy and Structure

The stratigraphy and structure of the uppermost bedrock formation, the Burlington-Keokuk Limestone, together influence the permeability and direction of groundwater flow in the shallow aquifer beneath the chemical plant.

4.1.1 Stratigraphy

Previous subsurface investigations have divided the limestone into two units based primarily on the degree of weathering: the upper weathered unit and the lower unweathered unit. The weathered unit typically exhibits a strongly weathered subzone that shows a considerably higher degree of weathering and is characterized by vuggy, weakly cemented chert breccia with minor limestone fragments in a sandy, clayey matrix (Ref. 4). This zone is qualitatively recognized as the strongly weathered subunit and is generally found at the top of the weathered unit, although it is discontinuous across the site. Hydrologic testing in the weathered and unweathered Burlington-Keokuk generally shows higher hydraulic conductivity values in the weathered unit (Ref. 5). The strongly weathered subunit averages still higher results than the weathered unit (Ref. 4). Decreased weathering, solution features, and fracture frequencies with depth support the hydraulic conductivity testing results.

The stratigraphy beneath the pumping test area at the chemical plant is shown in cross sections on Figure 4-1. The location map inset on the figure shows a plan view of the section traces. The cross sections are comprised of the following modeled surfaces: ground topography, top of bedrock, weathered/unweathered units contact, and April 1998 shallow groundwater. Schematics of each well on the section line are shown to give an accurate perspective of the well placement in relation to the geology and groundwater surface. All of the wells installed as part of this program were screened entirely within the weathered unit, including the pumping well (MW-3028).

Although not shown on the cross sections, each well exhibited a relatively thick strongly weathered zone within the weathered unit, actually comprising the majority of the weathered unit thickness. Rock core from well MW-3029 (Section A-A') was identified as entirely strongly weathered (see logs in Appendix A). Well MW-4028 exhibited strongly weathered rock for all but the lower 5 ft of the cored section (Section B-B'). Thick sequences of semi-consolidated chert breccia in a clay matrix were common in the wells, particularly near the bedrock surface. The thickness evident in rock core from this area corresponds with previously mapped thickness of the strongly weathered subunit, which is greater than 20 ft in this area (Ref. 4).

The water table occurs within the weathered unit in all of the new wells, but is found at the base of the overburden (residuum unit) in wells MW-2036 (Section A-A') and MWS-21 (Section B-B'). These two wells are located within the same low bedrock area, which is situated below the groundwater surface, resulting in a saturated residuum/limestone contact. Where this occurs, previous hydrologic and tracer testing has shown high permeability and preferential flow through residual gravels, voids, and fractures in the highly weathered limestone (Ref. 5).

4.1.2 Bedrock Surface Structure

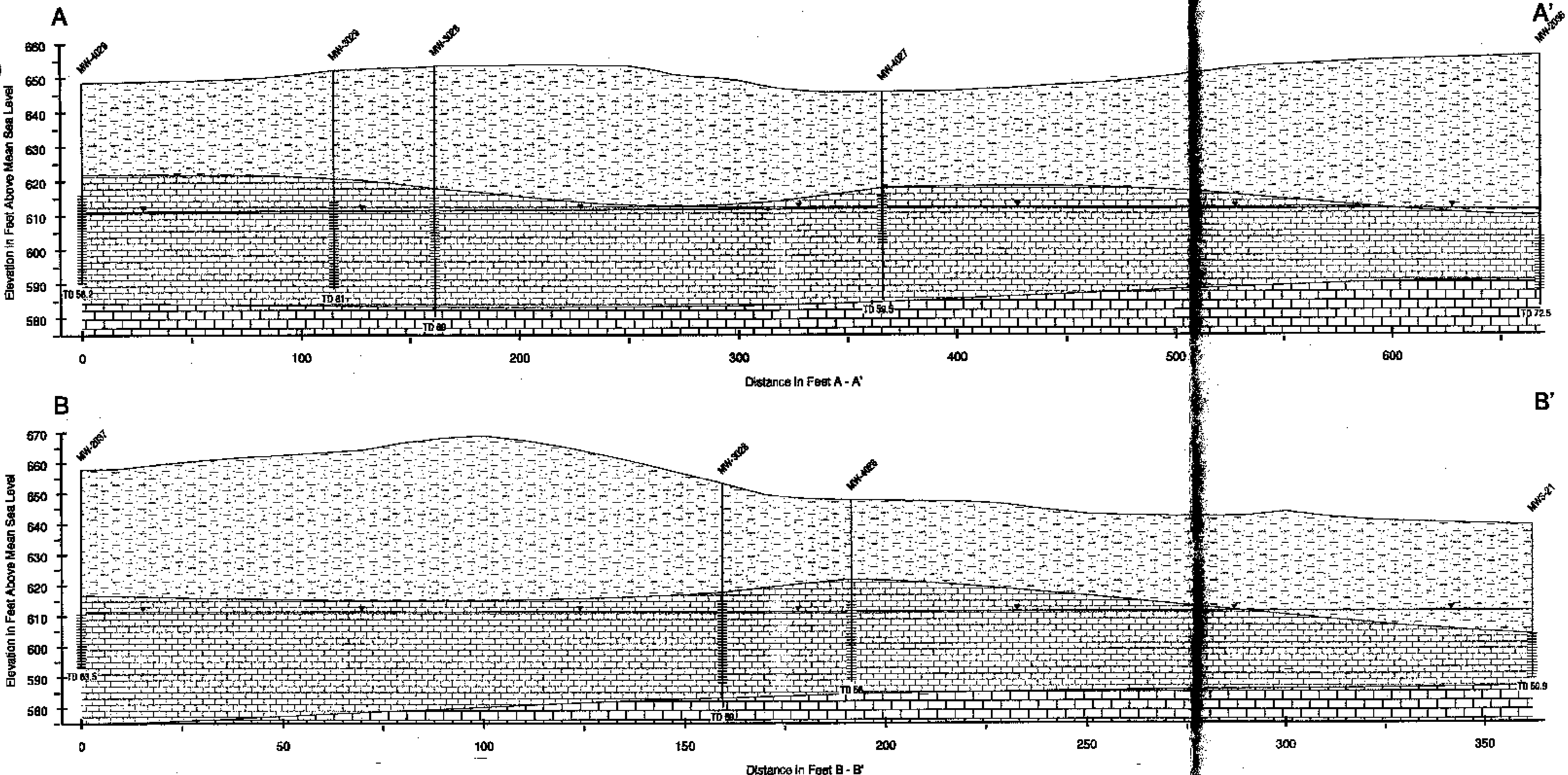
Drilling performed at the chemical plant and training area has previously identified linear bedrock lows on the surface of the Burlington-Keokuk Limestone (Ref. 5). As mapped, these topographic lows resemble surface drainages and appear to be pre-glacial channels formed by surface erosion of exposed Mississippian limestone (Figure 4-2).

In the vicinity of the pumping well, a bedrock low can be identified, with the lowest elevation centered around MWS-21. This paleochannel feature has an initial north-south orientation, which turns southwest at MWS-21, then northwest in the vicinity of MW-4004. Because of the lack of subsurface data north of MW-4004 and MW-4005, the channel morphology in this area is somewhat projected, but further to the northwest, the channel appears to join a more regionally-defined bedrock low (Figure 4-2). This paleochannel feature is also somewhat coincident with a shallow trough that is evident on the shallow groundwater surface (Section 5).

4.2 Fracture Frequency/RQD Results

During drilling of the test wells, fractures were observed in the bedrock core and noted on borehole logs (Appendix A). Fracture frequency and Rock Quality Designation (RQD) were also documented on the logs. RQD is a qualitative determination of rock quality calculated by taking the cumulative length of recovered solid pieces of core that are 4 in. or greater in length in a core run divided by the length of the core run, expressed as a percentage. The tabulated fracture data for each well are presented in Table 4-1.

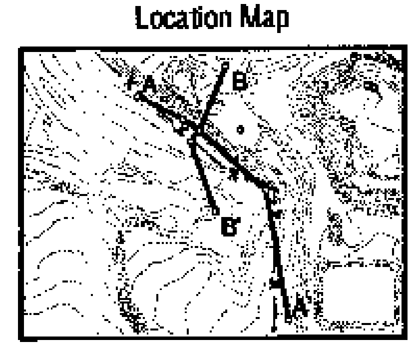
Fracture frequencies were higher in core from the strongly weathered portion of the weathered Burlington-Keokuk Limestone, averaging from 4.9 to 6 fractures per foot in the test wells. This can be attributed to the semi-consolidated/brecciated rock fabric commonly found in this subunit. The heavily weathered nature is also reflected in the low RQD averages, which ranged from 5% to 32%, with the highest average RQDs for this zone occurring in the pumping well (MW-3028). The weathered unit, without the strongly weathered subzone factored in, shows much lower average fracture frequencies, ranging from 2.1 to 3.3 fractures per foot of rock drilled. The RQD averages ranged from 42% to 86% in this unit. The unweathered unit was



LEGEND

- Overburden
- Weathered Burlington-Keokuk Limestone
- Unweathered Burlington-Keokuk Limestone
- Monitored Interval
- Shallow Groundwater Surface (April 1998)

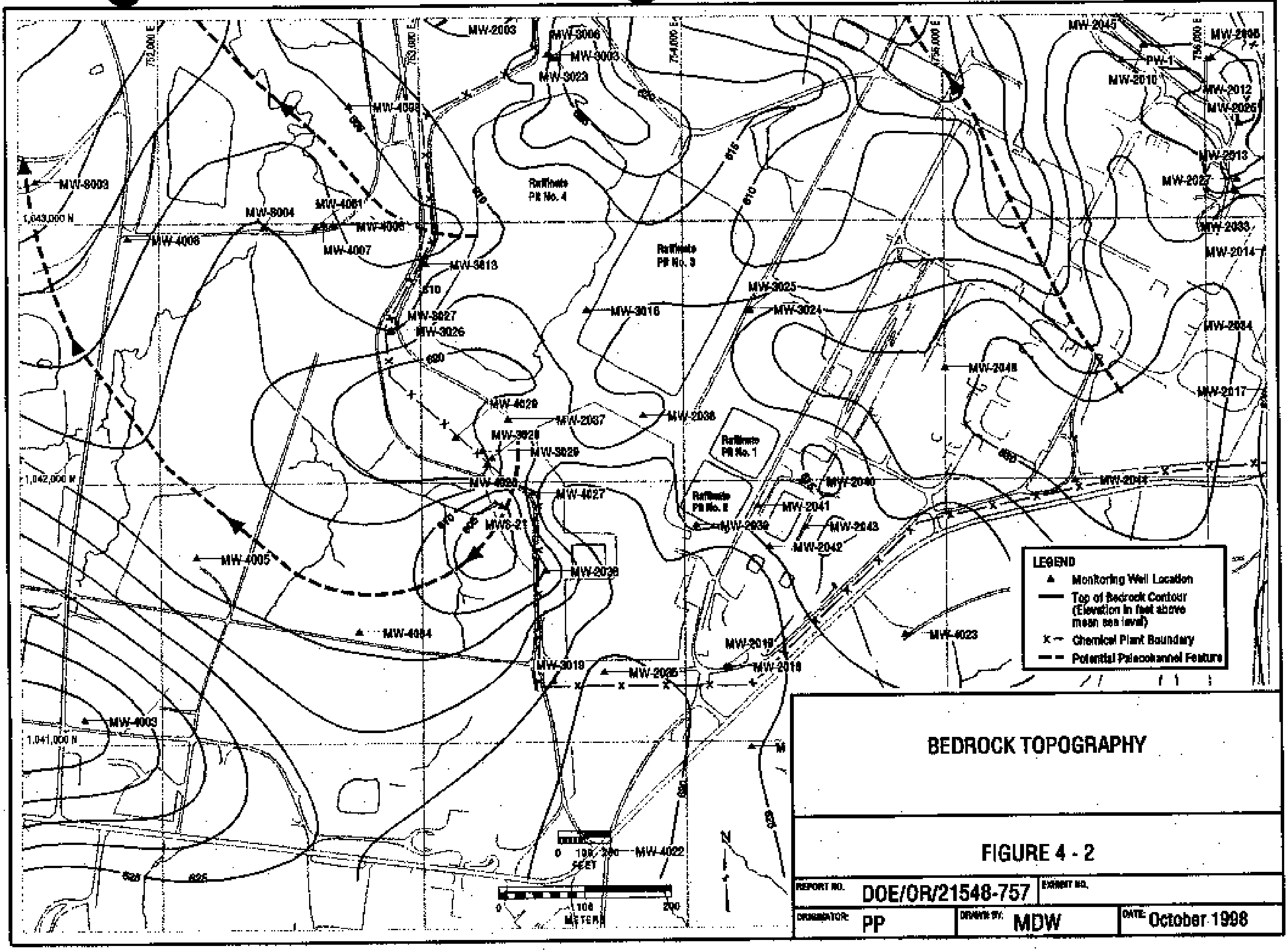
Location Map



HYDROSTRATIGRAPHIC CROSS SECTIONS

FIGURE 4-1

REPORT NO. DOE/OR/21548-757	EXHIBIT NO.		
ORIGINATOR: PCP	DRAWN BY: CLC	DATE: October 1998	



BEDROCK TOPOGRAPHY

FIGURE 4 - 2

REPORT NO.	DOE/OR/21548-757	EXHIBIT NO.	
ORIGINATOR: PP	DRAWN BY: MDW	DATE: October 1998	

Table 4-1 Fracture/RQD Data

Well	Stratigraphic Unit	Fracture Frequency (Fractures/ft.)	Weighted Average RQD %
MW-3028	Strongly Weathered BK	4.9	32
	Weathered BK	2.7	46
	Unweathered BK	3.4	30
MW-3029	Strongly Weathered BK	5.0	26
MW-4027	Strongly Weathered BK	5.5	13
	Weathered BK	2.1	82
MW-4028	Strongly Weathered BK	5.3	17
	Weathered BK	2.2	71
MW-4029	Strongly Weathered BK	6.0	5
	Weathered BK	3.3	48

RQD = Rock Quality Designation
BK = Burlington-Keokuk Limestone

intersected only in the pumping well and showed a somewhat uncharacteristically high fracture frequency and resulting low RQD results (Table 4-1).

Increased fracture frequencies and lower RQD values can be correlated with increased rock weathering and solutioning in the Burlington-Keokuk Limestone. The weathered unit exhibits zones of intense weathering (strongly weathered zones) that undoubtedly control groundwater movement where saturated.

Near-horizontal bedding plane fractures were the predominant type encountered during drilling. This agreed with previous fracture studies at the chemical plant using angle hole data which have shown an approximate 20:1 horizontal to vertical fracture ratio in the weathered limestone unit (Ref. 5). As can be expected in vertical boreholes, very few vertical or near-vertical fractures were encountered in the test wells, and those that were noted, were almost always in chert beds and not continuous fractures. The lone near-vertical fracture that appeared to be continuous and showed evidence of water movement was in well MW-4028 at a depth of 43.2 ft (in the strongly weathered zone).

4.3 Packer Testing

Hydraulic conductivity estimates based on packer tests performed during the drilling of the pumping well (MW-3028) and the first observation well (MW-4027), are generally low. As discussed in Section 2, the lower than anticipated hydraulic conductivity values created a bit of uncertainty as to where to locate the pumping well. The calculated hydraulic conductivity results from the testing are given in Table 4-2, along with the stratigraphic unit in which the test was performed. Hydraulic conductivity calculation sheets are provided in Appendix B.

Table 4-2 Summary of Packer Testing Results

Test Interval (feet b.g.s.)	Test Number	Test Pressure (psi)	Hydraulic Conductivity (cm/sec)	Average K for Interval (cm/sec)	Stratigraphic Unit
Well MW-3028 (Pumping Well) Depth to Bedrock = 31.5 ft. Static Water Level = 37.8 ft.					
34.3 – 43.0	1	10	4.45×10^{-4}	4.56×10^{-4}	Strongly Weathered Burlington Keokuk Limestone
	2	15	4.36×10^{-4}		
	3	20	4.50×10^{-4}		
	4	10	4.93×10^{-4}		
39.3 – 48.0	1	10	1.06×10^{-3}	1.08×10^{-3}	Strongly Weathered Burlington Keokuk Limestone
	2	15	9.63×10^{-4}		
	3	20	1.05×10^{-3}		
	4	10	1.24×10^{-3}		
47.5 – 58.0	1	15	7.12×10^{-4}	5.01×10^{-4}	Strongly Weathered Burlington Keokuk Limestone
	2	25	5.88×10^{-4}		
	3	35	3.69×10^{-4}		
	4	25	4.03×10^{-4}		
	5	15	4.32×10^{-4}		
57.5 – 69.0	1	15	7.55×10^{-6}	9.88×10^{-6}	Weathered Burlington Keokuk to 59.3' then Unweathered BK Limestone
	2	25	1.06×10^{-5}		
	3	35	1.28×10^{-5}		
	4	20	8.53×10^{-6}		
Well MW-4027 Top of Bedrock = 27.5 ft. Static Water Level = 33.4 ft.					
29.0 – 39.5	1	10	8.93×10^{-5}	1.68×10^{-4}	Strongly Weathered Burlington Keokuk Limestone
	2	25	9.45×10^{-5}		
	3	20	1.82×10^{-4}		
	4	10	2.11×10^{-4}		
	5	15	2.07×10^{-4}		
	6	20	2.00×10^{-4}		
	7	10	2.15×10^{-4}		
39.0 – 49.5	1	10	5.26×10^{-5}	1.32×10^{-4}	Strongly Weathered Burlington Keokuk Limestone to 45.5' then Weathered
	2	20	7.76×10^{-5}		
	3	30	1.85×10^{-4}		
	4	10	2.10×10^{-4}		
49.0 – 59.5	1	15	3.03×10^{-6}	3.41×10^{-6}	Weathered Burlington Keokuk Limestone
	2	25	4.55×10^{-6}		
	3	35	5.97×10^{-6}		
	4	10	9.76×10^{-8} *		

* Below quantification limit but used in average hydraulic conductivity value for interval.
b.g.s. Below ground surface

The results from the testing followed trends noted from previous packer testing at the site, such as decreasing permeability with depth and the highest permeability exhibited in the strongly weathered portion of the Burlington-Keokuk Limestone. The 39.3 ft to 48.0 ft test interval in the pumping well exhibited the highest measured hydraulic conductivity of the packer testing, with an average hydraulic conductivity of 1.08×10^{-3} cm/sec. This interval straddles the area of circulation loss and 1-ft bit drop (probable void) noted during drilling that occurred at 44 ft to

45 ft below ground surface. This zone is likely a significant contributor of groundwater to the well.

The packer testing results were approximately one to two orders of magnitude less than calculated hydraulic conductivities for these two wells from the pumping tests (Section 5). This difference can possibly be attributed to plugging of fractures in the limestone with drill cuttings during coring. The limestone is very clay-rich which would tend to pack tightly into small fractures during drilling, and also during the water injection testing, even though the borehole was flushed before each test. These processes are contrasted with surging and pumping of the borehole during development, which likely pulls out both natural and drilling-related material from the fractures allowing better flow. This is supported by the initial pumping results, particularly in MW-3028 where after minimal development by surging , the well was able to sustain greater than 5 gpm. The initial and subsequent development of these two wells significantly improved the hydraulic conductivity as evidenced by increased well productivity, more so in the pumping well than in MW-4027.

5. AQUIFER TEST ANALYSIS

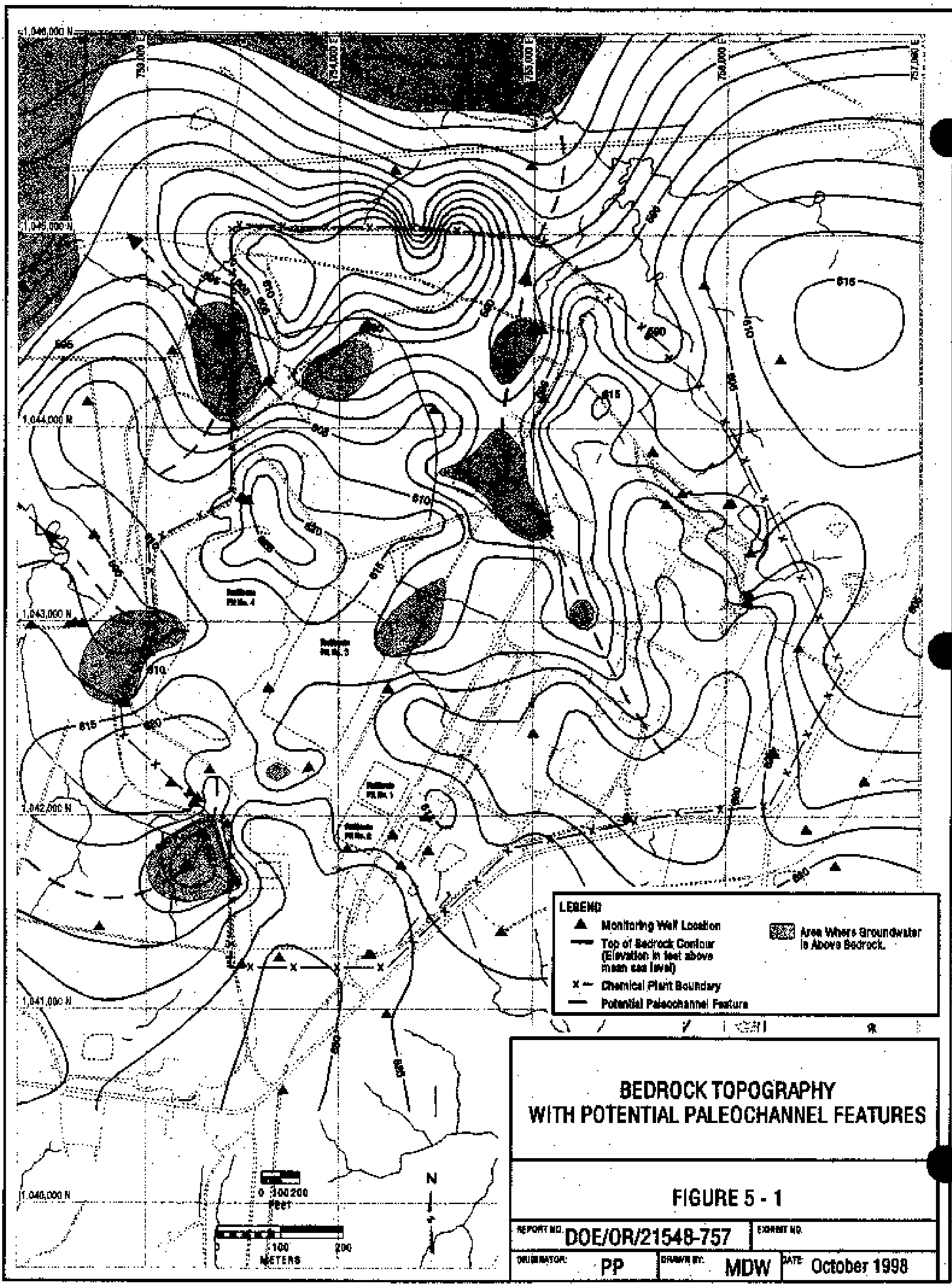
5.1 Hydrogeology

The shallow bedrock aquifer has been conceptualized as a diffuse flow system with superimposed conduit flow. The conduit system is convergent based on the results of dye tracer tests which demonstrate emergence at Burgermeister Spring from several surface and groundwater injection points north of the groundwater divide. South of the divide, groundwater remains within surface drainages. A losing segment of Schote Creek and linear depressions or troughs in the top of the limestone bedrock have been identified as high conductivity pathways in communication with Burgermeister Spring (Figure 5-1) (Ref. 5). The conduit flow system was not identified in three aquifer tests conducted in 1989 (Ref. 6).

As a result of topographic influence on the water table, an east-west groundwater divide roughly coincides with a surface water divide that separates the Missouri and Mississippi River drainages. At the chemical plant, the location of the ground-water divide is south of the raffinate pits and is also coincident with the surface topographic divide (Figure 5-2).

Burgermeister Spring and other associated springs (SP-6302 and SP-6303) are thought to be the primary discharge points for groundwater in the shallow aquifer north of the groundwater divide. This discharge includes water which enters the flow system off-site through losing stream reaches of Schote Creek. Historical data indicate relatively low discharge rates under baseflow conditions (approximately 0.07 ft^3/sec) and much higher rates (maximum 4 ft^3/sec) following precipitation events.

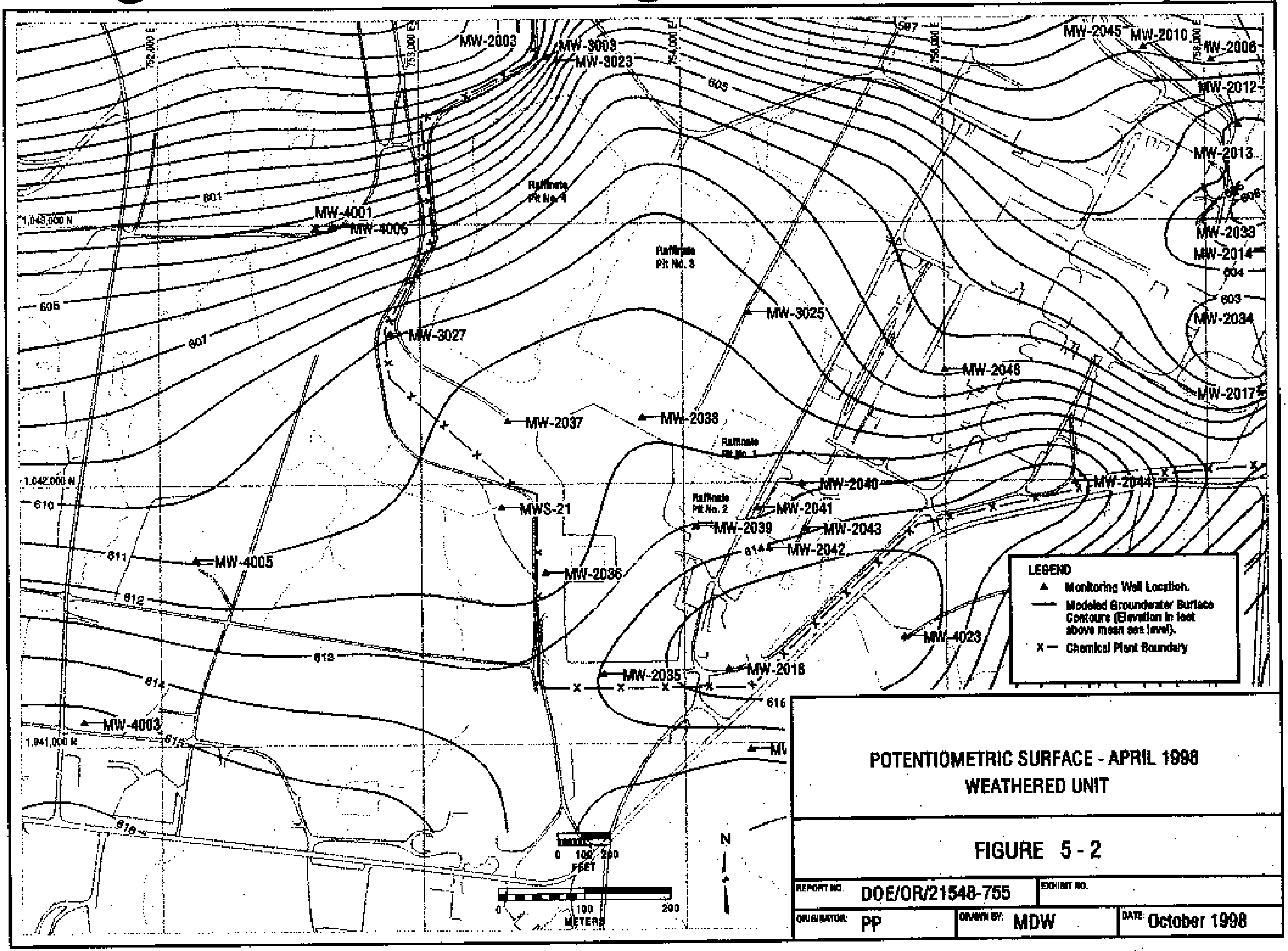
Groundwater levels fluctuate with time. Smaller groundwater fluctuations (less than or equal to 1 ft) are observed in several wells located in the southern and north-central portions of the chemical plant. Larger fluctuations are observed at wells located on the western part of the training area and in a few scattered locations within the chemical plant. Small fluctuations typically occur in areas of higher hydraulic conductivity. For example, at MW-2037 and MW-2038, south of the raffinate pits, hydraulic conductivities greater than 10^{-3} cm/s have been estimated and fluctuations of less than 1 ft have been measured. The location-dependence of the water-level fluctuations may be attributed to the properties and the thickness of the vadose zone and the surface topography. In general, the locations with greater fluctuations are in areas of thin overburden. In these locations, the greatest fluctuations are likely the result of quick movement of infiltration from precipitation and/or runoff into the groundwater system and the slow movement of water out of the well into the aquifer. Conversely, the locations with smaller groundwater fluctuations are in areas where groundwater moves quickly within the bedrock aquifer (Ref. 5).



BEDROCK TOPOGRAPHY WITH POTENTIAL PALEOCHANNEL FEATURES

FIGURE 5 - 1

REPORT NO.	DOE/OR/21548-757	EXHIBIT NO.			
ORIGINATOR:	PP	DRAWN BY:	MDW	DATE:	October 1998



POTENTIOMETRIC SURFACE - APRIL 1998
WEATHERED UNIT

FIGURE 5 - 2

REPORT NO. DOE/OR/21548-755		EXHIBIT NO.	
ORIGINATOR: PP	DRAWN BY: MDW	DATE: October 1998	

Analysis of core from angled borings indicates that fracturing in the shallow bedrock aquifer is predominantly horizontal and typically occurs along interbeds and bedding planes (Section 4). Both horizontal and vertical fracture densities are significantly higher in the upper weathered bedrock than in the lower unweathered unit. The aquifer becomes less permeable with depth because of the decreased weathering and associated dissolution features. In the weathered unit, the hydraulic conductivity ranges from 10^{-7} cm/s to 10^{-2} cm/s (Ref. 5). The upper part of the weathered unit shows a greater variation in hydraulic conductivity than the lower part. For example, within the top 15 ft, the range of hydraulic conductivity values is representative of the entire weathered unit; however, 35 ft below the top of the bedrock, the hydraulic conductivity ranges only from 10^{-6} cm/s to 10^{-4} cm/s. The highest estimates occur at locations where the contact between the residuum and the top of weathered bedrock is saturated (Figure 5-1). Locations of high hydraulic conductivity generally correspond to linear depressions in the bedrock topography where the limestone is highly fractured. In the unweathered unit, the hydraulic conductivity typically ranges from 10^{-7} cm/s to 10^{-5} cm/s (Ref. 5).

Although almost all of the monitoring wells at the chemical plant pump dry during low rates of purging, two wells sustained high flush water injection rates (10 gpm to 25 gpm) following emplacement of dye tracers. These are MW-2032, which was found to be in direct hydraulic communication with Burgermeister Spring, and MW-2037, which typically has some of the highest TCE concentrations of any well. Analysis of bedrock topography combined with the high sustainable injection suggest that these wells are in the high hydraulic conductivity conduit system. The fact that MW-2032 pumped dry during low rate purging (approximately 1 gpm) suggests that the most permeable zone is located at and above the water table.

Dissolution features, including secondary intergranular porosity, are present in the weathered unit and generally are oriented parallel to bedding planes. Loss of circulation and core loss were common during drilling in the northern part of chemical plant area (Ref. 5). During the test well drilling, circulation was maintained in the boreholes, but significant core loss occurred due to the extremely weathered nature of the upper bedrock. Preferential flow along horizontal features likely results in the aquifer being highly anisotropic with the horizontal hydraulic conductivity much greater than the vertical hydraulic conductivity. Water quality data and high barometric efficiency observed in observation wells used for pump tests provide indication of low relative vertical hydraulic conductivity.

Most of the aquifer recharge moves laterally above the unweathered limestone based on the generally lower hydraulic conductivity, lack of tritium, and lower nitrate levels for the unweathered unit (Ref. 7). The presence of tritium and larger Ca/Mg ratios in water samples from the weathered upper part of the shallow aquifer are evidence of shorter residence time (Ref. 7).

Recharge to conduits is most likely concentrated in areas where the overburden is thin or absent. Surface water becomes shallow subsurface flow along losing stream reaches and then reappears at springs to become surface water again. Localized recharge likely also occurs as preferential infiltration through hairline fractures, discrete permeable zones, and macropores (Refs. 5 and 7).

5.2 Static Water Levels

Static water level monitoring was performed in the test well and five nearby monitoring wells to determine antecedent trends and to evaluate the effect of external influences (i.e., those not related to pumping such as precipitation and changes in atmospheric pressure). A plot showing precipitation, barometric pressure change, and relative water levels for the week preceding the step drawdown test is shown on Figure C.1 in Appendix C. This figure shows a strong inverse correlation between barometric pressure change and the relative water level in all six wells. The barometric efficiency is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure or

$$BE = \gamma \Delta h / \Delta p$$

where: γ = specific weight of water
BE = barometric efficiency
Δh = change in water level
Δp = change in atmospheric pressure

The relatively high observed barometric efficiency (approximately 50%) is an indication that the shallow bedrock aquifer is semi-confined due to low vertical hydraulic conductivity and also that the aquifer matrix is relatively incompressible. Atmospheric pressure fluctuations do not cause appreciable water level fluctuations in unconfined aquifers because the pressure is borne equally by the water in the well and in the aquifer (Ref. 9).

Although the water levels at the end of the static water level monitoring period are not appreciably different than at the beginning of the period, a decrease of nearly 0.5 ft occurred in all six wells within a period of approximately 30 hours. This decrease was coincident with a high pressure system that moved into the area on June 13 and 14. As such, evaluation of drawdown caused by pumping involves consideration of barometric pressure fluctuations, particularly when the total drawdown is less than 1 ft. In the following analysis, corrections were made to the water level recovery data assuming a barometric efficiency of 50% for all wells. Corrections were made only for the recovery data because barometric pressure data were not available for the period of pumping due to a malfunctioning data logger.

5.3 Step Drawdown Test

5.3.1 Analysis of Pumping Data

The step drawdown test at MW-3028 lasted approximately 8 hours followed by approximately 2.5 days of monitored water level recovery. The discharge was step-wise increased from an initial rate of 6.3 gpm to a maximum 23.0 gpm in the fourth and final pumping period. The total discharge was in excess of 8,700 gal. Water level monitoring took place in the pumping well, and for qualitative purposes in MW-2037 (r = 159.5 ft), MWS-21 (r = 188.9 ft) and in MW-4027 (r = 204.5 ft). Drawdown versus log time plots for the period of pumping are shown in Figures C.2 through C.4 in Appendix C. The pumping well shows log-linear best fit lines for each of the last three steps (Figure C.2). The posted fit statistics indicate a reasonably strong log-linear trend for each step with the lowest correlation coefficient (R-squared) equal to 0.94 (1.00 = perfect fit).

Measured from the top of the well casing, the initial water level in the pumping well was 40.74 ft, the screened interval was from 40 ft to 60 ft, and the pump intake was situated at approximately 55 ft. The total available drawdown thus was approximately 14 ft, and the initial saturated screened interval was 19 ft.

Drawdown at the end of the test was 3.23 ft in the pumping well, which is roughly 17% of the initial saturated screened interval and 23% of the available drawdown. Although the water level never approached equilibrium, as would be indicated by the water level ceasing to decline, it appeared that the sustainable pumping rate possibly exceeded 23 gpm based on the small total drawdown in comparison to the amount available. For comparison, the estimated sustainable yield at the three previous pumping test locations was 0.3 gpm (Ref. 6).

The pumping well step data were evaluated quantitatively using the method of Birsoy (Ref. 10). The Birsoy calculation (Appendix C) incorporates the correction scheme of Jacob (Ref. 11) to account for decreased saturated thickness caused by pumping. The transmissivity estimate based on this analysis is 7,600 gal/day/ft. For comparison, transmissivity estimates based on analysis of the pumping well data for the 1989 constant rate aquifer tests are three orders of magnitude lower, ranging from 2.9 gal/day/ft to 9.1 gal/day/ft (Ref. 6).

5.3.2 Analysis of Recovery Data

Water level recovery from the step test was analyzed using the Theis Residual Drawdown Recovery Method (Ref. 12) after applying the correction of Harrill (Ref. 13) to account for the variations in discharge. The recovery data in the pumping well with residual drawdown plotted as a function of t/t' are shown in Figure C.5 in Appendix C, where t is the time since pumping started and t' is the time since pumping stopped. Time increases from right to left on a t/t' plot. The data plots as two roughly parallel line segments separated by a transition from t/t' of 1,000 to 10. Parallel line segments are characteristic of double porosity fractured rock aquifers (Refs. 14 and 15), although in this case the parallel line segments are not well defined and the offset is relatively minor. Note that the recovery data intercept the zero drawdown line at a t/t' value of approximately 1, indicating full water level recovery following the relatively short duration test.

A transmissivity of 6,400 gal/day/ft was estimated based on log-linear regression of the recovery data for t/t' values between 2 and 10. Only the late straight line segment data (low t/t' values) were analyzed as the early recovery data potentially were affected by wellbore storage and/or skin effects (Ref. 16). According to the equation of Hargis (Ref. 17), the wellbore storage effects based on this transmissivity have not completely dissipated until a t/t' value of 19. However, the data trend does not exhibit the characteristic steep initial slope caused by wellbore storage and skin effects (Figure C.5). The data trend also does not exhibit the sharp slope change characteristic of data affected by a linear barrier boundary. The transmissivity estimate is in close agreement with the estimate based on the Birsoy analysis for the pumping data.

5.4 Constant Discharge Aquifer Tests

5.4.1 Boundary Conditions

A preliminary short-term constant rate aquifer test was performed at MW-3028 in order to evaluate the pumping and data collection systems and to facilitate locating additional observation wells. A constant pumping rate of 31 gpm was maintained for approximately 12.5 hours. A higher pumping rate was chosen based on the step-drawdown test results which suggested a sustainable yield potentially in excess of 23 gpm. Pumping at near the sustainable yield was desired in order to obtain interpretable drawdown at observation wells and to better evaluate aquifer boundary conditions.

The data collected during the 31 gpm test revealed two boundary conditions that were not evident from the step test. First, the aquifer response to pumping over the longer period of constant discharge is not characteristic of radial flow. Drawdown trends for the pumping and observation wells are curvilinear, concave downward when plotted as drawdown versus log time (Figures C.6 through C.10), and linear when plotted on fully logarithmic plots (Figures C.11 through C.15). In contrast, analytical solutions for radial flow to a well (e.g., the Theis (Ref. 12) nonequilibrium equation) predict a linear relationship for drawdown versus log time, which is curvilinear, and concave downward on a log-log plot (Figure C.16).

Second, a sharp increase in the rate of decline in the water level was observed when the drawdown in the pumping well reached approximately 5.5 ft (Figure C.6). From this point, the water level lowered rapidly to the pump intake. A possible explanation for the increased rate of drawdown is that the cone-of-depression intercepted a barrier boundary, which by image well theory (Ref. 18) would cause a doubling of the drawdown slope. In this case, however, the sharp increase in drawdown resulted in more than a doubling of slope in the pumping well but was not observed in nearby observation well MW-3029 (Figure C.7), nor in the three other monitored observation wells (Figures C.8 through C.10).

Based on this fact, and with reference to the hydrogeologic conceptual model, the boundary condition which caused the increased drawdown likely is not a lateral barrier boundary but instead is a decrease in the hydraulic conductivity with depth, possibly the result of dewatering of a portion the solutioned fracture system (i.e., conduit). This conclusion is supported by the observation of the pumping water level surface becoming turbulent from cascading water when the drawdown reached approximately 5.7 ft during the long-term test. Also, an increased rate of drawdown occurred at approximately the same water level elevation in the pumping well during the 18-day long-term test (Figure C-17). This despite the fact that the total pumped volume at the time of the inflection point was approximately 15 times greater during the long-term test than during the short-term test.

Packer test results for the MW-3028 borehole did not indicate a significant depth dependency for hydraulic conductivity but also did not indicate a significant change in hydraulic conductivity at any depth (Section 4.3). It is reasoned based upon comparison of packer test results with aquifer test results that well development subsequent to packer testing appreciably increased the effective hydraulic conductivity in the upper interval of the MW-3028 borehole. Also, based on the pattern of drawdown in the short- and long-term constant rate tests, the bulk of the transmissivity in the formation adjacent MW-3028 is provided by the interval from the water table to a depth of approximately 47 ft below top of casing, which equates to approximately to the first 6 ft of drawdown for both the short- and long-term tests. A 1-ft. solution void was encountered at approximately 46 ft (below the top of casing) during drilling of the MW-3028 borehole (Appendix A).

Semi-logarithmic plots of the pumping data for the long-term test (Figures C.17 through C.27) show curvilinear trends similar to those observed for the short-term tests. Fully logarithmic plots (Figures C.28 through C.38) show a strong linear log-log relationship that develops early during pumping and continues through the end of the test. The curvilinear semi-log trend effectively precludes analysis of the drawdown data using straight line techniques based on the assumption of radial flow. The observed linear log-log relationship is, in fact, characteristic of parallel flow, which is also commonly referred to as "linear flow" in petroleum engineering literature (Refs. 19 and 20).

An analytical model for a parallel flow system, which is a close analog to the hydrogeologic conceptual model for the conduit flow system at chemical plant (Section 5.1), is a single permeable vertical dike which intrudes a much lower transmissivity fractured rock aquifer (Refs. 21, 22, and 23). The fractured dike is linear, infinitely long, and has a finite width and finite hydraulic conductivity. The dike is confined above and below by impermeable unfractured bedrock and the well is represented as a plane sink. The idealized dike-aquifer flow system is depicted in Figure 5-3.

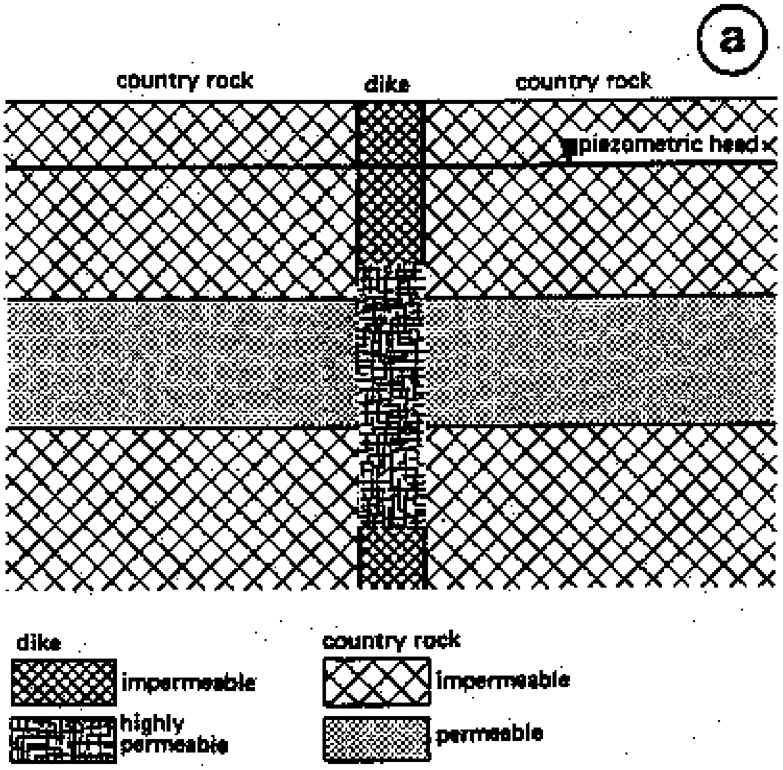
When the well is pumped at a constant rate, three characteristic time periods can be distinguished: early time, medium time, and late time. The theoretical response for the pumping well at early and medium times is illustrated in Figure C.39 in Appendix C. At early times, all the water is derived from parallel flow within the dike and none is contributed from the lower transmissivity aquifer. At medium times, all the water is supplied from dominantly parallel flow from the aquifer and none is contributed from storage in the dike. A log-log plot of the pumping well time-drawdown data yields a linear trend with a slope of 0.25 during this period. Finally, at late times, the flow is pseudo-radial and a semi-log plot of the time-drawdown data yields a straight line. The late time radial flow pattern is not expected to develop unless the width of the high transmissivity feature is quite low such as a dike not wider than a few centimeters or an individual fracture (Ref. 16).

Pseudo-radial flow does not appear to have developed during the long-term test. The slope of the line of regression for the pumping well drawdown data during the period from 1 to 10,000 minutes is 0.25 (Figure C.28), which is consistent with the theoretical response for medium pumping times. Later data are positioned above the linear trend and are likely the result of the total drawdown extending below the depth-related boundary.

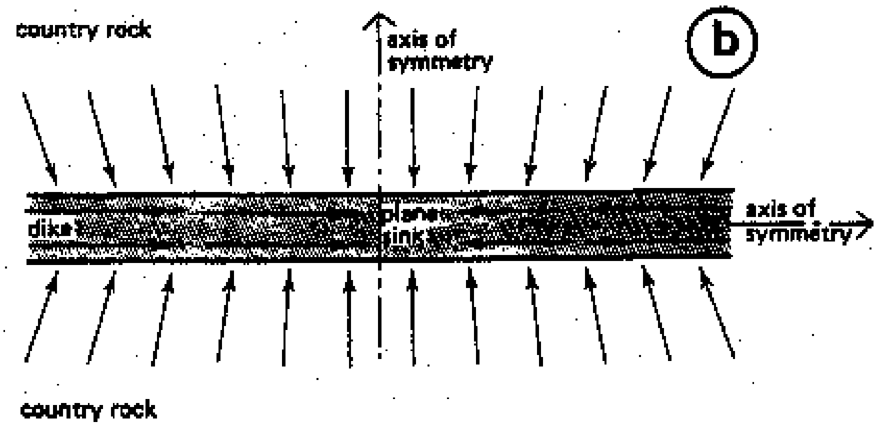
While all of the wells exhibited linear log-log trends, the slope of the trend generally increases with increasing distance from the pumping well (Figures C.28 through C.38). The slope of 0.25 for the pumping well regression line is the lowest (Figure C.28). The slopes range from 0.38 to 0.66 for the six observation wells within 205 ft of the pumping well (Figures C.29 through C.34). Slopes of approximately 1.0 occur for the three most distant weathered bedrock wells (Figures C.35 through C.38). This pattern suggests a gradational horizontal boundary between the weathered conduit feature and the surrounding less transmissive aquifer.

5.4.2 Area of Influence

A plot of drawdown versus distance after 10 days of pumping during the long-term test is shown in Figure C.40. The data for the pumping and six closest observation wells form an approximate log-linear trend, assuming an effective radius of 0.5 ft for the pumping well.



A: Cross-section showing an aquifer of low permeability in hydraulic contact with the highly permeable, fractured part of a vertical dike;



B: Plan view: parallel flow in the pumped dike and parallel-to-near-parallel flow in the aquifer
Modified from Kruseman and de Ridder (1990)

NOT TO SCALE

COMPOSITE DIKE-AQUIFER SYSTEM

FIGURE 5-3

REPORT NO.: DOE/OR/21548-757		EXHIBIT NO.: A/PI/039/1198	
ORIGINATOR: RC	DRAWN BY: GLN	DATE: 11/13/98	

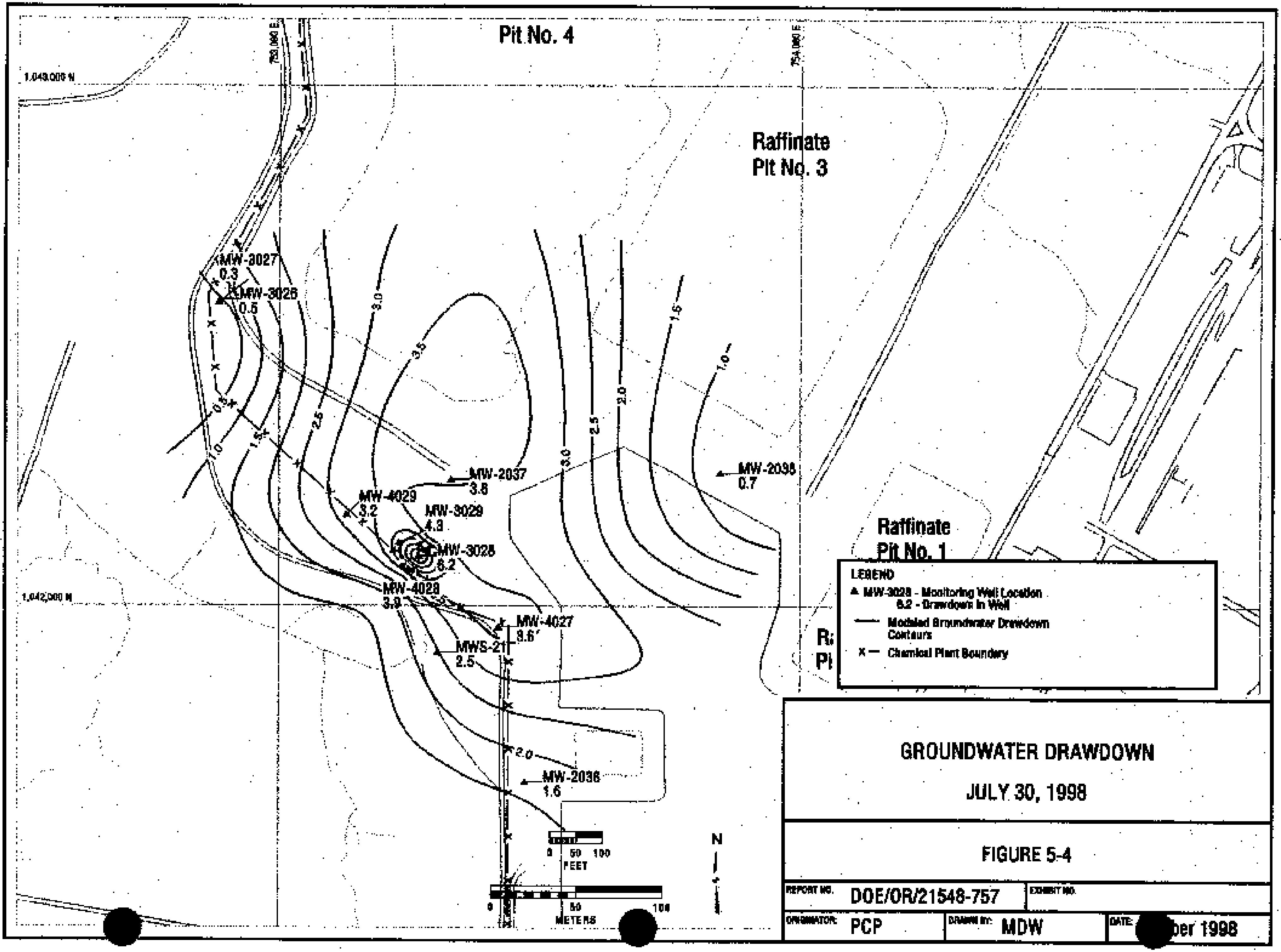
However, the four most distant wells fall considerably above the line of regression for the closer wells. The zero drawdown intercept occurs at 255,000 ft, although in reality only a small amount of drawdown (0.15 ft.) was measured at a distance of 620 ft in MW-3027. Because the zero-drawdown intercept is such a large number, the storage coefficient calculated using the straight-line method is very low (3×10^{-6}), lower than the normal range for confined aquifers (Ref. 18). In reality, the effective storage coefficient was likely higher than calculated because the area of influence was much smaller than the assumed 255,000 ft.

A distance-drawdown plot for the last day of pumping (time = 18 days) is shown in Figure C.41. It can be seen that the four most distant wells are now positioned nearer the line of regression for the closer wells. This is consistent with the delayed drawdown pattern predicted for wells in the low transmissivity aquifer according to the dike-aquifer analytical model (Refs. 21, 22, and 23). Their method of analysis involves plotting the ratio of drawdown in the observation well to drawdown in the pumping well versus time and performing curve matching using the type curve for wells in the low transmissivity aquifer (Figure C.42). It can be seen that parallel flow in the aquifer causes the curve to asymptotically approach a drawdown ratio of 1 after a delay caused by the resistance of the low transmissivity aquifer.

Assuming an isotropic aquifer, the extent of hydraulic influence (i.e., where drawdown occurred) is several thousand feet from the pumping well at the end of the test based on a regression of the data for all eleven routinely monitored wells (Figure C.43). In reality, the observed drawdown is not symmetrical. For example, MW-3029 had more drawdown than MW-4028 even though MW-3029 is the more distant well. MW-2037 also plots below the regression line suggesting anisotropy, although the same effect could also be the result of hydraulic communication along an isotropic, high hydraulic conductivity trend. Based on the hydrogeologic conceptual model, the orientation of the high conductivity paleochannels is a more significant control on the area of hydraulic influence than anisotropy.

Heterogeneous and/or anisotropic conditions are also made apparent by inspection of a plot of drawdown versus time over radius squared (t/r^2) (Figure C.44). For a homogeneous and isotropic aquifer, all the observation well data would plot on a Theis curve-shaped trend (Figure C.16). Instead, data for the nearest wells (MW-4028 and MW-3029) plot as two parallel trends which are steeper than a Theis curve and are crossed by the data from the more distant observation wells.

The observed aquifer response to pumping is obviously inconsistent with that which would be associated with radial flow in a homogeneous and isotropic aquifer. Rather than a cone of depression, pumping within an elongate zone of high permeability results in the development of a trough of depression (Refs. 16 and 24). The maximum drawdown (Figure 5-4) on the day before the long-term test ended was to the northwest and east of the pumping well, but lacks enough



GROUNDWATER DRAWDOWN

JULY 30, 1998

FIGURE 5-4

REPORT NO. DOE/OR/21548-757		EXHIBIT NO.	
ORIGINATOR: PCP	DRAWN BY: MDW	DATE: ber 1998	

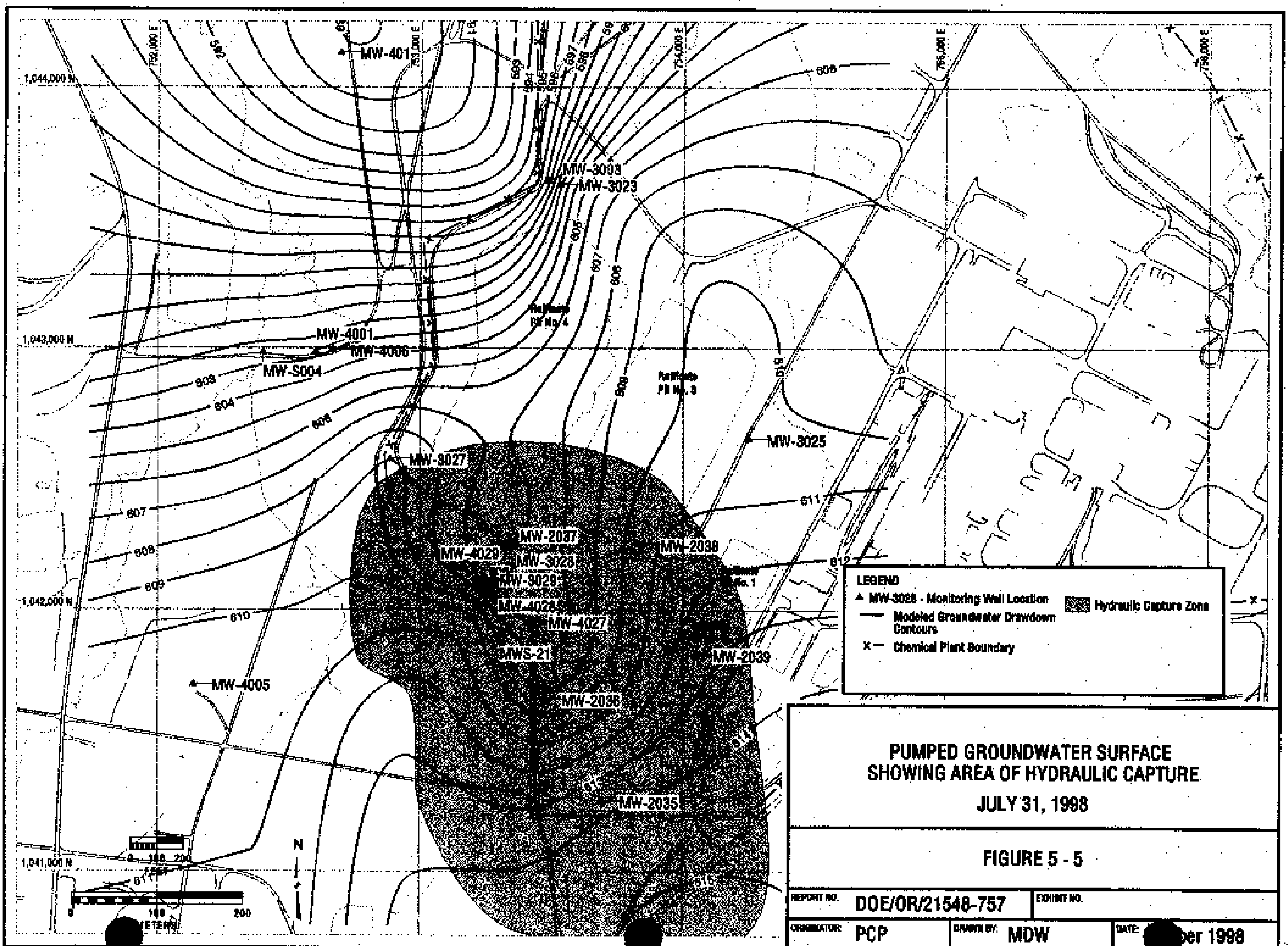
control points to verify the existence of a trough-shaped area of influence. The direction of observed maximum drawdown is approximately coincident with the north-south orientation of the bedrock depression in the vicinity of the pumping well (Figure 5-1). Data from the last day of the test was not used for contouring because the depth-related boundary had by that time caused excess drawdown in the pumping well.

The hydraulic capture zone (i.e., that portion of the aquifer that contains groundwater that will eventually be drawn into the well) extends out from MW-3028 as shown in Figure 5-5 and 5-6. The area of hydraulic influence does not equate with the hydraulic capture zone despite the relatively slight natural (non-pumping) hydraulic gradient. For example, MW-3027 is outside the zone of capture despite a total drawdown of approximately 0.5 ft. Visual evidence of hydraulic capture between wells occurred approximately 13 days into the long-term test with the arrival at MW-3028 of Rhodamine WT dye that had been injected into MW-2037 (Section 6).

5.4.3 Aquifer Properties

Quantitative analysis using equations developed for radial flow is problematic in this case because of the probable occurrence of parallel flow. The application of curve-matching and straight-line procedures for the pumping period data generally is not possible due to the large deviation which occurs between the theoretical and actual responses to pumping. The data which are most readily analyzed using standard straight-line procedures are the recovery data from the short-term test (Figures C.45 through C.49) and the long-term test (Figures C.50 through C.57). The results of these analyses are presented in Table 5-1, which indicates reasonably good agreement with estimates of transmissivity (T) from the step-drawdown test.

To facilitate comparison with estimates for other porous and/or fractured media, a range of hydraulic conductivity (K) estimates is presented based on a range of saturated thicknesses (b). Highest hydraulic conductivity is calculated when the assumed saturated thickness is 1 ft, which corresponds to the approximate interval of a void encountered during the drilling of MW-3028 (Appendix A). Much lower estimates are calculated assuming the initial saturated screened interval of 19 ft, which also corresponds roughly to the thickness of the saturated strongly weathered interval. In any event, transmissivity is a more direct indication of the ability of the aquifer to transmit water than hydraulic conductivity.

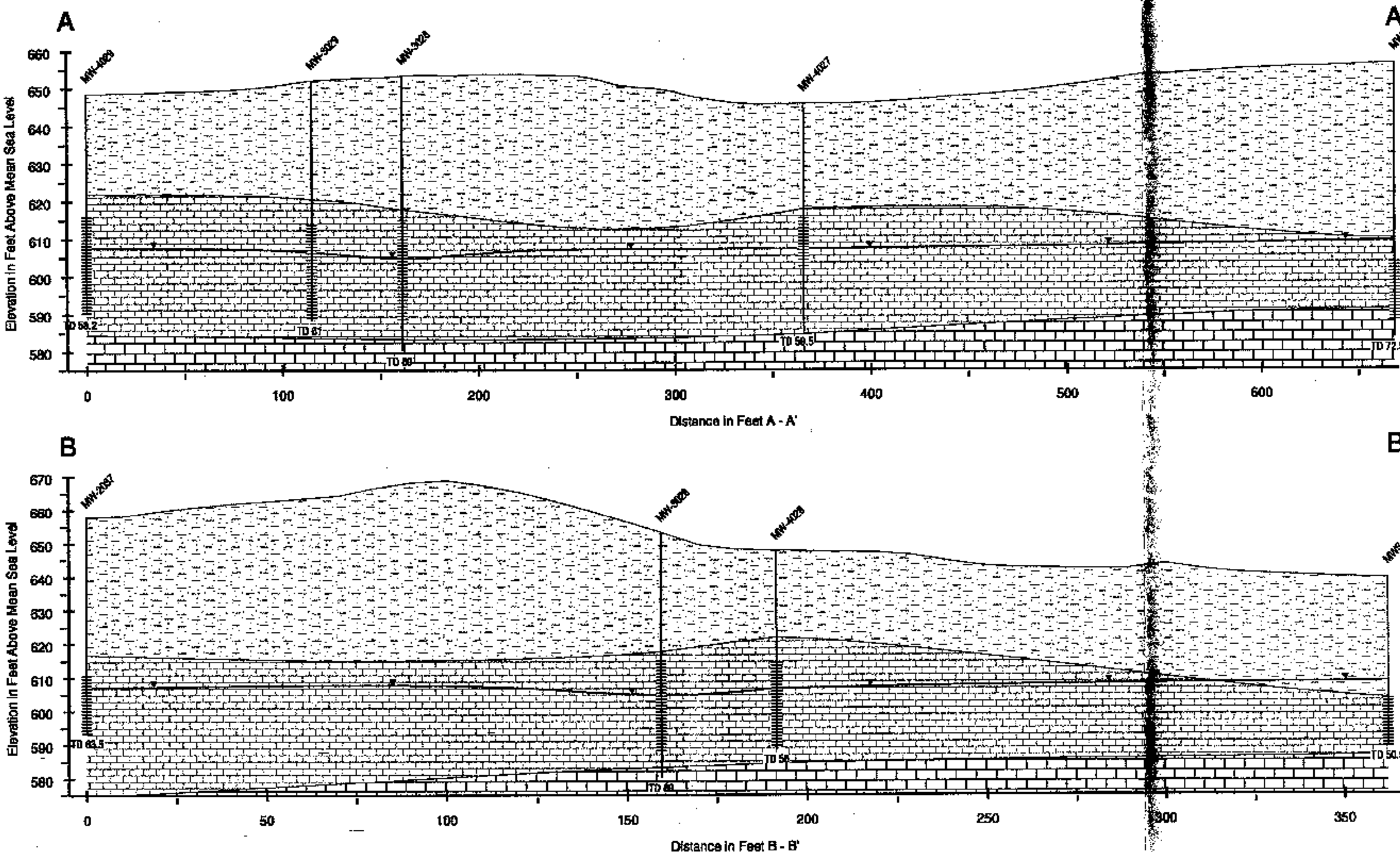


PUMPED GROUNDWATER SURFACE SHOWING AREA OF HYDRAULIC CAPTURE

JULY 31, 1998

FIGURE 5 - 5

REPORT NO. DOE/OR/21548-757	EXHIBIT NO.	
ORIGINATOR: PCP	DRAWN BY: MDW	DATE: ber 1998



LEGEND

Overburden

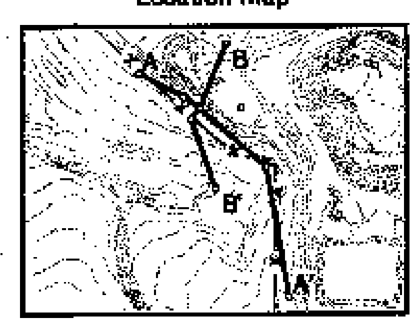
Weathered Burlington-Keokuk Limestone

Unweathered Burlington-Keokuk Limestone

Monitored Interval

Pumped Groundwater Surface (July 1998)

Location Map



HYDROSTRATIGRAPHIC CROSS SECTIONS WITH PUMPED GROUNDWATER SURFACE

FIGURE 5-6

REPORT NO. DOE/OR/21548-757	EXHIBIT NO.	
ORIGINATOR: PCP	DRAWN BY: CLC	DATE: October 1998

Table 5-1 Aquifer Properties by Radial Flow Analysis

Test	Method	Well	r (ft)	T (gpd/ft)	K (cm/sec) b = 1 ft	K (cm/sec) b = 19 ft
Step-Pumping	Birsoy and Summers (1980) (Ref. 10)	MW-3028	0	7.6×10^{3}	3.6×10^{-1}	1.9×10^{-2}
Step-Recovery	Theis Recovery (1935) w/ Harrill's (1970) Correction (Refs. 12 and 13)	MW-3028	0	6.4×10^{3}	3.0×10^{-1}	1.6×10^{-2}
Short-term Recovery	Theis Recovery (1935) (Ref. 12)	MW-3028	0	4.9×10^{3}	2.3×10^{-1}	1.2×10^{-2}
Short-term Recovery	Theis Recovery (1935) (Ref. 12)	MW-3029	46.5	4.9×10^{3}	2.3×10^{-1}	1.2×10^{-2}
Long-term Recovery	Theis Recovery (1935) (Ref. 12)	MW-3028	0- 204.5	1.1×10^{3} - 1.5×10^{3}	5.0×10^{-2} - 7.3×10^{-2}	2.6×10^{-3} - 3.8×10^{-3}
Long-term Pumping	Cooper and Jacob (1946) - Distance-Drawdown (Ref. 25)	various	various	6.9×10^{3}	3.3×10^{-1}	1.7×10^{-2}

Inspection of the recovery data from the long-term tests (Figures C.50 through C.57) reveals that incomplete water level recovery occurs from the long-term test. The projected residual drawdown at a t/t' value of 1 is approximately 1-ft for the pumping well (Figure C.50). Failure to completely recover is characteristic of an aquifer of limited extent with no recharge when pumping permanently lowers the static water level (Ref. 26).

Consistent with the short-term test, an initial rapid filling of the wellbore after pump shut down did not occur, which suggests that wellbore storage and/or skin effects were not significant in the pumped well. Instead, the recovery trend is relatively flattened for t/t' values greater than 10 (i.e., for data from the first 2 days of recovery). The trend of the late time recovery data were used to determine transmissivity values in accordance with the recommendations of Hargis (Ref. 17).

The results of curve-matching for observation well data from the long-term test using the solutions of Boonstra and Boehmer (Ref. 21) for flow in a composite dike-aquifer system are presented in Table 5-2. A family of type curves for observation wells within the pumped dike are given in Figure C.58. The curve matching procedure yields estimates for the product of the width and the transmissivity of the dike/conduit (W_dT_d), and product of the width and the storativity of the dike/conduit (W_dS_d), and the product of the storativity and transmissivity of the surrounding aquifer (T_eS_e). Separate values of T_d and S_d are not possible without an estimate of the width of the dike/conduit (W_d).

Table 5-2 Aquifer Properties by Curve Matching Procedure for Fractured Dike-Aquifer Analytical Model

By Direct Calculation					Assuming W_d = 50 ft			
Well	r (ft)	W_dT_d (m^3/day)	W_dS_d (m)	T_cS_c (m^2/day)	T_d (gpd/ft)	S_d	K (cm/sec) b = 1 ft	K (cm/sec) b = 19ft
MW-4028	32.2	1.8×10^{3}	3.3×10^{-2}	1.1	9.5×10^{3}	2×10^{-3}	4.5×10^{-1}	2.3×10^{-2}
MW-3029	46.5	3.0×10^{3}	9.1×10^{-3}	2.4×10^{-1}	1.6×10^{4}	6×10^{-4}	7.5×10^{-1}	4.0×10^{-2}
MW-2037	159.5	1.1×10^{3}	1.8×10^{-1}	1.5×10^{-1}	5.8×10^{3}	1.2×10^{-2}	2.7×10^{-1}	1.4×10^{-2}
MW-4029	161.2	2.5×10^{3}	3.4×10^{-2}	2.5×10^{-1}	1.3×10^{4}	2×10^{-3}	6.2×10^{-1}	3.2×10^{-2}
MWS-21	186.9	7.9×10^{2}	2.1×10^{-1}	3.6×10^{-1}	4.2×10^{3}	1×10^{-2}	2×10^{-1}	1×10^{-2}
MW-4027	204.5	6.3×10^{2}	3.5×10^{-2}	1.6×10^{-1}	3.3×10^{3}	2×10^{-3}	1.6×10^{-1}	8.2×10^{-3}

W_d width of dike
T_d transmissivity within the dike
S_d storativity within the dike
b aquifer thickness
r radius from well

Data from the six closest observation wells were analyzed as if all were completed in the pumped dike/conduit. This was done because the width and orientation of the high transmissivity zone is not known with precision and because the boundary with the lower transmissivity aquifer likely is gradational rather than abrupt. For comparative purposes, transmissivity (T_d), storage (S_d), and hydraulic conductivity (K) values were calculated assuming an effective width of 50 ft. This width resulted in transmissivity and hydraulic conductivity values of the same magnitude as estimated using equations for radial flow. The storage term, S_d, ranges from approximately 10^{-3} to 10^{-2}, which theoretically represents drainable fracture porosity. The actual width of the high transmissivity feature may be greater or less than assumed, and the boundary with the less transmissive aquifer is likely gradational because it is controlled by weathering.

The pumping well data could not be analyzed using the curve matching procedure of Boehmer and Boonstra (Ref. 21) for late pumping times because the slope of the data trend remained at 0.25 throughout the period of pumping (Figure C.28). The pumping well drawdown data were used as a check on the type curve analyses for the observation wells, however, using equations presented in Kruseman and de Ridder (Ref. 16). When the observation well data could be reasonably matched to more than one type curve, as occurred in several cases, the value of the lumped parameter $W_dT_d(S_cT_c)^{0.5}$ for each match point was compared with the value obtained using the pumping well data. Aquifer property estimates in Table 5-2 are based upon the observation well match point for which the lumped parameter estimate was in closest agreement to the lumped parameter estimate obtained with the pumping well data.

None of the observation well data could be matched with confidence to the type curve for the low transmissivity aquifer (Figure C.42). The data for all nine routinely monitored observation wells when plotted as drawdown ratio versus time are shown in Figure C.59. The data trends for the six closest observation wells cannot be matched well to the type curve because they exhibit a flatter shape than the theoretical trend. The data for MW-2036, MW-2038, and MW-3027 (r = 479.9, 598.2, and 619.8 ft, respectively) are too erratic for curve matching.

5.4.4 Sustainable Yield

Accurate quantification of sustainable yield is not possible because the pumping water level never approached equilibrium during the long-term test. Rather than asymptotically trending towards stabilization as normally occurs, the water levels continued on a downward trend throughout the 18-day period of pumping. The increased rate of drawdown in the pumping well that occurred when the drawdown reached approximately 5.5 ft in the long-term test (Figure C.17) is similar to that observed during the short-term test (Figure C.6) and suggests that the well eventually would have pumped dry if the test were continued. The sustainable yield is therefore somewhat less than 10.7 gpm, although an equivalent or higher pumping rate might be achievable for an intermittent pumping regimen or if the aquifer were artifically recharged upgradient of the extraction wells.

6. GROUNDWATER QUALITY

Between June 10 and July 31, 1998, a total of 47 groundwater samples was obtained from the pump test field effort. Analytical parameters include trichloroethylene (TCE), tetrachloroethene (PCE), dichloroethene (DCE), nitrate, sulfate, iron, manganese, uranium and nitroaromatic compounds. The volatile organics were collected for the purpose of identifying any upward or downward trends in concentrations apparent as the aquifer responded to pumping. The remaining parameters were analyzed to provide baseline values for groundwater quality as well as to provide contaminant concentrations for treatment requirements.

6.1 Sampling Events

Groundwater samples were taken from pumping well MW-3028 during the following events:

- Development of the well (1 sample).
- Step-drawdown test (four samples).
- Short-term pumping test (five samples).
- Prior to start of the long-term pumping test (one sample).
- Long-term pumping test (29 samples).

Samples from the long-term test were initially taken once per shift (8 hours), then decreased to twice per day.

The off-site locations impacted by the earlier tracer test were sampled prior to the initiation of the multi-well pump test (Ref. 29). These locations encompassed monitoring wells MWS-003, MWS-004, MWS-021, MWS-112 and Burgermeister Spring (SP-6301).

Samples were obtained during the development of observation wells MW-4027 and MW-4029. No samples were taken from MW-3029 and MW-4028, as these wells are located within 50 ft of the pumping well. The assumption was made that due to the close proximity of these wells to MW-3028, any water drawn into these observation wells would essentially be of the same quality as that reported for MW-3028.

All sampling activities were conducted in accordance with the following Weldon Spring site standard operating procedures:

- ES&H 4.1.1 *Numbering System for Environmental Samples and Sampling Locations*
- ES&H 4.4.1 *Groundwater Sampling*
- ES&H 4.1.2 *Initiation, Generation and Transfer of Environmental Chain of Custody*

- ES&H 1.1.4 *Logbook Procedure*
- ECDI -3 *Hazardous Material/Sample Transportation Activity (HMSTA) Operations*

All samples were collected, preserved and containerized according to the requirements set forth in the *Pilot Pumping Test for the Groundwater Operable Unit at the Weldon Spring Site* (Ref. 2). This report also specified the following quality control sample requirements: matrix spike/matrix duplicate, one per 20; field replicate, one per 20; and trip blanks, one per shipment. These requirements were met during the sampling event with the exception of field blank samples, which were not collected.

Table 6-1 presents the analytical results from the pumping test sampling. The raw analytical data are summarized in Appendix D. Figure 6-1 presents the TCE data obtained from selected test wells prior to the start of the long-term test. This figure also includes data results from the June 1998 routine sampling for MW-2037 and MW-2038, which, while not included in the scope of this field effort, are located just upgradient of the pumping wells. Due to the longer than expected recovery period, samples were not collected for the analysis of TCE for inclusion in this report.

6.2 Analytical Results

In monitoring well MW-3028, concentrations of TCE ranged from 370 μg/l to 717 μg/l, which is significantly greater than the maximum contaminant level (MCL) of 5 μg/l. PCE was detected during the short-term pumping test at 21 μg/l; the remaining samples were primarily non-detects (82% of data). It was noted that the detection limits reported ranged from 5 μg/l to 50 μg/l (compared to an MCL of 5 μg/l) because some samples required dilution due to high levels of TCE. Approximately 13% of the PCE data were reported as estimated values (detected below the detection limit). These data ranged from 1 μg/l to 6.8 μg/l. DCE was reported at estimated values ranging from 8 μg/l to 16 μg/l, well below the MCL of 100 μg/l for this parameter.

The full suite of volatile organics were analyzed during the development of both MW-3028 and MW-4027. Chloroform and methylene chloride were detected in both samples; these chemicals are common laboratory contaminants. Other parameters were obtained periodically for process monitoring evaluation. These parameters are summarized in Table 6-1.

Table 6-1 Analytical Data Results - Pilot Pumping Test

Date	Location/Time	TCE (µg/l)	PCE (µg/l)	DCE (µg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Iron (µg/l)	Manganese (µg/l)	Uranium (pCi/l)	Nitroaromatic Compounds (µg/l)
6/10/98	4027	4	23	*	*	*	*	*	*	*
6/10/98	3028-061098	420	ND@20	(6.0)	*	*	*	*	*	*
6/19/98	3028-STL1	470	ND@50	(15.0)	*	*	*	*	*	*
6/19/98	3028-STL2	530	ND@25	(9.0)	*	*	*	*	*	*
6/19/98	3028-STL3	530	(6.0)	(13.0)	*	*	*	*	*	*
6/19/98	3028-STL4	480	ND@25	(16.0)	*	*	*	*	*	*
7/1/98	3028-070198-01	403	21.0	*	*	*	*	*	*	*
7/1/98	3028-070198-02	532	(6.8)	*	253	*	430	25.7	0.996	0.024 - 0.77[a]
7/1/98	3028-070198-03	517	ND@10.0	*	*	*	*	*	*	*
7/2/98	3028-070298-01	*	*	*	215	120	*	*	*	*
7/2/98	3028-070298-02	*	*	*	276	160	*	*	*	*
7/6/98	3028-070698	543	ND@6.7	*	*	*	*	*	*	*
7/6/98	6301-070698-L	ND	ND	*	*	*	*	*	*	*
7/6/98	S003-070698	ND	ND	*	*	*	*	*	*	*
7/6/98	S004-070698	(0.69)	ND	*	*	*	*	*	*	*
7/6/98	S021-070698	182	ND	*	*	*	*	*	*	*
7/6/98	S112-070698	ND	ND	*	*	*	*	*	*	*
7/10/98	4029-071098	421	ND	*	*	*	*	*	*	*
7/13/98	3028-071398-0953	435	(1.24)	*	*	*	*	*	*	*
7/13/98	3028-071398-1810	439	ND@25	*	*	*	*	*	*	*
7/14/98	3028-071498-0215	499	ND@25	*	*	*	*	*	*	*
7/14/98	3028-071498-1010	420	ND@25	*	222	110	*	*	*	*
7/14/98	3028-071498-1810	350	ND@25	*	*	*	*	*	*	*
7/15/98	3028-071598-0210	510	ND@25	*	*	*	*	*	*	*
7/15/98	3028-071598-1010	572	ND	*	174	110	*	*	*	*
7/15/98	3028-071598-2145	652	ND	*	*	*	*	*	*	*
7/16/98	3028-071698-1025	623	ND	*	*	*	*	*	*	*
7/16/98	3028-071698-2200	480	ND@10	*	*	*	*	*	*	*
7/17/98	3028-071798-1000	470	ND@10	*	*	*	*	*	*	*

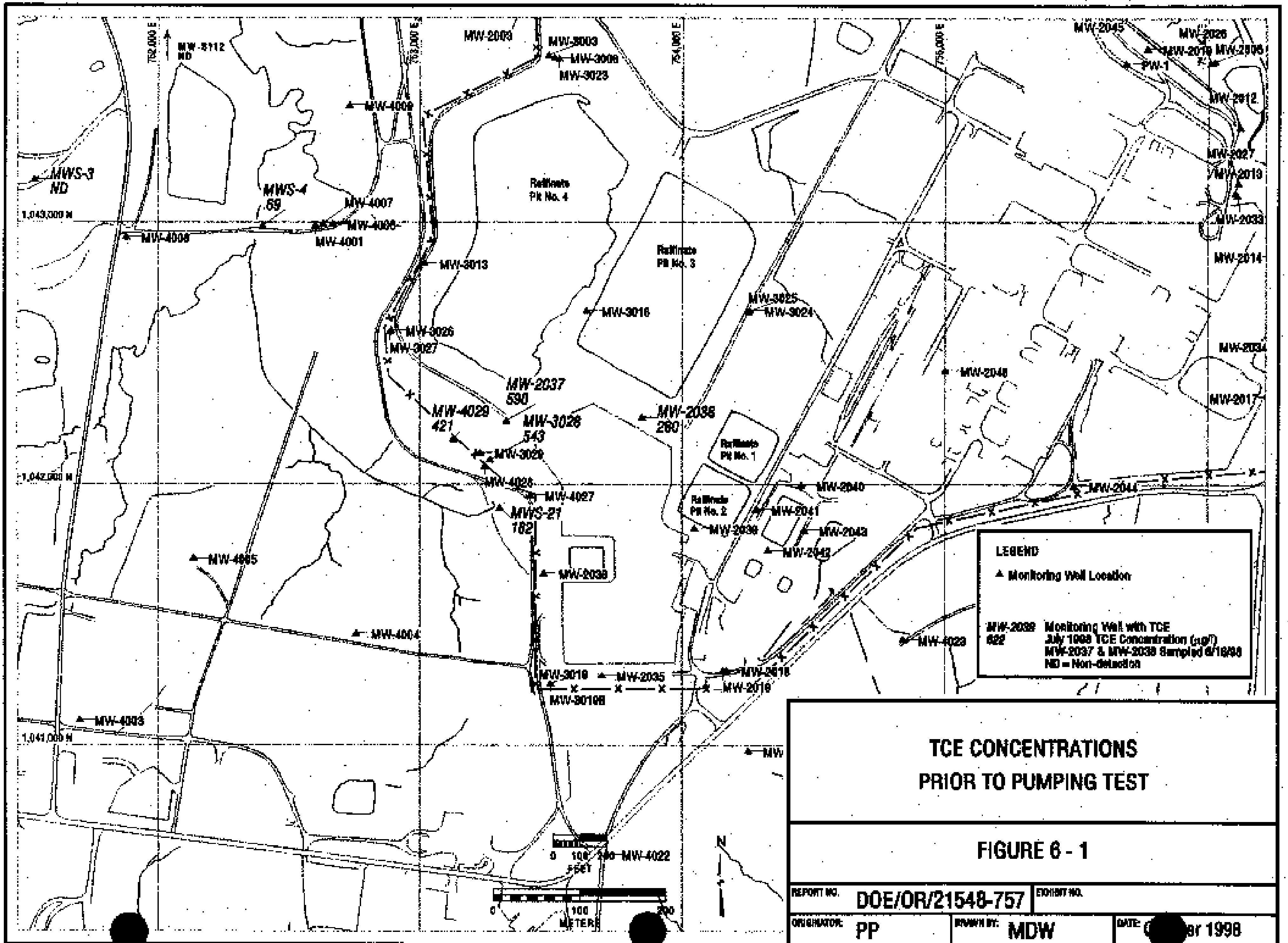
Table 6-1 Analytical Data Results - Pilot Pumping Test (Continued)

Date	Location/Time	TCE (µg/l)	PCE (µg/l)	DCE (µg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Iron (µg/l)	Manganese (µg/l)	Uranium (pCi/l)	Nitroaromatic Compounds (µg/l)
7/18/98	3028-071898-0200	470	ND@10	*	*	*	*	*	*	*
7/19/98	3028-071998-0230	500	ND@10	*	*	*	*	*	*	*
7/20/98	3028-072098-0240	440	ND@10	*	*	*	*	*	*	*
7/20/98	3028-072098-1430	410	ND	*	*	*	*	*	*	*
7/21/98	3028-072198-0230	380	ND	*	*	*	*	*	*	*
7/21/98	3028-072198-1430	400	ND	*	*	*	*	*	*	*
7/22/98	3028-072298-0230	380	ND	*	*	*	*	*	*	*
7/22/98	3028-072298-1410	370	ND	*	*	*	*	*	*	*
7/23/98	3028-072398-1230	390	ND	*	*	*	*	*	*	*
7/24/98	3028-072498-1410	643	ND	*	*	*	*	*	*	*
7/25/98	3028-072598-1530	671	ND	*	*	*	*	*	*	*
7/26/98	3028-072698-0630	717	(1.53)	*	*	*	*	*	*	*
7/26/98	3028-072698-1430	701	(1.73)	*	*	*	*	*	*	*
7/27/98	3028-072798-1425	580	(1.0)	*	*	*	*	*	*	*
7/28/98	3028-072898-0956	600	ND	*	*	*	*	*	*	*
7/29/98	3028-072998-1115	510	ND	*	*	*	*	*	*	*
7/30/98	3028-073098-0940	580	ND	*	*	*	*	*	*	*
7/31/98	3028-073198-1240	590	ND	*	*	*	*	*	0.880	*

individual parameters and concentrations as follows: 1,3,5-TNB@ 0.33; 1,3-DNB @ (0.081); 2,4,6-TNT @ ND; 2,4-DNT @ 0.77; 2,6-DNT @ 0.12; NB @ 0.024

( ) = estimated value

* = Not analyzed



TCE CONCENTRATIONS PRIOR TO PUMPING TEST

FIGURE 6 - 1

REPORT NO. DOE/OR/21548-757		EXHIBIT NO.	
ORIGINATOR: PP	DRAWN BY: MDW	DATE: O[illegible]er 1998	

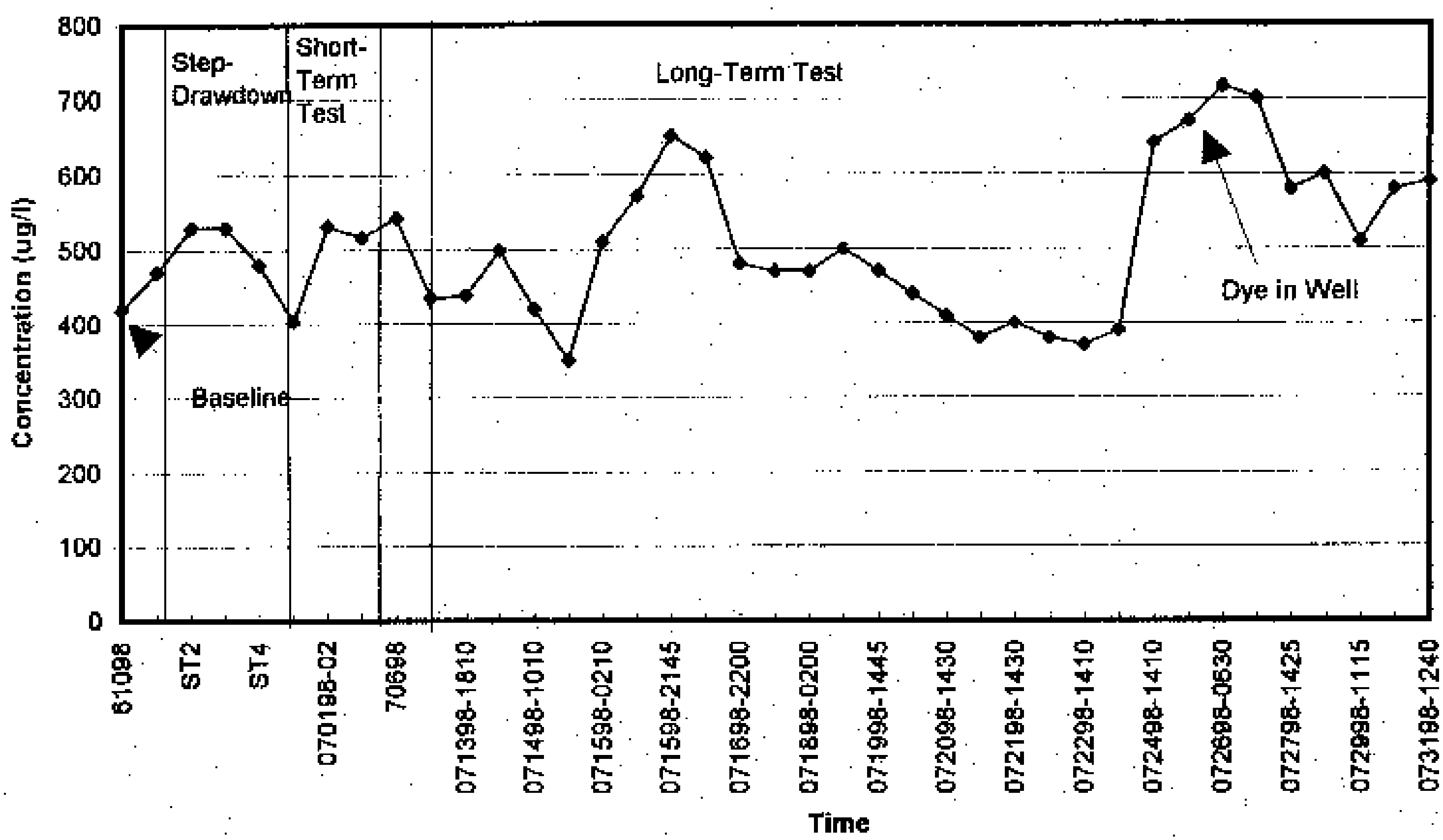
The results for the off-site wells and Burgermeister Spring indicate that of the five locations, TCE was detected in monitoring well MWS-021 at 182 µg/l and in MWS-004 at 0.69 µg/l. MWS-021 is located approximately 170 ft to the southwest of MW-3028 (Figure 6-1). The remaining locations were reported as non-detects. No PCE was detected in the off-site wells or in Burgermeister Spring.

From the one-time sampling event for the observation wells, it was noted that MW-4029 exhibited a high level of TCE contamination (421 µg/l). No PCE was detected in this well. Results from observation well MW-4027 indicated TCE levels (4.0 µg/l) less than the MCL, while PCE was detected at 23 µg/l. This well location is adjacent to the soil boring location where PCE was detected in soil gas at 185 parts per billion by volume (ppbv) during the 1997 soil gas survey (Ref. 27).

A graphical representation of the TCE data collected from the pumping well (MW-3028) throughout the field effort is shown in Figure 6-2. It can be seen that TCE concentrations decreased during Day 2 of the long-term pump test to the lowest value detected throughout the study (370 µg/l), then increased rapidly through Day 5. At this point, concentrations declined again, and during Days 8-10, concentrations were below the initial value detected during well development. After 10 days of pumping, however, TCE concentrations increased to the highest values seen throughout the study (717 µg/l) and remained well above 500 µg/l for the remainder of the study. It was noted at this time "pink water" was observed during sampling of the well, indicating a connection with monitoring well MW-2037, which exhibits high levels of TCE. Rhodamine WT dye (which produces a pinkish tint to water) had been injected into MW-2037 on May 8, 1998 for the performance of a tracer test.

6.3 Quality Control

Quality control samples were obtained in the form of both matrix spike/matrix duplicates and trip blanks. Quality control data are presented in Appendix D. Results from these samples were used to assess the accuracy and precision of the reported analytical data. Accuracy is defined by how close an analyzed value was to the true value and is usually associated with matrix spike recoveries. A value of 100% constitutes the highest accuracy. Precision is defined as how closely two analyzed values match each other (i.e., the repeatability of the measurements). Precision is normally expressed as the relative percent difference (RPD). An RPD of 0% constitutes the highest precision. RPDs are calculated for samples whose analytical concentrations are greater than five times the detection limit.



MW-3028
TCE CONCENTRATIONS

FIGURE 6-2

REPORT NO.: DOE/OR/21548-757	SUBJECT NO.: A/CP/057/1098	
ORIGINATOR: RC	DRAWN BY: LGB	DATE: 10/28/98

Matrix spike/matrix duplicate data for MW-3028 were provided for both volatile organics and nitroaromatic compounds. Data results for volatile organics show that the percent recovery for the matrix spike samples was reported as 80% for PCE and 95% for TCE. The matrix duplicate sample ranges were 89% for PCE and 96% for TCE. Data results for the nitroaromatic compounds indicate that percent recoveries ranged from 106% to 108%. All recoveries are within the acceptable range (+/- 30%) recommended by the Environmental Protection Agency's Contract Laboratory protocol.

Relative percent differences were calculated for the PCE quality control data. These calculations showed RPDs of 7% and 17%, for the matrix duplicate and matrix spike, respectively. These recoveries are also within an acceptable range.

Trip blanks were submitted with each shipment to provide additional quality control data. Neither TCE nor PCE was detected in any of the trip blank samples.

7. MANAGEMENT AND DISPOSITION OF INVESTIGATION DERIVED WASTES

All waste streams generated during these activities were coordinated with representatives from Compliance, Environmental Safety and Health (ES&H), and the Waste Maintenance Group and managed in accordance with ECDI-18, *Handling and Disposition of Site Generated Wastes.* The anticipated wastes generated during pumping test operations included personal protective equipment (PPE), miscellaneous trash, decontamination water, and extracted groundwater. The PPE and miscellaneous trash were segregated and placed with other site-generated PPE or trash and managed accordingly. Waste generated during well installation (soil and rock cuttings, coring and drilling water) was managed as specified in Task 1 of Work Package-510.

Based on groundwater quality data from surrounding monitoring wells, the water extracted from the pumping well and the observation wells was considered hazardous waste. In accordance with 40 CFR 261 Subpart B, waste exceeding the toxic characteristic leaching procedure (TCLP) level for trichloroethylene (TCE) of 0.5 mg/l are hazardous waste and must be managed and treated accordingly.

During well development, the extracted groundwater was pumped into 55-gallon drums placed in a metal tub for secondary containment. Approximately 1,000 gal of wastewater was generated during development of the pumping well and surrounding observation wells. This water was transferred to a 1,000-gal portable tanker and transported to Pad 4 at the Chemical Stabilization and Solidification (CSS) Pilot Scale Facility. The TCE was removed using activated carbon and subsequently transferred to the raffinate pits to remove excess nitrate concentrations.

In anticipation of potentially large flow rates from the pumping well, two 4-cu yd boxes, each holding approximately 3,000 lb. of activated carbon, were placed at the temporary storage area (TSA) as in-line treatment for TCE (Figure 3-1). The treated water was discharged to the TSA surface impoundment for further treatment. Box A was used during the higher pumping rate step-drawdown test, but was not needed for the long-term test due to the lower pumping rates. Post-treatment TCE concentrations were all non-detect at a detection limit of 1 µg/l.

Approximately 280,000 gal of TCE-contaminated water were extracted during the pumping tests and treated via carbon adsorption in Treatment Box B (Figure 3-1). Assuming an average TCE concentration in groundwater of 500 µg/l, the mass of 1.20 lb of TCE was removed from the aquifer through treatment. This value was calculated as follows:

$$279{,}723\ gal\ H_2O\ x\ \frac{3.79\ l}{gal}\ x\ \frac{500\ \mu g\ TCE}{l}\ x\ \frac{1\ lb}{4.53\ x\ 10^{+8}\ \mu g} = 1.20\ lbs\ TCE$$

The metal tub used as secondary containment was decontaminated and returned to storage. All water used for decontamination (i.e., water used to decontaminate the static water level (SWL) indicator or other small tools) or resulting from sampling activities was placed in 5-gal containers located at both sample ports. This water and any water remaining in the discharge line was managed as a hazardous waste, placed in 55-gal containers and taken to the CSS pilot scale facility for treatment. When the tests and area cleanup were completed, the 55-gal containers were decontaminated in accordance with ECDI-10 - *Container Management Instruction* and taken to Building 434 for safe compaction or decontamination and reuse.

8. SUMMARY AND CONCLUSIONS

8.1 Summary

Drilling, well installation, and aquifer testing were conducted in the trichloroethene (TCE) -impacted area south of the raffinate pits from May 18, 1998, through August 31, 1998. A large diameter pumping well and four smaller observation wells were drilled, installed, and developed during this time period. A series of aquifer tests was then performed in the pumping well to reach the following objectives:

- Determine the aquifer responses to groundwater withdrawal in the area of TCE contamination. No previous data of this type existed for this part of the site.
- Provide data such as aquifer parameters which are required to evaluate potential groundwater remediation techniques.
- Obtain groundwater samples to further delineate the distribution of TCE in groundwater.

The objectives for the program were accomplished. Aquifer characteristics obtained from the pumping tests will allow an evaluation of the practicality and effectiveness of techniques considered for remediation of TCE in groundwater.

8.2 Conclusions

A better understanding of the hydrogeologic framework in the TCE-impact area was attained during the drilling and well installation. It is evident that the stratigraphy and structure of the weathered Burlington Keokuk Limestone have significant influence on the permeability and direction of groundwater flow in the shallow aquifer beneath the chemical plant.

8.2.1 Hydrogeologic Data Analysis

In general, the results of the hydrogeologic data analysis were in agreement with previous testing results and the hydrogeologic conceptual model of the site. Specific conclusions from the hydrogeologic data analysis are:

- In the area of TCE impact, a relatively thick sequence of strongly weathered limestone bedrock is present. Most of the weathered Burlington-Keokuk unit thickness is composed of the strongly weathered subunit.

- In the vicinity of the pumping well, a bedrock low can be identified, with the lowest elevation centered around MWS-21. This paleochannel feature has a north-south orientation.

- Fracture frequencies and orientations in the weathered Burlington-Keokuk Limestone, including the strongly weathered unit, were consistent with previous studies.

- The results from the hydraulic conductivity testing followed trends noted from previous packer testing at the site, such as decreasing permeability with depth and the highest permeability exhibited in the strongly weathered unit of the Burlington-Keokuk Limestone.

8.2.2 Aquifer Test Analysis

The general conclusion from the pumping test is that the shallow aquifer in the area of TCE impact is more transmissive than previously suggested. Specific conclusions based on the aquifer test results are:

- The relative high observed barometric efficiency (approximately 50%) is an indication that the shallow bedrock aquifer is semi-confined due to low vertical hydraulic conductivity.

- The shallow aquifer at the test location is considerably more transmissive than at previously tested locations. Transmissivity estimates ranging from 6,400 gpd/ft to 7,600 gpd/ft were determined from the step-drawdown test. Previous aquifer tests estimated transmissivity values ranging from 2.9 gpd/ft to 9.1 gpd/ft.

- The data collected from the constant rate aquifer test revealed two boundary conditions in the area of TCE impact. First, the aquifer response to pumping over the longer period of constant discharge is not characteristic of radial flow. Second, a vertical boundary controlled by the decrease in the hydraulic conductivity with depth results in dewatering of the conduit system below a specified depth.

- Based on the pattern of drawdown during the constant rate test, the bulk of the transmissivity in the formation adjacent to the pumping well is provided by the interval from the water table to the depth of approximately 43 ft below the ground surface. A 1-ft solution void was encountered in this interval during installation of the pumping well.

- Groundwater flow to the test well during the 18-day test appeared to be parallel, rather than radial. Radial flow equations do not accurately describe the aquifer response to pumping.

- The observed aquifer behavior is consistent with the hydrogeologic conceptual model comprised of a low transmissivity limestone aquifer with superimposed conduit flow. The current conceptual model is analogous to the permeable fractured dike analytical model of Boonstra and Boehmer. Their model predicts a linear log-drawdown versus log-time relationship, as was observed during the aquifer tests.

- The direction of the maximum drawdown observed during the test was approximately coincident with the north-south orientation of the bedrock low in the vicinity of the pumping well.

- Hydraulic capture over a large portion of the TCE contaminated aquifer resulted from pumping at a single location.

- Incomplete water level recovery occurred from the long-term test. Failure to completely recover is characteristic of an aquifer of limited extent and with limited recharge when pumping significantly lowers the static water level. The possibility of semi-permanently dewatering the shallow aquifer in the vicinity of the test site poses a potential obstacle to long-term continuous pumping.

- The sustainable pumping rate is less than 10.7 gpm but cannot be quantified without further long-term testing.

- Despite likely exceeding the sustainable yield, approximately 280,000 gal of TCE-contaminated water were extracted from the shallow aquifer. This amounts to the removal of 1.2 lb of TCE assuming an average concentration of 500 μg/l.

8.2.3 Groundwater Quality

Volatile organic samples were collected to identify trends in concentrations as a result of groundwater extraction. Specific conclusions of these analyses are:

- A baseline value of 420 μg/l was established in the pumping well prior to starting the aquifer tests. During the testing, TCE values ranges from 370 μg/l to 717 μg/l at this location.

- PCE was detected in the pumping well during the single well pump test at 21 µg/l; the remaining samples were primarily non-detects.

- TCE concentrations in the pumping well increased to greater than 600 µg/l by Day 5 of pumping and then decreased and stabilized near the baseline level of 420 µg/l. After 10 days of pumping, TCE concentrations increased to the highest values seen throughout the study (717 µg/l) and then stabilized at levels greater than 500 µg/l. It was noted at Day 10 that Rhodamine WT dye was observed in the pumping wells. This dye was injected May 8, 1998, in MW-2037, which exhibits some of the highest TCE concentrations.

- TCE was detected in MWS-21 and MWS-4 during the testing period, but TCE was not detected in Burgermeister Spring. No PCE was detected in the off-site wells or in Burgermeister Spring.

- Quality control data for the sampling events were within the acceptable ranges recommended by EPA protocol.

8.2.4 Management and Disposition of Investigation Derived Wastes

Waste streams generated during these activities were handled and managed in accordance with the appropriate standard operating procedures identified in the testing plan (Ref. 2). Specific conclusions from the management of these wastes are:

- Extracted water generated during this study was assumed to be categorized as a hazardous material (40 CFR 261, Subpart B) based on previous groundwater quality data. During most of the testing, TCE concentrations were greater than 500 µg/l.

- Extracted water was treated to remove TCE through the use of activated carbon. Post-treatment TCE concentrations were all less than the detection limit of 1 µg/l.

8.3 Discussion

The general conclusion from the pumping tests is that groundwater can be extracted from the portion of the aquifer exhibiting TCE contamination using conventional wells. However, during the pumping test approximately 280,000 gallons of water was removed during the long-term test resulting in the removal of 1.2 lb of TCE from the shallow aquifer. Removal of any TCE, while encouraging, does not necessarily indicate that groundwater extraction would be effective as a means of accelerating cleanup.

At the U.S. Department of Energy site at Oak Ridge, Tennessee, for example, it was concluded that remediation of a doubly porous, fractured limestone and shale aquifer by natural flushing would be nearly as rapid as active remediation through groundwater extraction, because of the rate-limiting effects of matrix diffusion from the primary pore spaces (Ref. 28). However, the development of karst conduit flow is considered an indication of the absence of primary porosity (Ref. 29). Tomasko (Ref. 30) determined that the shallow aquifer at the chemical plant can be simulated as a fracture dominated, single porosity system, although diffusion-limited mass transfer from the low-permeability limestone into the conduit system poses an analogous problem to that of contaminant removal in a double porosity aquifer.

Wolfe, et al. (Ref. 29) provides a comprehensive discussion of the occurrence, fate, and transport of dense nonaqueous phase liquids, such as TCE, in a variety of karst setting, including discussions of contaminant removal in double porosity aquifers. Factors listed as controlling the residence time of the chlorinated solvents released into karst aquifers include its location relative to the water table and degree of hydraulic connection between areas of solvent accumulation and karst conduit systems.

Of additional importance is the dewatering of the shallow aquifer in the area of TCE impact that occurs under continuous groundwater extraction. Forty-two days after completion of the pumping portion of the test, complete recovery of the aquifer had not occurred. This behavior could be considered to be consistent with the conceptual model for the shallow aquifer at the chemical plant that consists of superimposed conduit flow on a diffuse flow system. Likely, the previous pumping tests performed at the chemical plant did not intersect these bedrock lows where preferential flow occurs and are representative of the lower transmissivity limestone. The pumping tests outlined in this report were explicitly performed in the area of preferential flow to determine the aquifer characteristics of the more transmissive bedrock lows.

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CODE OF FEDERAL REGULATIONS

40 CFR 261, Subpart B

PROCEDURES AND DEPARTMENTAL INSTRUCTIONS

ES&H 1.1.4 *Logbook Procedure*

ES&H 4.1.1	*Numbering System for Environmental Samples and Sampling Locations*
ES&H 4.1.2	*Initiation, Generation, and Transfer of Environmental Chain-of-Custody*
ES&H 4.4.1	*Groundwater Sampling*
ES&H 4.4.7	*Soil, Rock Core, and Rock Chip Borehole Logging and Storage*
ES&H 4.4.8	*Monitoring Well Installation and Development*
ECDI-3	*Hazardous Material/Sample Transportation Activity Operations*
ECDI-10	*Container Management Instruction*
ECDI-18	*Handling and Disposition of Site Generated Wastes*

APPENDIX A
Borehole Logs, Well Diagrams and Well Development Forms

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

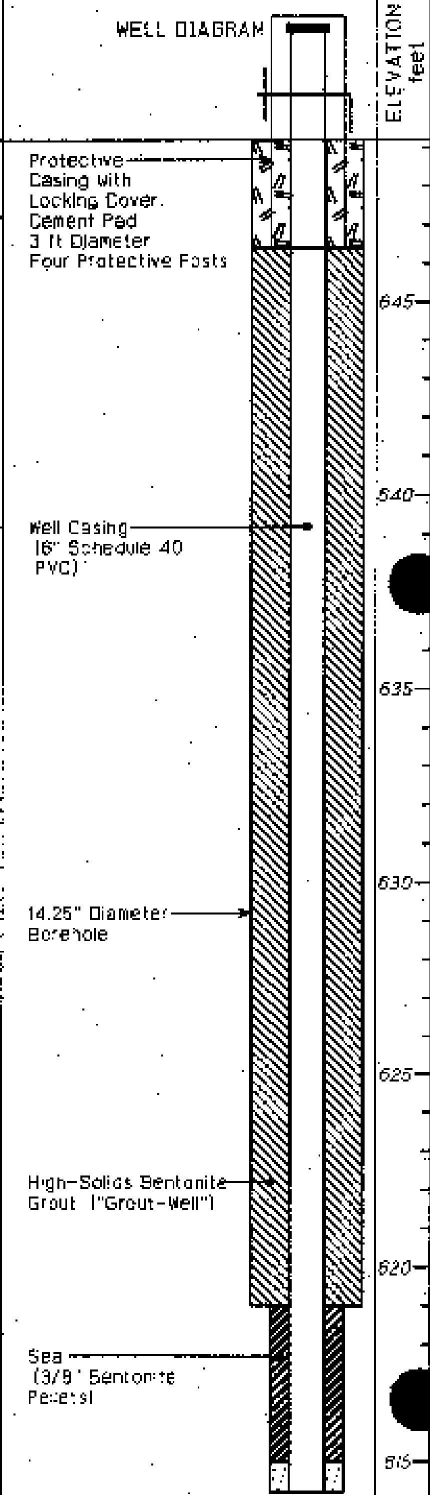
WSWLOG-C

HOLE NUMBER	MW-3028
SHEET 1 OF 2	
NORTH (Y):	1042096.[illegible]
EAST (X):	753269.49
TOC ELEVATION	651.92
GROUND ELEVATION	649.20
STICKUP	2.72
HYDR CONDUCTIVITY (CM/SEC)	K= 4.6E-4

WELL STATUS/COMMENTS: ACTIVE	LOCATION: South of Raff. Pit 4	
DRILLING CONTRACTOR: GEOTECHNOLOGY INC	DRILL RIG MAKE & MODEL: CME 850, HSA/NQWL CORE/SCHRAMM AIR ROT.	
HOLE SIZE & METHOD: 14 1/4" HSA to 30.0' then 10" Air	ANGLE FROM HORIZONTAL & BEARING: Vertical	BOTTOM OF HOLE (TD): 89.0
DRILL FLUIDS & ADDITIVES: WATER/AIR	CASING TYPE, DEPTH, SIZE: 6" Schedule 40 PVC	BEDROCK: 31.5
DATE START: 5-18-1998	DATE FINISH: 6-8-1998	WATER LEVELS & DATES: ▽ ▼

LITHOLOGY BY: PAUL PATCHIN

DEPTH feet	SAMPLE	SAMPLE/RUN Number	PERCENT Recovery (0–100)	N# or ROD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
0					Fill	FILL, (suspect soil pile); silty clay, dry, light yellowish brown, locally gravelly.	Fill
					CL	SILTY CLAY, dark brown to black, medium plasticity, organic rich (original topsoil).	
					CL CH	SILTY CLAY, medium reddish brown, soft, moist, medium plasticity, mottling with gray, plasticity increasing with depth, MnOx nodules (5%) from 5'-10', also consistency to stiff. CL/CH.	Qfv
10					CL	SILTY CLAY, with sand (10%), and fine gravel <5% low to medium plasticity, strong brown, (7.5 yr 4/6), slightly moist to moist, stiff. Gravel is subrounded to 1/2 inch some MnOx staining. CL.	Qct
20						At 20' becoming moist, soft to medium stiff, less gravel.	
					ML	CLAYEY SILT, almost equal fractions clay/silt, dark yellowish brown (10 yr 3/4), slightly moist, low plasticity, no gravel. ML.	
24					CL	SILTY CLAY, with GRAVEL (~15% chert gravel to 2"), brown (7.5YR4/4) medium plasticity, stiff to very stiff. CL.	
25					CL	@25' very hard drilling, chert gravel (to 2") in cuttings. "Residium" (atypical) soil on end of center bit brownish yellow gravelly clay, chert, and limestone rock pieces.	pPr
30						Auger refusal at 30.0' switched to NQ coring. Drill through to 31.5' easily, no sampling, likely residuum. Top of Rock @ 31.5'.	
31.5	■	RUN-1	62/90"	9	CL GC	31.5 – 32.0' GRAVEL (CHERT) WITH CLAY. Chert gravel fine to 2" in matrix of pale yellow plastic clay (40%). Chert is very hard, medium gray (5B5/1)	Mbkbu
					chrt	mod. weathered, with FeOx stain, minor vugginess and alteration. Clay is plastic. Core loss 32–33'.	
35							



■ Sample Interval ☐ No Sample Taken ▽minimum ▼maximum ▼average

HOLE NUMBER	MW-3028
SHEET 2 OF 2	
NORTH (Y):	1042096.61
EAST (X):	753269.49

WELDON SPRING SITE REMEDIAL ACTION PROJECT
BOREHOLE AND WELL COMPLETION LOG

WSMLOG-C

WELL STATUS/COMMENTS: ACTIVE

LOCATION: South of Raff. Pit 4

SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class
			chrt (33.0–39.0')
RUN-2	42/48"	60	lms chrt (39.0–54.0')
RUN-3	25/36"	30	
RUN-4	6/12"	0	
RUN-5	12/12"	90	
RUN-6	45/50"	45	
RUN-7	38/38"	38	
RUN-8	24/31"	0	
RUN-9	18/28"	0	
RUN-10	48/48"	83	lms chrt (60.7–65.5')
RUN-11	56/56"	30	lms (65.5–69.0')

DEPTH feet: 40, 45, 50, 55, 60, 65, 70, 75

ELEVATION feet: 610, 605, 600, 595, 590, 585, 580, 575

STRAT. UNIT: Mbksw (to approx. 60.7'); Mbkw (60.7'–65.5'); Mbku (65.5'–69.0')

DESCRIPTION AND REMARKS

33.0 – 39.0' CHERT (80%) and ARGILLACEOUS LIMESTONE, interbedded and brecciated, chert is primarily very light gray (N8) with zones stained with FeOx to dark yellowish orange (10YR6/6), very hard, brecciated with some beds (or nodules) at 33.1–33.8' and 32.5–32.7', overall mod. weathered, with vugs to 3/4", limestone is very silty and argillaceous (almost no HCL reaction), dark yellowish orange (10 yr 6/6), fine grained, very weathered and altered with abundant FeOx, soft to moderately hard, minor MnOx in fractures no fossils, thin-bedded.

39.0 – 54.0' ARGILLACEOUS LIMESTONE and CHERT, Interbedded and finely divided together, approximately 70/30%. Primarily dark yellowish orange (10YR6/6) to occasionally moderately yellowish brown (10YR5/4). Limestone is very fine grained, moderately to highly weathered, hard, very thin bedded with brecciated texture common, locally silty with conspicuous MnOx specs, pinhole vugs chert is interbedded and brecciated with limestone, very pale orange (10YR8/2), very hard, fossilifious, with MnOx on microfractures. Occasional nodules and beds to .5'

43.8'–44.8' Soft drilling probable void. LOST CIRCULATION at 43.8'. REGAINED CIRCULATION (gradually to 75% return) at 44.5'.

46.0'–47.0' Soft drilling

48.0' LOST CIRCULATION (permanently)

52.1–53.6' Very brecciated with secondary calcite-filled vugs.

54.0' – 60.7' ARGILLACEOUS LIMESTONE and CHERT as above, but with gradual color change to grayish orange (10YR7/4) and increase in silt content and porosity (high), Vuggy with secondary calcite and qtz (drusy) infilling common. 2" Vug with calcite and hematite infilling at 52.7', highly weathered to 59.3 then moderately weathered.

60.7' – 65.5' ARGILLACEOUS LIMESTONE AND CHERT, with some interbedded chert, yellowish gray (5YR7/2), hard to very hard, slightly weathered, thinly bedded, finely divided in areas with chert, slightly stylolitic, with blebs of cleaner limestone throughout, moderate porosity, dense. Chert is light bluish gray (5B7/1), very hard as nodules and brecciated zones.

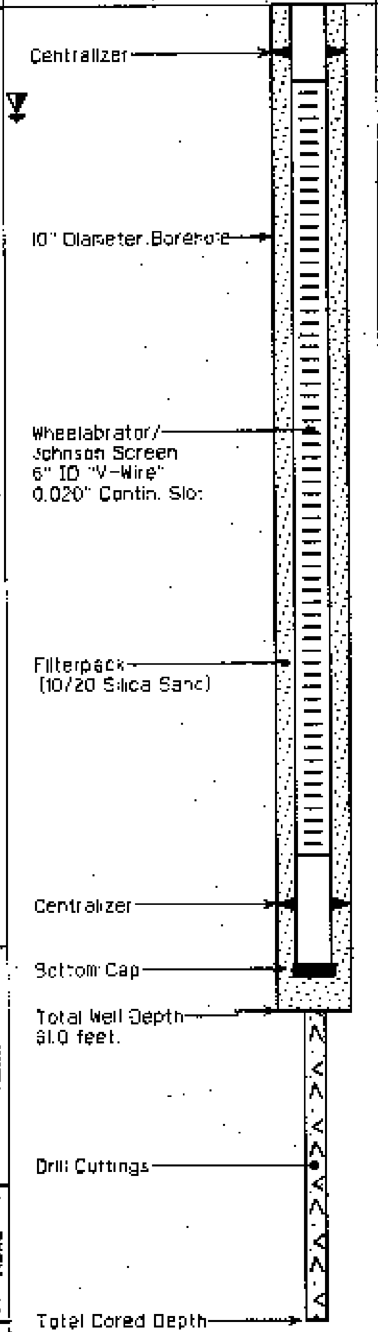
65.5' – 69.0' LIMESTONE, very light gray (N8) with occasional chert nodules, fresh, unaltered, fine to medium grained, medium bedded, very hard, stylolitic, very fossiliferous, very little porosity, no FeOx

Total cored depth 69.0 feet. Reamed hole to 10" to 81.0' and and installed 6" pumping well (see well diagram).

Note: Soil color is indexed on the Munsell soil color chart. Rock color is from the GSA rock color chart.

CONSTANT HEAD SINGLE PACKER TEST RESULTS:
- 34.3–43.0 ft. K=4.6E–4 cm/sec
- 39.3–48.0 ft. K=1.1E–3 cm/sec
- 47.5–59.0 ft. K=5.0E–4 cm/sec
- 57.5–69.0 ft. K=9.9E–8 cm/sec

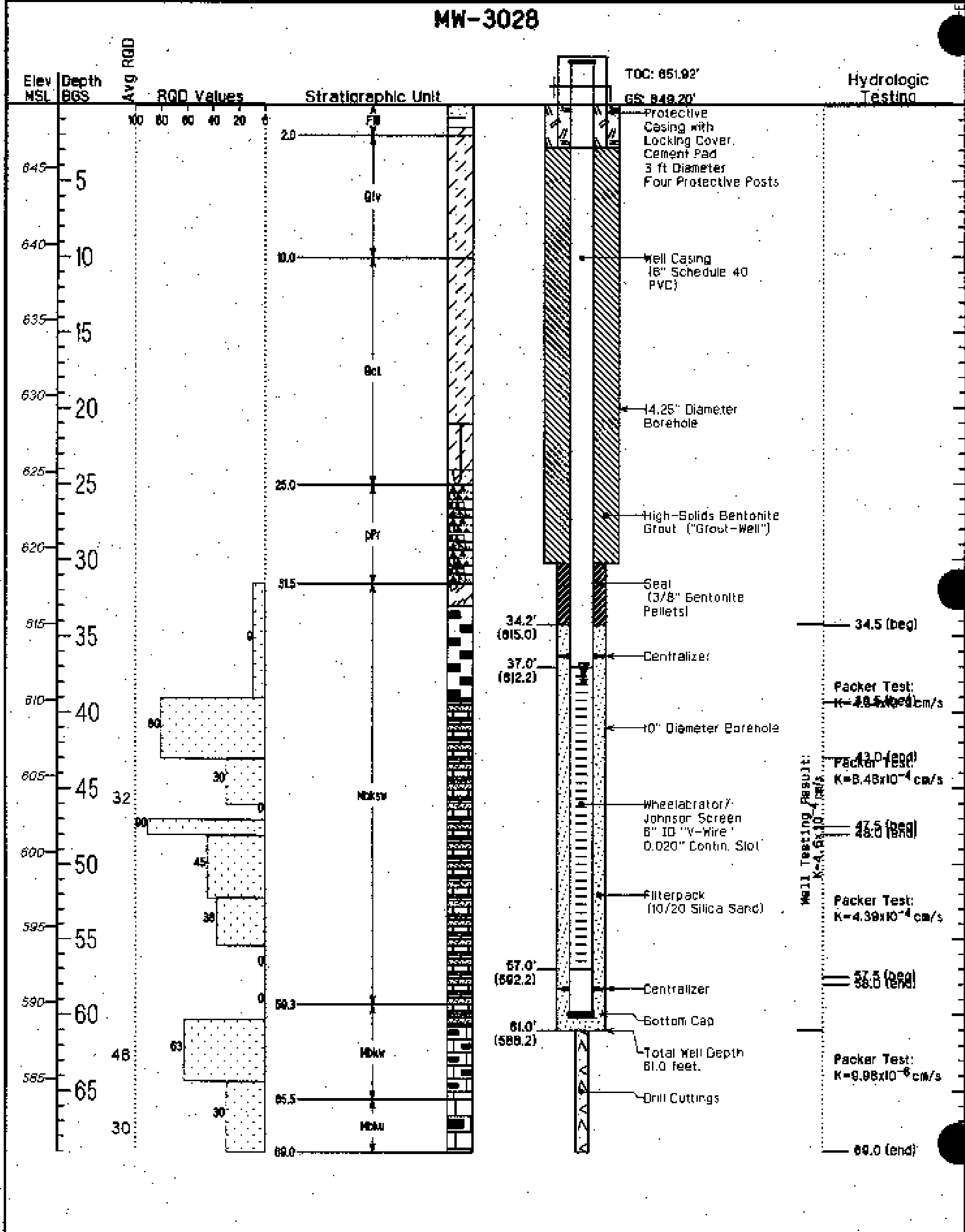
WELL DIAGRAM



Sample Interval ☐ No Sample Taken ▽minimum ▼maximum ▽average

BORECHOLE DIAGRAM

MW-3028



minimum maximum average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

WSMLOG-C

HOLE NUMBER	MW-3029
SHEET 1 OF 2	
NORTH (Y):	1042123.34
EAST (X):	753231.36
TOC ELEVATION	653.48
GROUND ELEVATION	649.49
STICKUP	3.99
HYDR CONDUCTIVITY (cm/sec)	K= No Test

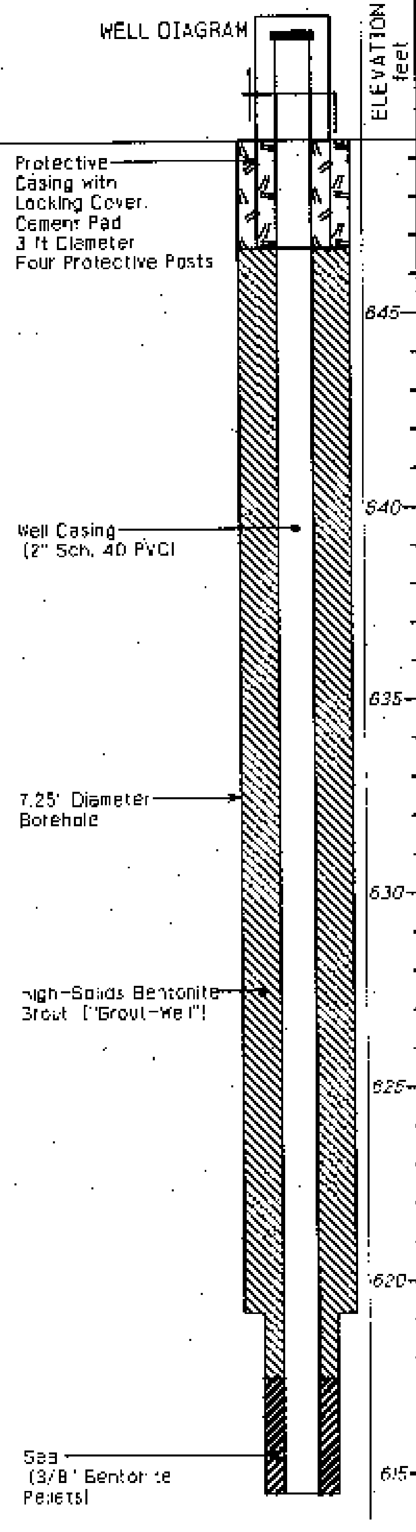
WELL STATUS/COMMENTS: ACTIVE	LOCATION: 47 ft. west of MW-3028	
DRILLING CONTRACTOR: GEOTECHNOLOGY INC	DRILL RIG MAKE & MODEL: CME 850, HSA/NQWL CORE/SCHRAMM AIR ROT.	
HOLE SIZE & METHOD: 7 1/4" Auger to 30.3' then 6" Ai	ANGLE FROM HORIZONTAL & BEARING: Vertical	BOTTOM OF HOLE (TD): 61.0
DRILL FLUIDS & ADDITIVES: WATER/AIR	CASING TYPE, DEPTH, SIZE: 2" Schedule 40 PVC	BEDROCK: 30.3
DATE START: 6-24-1998	DATE FINISH: 6-26-1998	WATER LEVELS & DATES: ▽ ▼

DEPTH (FT.) FROM GROUND ELEV. TO

LITHOLOGY BY: PAUL PATCHIN

DEPTH feet	SAMPLE	SAMPLE/RUN Number	PERCENT Recovery (0–100)	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
					Fill	4" ROCK FILL.	Rock Fill
					ML	CLAYEY SILT, dark yellowish brown (10Y3/4), soft, moist, low plasticity, roots, TOPSOIL/LOESS	Topsoil/Loess
5							
					CL	SILTY CLAY, yellowish brown (10YR5/8), with minor (<5%) fine gravel minor very fine sand (<5%), damp to moist, firm low plasticity, CL	Qct
10							
15							
						17.0' Gravels, color to 10YR4/4, gravels to 1 inch, subrounded, decrease in sand.	
20							
25							
					CL	GRAVELLY CLAY, yellowish brown (10YR5/4), damp, medium plasticity, approximately 15% gravel (limestone and chert), stiff.	pR
30						Top of Rock 30.3 ft	
		RUN-1	10/46"	0	chrt	.8 ft of recovery in Run I. Recovered core is chert pieces and chert "void fill" gravel. Chert is mottled white (N9) to light gray I (N7) with FeOx staining, very hard, mod. weathered, fossiliferous, some clay.	Mbksw
35							

WELL DIAGRAM



ELEVATION feet

■ Sample Interval ☐ No Sample Taken ▽minimum ▼maximum ▼average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

WSMLOG-C

HOLE NUMBER: MW-3029

SHEET 2 OF 2

NORTH (Y): 1042123.3

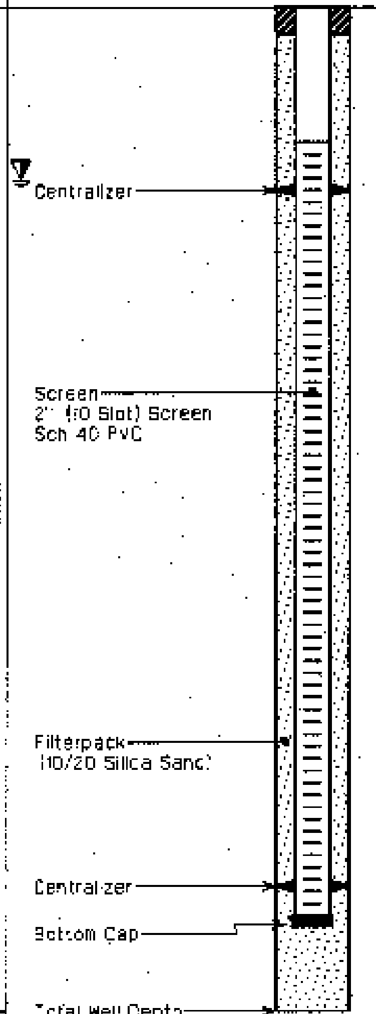
EAST (X): 753231.36

WELL STATUS/COMMENTS: ACTIVE

LOCATION: 47 ft. west of MW-3028

DEPTH feet	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
	RUN-2	2/26"	0	chrt	.2 ft of recovery in Run 2. Chert as above. Possible voids from 36.7'-37.7' and 38.0-38.2'.	MDk9M
40	RUN-3	14/80"	0	lms chrt	1.2 ft of recovery in Run 3. Approximately .6 ft of weathered chert as above with the remainder Argillaceous Limestone and Chert (50/50), brecciated together. Limestone is dark yellowish orange, (10YR6/6) very fine grained, mod. to highly weathered, moderate porosity, moderately hard, occasional vugs to 1". MnOx specks present. 41.2-43.5' very soft drilling, possible void.	
45	RUN-4	1/56"	0		Core loss 43.5-46.1 ft.	
50	RUN-5 / RUN-6	8/12" / 42/52"	0 / 60	lms chrt	48.1 - 57.0' ARGILLACCOUS LIMESTONE (65%) and Chert (35%) interbedded and brecciated together. Limestone is dark yellowish orange (10YR6/6) to grayish orange (10YR7/4), very fine grained, very thin bedded and brecciated, mod. to highly weathered with vugs pinpoint to 2", mod. hard to hard localized silty porous zones to 1/2" throughout. 1/2" vug @ 52.7' with secondary calcite crystals, large (2") cavity @ 54' with secondary hematite/limonite, and calcite vug filling at 54.2'. Chert is very light gray (N8) to grayish orange (10YR7/4), very hard, slightly to mod. weathered, fossiliferous, brecciated (some angular pieces) as nodules/beds to 2", MnOx streaks (fracture filling) common. Overall, porosity is moderate and gradually increasing with depth (to high).	
55	RUN-7	74/78"	72			
60				lms	57.0 - 60.0' SILTY DOLOMITIC LIMESTONE (70%) and CHERT (30%), grayish orange (10YR7/4) to yellowish gray (5Y8/1), HIGH porosity, very vuggy and solutioned (pinpoint to 1"), with abundant secondary calcite and limonite, very brecciated dolomitic (delayed HCL reaction) predominantly highly weathered (bone marrow texture). Chert is as above, euhedral calcite crystals, occasional clay filling in fracts./vugs, MnOx specks in limestone.	
					Total cored depth 60.0'. Reamed hole to 6" to 61.0' and installed 2" observation well.	
65					Note: Soil color is indexed on the Munsell soil color chart. Rock color is from the GSA rock color chart.	
					No packer testing performed in the borehole.	
70						
75						

WELL DIAGRAM

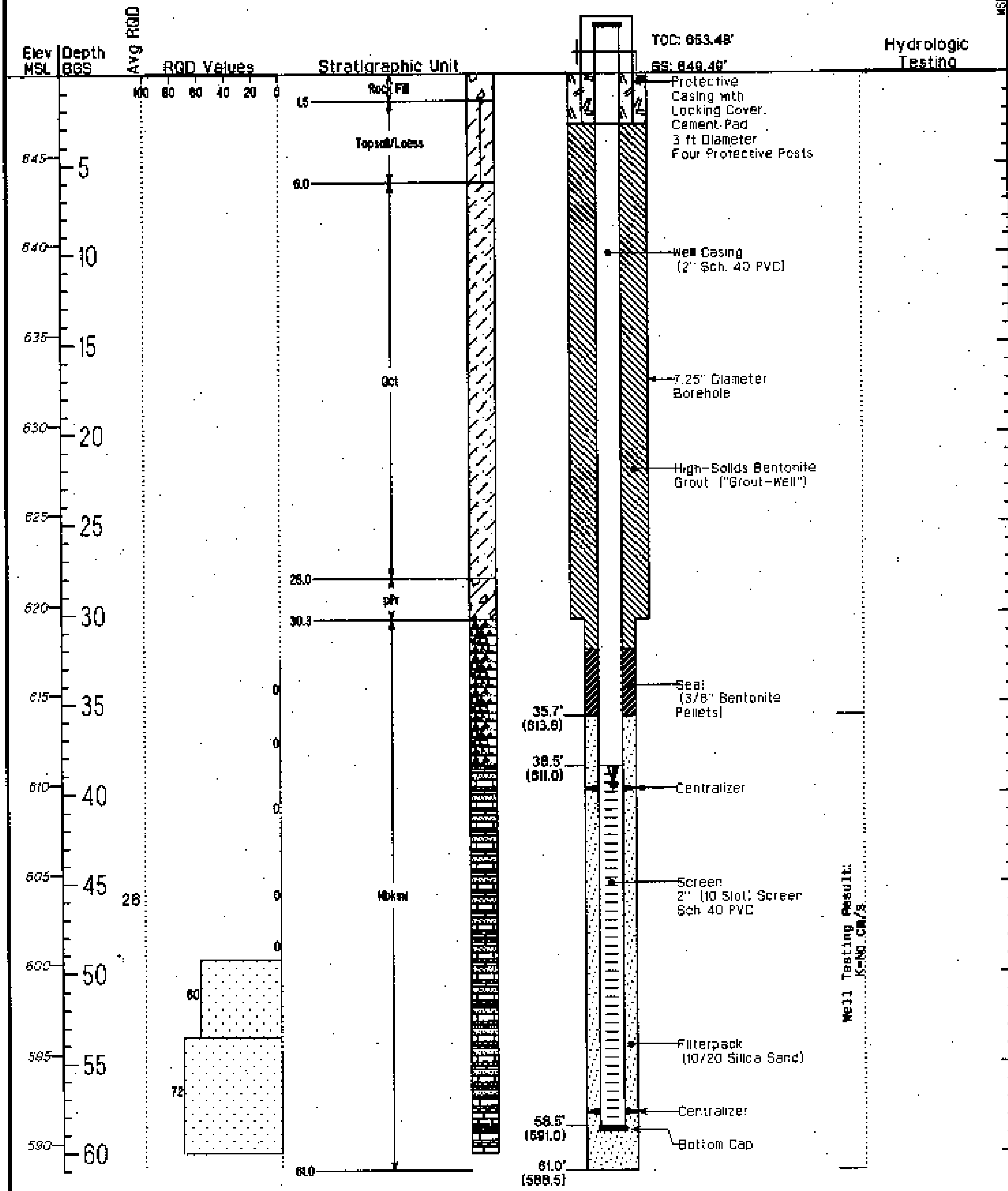


ELEVATION feet: 610, 605, 600, 595, 590, 585, 580, 575

■ Sample Interval □ No Sample Taken ▽minimum ▼maximum ▼average

BOREHOLE DIAGRAM

MW-3029



minimum maximum average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

WSWLOG-C

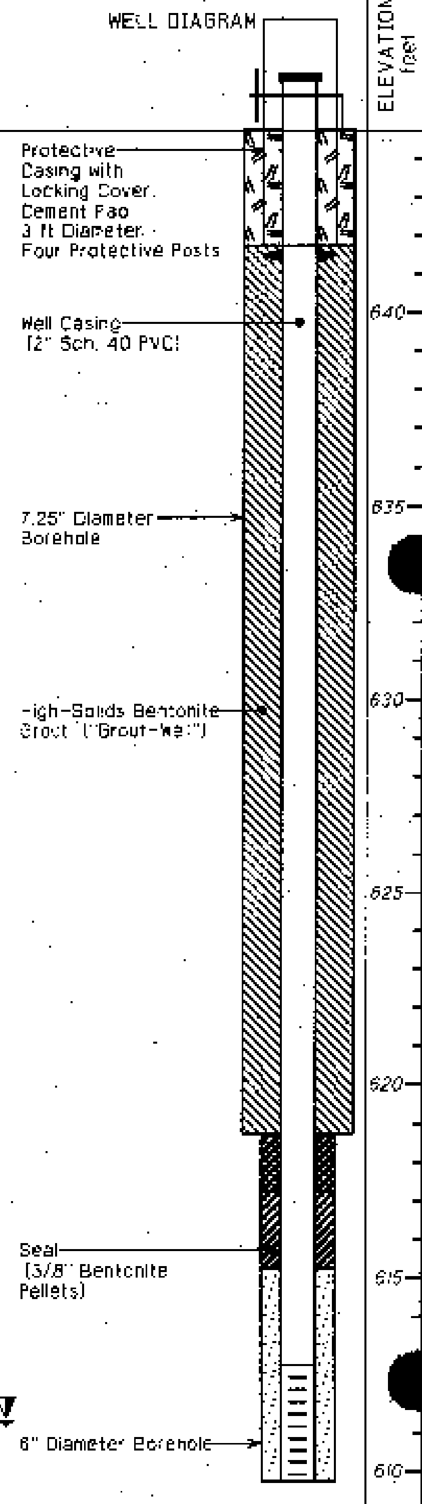
HOLE NUMBER	MW-4027
SHEET 1 OF 2	
NORTH (Y):	1041959.5
EAST (X):	753421.25
TOC ELEVATION	647.77
GROUND ELEVATION	644.74
STICKUP	
HYDR CONDUCTIVITY (cm/sec)	K= 1.7E-4

WELL STATUS/COMMENTS: ACTIVE		LOCATION: Army Side Fence Corner New TSA
DRILLING CONTRACTOR: GEOTECHNOLOGY INC		DRILL RIG MAKE & MODEL: CME 850, HSA/NQWL CORE/SCHRAMM AIR ROT.
HOLE SIZE & METHOD: 3 3/4" Auger to 27.5'	ANGLE FROM HORIZONTAL & BEARING: Vertical	BOTTOM OF HOLE (TD): 59.5
DRILL FLUIDS & ADDITIVES: WATER/AIR	CASING TYPE, DEPTH, SIZE: 2" Schedule 40 PVC	BEDROCK: 27.5
DATE START: 5-26-1998	DATE FINISH: 6-3-1998	WATER LEVELS & DATES: ▽ ▼

DEPTH (FT.) FROM GROUND ELEV. TOC

LITHOLOGY BY: PAUL PATCHIN

DEPTH feet	SAMPLE	SAMPLE/RUN Number	PERCENT Recovery (0–100)	N# or RQD	GRAPHIC LOG	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
0						Fill	TOPSOIL/LOESS, very dark grayish brown (10YR3/2), moist, roots, organics.	Fill
						CH	SILTY CLAY, mottled brownish yellow (10 yr 6/8), with minor light gray (N7), high plasticity, moist, soft, occasional Fe bleb, CH.	Qfv
5								
						CL	SILTY CLAY with SAND, strong brown (7.5 yr 4/6), 10% fine sand, ~10% gravel fine to 2", moist, soft to firm, gravel is primarily chert but some igneous, MnOx streaks and FeOx blebs, medium plasticity, CL.	Qct
10								
15								
							Harder drilling (gravel and cobbles) at 18.0'.	
20						CL	SILTY CLAY with SAND, color change to reddish brown (5YR4/4), consistancy is firm to stiff, decrease in sand and gravel, medium plasticity, CL.	
						GC CL	GRAVELLY CLAY, yellowish brown (10YR5/8), moist, medium to high plasticity, increase in gravel.	Qr
25							Soil at end of pilot bit was wet.	
							Auger Refusal at 27.5' (Top of Bedrock). Switch to NQWL coring.	
		RUN-1	3/84"	0		chrt	Core Loss for all but .3' of the first run. Recovered core is FRACTURED CHERT, light gray, hard, weathered, with FeOx stain. loss for all but .3' of the first run	Mbksw
30								
35		RUN-2	21/42"	0				



▮ Sample Interval ☐ No Sample Taken ▽minimum ▼maximum ▼average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

WSMLOG C

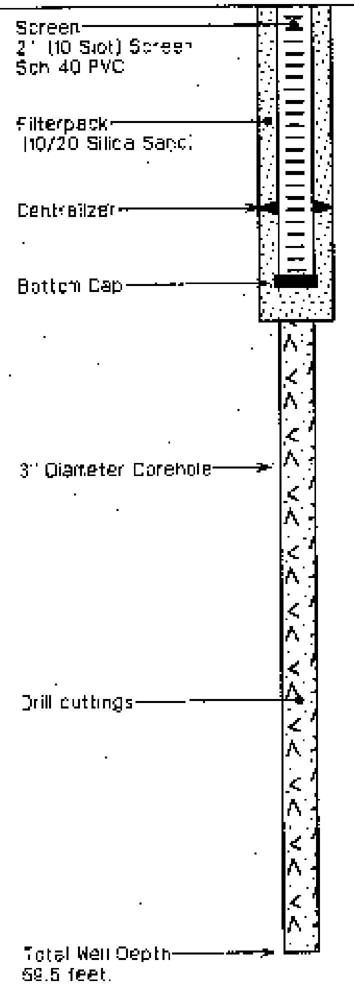
HOLE NUMBER	MW-4027
SHEET	2 OF 2
NORTH (Y):	1041959.59
EAST (X):	753421.25

WELL STATUS/COMMENTS: ACTIVE

LOCATION: Army Side Fence Corner New TSA

DEPTH feet	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
				chrt		
				chrt	35.8 - 36.3' CHERT RUBBLE, light gray (N7), very hard, slightly weathered, fossiliferous.	
	RUN-3	18/18"	67	lms chrt	36.3 - 45.5' CHERT (65%) and ARGILLACEOUS LIMESTONE (35%), interbedded /brecciated together. Chert is primarily grayish orange (10YR7/4) but occasionally very light gray (N8), very hard, highly brecciated from 36.3'-38.5', slightly weathered, with abundant fossils and microfractures with MnOx healing. Limestone is silty, dark yellowish orange (10YR6/6), moderately hard, highly weathered, vuggy (pinpoint to 3"), thinly bedded, abundant FeOx with very soft, silty beds (occasionally to 2").	Mbksw
40	RUN-4	36/42"	N			
	RUN-5	24/24"	45			
45	RUN-6	12/12"	30		Very hard 45.0'-46.0'	
	RUN-7	42/42"	74	lms	45.5 - 49.5' SILTY LIMESTONE with MINOR CHERT (20%), as nodules and interbeds. Limestone is very silty and porous, color as above, thin bedded, with conspicuous MnOx specks throughout, hard, mod. weathered. Chert is light gray as nodules, very hard, slightly weathered	
50	RUN-8	120/120"	87	lms	49.5 - 55.5' SILTY LIMESTONE/CALCARCOUS SILTSTONE with with BRECCIATED CHERT (20%). Limestone has almost no HCL reaction (silt content) is yellowish gray (5Y7/2) to light olive gray (5Y5/2). Extremely porous with vuggy "bone marrow" texture, vugs to 1/2" with drusy quartz filling, abundant clay on fractures moderate to highly weathered. Chert is very light gray (N8), brecciated, moderately weathered, very hard. Lost circulation 50.2 then regained at 50.5'.	Mbkw
55				lms	55.4 - 59.5' ARGILLACEOUS LIMESTONE with some CHERT (15%), limestone is yellowish gray (5Y7/2) to very light gray (N8), slightly weathered, some zones of more silt, FeOx stain, and brecciation, with chert from 57.2'-58.0' and 59.2'-59.5', hard to very hard, stylolitic, fossiliferous, thin to medium bedded. Chert is as above in beds to .5' and minor divided with limestone.	
60					Note: Based on MW-302B, contact with unweathered Burlington Keokuk Limestone estimated at 60.5'	
					Total Cored Depth 59.5' Reamed hole to 6" to 43.2' and installed 2" observation well.	
65					Note: Soil color is indexed on the Munsell soil color chart. Rock color is from the GSA rock color chart.	
					CONSTANT HEAD SINGLE PACKER TEST RESULTS: 28.0-39.5 ft. K=1.7E-4 cm/sec 39.0-48.5 ft. K=1.3E-4 cm/sec 49.0-59.5 ft. K=3.4E-6 cm/sec	
70						
75						

WELL DIAGRAM

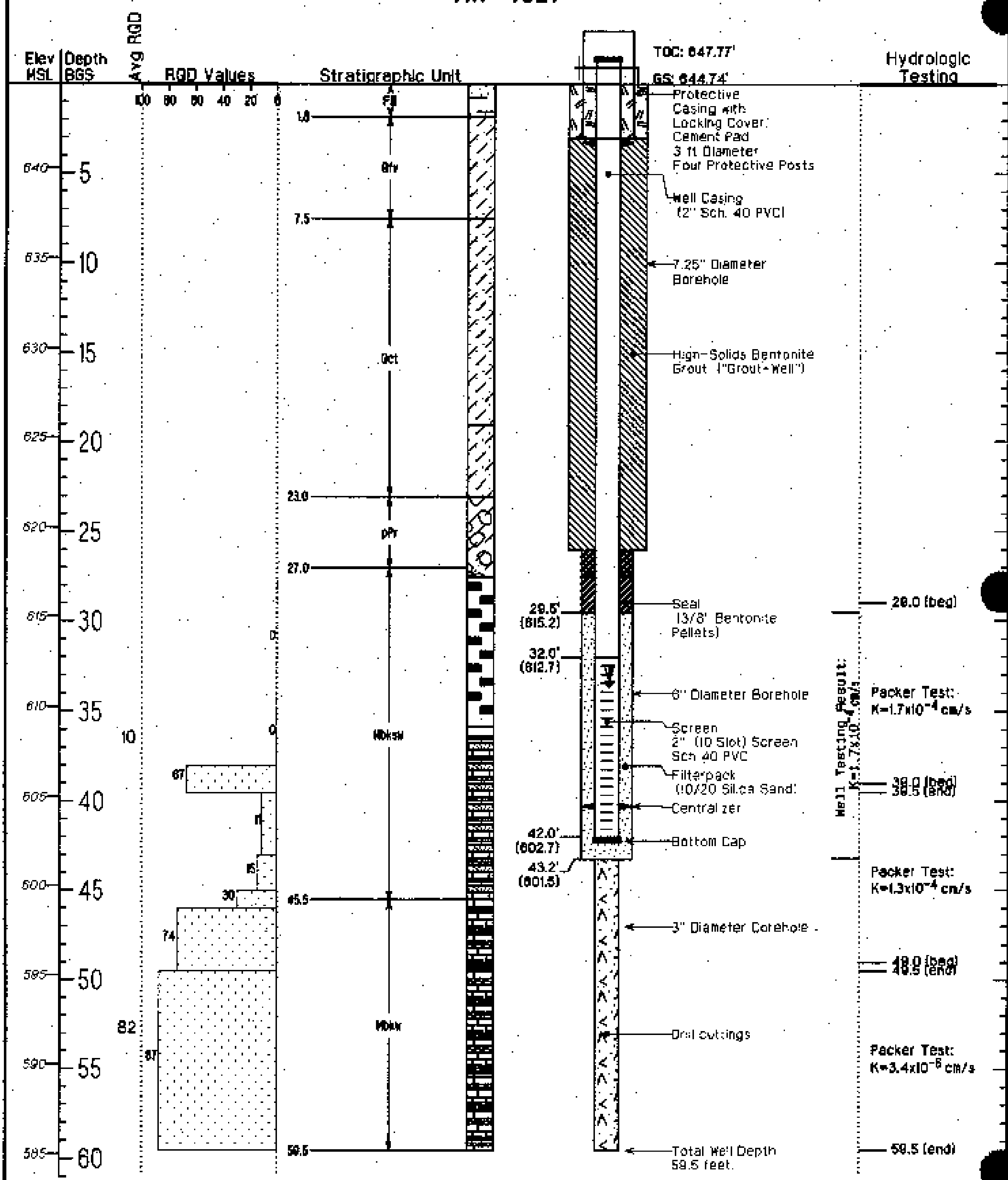


ELEVATION feet
605
600
595
590
585
580
575
570

■ Sample Interval □ No Sample Taken ∇ minimum ▼ maximum ∇ average

BOREHOLE DIAGRAM

MW-4027



minimum maximum average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

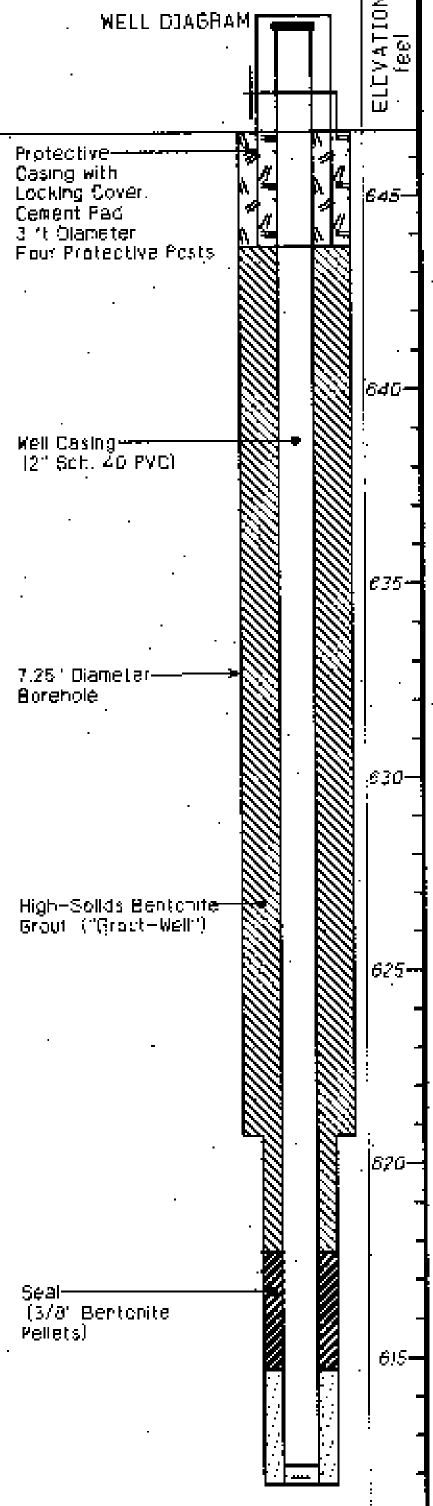
WSMLOG-C

HOLE NUMBER	MW-4028
SHEET 1 OF 2	
NORTH (Y):	1042071.69
EAST (X):	753249.08
TOC ELEVATION	650.35
GROUND ELEVATION	646.71
STICKUP	3.64
HYDR CONDUCTIVITY (cm/sec)	K= No test

WELL STATUS/COMMENTS	ACTIVE
LOCATION	32 ft. southwest of MW-3028
DRILLING CONTRACTOR	GEOTECHNOLOGY INC
DRILL RIG MAKE & MODEL	CME 850, HSA/NDWL CORE/SCHRAMM AIR ROT.
HOLE SIZE & METHOD	7 1/4" Auger to 25.5' then 6" Air
ANGLE FROM HORIZONTAL & BEARING	Vertical
DEPTH (FT.) FROM GROUND ELEV. TO: BOTTOM OF HOLE (TD)	58.0
DRILL FLUIDS & ADDITIVES	WATER/AIR
CASING TYPE, DEPTH, SIZE	2" Schedule 40 PVC
BEDROCK	26.0
DATE START	6-29-1998
DATE FINISH	7-02-1998
WATER LEVELS & DATES	

LITHOLOGY BY: PAUL PATCHIN

DEPTH feet	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
0				Topsoil	TOPSOIL, (clayey silt), very dark grayish brown (2.5y 3/2), low plasticity, slightly moist, ML	Topsoil/Loess
				CL	SILTY CLAY, dark yellowish brown (10YR4/4), low to mod. plasticity, firm, FeOx blebs, CL	Qrx?
5					SILTY CLAY, as above but increased plasticity (moderate to high), with minor gray mottling and FeOx blebs, minor very coarse sand particles in the clay, CL	Qfy
10					SILTY CLAY as above, but less plasticity and no mottling, slight increase of sand with depth, firm, CL	
15				CL	SANDY, SILTY, CLAY, olive brown (2.5Y4/4), increased plasticity, gravel (chert) pieces (<5%), to 3/4", CL	Qct
					18.0 ft color changes to dark yellowish brown (10YR4/4).	
20						
				CL	Gravel increasing	pPr
25					Auger refusal at 25.5 ft. Driller indicates top of rock at 26.0 ft.	
				BC chrt	Top of Rock 26.0 ft	Mbksw
					No sampling 26.0 - 27.5'	
	RUN-1	51/72"	0			
				lms chrt	28.5 - 28.7 CHERT GRAVEL, highly weathered, white (N9) vuggy, hard.	
30				loss	28.7 - 29.8' LIMESTONE, slightly argillaceous, with minor chert (20%) as nodules. Limestone is grayish orange (10YR7/4), slightly mottled to 29' the abruptly changes to yellowish (5Y8/1), overall is thin bedded, very dense, very hard, very fossiliferous, slightly to moderately weathered, very closely fractured.	
				chrt	29.8 - 32.2 CORE LOSS (approximate)	
	RUN-2	14/48"	0	loss	32.2 - 33.7' CHERT, light gray (N7) to grayish orange (10YR7/4) thin-bedded or brecciated to nodular, moderately weathered hard to very hard,	
35						



■ Sample Interval □ No Sample Taken ▽ minimum ▼ maximum ▼ average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

WSMLOG-C

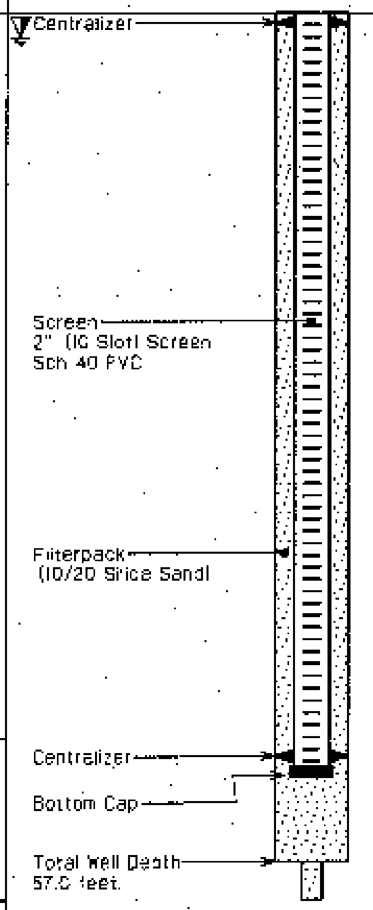
HOLE NUMBER	MW-4028
SHEET	2 OF 2
NORTH (Y)	1042071.6
EAST (X)	753249.08

WELL STATUS/COMMENTS: ACTIVE

LOCATION: 32 ft. southwest of MW-3028

DEPTH feet	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
				loss	extremely close fracture spacing (rubblized); abundant light green clay filling in brecciated areas, abundant FeOx staining in clay and fractures, vuggy.	
	RUN-3	16/68"	0	GC chrt	1.2 ft of recovery in Run 2. Approximate interval of 36.5 – 37.2' is CHERT GRAVEL, (void fill), very vuggy, mod. to highly weathered white (N9), with orange FeOx staining, minor clay.	
40				lms chrt	37.2 – 52.0' ARGILLACEOUS LIMESTONE AND CHERT (60/40). Limestone is dark yellowish orange (10YR6/6), very thin-bedded/brecciated chert, mod. hard; to soft (in highly weathered zones), very fine grained, mod. to highly weathered, mod. porosity, abundant MnOx specks and microfracture filling. Chert is finely divided to brecciated with the limestone, with occasional beds/nodules @43.2-43.5', 44.0-44.7', 47.4-47.7', and 50.0-50.3', very pale orange (10YR8/2) to white (N9), mod. to highly weathered, closely fractured with heavy FeOx and MnOx staining, very fossiliferous. Highly weathered zone @ 42.8-44.0'. Occasional vugs to 2" with heavy FeOx.	Mbksw
	RUN-4	8/20"	0			
45	RUN-5	16/24"	0			
	RUN-6	30/33"	64			
	RUN-7	22/32"	41			
50						
	RUN-8	62/62"	71			
55				lms chrt	52.0 – 58.0' SILTY DOLOMITIC LIMESTONE and CHERT finely divided and interbedded together (approx 70/30). Limestone is grayish orange (10YR7/4) to 53.8' then yellowish gray (5Y7/2), very fine grained, thin-bedded, mod. to highly weathered to 53.8', with vugs and cruzy quartz and "bone marrow" texture, then mod. weathered. Limestone is dolomitic (delayed HCL reaction & stronger when powdered), vuggy (pinpoint to 1/2"), HIGHLY POROUS, mod. hard, little to no MnOx specks, closely-spaced fractures with FeOx. Chert is white (N9), brecciated/finely divided with limestone, with nodules to 4", very hard, fossiliferous, with abundant healed microfractures, slightly weathered, increasing with depth (to high). @56.7' Color to light olive gray (5Y6/1), also stylolites and extreme porosity.	Mbkw
60					Total cored depth 58.0'. Reamed hole to 6" to 57.0' and installed 2" observation well.	
					Note: Soil color is indexed on the Muncell soil color chart. Rock color is from the GSA rock color chart.	
65					No packer testing performed in the borehole.	
70						
75						

WELL DIAGRAM

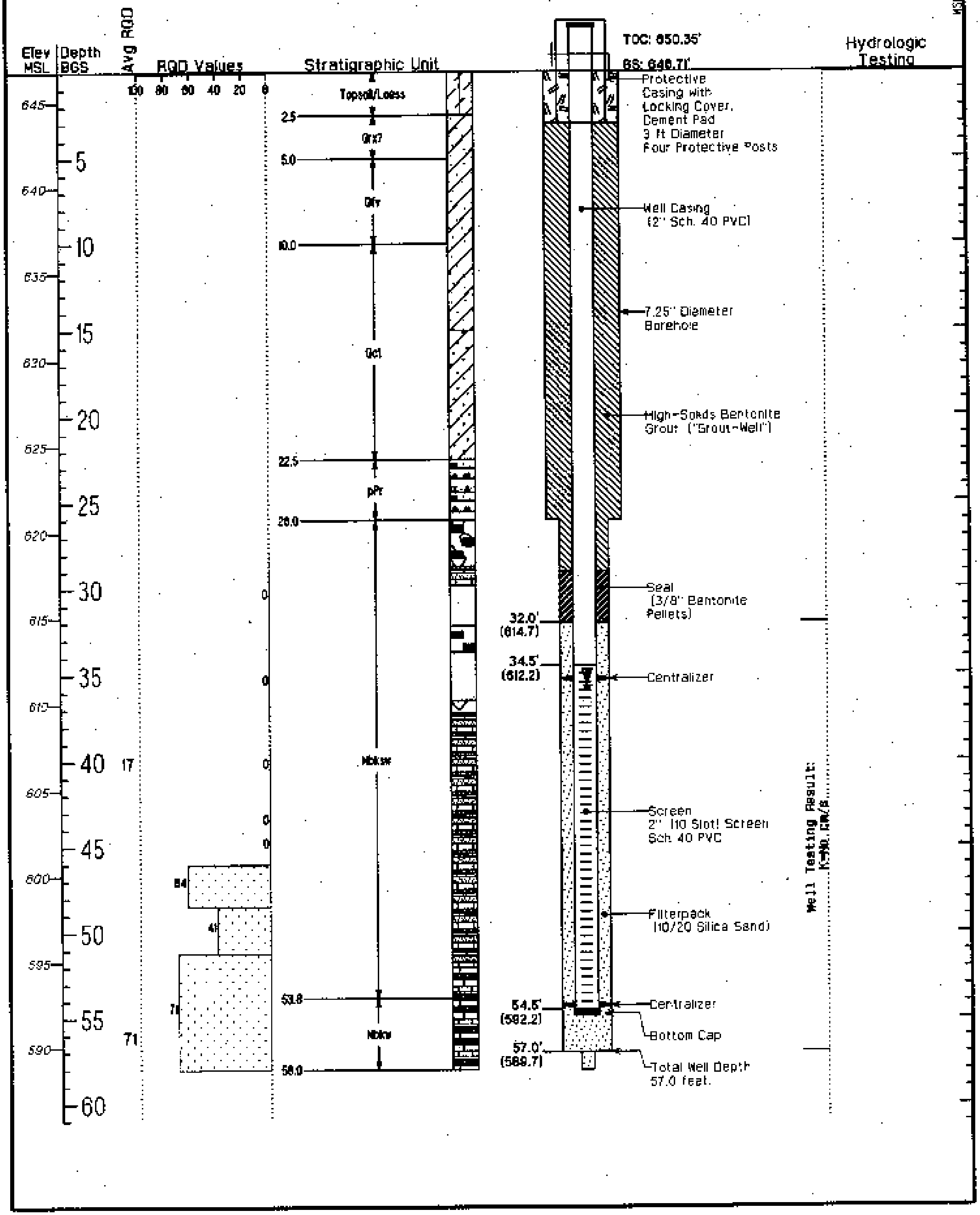


ELEVATION feet: 610, 605, 600, 595, 590, 585, 580

Sample Interval · No Sample Taken · minimum · maximum · average

BOREHOLE DIAGRAM

MW-4028



minimum maximum average

WELDON SPRING SITE REMEDIAL ACTION PROJECT
BOREHOLE AND WELL COMPLETION LOG

WSHL06-C

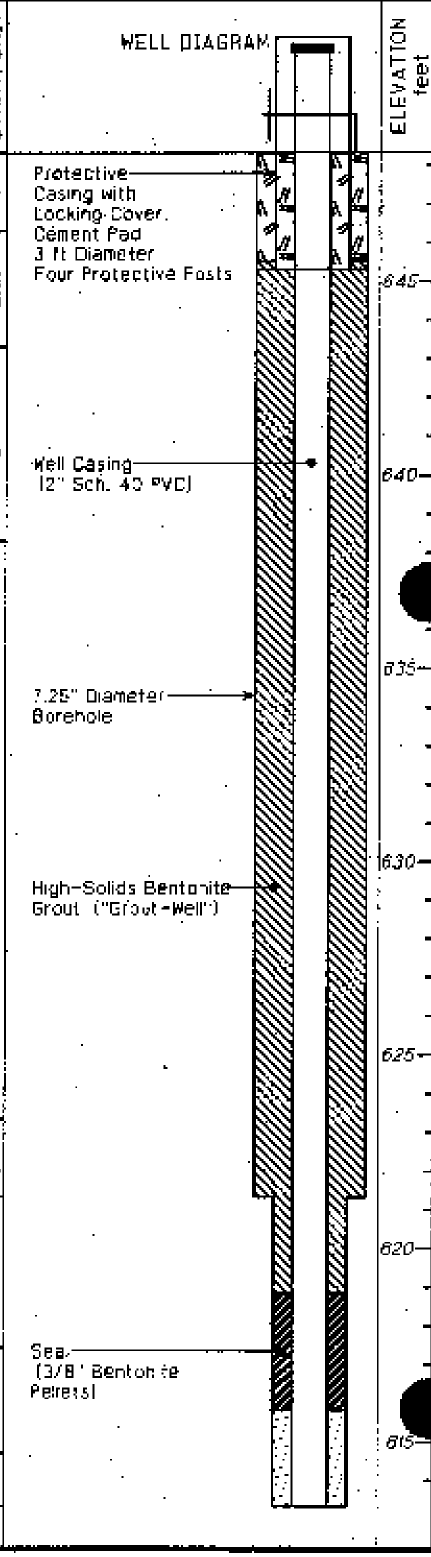
HOLE NUMBER	MW-4029
SHEET 1 OF 2	
NORTH (Y):	1042175.9
EAST (X):	753129.19
TOC ELEVATION	651.28
GROUND ELEVATION	648.32
STICKUP	2.96
HYDR CONDUCTIVITY (cm/sec)	K= No test

WELL STATUS/COMMENTS: ACTIVE	LOCATION: 161 ft. northwest of MW-3028	
DRILLING CONTRACTOR: GEOTECHNOLOGY INC	DRILL RIG MAKE & MODEL: CME 850, HSA/NQWL CORE/SCHRAMM AIR ROT.	
HOLE SIZE & METHOD: 7 1/4" Auger to 27.0' then 6" Air	ANGLE FROM HORIZONTAL & BEARING: Vertical	BOTTOM OF HOLE (TD): 58.2
DRILL FLUIDS & ADDITIVES: WATER/AIR	CASING TYPE, DEPTH, SIZE: 2" Schedule 40 PVC	BEDROCK: 27.0
DATE START: 7-06-1998	DATE FINISH: 7-09-1998	WATER LEVELS & DATES: ▽ ▼

(DEPTH (FT.) FROM GROUND ELEV. TO)

LITHOLOGY BY: PAUL PATCHIN

DEPTH feet	SAMPLE	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
					ML	TOPSOIL/LOESS, (clayey silt) dark brown, roots, organics	Topsoil/Loess
					ML CL	SILTY CLAY/CLAYEY SILT, brown (7.5YR4/3), firm, slightly moist, low plasticity, CL/ML	Grx?
5					CL CH	SILTY CLAY, dark yellowish brown (10YR4/4), slightly moist, mod. plasticity, firm, trace fine gravel, FeOx blebs, CL/CH	Qfv
10					CL	17.0' Color change to yellowish brown (10YR5/8), slight increase in fine sand.	Qct
						SILTY, SANDY CLAY, dark yellowish brown (10YR4/4), low to mod. plasticity, slightly moist, minor very fine gravel to coarse sand, FeOx blebs, CL	
15						@18.0' Coarse gravel	
20						@21.0' Increase in moisture and plasticity.	
					CL	GRAVELLY CLAY, brown (10YR4/3), moist, medium plasticity, approximately 15% fine gravel to 1" (chert), firm to stiff, CL	
25					CL	GRAVELLY CLAY, light olive brown (2.5Y5/4), approx. 10-15% chert and limestone gravel, clay is calcareous, low plasticity, stiff, slightly sandy, CL	pPr
					chrt	Top of Rock 27.0 ft	Mbksw
						No sampling from 27.0 - 29.2'	
30		RUN-1		0		29.2 - 29.9' CHERT pieces, white (N9), to dark yellowish orange (10YR8/6), mod. to highly weathered.	
		RUN-2	27/40"	0			
					lms. chrt	Core Loss from approx. 29.9 - 30.9'	Mbkw
						30.9 - 33.6' LIMESTONE, yellowish gray (5Y8/1), slightly argillaceous, minor chert (<5%) as nodules and occasionally interbeds to breccia, hard to very hard, dense, medium to coarsely crystalline, thin-bedded which appears to gently dip	
		RUN-3	28/37"	0	chrt clay		
35							Mbksw



▮ Sample Interval ☐ No Sample Taken ▽minimum ▼maximum ▼average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

BOREHOLE AND WELL COMPLETION LOG

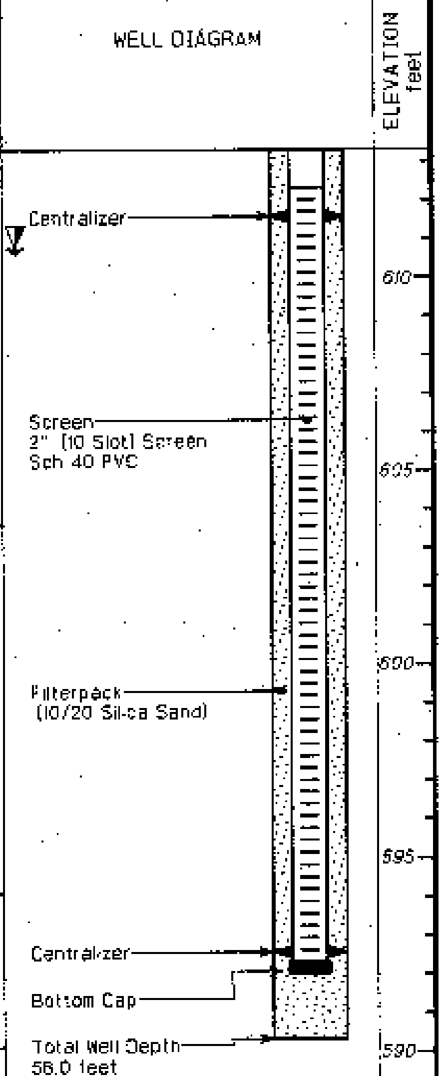
WSHLOG-C

HOLE NUMBER	MW-4029
SHEET 2 OF 2	
NORTH (Y):	1042175.97
EAST (X):	753129.19

WELL STATUS/COMMENTS: ACTIVE

LOCATION: 181 ft. northwest of MW-3028

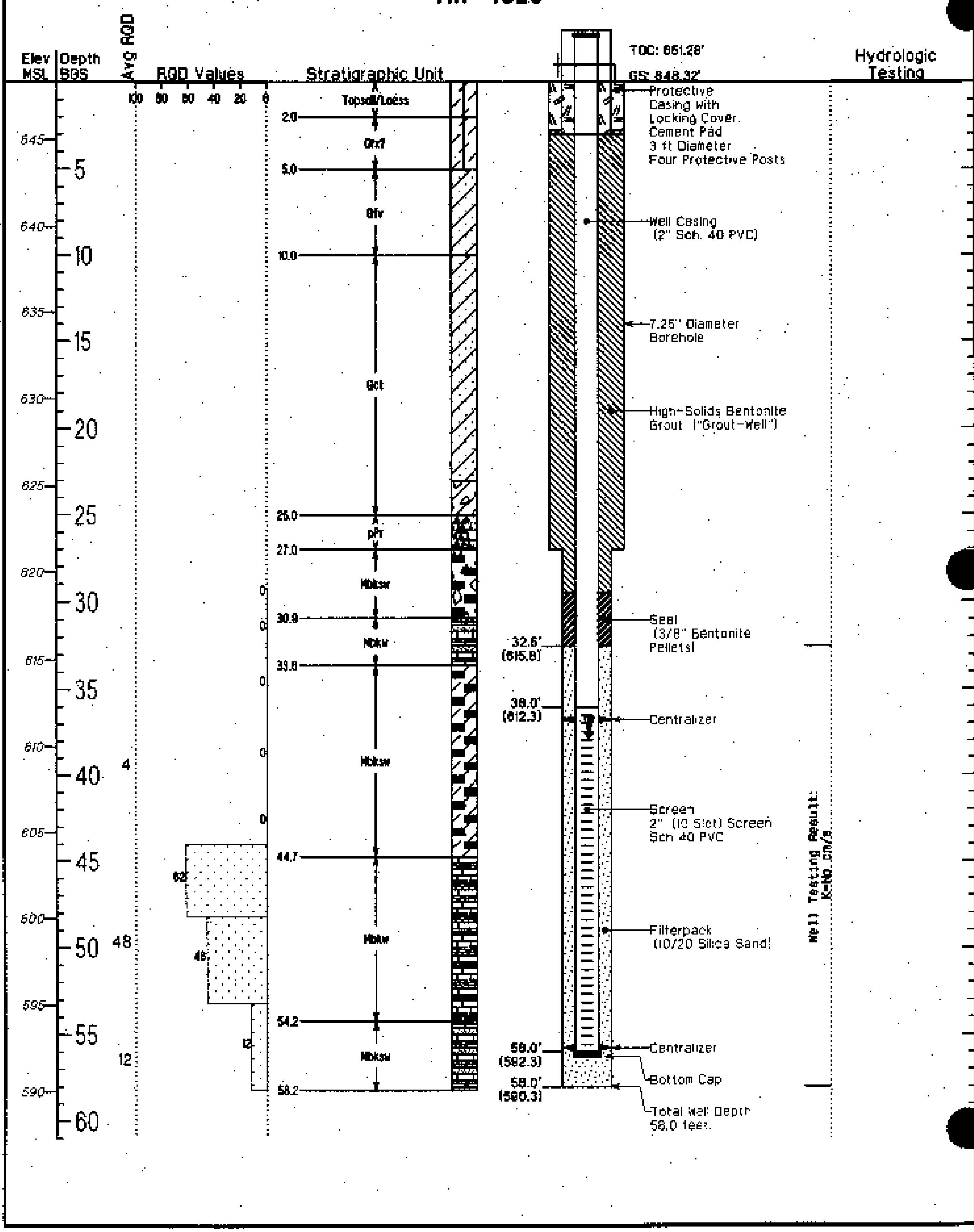
DEPTH feet	SAMPLE/RUN Number	PERCENT Recovery	N# or RQD	SOIL/ROCK class	DESCRIPTION AND REMARKS	STRAT. UNIT
	RUN-4	25/62"	0	chrt clay	at approx. 30 degrees from horizontal, slightly to mod. weathered, stylolitic, closely spaced fratures with abundant green clay infilling, occasional limonite after pyrite as blebs, fracture filling, and framing chert nodules. Chert is very light gray (N8) except where stained with limonite, very hard, predominantly nodular.	MDksw
40	RUN-5	25/30"	0		33.6 – 44.7' CHERT AND CLAY BRECCIA, approx. 60% chert brecciated in clay matrix. Chert is very light gray (N8) to dark yellowish orange (10YR7/4) (minor), irregular brecciated texture, (almost no discernable bedding), mod. weathered, very hard. Clay is yellowish gray (5Y7/2), very stiff to hard, waxy, with some beds to 1", often FeOx-stained. Chert has vugs (pinpoint to .5"), highly weathered from 43.0 – 46.2'. Chert as rubble from 44.4 – 44.7', overall, nodules are very fossiliferous.	MDksw
	RUN-6	45/50"	62			
45–50	RUN-7	60/60"	46	lms chrt	ARGILLACEOUS LIMESTONE and CHERT, interbedded and brecciated together (approx. 70/30) Limestone is dark yellowish orange (10YR6/6), very fine grained, mod. weathered, thin-bedded, mod. hard. Chert as nodules and minor brecciated zones, light gray (N7) to white (N8), very hard, very fossiliferous, with minor MnOx in fracts. Limestone becomes more porous with depth and slightly less HCL reaction. Vuggy from 49.2–49.7', and other small zones, abundant MnOx specks throughout.	MDksw
	RUN-8	44/60"	12			
55				lms chrt	54.2 – 58.2' ARGILLACEOUS LIMESTONE and CHERT. Limestone is very argillaceous, light olive gray (5Y6/1) to grayish orange (10YR7/4), moderate to high porosity, mod. to highly weathered, abundant solution features (vugs) and secondary quartz filling ("bone marrow" drusy quartz) particularly at 54.2–54.6' and 56.0–56.2'. Chert is brecciated and bedded, chert bed (nodule) at 57.6–58.2', moderately weathered, colors as above, some clay and highly weathered from 56.7–57.2'.	MDksw
60					Total cored depth 58.2'. Reamed hole to 9" to 58.0' and installed 2" observation well.	
					Note: Soil color is indexed on the Munsell soil color chart. Rock color is from the GSA rock color chart.	
					No packer testing performed in the borehole.	



Sample Interval No Sample Taken minimum maximum average

BOREHOLE DIAGRAM

MW-4029



∇minimum ∇maximum ∇average

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU - Pilot Pumping Test WORK PACKAGE NO. 510

DEVELOPED BY GEOTECHNOLOGY, INC.

1. Well No.: MW-3028 Well Locations: (South of PIT 4) 1042097.185239 N 753269.653499 E

2. Date of Installation: 5-18-98 ⇒ 6-8-98

3. Date of Development: 6-9-98

4. Static Water Level: Before Development 40.6 T.O.C. ft.; At least 24 hrs. after ______ ft.

5. Organic Vapor: Before development N/A ppm; After development N/A ppm.

6. Quantity of water loss during drilling, if used: N/A gal.

7. Quantity of standing water in well and annulus before development: 52.1 gal.

8. Depth from top of well casing to bottom of well: 62.8 ft. (from Well Installation Diagram)

9. Well diameter: 6 in.

10. Screen length: 20.0 ft.

11. Minimum quantity of water to be removed: 156.3 gal. (3 vol.)

12. Depth to top of sediment: Before development ______ ft.; After development ______ ft.

13. Physical character of water (before/after development): ______

14. Type and size of well development equipment: GRUNDFOS Redi Flo 4" Pump + 6" surge

15. Description of surge technique: Alternating cycles of surge and pump.

16. Height of well casing above ground surface: 3.0 ft. (from Well Installation Diagram).

17. Quantity of water removed: ______ gal. Time for removal: ______ hr./min.

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU - Pilot Pumping Test WORK PACKAGE NO. 510

DEVELOPED BY GEOTECHNOLOGY, INC. CHECKED BY P. Patchin SHEET 2 OF 2

1. Well No.: MW - 3028 Well Locations: (SOUTH ~~EAST~~ OF PIT 4) 1042097.185239 N 753269.658499 E

6-9-98

Date/ Time	Hrs. Dev./ Cum. Hrs. Dev.	Gals. Purged/ Cum. Gals. Purged	pH	Temp.	Cond. (x 100) μs/cm	Remarks
1318		15 / 15	6.95	70.8	12.99	Color: TURBID
1323		85 / 100	6.89	72.4	10.81	: slightly cloudy
1329		50 / 150	6.81	69.3	10.48	:Clear
1335		50 / 200	6.74	72.1	11.40	:clear
1339		50 / 250	6.71	67.8	10.22	"
1343		50 / 300	6.70	66.4	10.19	"
1349		50 / 350	6.66	66.3	10.35	"
6-10-98		170 / 520	NO parameters (Already stable)			Clear

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME ______________ WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY, INC.

1. Well No.: MW-3029 Well Locations: S. of Pit 4
2. Date of Installation: 6-26-98
3. Date of Development: 6-30-98
4. Static Water Level: Before Development 42.3 T.O.C. ft.; At least 24 hrs. after – ft.
5. Organic Vapor: Before development – ppm; After development – ppm.
6. Quantity of water loss during drilling, if used: ______ gal. ?
7. Quantity of standing water in well and annulus before development: ______ gal.

Depth from top of well casing to bottom of well: 61.5 T.O.C. ft. (from Well Installation Diagram)

9. Well diameter: 2 in.
10. Screen length: 20 ft.
11. Minimum quantity of water to be removed: ______ gal.
12. Depth to top of sediment: Before development – ft.; After development – ft.
13. Physical character of water (before/after development): ______________
14. Type and size of well development equipment: 2" grundfos pump AND surge block
15. Description of surge technique: Alternating cycles of surge and pump.

16. Height of well casing above ground surface: ~~42.3~~ 3.0 T.O.C. ft. (from Well Installation Diagram).
17. Quantity of water removed: ______ gal. Time for removal: ______ hr./min.

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME ______________ WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY CHECKED BY P. Patchin SHEET 2 OF 2

1. Well No.: MW-3029 Well Locations: S. OF PIT 4

Date/ Time	Hrs. Dev./ Cum. Hrs. Dev.	Gals. Purged/ Cum. Gals. Purged	pH	Temp.	Cond. (x 100)	Remarks
6-30-98 1030	0. / 0.	5 / 5	6.97	68.3	12.27	TURBID
	/	5 / 10	6.66	65.0	11.49	TURBID clearing
	/	5 / 15	6.58	64.2	11.46	↓
	/	5 / 20	6.60	64.0	11.65	↓
	/	5 / 25	6.59	64.2	11.66	↓
	/	5 / 30	6.56	63.9	11.89	slightly Cloudy / near clear
	/	5 / 35	6.56	63.8	11.89	A.A. — clear
	/	5 / 40	6.52	64.0	11.97	Clear
	/	5 / 45	6.50	63.2	12.15	"
1050	/	5 / 50	6.51	63.0	12.17	"

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU Pilot Pumping Test WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY, INC.

1. Well No.: MW-4027 Well Locations: Army Prop.
2. Date of Installation: 6/3/98
3. Date of Development: 6/10/98
4. Static Water Level: Before Development 36.5 ft.; At least 24 hrs. after ______ ft.
5. Organic Vapor: Before development N/A ppm; After development N/A ppm.
6. Quantity of water loss during drilling, if used: ______ gal.
7. Quantity of standing water in well and annulus before development: 5.4 gal.
8. Depth from top of well casing to bottom of well: 46.1 ft. (from Well Installation Diagram)
9. Well diameter: 2" in.
10. Screen length: 10.0 ft.
11. Minimum quantity of water to be removed: 16.2 gal.
12. Depth to top of sediment: Before development — ft.; After development — ft.
13. Physical character of water (before/after development): ~~Grundfos~~ CB 6-10-98
14. Type and size of well development equipment: Grundfos 2" pump
15. Description of surge technique: alternating cycles of surge and pump
16. Height of well casing above ground surface: 2.9 ft. (from Well Installation Diagram).
17. Quantity of water removed: ______ gal. Time for removal: ______ hr./min.

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU Pilot Pumping test WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY, INC CHECKED BY P. Patchin SHEET 2 OF 2

1. Well No.: MW-4027 Well Locations: Army Prop.

6-10-98

Date/ Time	Hrs. Dev./ Cum. Hrs. Dev.	Gals. Purged/ Cum. Gals. Purged	pH	Temp.	Cond. (x 100)	Remarks
1035		5 / 5	6.13	69.5	4.12	H_2O color: Turbid
1038		5 / 10	6.14	69.7	3.90	Turbid, but clearing
1041		5 / 15	6.00	68.3	3.84	cloudy
1044		5 / 20	5.91	69.4	3.84	P. cloudy; clearing
1047		5 / 25	5.84	69.1	3.99	slightly cloudy / INSTALL GFCI*
1059		5 / 30	5.80	69.2	4.02	cloudy
1101		5 / 35	5.75	68.9	3.95	TURBID / RECHARGE SURGE
1123		5 / 40	5.68	68.7	4.08	TURBID
1126		5 / 45	5.67	68.0	4.10	clearing: TURBID
1129		5 / 50	5.68	67.8	4.14	slightly cloudy
1132		5 / 55	5.66	68.0	4.14	mostly clear
1135		5 / 60	5.68	68.0	4.16	" "
1139		5 / 65	5.68	67.9	4.18	clear
1142		5 / 70	5.67	67.6	4.19	mostly "
1145		5 / 75	5.66	67.5	4.19	mostly clear to clear
1325		15 / 90	NO	parameters		Clear

* GFCI - did not work

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME 6WOU Pilot Pumping Test WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY, INC.

1. Well No.: 4028 Well Locations: S. of Pit 4 / Army Prop.

2. Date of Installation: 7-2-98

3. Date of Development: 7-8-98

4. Static Water Level: Before Development 39.5 TOC ft.; At least 24 hrs. after ________ ft.

5. Organic Vapor: Before development — ppm; After development — ppm.

6. Quantity of water loss during drilling, if used: ______ gal.

7. Quantity of standing water in well and annulus before development: ________ gal.

8. Depth from top of well casing to bottom of well: 58.5 ft. (from Well Installation Diagram)

9. Well diameter: 2 in.

10. Screen length: 20.0 ft.

11. Minimum quantity of water to be removed: 9.69 gal. 3 vol's. (1 vol = 3.23)

12. Depth to top of sediment: Before development — ft.; After development — ft.

13. Physical character of water (before/after development): ____________

14. Type and size of well development equipment: 2" grundfos pump and surge block

15. Description of surge technique: alternating cycles of pump & surge.

16. Height of well casing above ground surface: 3.0 ft. (from Well Installation Diagram).

17. Quantity of water removed: 100 gal. Time for removal: 1.0 hr./min.

WELDON SPRING SITE REMEDIAL ACTION PROJECT

GWOU MONITORING WELL DEVELOPMENT FORM

PROJECT NAME Pilot Pumping Test WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECH. CHECKED BY P. Patchin SHEET 2 OF 2

1. Well No.: 4028 Well Locations: S. of Pit 4

Date/ Time	Hrs. Dev./ Cum. Hrs. Dev.	Gals. Purged/ Cum. Gals. Purged	pH	Temp.	Cond.	Remarks ≈ 5 gals/min.
7-8-98 1308	/	5 / 5	7.16	70.1	14.56	TUBID - starting to clear slightly by 5 gals.
1310	/	5 / 10	6.77	69.0	14.88	As Above
1312	/	5 / 15	6.75	66.8	14.68	very cloudy ← up to 5 gal
13:13	/	5 / 20	6.69	66.2	14.47	cloudy clearing
	/	5 / 25	6.64	65.7	14.35	"
	/	5 / 30	6.60	64.4	14.29	" ↓
	/	5 / 35	6.58	64.3	14.32	"
	/	5 / 40	6.46	64.3	14.32	clear - slightly cloudy
	/	5 / 45	6.44	64.6	14.32	
1320	/	5 / 50	6.46	64.1	14.28	clear

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU Pilot Pump TEST WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECHNOLOGY, INC.

1. Well No.: 4029 Well Locations: S. OF PIT 4

2. Date of Installation: 6-9-98

3. Date of Development: 6-10-98

4. Static Water Level: Before Development 40.4 T.O.C. ft.; At least 24 hrs. after ________ ft.

5. Organic Vapor: Before development — ppm; After development — ppm.

6. Quantity of water loss during drilling, if used: ________ gal.

7. Quantity of standing water in well and annulus before development: ________ gal.

8. Depth from top of well casing to bottom of well: 37.5 ft. (from Well Installation Diagram)

9. Well diameter: 2 in.

10. Screen length: 20 ft.

11. Minimum quantity of water to be removed: ________ gal.

12. Depth to top of sediment: Before development ________ ft.; After development ________ ft.

13. Physical character of water (before/after development): ________

14. Type and size of well development equipment: 2" GRUNDFOS & surge block

15. Description of surge technique: Alternating cycles of surge and pump.

16. Height of well casing above ground surface: ≈ 3.0 ft. (from Well Installation Diagram).

17. Quantity of water removed: ________ gal. Time for removal: ________ hr./min.

WELDON SPRING SITE REMEDIAL ACTION PROJECT

MONITORING WELL DEVELOPMENT FORM

PROJECT NAME GWOU Pilot Pump Test WORK PACKAGE NO. 510 T-1

DEVELOPED BY GEOTECH. CHECKED BY P. Patikin SHEET 2 OF 2

1. Well No.: 4029 Well Locations: S. OF PIT 4

Date/ Time	Hrs. Dev./ Cum. Hrs. Dev.	Gals. Purged/ Cum. Gals. Purged	pH	Temp.	Cond.	Remarks
6-10-98 0734	/	5 / 5	6.86	65.5	10.34	TURBID -
	/	5 / 10	6.65	63.4	10.97	A.A.
	/	5 / 15	6.58	63.0	11.37	A.A. - clearing slightly
		5 / 20	6.58	61.6	12.30	A.A.
		5 / 25	6.52	61.4	12.96	cloudy
		5 / 30	6.50	61.2	13.30	"
		5 / 35	6.44	60.7	13.48	"
		5 / 40	6.45	60.7	13.82	"
		5 / 45	6.42	60.3	14.05	"
		5 / 50	6.41	60.4	14.29	"
		5 / 60	6.43	60.2	14.83	"
		5 / 65	6.41	60.6	14.98	clearing to cloudy
		5 / 70	6.39	60.8	15.06	A.A.
		5 / 75	6.38	60.5	15.14	A.A.
		5 / 80	6.39	60.6	15.20	A.A
0755		5 / 85	6.38	60.4	15.25	A.A to clear

APPENDIX B
Packer Testing Calculations

MW-3028a (34.3' - 43.0')

Given:

$L := (43.0 - 34.3) \cdot ft$ $L = 8.7 \cdot ft$ ...test interval length

$psi \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$v := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 40.5 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 10 \\ 15 \\ 20 \\ 10 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 5.01 \\ 5.77 \\ 6.80 \\ 5.49 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $V1 := \frac{Q}{A1}$ ... velocity $R1 := \frac{DP1 \cdot V1}{v}$ if R1 > 2000, flow is turbulent $R1 = \begin{bmatrix} 16965 \\ 19539 \\ 23027 \\ 18591 \end{bmatrix}$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1,DP1) := Find(ff1)$ $i := 1..rows(Q)$

$ff1_i := FRICFRAC(R1_i, DP1)$ $ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{(V1_i)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $V2 := \frac{Q}{A2}$ ... velocity $R2 := \frac{DP2\cdot V2}{\nu}$ if R2 > 2000, flow is turbulent

$$R2 = \begin{bmatrix} 22475 \\ 25884 \\ 30505 \\ 24628 \end{bmatrix}$$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot10^{-3}$ ... relative roughness $ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2,DP2) := Find(ff2)$ $i := 1..rows(Q)$ $ff2_i := FRICFRACP(R2_i, DP2)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{(V2_i)^2}{2\cdot g}$ ... Darcy Weisbach

3) Calculate Total Head, H_T:

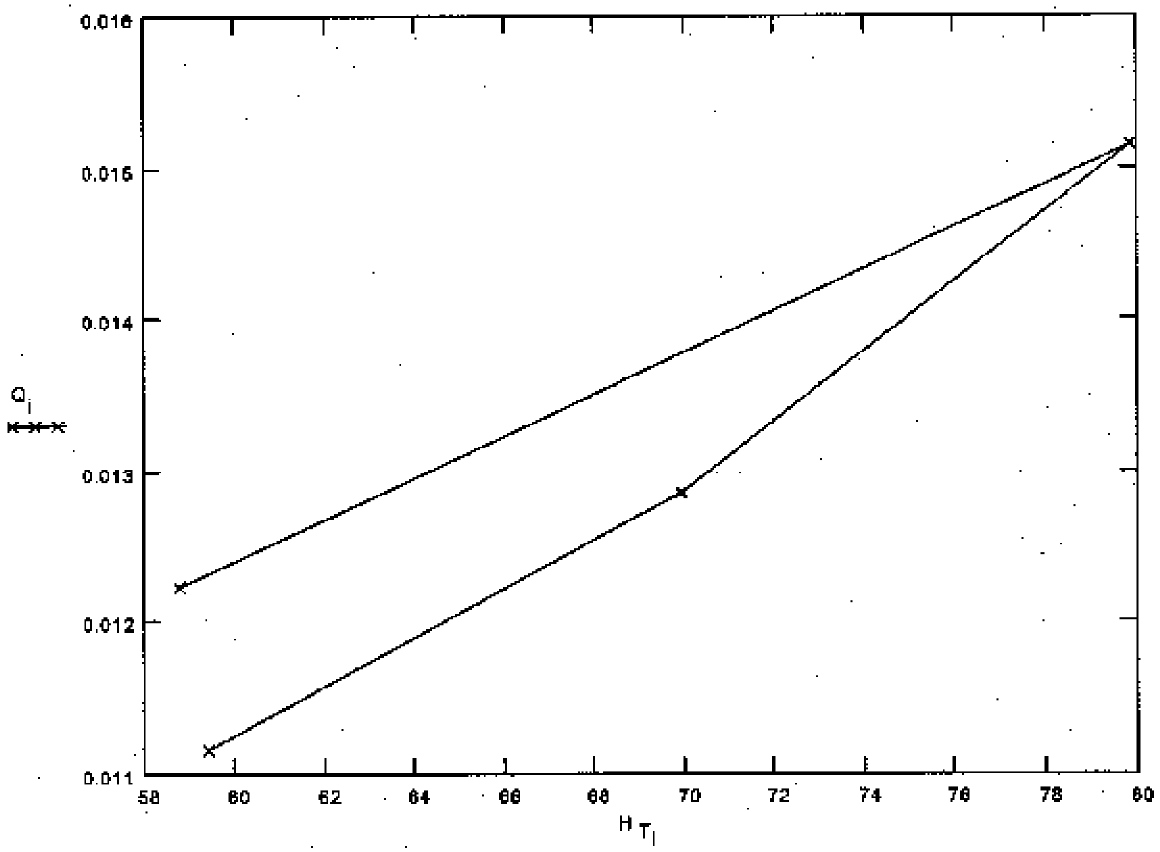
$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

$$H_T = \begin{bmatrix} 59.42 \\ 69.92 \\ 79.86 \\ 58.78 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 23.07 \\ 34.6 \\ 46.13 \\ 23.07 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 2.55 \\ 3.31 \\ 4.48 \\ 3.02 \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 0.9 \\ 1.17 \\ 1.59 \\ 1.06 \end{bmatrix}\cdot ft$$

APPENDIX C
Aquifer Testing Graphs and Calculations

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2\cdot\pi\cdot L\cdot H_{T_i}}} \qquad K = \begin{bmatrix} 4.45\cdot10^{-4} \\ 4.36\cdot10^{-4} \\ 4.50\cdot10^{-4} \\ 4.93\cdot10^{-4} \end{bmatrix}\cdot\frac{cm}{sec} \qquad \text{mean}(K) = 4.56\cdot10^{-4}\cdot\frac{cm}{sec}$$



...plot of discharge (ft³/sec) versus total head (ft)

$$.01\cdot\frac{ft^3}{sec} = 4.49\cdot\frac{gal}{min}$$

MW-3028b (39.3' - 48.0')

Given:

$L := (48.0 - 39.3) \cdot ft$ $L = 8.7 \cdot ft$ ...test interval length

$psi \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$\nu := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 41.0 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 10 \\ 15 \\ 20 \\ 10 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 10.06 \\ 10.87 \\ 12.96 \\ 11.14 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $V1 := \frac{Q}{A1}$ ... velocity $R1 := \frac{DP1 \cdot V1}{\nu}$ if R1 > 2000, flow is turbulent $R1 = \begin{bmatrix} 34066 \\ 36809 \\ 43886 \\ 37723 \end{bmatrix}$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1, DP1) := Find(ff1)$ $\quad i := 1 .. rows(Q)$

$ff1_i := FRICFRAC\left(R1_i, DP1\right)$ $\quad ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{\left(V1_i\right)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $\quad V2 := \frac{Q}{A2}$ ... velocity $\quad R2 := \frac{DP2\cdot V2}{\nu}$ $\quad$ if R2 > 2000, flow is turbulent

$$R2 = \begin{bmatrix} 45129 \\ 48763 \\ 58138 \\ 49974 \end{bmatrix}$$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot 10^{-3}$ ... relative roughness $\quad ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2, DP2) := Find(ff2)$ $\quad i := 1 .. rows(Q)$ $\quad ff2_i := FRICFRACP\left(R2_i, DP2\right)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $\quad H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{\left(V2_i\right)^2}{2\cdot g}$ ... Darcy Weisbach

3) Calculate Total Head, H_T:

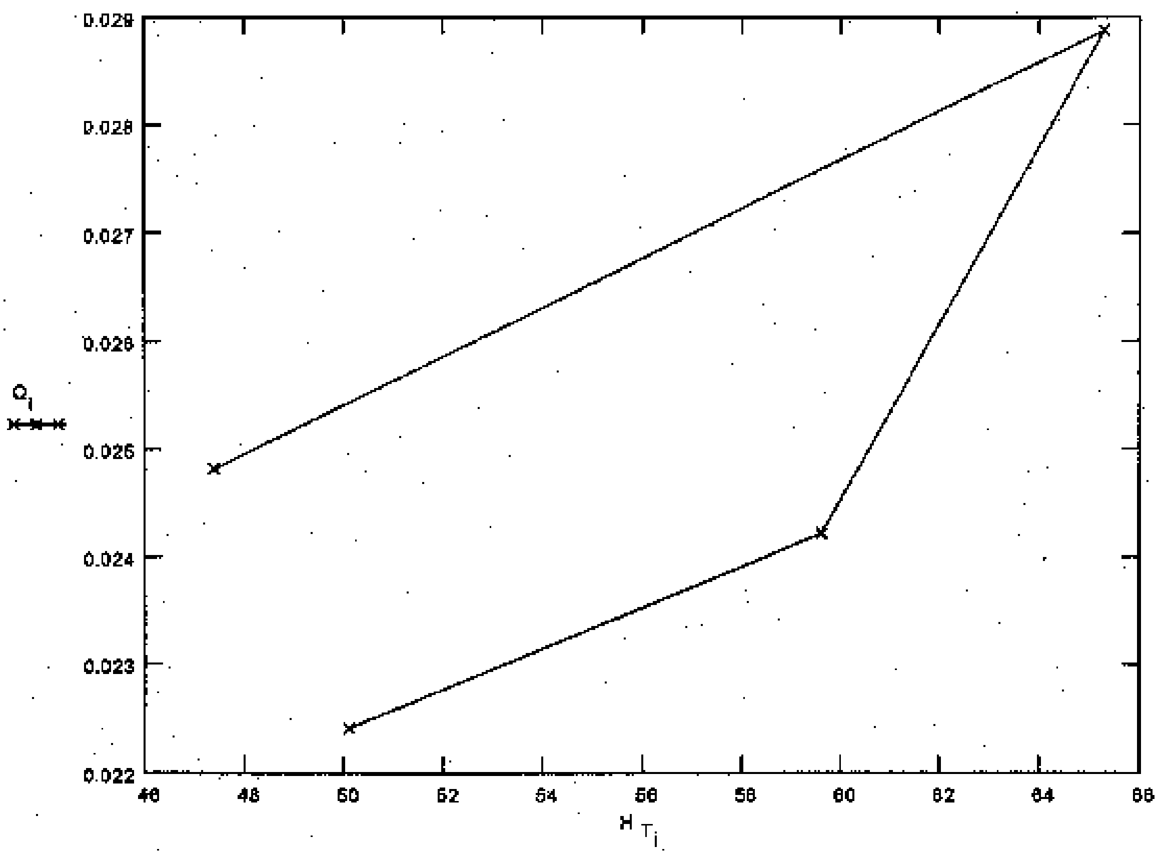
$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

$$H_T = \begin{bmatrix} 50.1 \\ 59.62 \\ 65.29 \\ 47.38 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 23.07 \\ 34.6 \\ 46.13 \\ 23.07 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 9.42 \\ 10.9 \\ 15.2 \\ 11.42 \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 3.35 \\ 3.88 \\ 5.44 \\ 4.07 \end{bmatrix}\cdot ft$$

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}}$$

$$K = \begin{bmatrix} 1.06 \cdot 10^{-3} \\ 9.83 \cdot 10^{-4} \\ 1.05 \cdot 10^{-3} \\ 1.24 \cdot 10^{-3} \end{bmatrix} \cdot \frac{cm}{sec} \qquad \text{mean}(K) = 1.08 \cdot 10^{-3} \cdot \frac{cm}{sec}$$



...plot of discharge (ft³/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

MW-3028c (47.5' - 58.0')

Given:

$L := (58.0 - 47.5)\cdot ft$ $\quad L = 10.5\cdot ft$ $\quad$ ...test interval length

$psi \equiv 2.3067\cdot ft$

$r := \frac{2.98}{2}\cdot in$ $\quad$ ...radius of NQ borehole

$\nu := 1.22\cdot 10^{-5}\cdot\frac{ft^2}{sec}$ $\quad$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824\cdot in$ $\quad$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622\cdot in$ $\quad$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 51.0\cdot ft$ $\quad$ ...3/4" pipe length

$LP2 := 3.5\cdot ft$ $\quad$ ...1/2" pipe length

$\varepsilon := 0.00014\cdot ft$ $\quad$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix}\cdot ft \qquad H_P := \begin{bmatrix} 15 \\ 25 \\ 35 \\ 25 \\ 15 \end{bmatrix}\cdot psi \qquad Q := \begin{bmatrix} 9.49 \\ 10.46 \\ 8.80 \\ 7.78 \\ 6.42 \end{bmatrix}\cdot\frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi\cdot\frac{DP1^2}{4}$ ... area $\qquad V1 := \frac{Q}{A1}$ ... velocity $\qquad R1 := \frac{DP1\cdot V1}{\nu}$ $\quad$ if R1 > 2000, flow is turbulent

$$R1 = \begin{bmatrix} 32136 \\ 35420 \\ 29799 \\ 26345 \\ 21740 \end{bmatrix}$$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388\cdot 10^{-3}$ $\quad$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1, DP1) := Find(ff1)$ $\quad i := 1 .. rows(Q)$

$ff1_i := FRICFRAC(R1_i, DP1)$ $\quad ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{(V1_i)^2}{2\cdot g}$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $\quad V2 := \frac{Q}{A2}$ ... velocity $\quad R2 := \frac{DP2\cdot V2}{\nu}$ if R2 > 2000, flow is turbulent

$$R2 = \begin{bmatrix} 42572 \\ 46923 \\ 39477 \\ 34901 \\ 28800 \end{bmatrix}$$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot 10^{-3}$ ... relative roughness $\quad ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2, DP2) := Find(ff2)$ $\quad i := 1 .. rows(Q)$ $\quad ff2_i := FRICFRACP(R2_i, DP2)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $\quad H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{(V2_i)^2}{2\cdot g}$ ... Darcy Weisbach

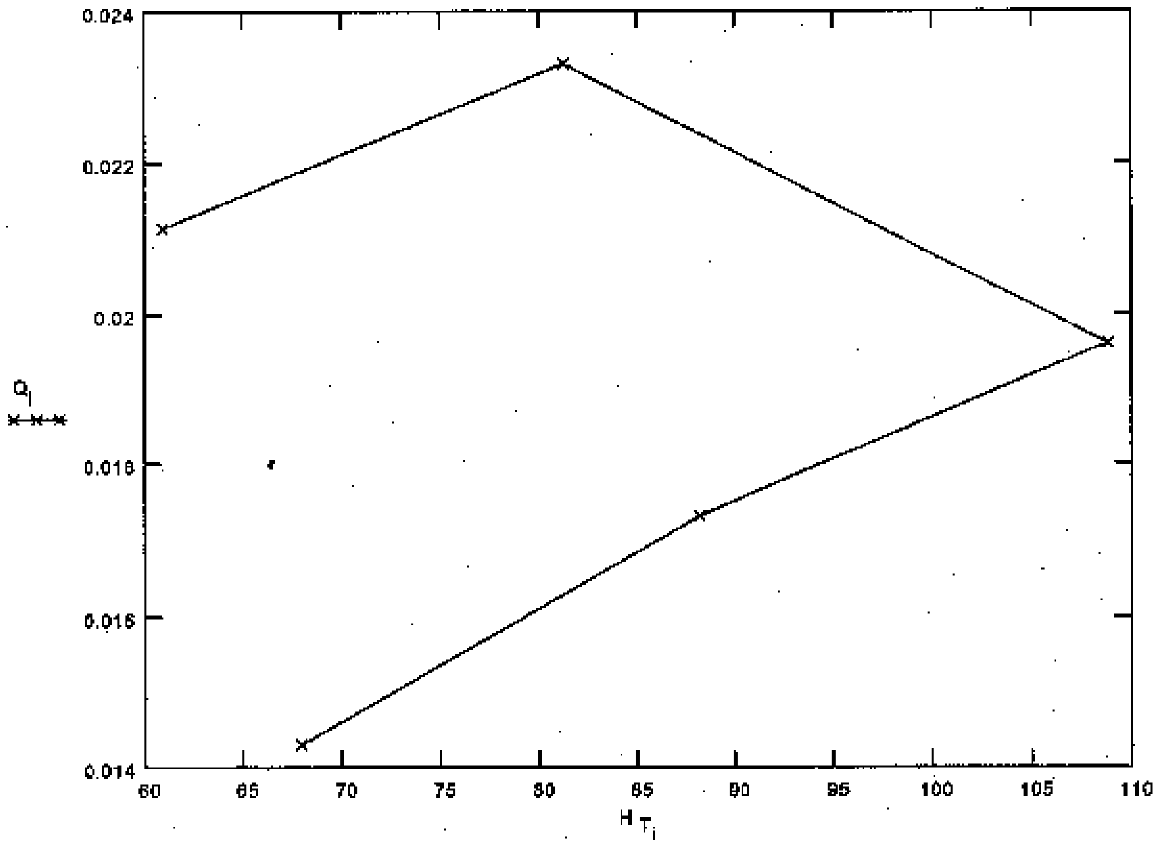
3) Calculate Total Head, H_T:

$H_T := H_G + H_P - H_{LP1} - H_{LP2}$

$$H_T = \begin{bmatrix} 60.9 \\ 81.25 \\ 108.82 \\ 88.17 \\ 67.9 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \\ 39.8 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 34.6 \\ 57.67 \\ 80.73 \\ 57.67 \\ 34.6 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 10.51 \\ 12.61 \\ 9.12 \\ 7.25 \\ 5.08 \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 2.99 \\ 3.61 \\ 2.59 \\ 2.05 \\ 1.43 \end{bmatrix}\cdot ft$$

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}} \qquad K = \begin{bmatrix} 7.12 \cdot 10^{-4} \\ 5.88 \cdot 10^{-4} \\ 3.69 \cdot 10^{-4} \\ 4.03 \cdot 10^{-4} \\ 4.32 \cdot 10^{-4} \end{bmatrix} \cdot \frac{cm}{sec} \qquad \text{mean}(K) = 5.01 \cdot 10^{-4} \cdot \frac{cm}{sec}$$



...plot of discharge (ft³/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

MW-3028d (57.5' - 69.0')

Given:

$L := (69.0 - 57.5) \cdot ft$ $L = 11.5 \cdot ft$ ...test interval length

$psi \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$\nu := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 61.0 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 38.7 \\ 38.7 \\ 38.7 \\ 38.7 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 15 \\ 25 \\ 35 \\ 20 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 0.13 \\ 0.24 \\ 0.36 \\ 0.17 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $\qquad V1 := \frac{Q}{A1}$ ... velocity $\qquad R1 := \frac{DP1 \cdot V1}{\nu}$ If R1 > 2000, flow is turbulent $\qquad R1 = \begin{bmatrix} 440 \\ 813 \\ 1219 \\ 576 \end{bmatrix}$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1,DP1) := Find(ff1)$ $i := 1 .. rows(Q)$

$ff1_i := FRICFRAC(R1_i, DP1)$ $ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{(V1_i)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $V2 := \frac{Q}{A2}$ ... velocity $R2 := \frac{DP2\cdot V2}{\nu}$ if R2 > 2000, flow is turbulent $R2 = \begin{bmatrix} 583 \\ 1077 \\ 1615 \\ 763 \end{bmatrix}$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot10^{-3}$ ... relative roughness $ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2,DP2) := Find(ff2)$ $i := 1 .. rows(Q)$ $ff2_i := FRICFRACP(R2_i, DP2)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{(V2_i)^2}{2\cdot g}$ ... Darcy Weisbach.

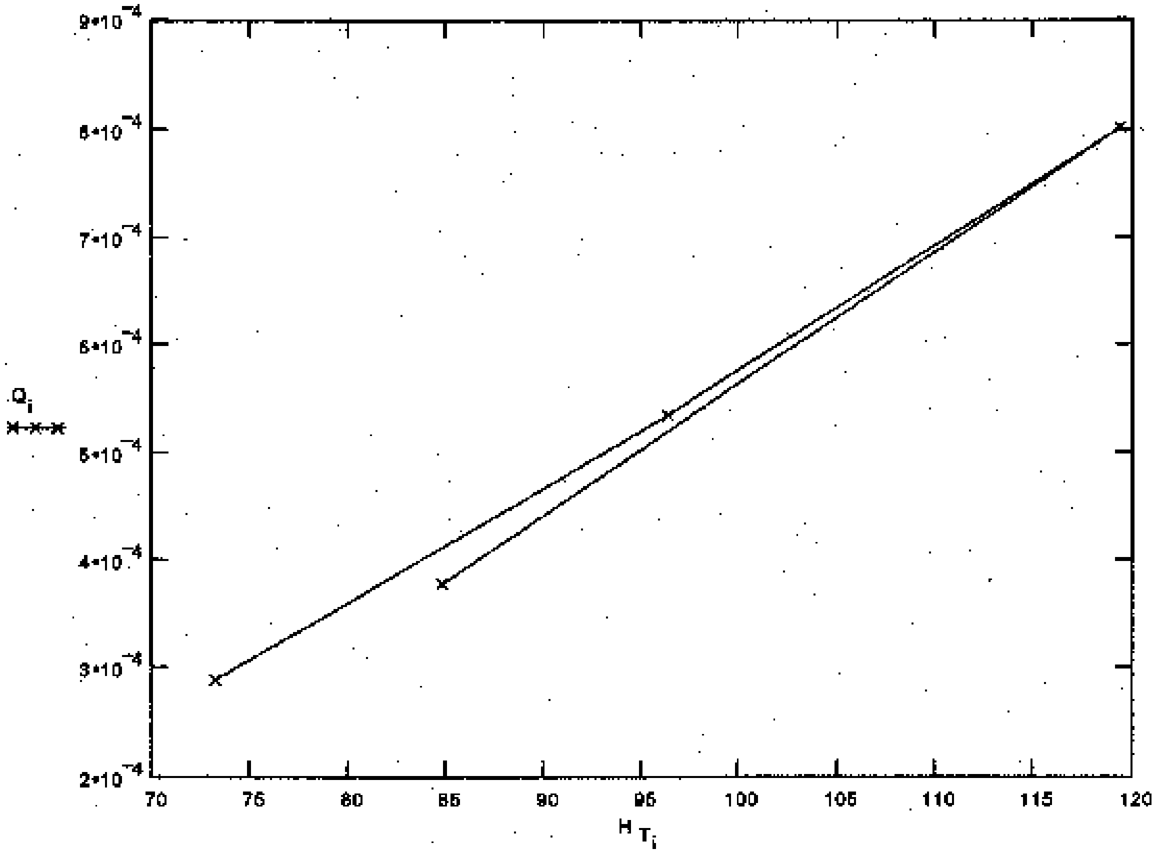
3) Calculate Total Head, H_T:

$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

$H_T = \begin{bmatrix} 73.29 \\ 96.34 \\ 119.39 \\ 84.82 \end{bmatrix}\cdot ft$ $H_G = \begin{bmatrix} 38.7 \\ 38.7 \\ 38.7 \\ 38.7 \end{bmatrix}\cdot ft$ $H_P = \begin{bmatrix} 34.6 \\ 57.67 \\ 80.73 \\ 46.13 \end{bmatrix}\cdot ft$ $H_{LP1} = \begin{bmatrix} 0.01 \\ 0.02 \\ 0.03 \\ 0.02 \end{bmatrix}\cdot ft$ $H_{LP2} = \begin{bmatrix} 2.17\cdot10^{-3} \\ 4.01\cdot10^{-3} \\ 6.01\cdot10^{-3} \\ 2.84\cdot10^{-3} \end{bmatrix}\cdot ft$

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}} \qquad K = \begin{bmatrix} 7.55 \cdot 10^{-6} \\ 1.06 \cdot 10^{-5} \\ 1.28 \cdot 10^{-5} \\ 8.53 \cdot 10^{-6} \end{bmatrix} \cdot \frac{cm}{sec} \qquad \text{mean}(K) = 9.88 \cdot 10^{-6} \cdot \frac{cm}{sec}$$



...plot of discharge (ft^3/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

MW-4027a (29.0' - 39.5')

Given:

$L := (39.5 - 29.0) \cdot ft$ $\quad L = 10.5 \cdot ft$ ...test interval length

$psl \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$v := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 30.5 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 10 \\ 15 \\ 20 \\ 10 \\ 15 \\ 20 \\ 10 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 0.92 \\ 1.49 \\ 3.28 \\ 2.76 \\ 3.22 \\ 3.60 \\ 2.81 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $\qquad V1 := \frac{Q}{A1}$ ... velocity $\qquad R1 := \frac{DP1 \cdot V1}{v}$ $\quad$ if R1 > 2000, flow is turbulent

$$R1 = \begin{bmatrix} 3115 \\ 5046 \\ 11107 \\ 9346 \\ 10904 \\ 12191 \\ 9515 \end{bmatrix}$$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... Initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1, DP1) := Find(ff1)$ $\quad i := 1 .. rows(Q)$

$ff1_i := FRICFRAC(R1_i, DP1)$ $\quad ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{(V1_i)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $\quad V2 := \frac{Q}{A2}$ ... velocity $\quad R2 := \frac{DP2\cdot V2}{\nu}$ $\quad$ if R2 > 2000, flow is turbulent

$$R2 = \begin{bmatrix} 4127 \\ 6684 \\ 14714 \\ 12381 \\ 14445 \\ 16150 \\ 12606 \end{bmatrix}$$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot 10^{-3}$ ... relative roughness $\quad ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2, DP2) := Find(ff2)$ $\quad i := 1 .. rows(Q)$ $\quad ff2_i := FRICFRACP(R2_i, DP2)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $\quad H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{(V2_i)^2}{2\cdot g}$ ... Darcy Weisbach

3) Calculate Total Head, H_T:

$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

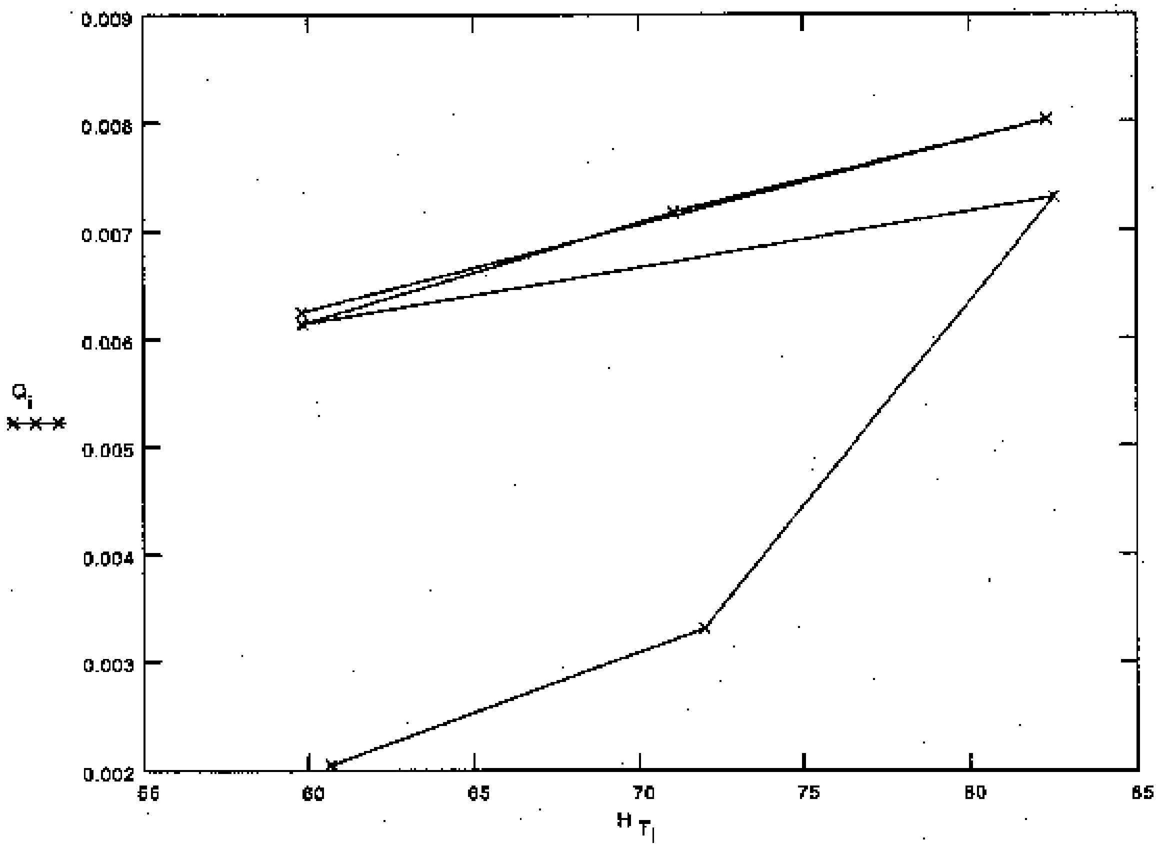
$$H_T = \begin{bmatrix} 60.63 \\ 71.98 \\ 82.53 \\ 59.82 \\ 71.04 \\ 82.3 \\ 59.78 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \\ 37.7 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 23.07 \\ 34.6 \\ 46.13 \\ 23.07 \\ 34.6 \\ 46.13 \\ 23.07 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 0.09 \\ 0.22 \\ 0.89 \\ 0.65 \\ 0.86 \\ 1.05 \\ 0.67 \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 0.04 \\ 0.1 \\ 0.41 \\ 0.3 \\ 0.39 \\ 0.48 \\ 0.31 \end{bmatrix}\cdot ft$$

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}}$$

$$K = \begin{bmatrix} 6.93 \cdot 10^{-5} \\ 9.45 \cdot 10^{-5} \\ 1.62 \cdot 10^{-4} \\ 2.11 \cdot 10^{-4} \\ 2.07 \cdot 10^{-4} \\ 2.00 \cdot 10^{-4} \\ 2.15 \cdot 10^{-4} \end{bmatrix} \cdot \frac{cm}{sec}$$

$$\text{mean}(K) = 1.68 \cdot 10^{-4} \cdot \frac{cm}{sec}$$



...plot of discharge (ft³/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

MW-4027b (39.0' - 49.5')

Given:

$L := (49.5 - 39.0) \cdot ft$ $\quad L = 10.5 \cdot ft$ ...test interval length

$psi \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$\nu := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 40.5 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 37.8 \\ 37.8 \\ 37.8 \\ 37.8 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 10 \\ 20 \\ 30 \\ 10 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 0.70 \\ 1.42 \\ 4.24 \\ 2.75 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $\qquad V1 := \frac{Q}{A1}$ ... velocity $\qquad R1 := \frac{DP1 \cdot V1}{\nu}$ $\quad$ if R1 > 2000, flow is turbulent $\qquad R1 = \begin{bmatrix} 2370 \\ 4809 \\ 14358 \\ 9312 \end{bmatrix}$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1, DP1) := Find(ff1)$ $i := 1 .. rows(Q)$

$ff1_i := FRICFRAC(R1_i, DP1)$ $ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{(V1_i)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $V2 := \frac{Q}{A2}$ ... velocity $R2 := \frac{DP2\cdot V2}{\nu}$ if R2 > 2000, flow is turbulent

$$R2 = \begin{bmatrix} 3140 \\ 6370 \\ 19021 \\ 12336 \end{bmatrix}$$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot10^{-3}$ ... relative roughness $ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2, DP2) := Find(ff2)$ $i := 1 .. rows(Q)$ $ff2_i := FRICFRACP(R2_i, DP2)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{(V2_i)^2}{2\cdot g}$ ... Darcy Weisbach

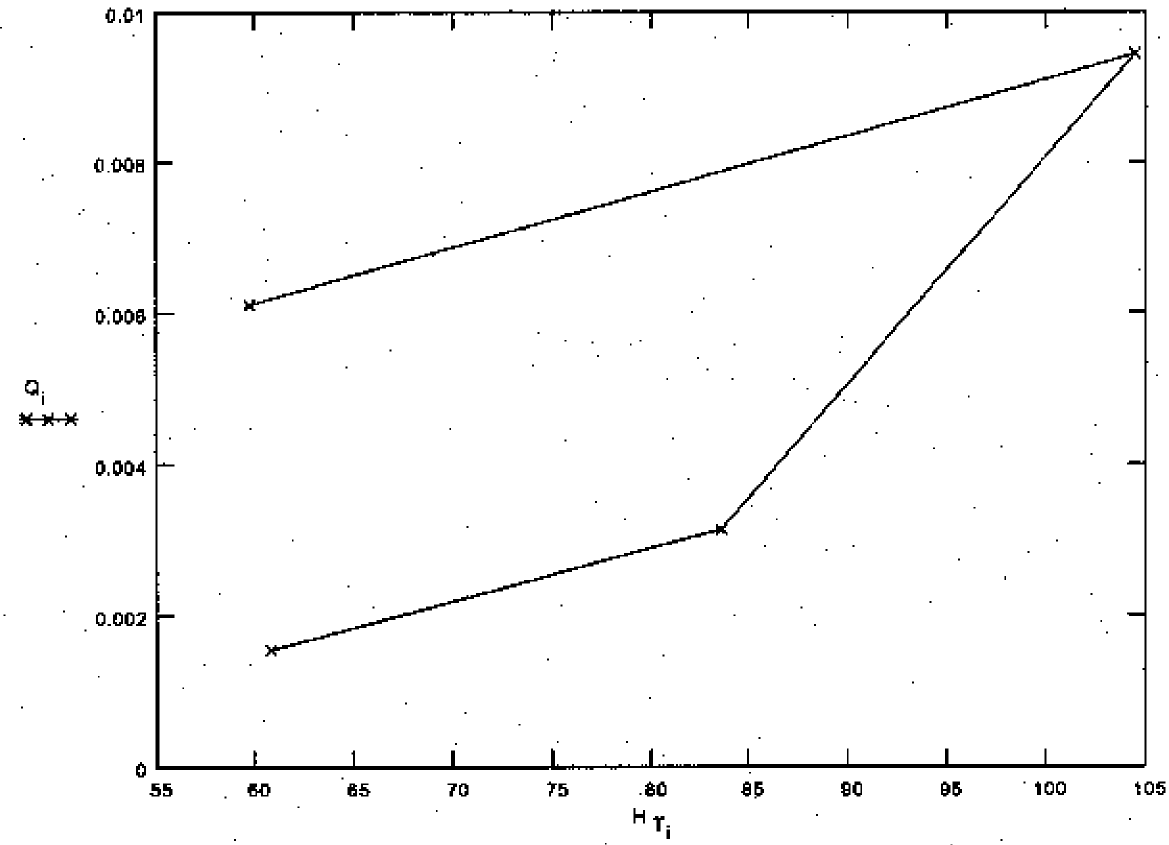
3) Calculate Total Head, H_T:

$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

$$H_T = \begin{bmatrix} 60.76 \\ 83.58 \\ 104.46 \\ 59.71 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 37.8 \\ 37.8 \\ 37.8 \\ 37.8 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 23.07 \\ 46.13 \\ 69.2 \\ 23.07 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 0.08 \\ 0.27 \\ 1.88 \\ 0.86 \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 0.03 \\ 0.09 \\ 0.66 \\ 0.3 \end{bmatrix}\cdot ft$$

4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}} \qquad K = \begin{bmatrix} 5.26 \cdot 10^{-5} \\ 7.76 \cdot 10^{-5} \\ 1.85 \cdot 10^{-4} \\ 2.10 \cdot 10^{-4} \end{bmatrix} \cdot \frac{cm}{sec} \qquad mean(K) = 1.32 \cdot 10^{-4} \cdot \frac{cm}{sec}$$



...plot of discharge (ft³/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

MW-4027c (49.0' - 59.5')

Given:

$L := (59.5 - 49.0) \cdot ft$ $L = 10.5 \cdot ft$ ...test interval length

$psi \equiv 2.3067 \cdot ft$

$r := \frac{2.98}{2} \cdot in$ ...radius of NQ borehole

$\nu := 1.22 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ ... kinematic viscosity of water @ 60 °F

$DP1 := 0.824 \cdot in$ ...id for 3/4" schedule 40 SS pipe (Driscoll, p. 976)

$DP2 := 0.622 \cdot in$ ...id for 1/2" packer pipe (assume schedule 40)

$LP1 := 50.5 \cdot ft$ ...3/4" pipe length

$LP2 := 3.5 \cdot ft$ ...1/2" pipe length

$\varepsilon := 0.00014 \cdot ft$ ... roughness factor for new iron pipe (Brater & King, p. 6-13)

gravity head H_G, pressure head H_P, and pumping rates Q:

$$H_G := \begin{bmatrix} 37.8 \\ 37.8 \\ 37.8 \\ 37.8 \end{bmatrix} \cdot ft \qquad H_P := \begin{bmatrix} 15 \\ 25 \\ 35 \\ 10 \end{bmatrix} \cdot psi \qquad Q := \begin{bmatrix} 0.048 \\ 0.095 \\ 0.155 \\ 0.0013 \end{bmatrix} \cdot \frac{gal}{min}$$

1) Calculate head loss through pipe (H_{LP1}) using Darcy-Weisbach equation:

Calculate velocity through packer, V1, and Reynolds Number, R1:

$A1 := \pi \cdot \frac{DP1^2}{4}$ ... area $V1 := \frac{Q}{A1}$ ... velocity $R1 := \frac{DP1 \cdot V1}{\nu}$ if R1 > 2000, flow is turbulent $R1 = \begin{bmatrix} 163 \\ 322 \\ 525 \\ 4 \end{bmatrix}$

Use Colebrook's equation to determine friction factor (Brater & King, p. 6-11):

$\frac{\varepsilon}{DP1} = 2.0388 \cdot 10^{-3}$ ...relative roughness

$ff1 := 0.02$ ... initial guess at friction factor

Given

$$ff1 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP1}\cdot\frac{1}{3.7}+\frac{2.51}{R1\cdot\sqrt{ff1}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRAC(R1,DP1) := Find(ff1)$ $\quad i := 1 .. rows(Q)$

$ff1_i := FRICFRAC\left(R1_i, DP1\right)$ $\quad ff1_i := if\left(R1_i < 2000, \frac{64}{R1_i}, ff1_i\right)$ ...ff for laminar flow = 64/R

$$H_{LP1_i} := ff1_i\cdot\frac{LP1}{DP1}\cdot\frac{\left(V1_i\right)^2}{2\cdot g}$$ ... Darcy Weisbach equation

2) Calculate head loss through packer, H_{LP2}:

Calculate velocity through packer, V2, and Reynolds Number, R2:

$A2 := \pi\cdot\frac{DP2^2}{4}$ ... area $\quad V2 := \frac{Q}{A2}$ ... velocity $\quad R2 := \frac{DP2\cdot V2}{\nu}$ if R2 > 2000, flow is turbulent $\quad R2 = \begin{bmatrix} 215 \\ 426 \\ 695 \\ 6 \end{bmatrix}$

Calculate friction factor, ff2:

$\frac{\varepsilon}{DP2} = 2.701\cdot10^{-3}$ ... relative roughness $\quad ff2 := 0.02$ ... initial guess at friction factor

Given

$$ff2 = \left(-2\cdot\log\left(\frac{\varepsilon}{DP2}\cdot\frac{1}{3.7}+\frac{2.51}{R2\cdot\sqrt{ff2}}\right)\right)^{-2}$$ ...ff for turbulent flow

$FRICFRACP(R2,DP2) := Find(ff2)$ $\quad i := 1 .. rows(Q)$ $\quad ff2_i := FRICFRACP\left(R2_i, DP2\right)$

$ff2_i := if\left(R2_i < 2000, \frac{64}{R2_i}, ff2_i\right)$ ...ff for laminar flow = 64/R $\quad H_{LP2_i} := ff2_i\cdot\frac{LP2}{DP2}\cdot\frac{\left(V2_i\right)^2}{2\cdot g}$ ... Darcy Weisbach

3) Calculate Total Head, H_T:

$$H_T := H_G + H_P - H_{LP1} - H_{LP2}$$

$$H_T = \begin{bmatrix} 72.4 \\ 95.46 \\ 118.52 \\ 60.87 \end{bmatrix}\cdot ft \quad H_G = \begin{bmatrix} 37.8 \\ 37.8 \\ 37.8 \\ 37.8 \end{bmatrix}\cdot ft \quad H_P = \begin{bmatrix} 34.6 \\ 57.67 \\ 80.73 \\ 23.07 \end{bmatrix}\cdot ft \quad H_{LP1} = \begin{bmatrix} 3.75\cdot10^{-3} \\ 7.43\cdot10^{-3} \\ 0.01 \\ 1.02\cdot10^{-4} \end{bmatrix}\cdot ft \quad H_{LP2} = \begin{bmatrix} 8.01\cdot10^{-4} \\ 1.59\cdot10^{-3} \\ 2.59\cdot10^{-3} \\ 2.17\cdot10^{-5} \end{bmatrix}\cdot ft$$

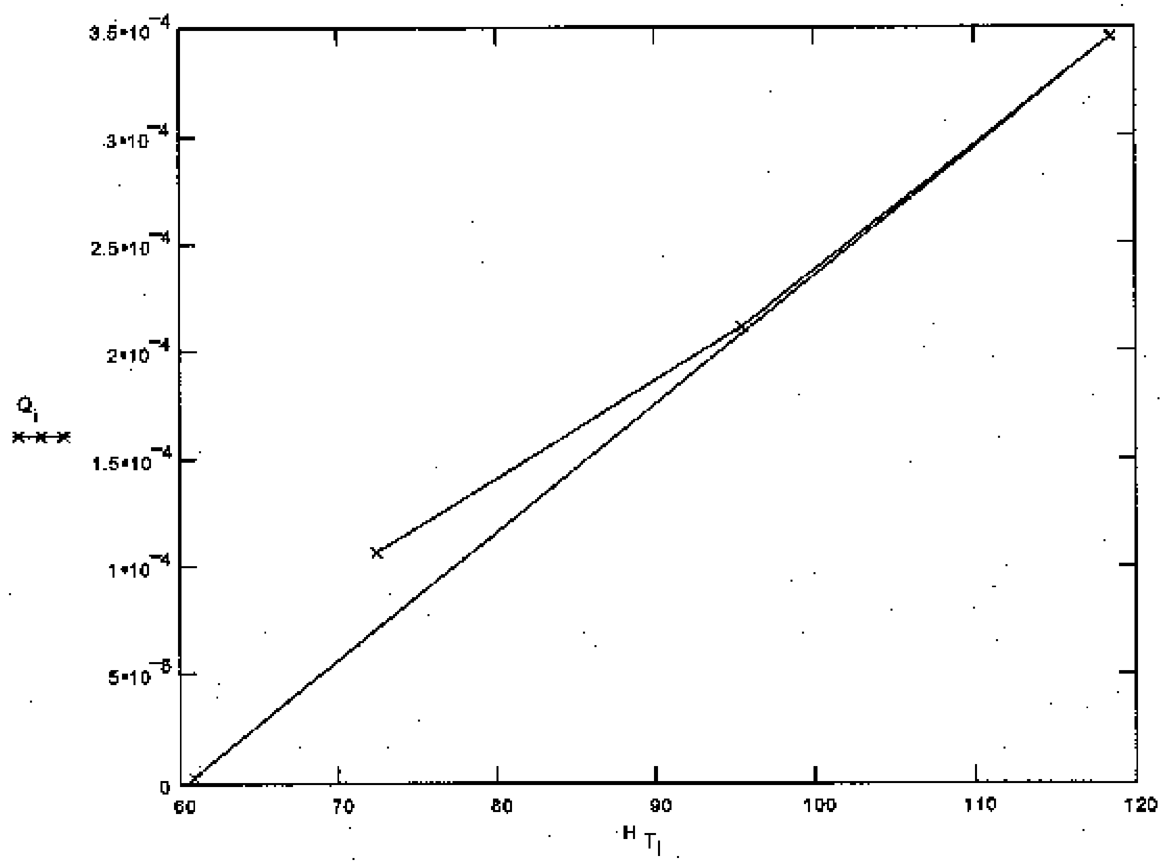
4) Calculate Hydraulic Conductivity, K (USBR 7310-89, p. 1255):

$$K_i := \overrightarrow{\frac{Q_i \cdot \ln\left(\frac{L}{r}\right)}{2 \cdot \pi \cdot L \cdot H_{T_i}}}$$

$$K = \begin{bmatrix} 3.03 \cdot 10^{-6} \\ 4.55 \cdot 10^{-6} \\ 5.97 \cdot 10^{-6} \\ 9.76 \cdot 10^{-6} \end{bmatrix} \cdot \frac{cm}{sec}$$

$$mean(K) = 3.41 \cdot 10^{-6} \cdot \frac{cm}{sec}$$

<—last K value is below quantification limit

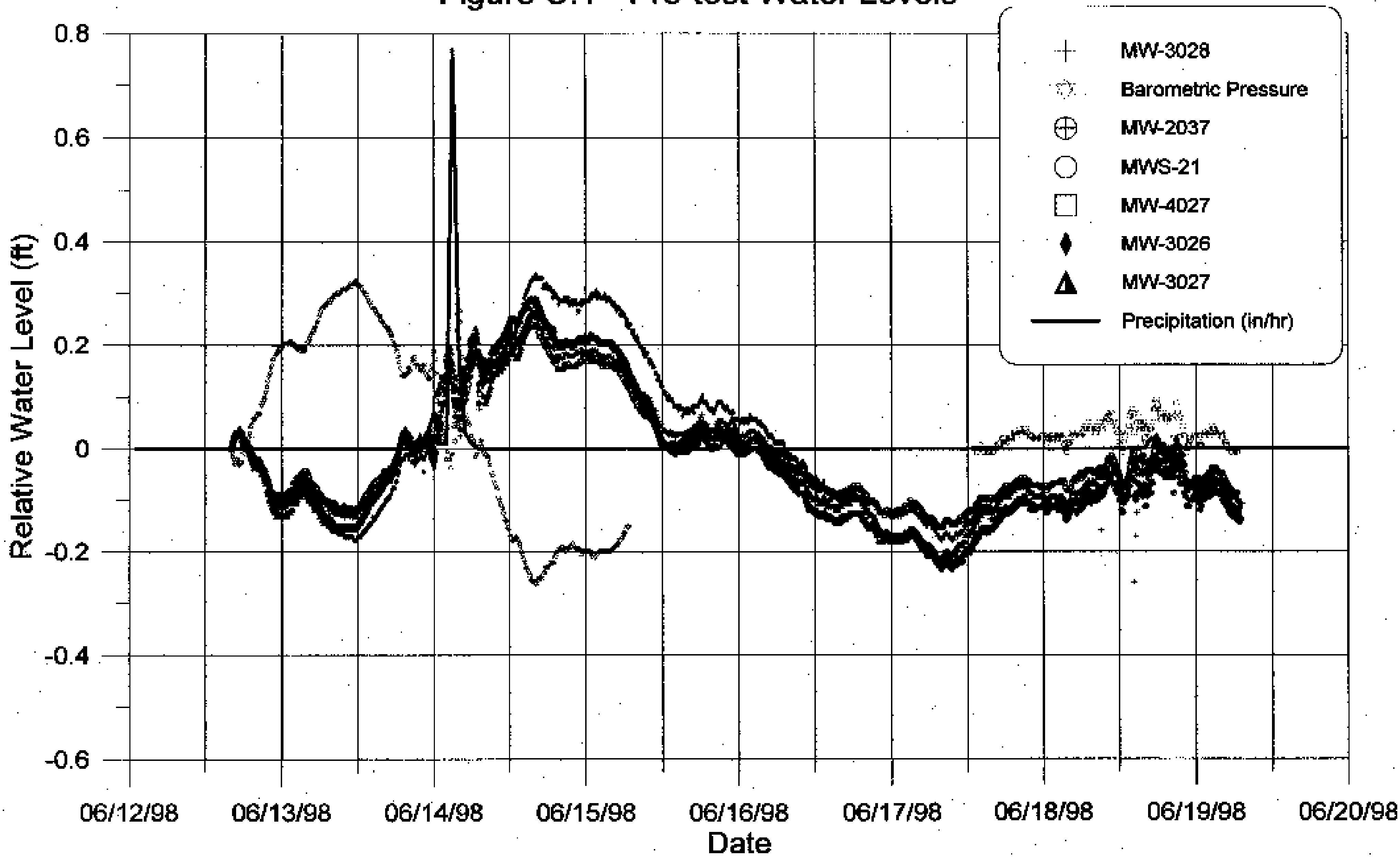


...plot of discharge (ft³/sec) versus total head (ft)

$$.01 \cdot \frac{ft^3}{sec} = 4.49 \cdot \frac{gal}{min}$$

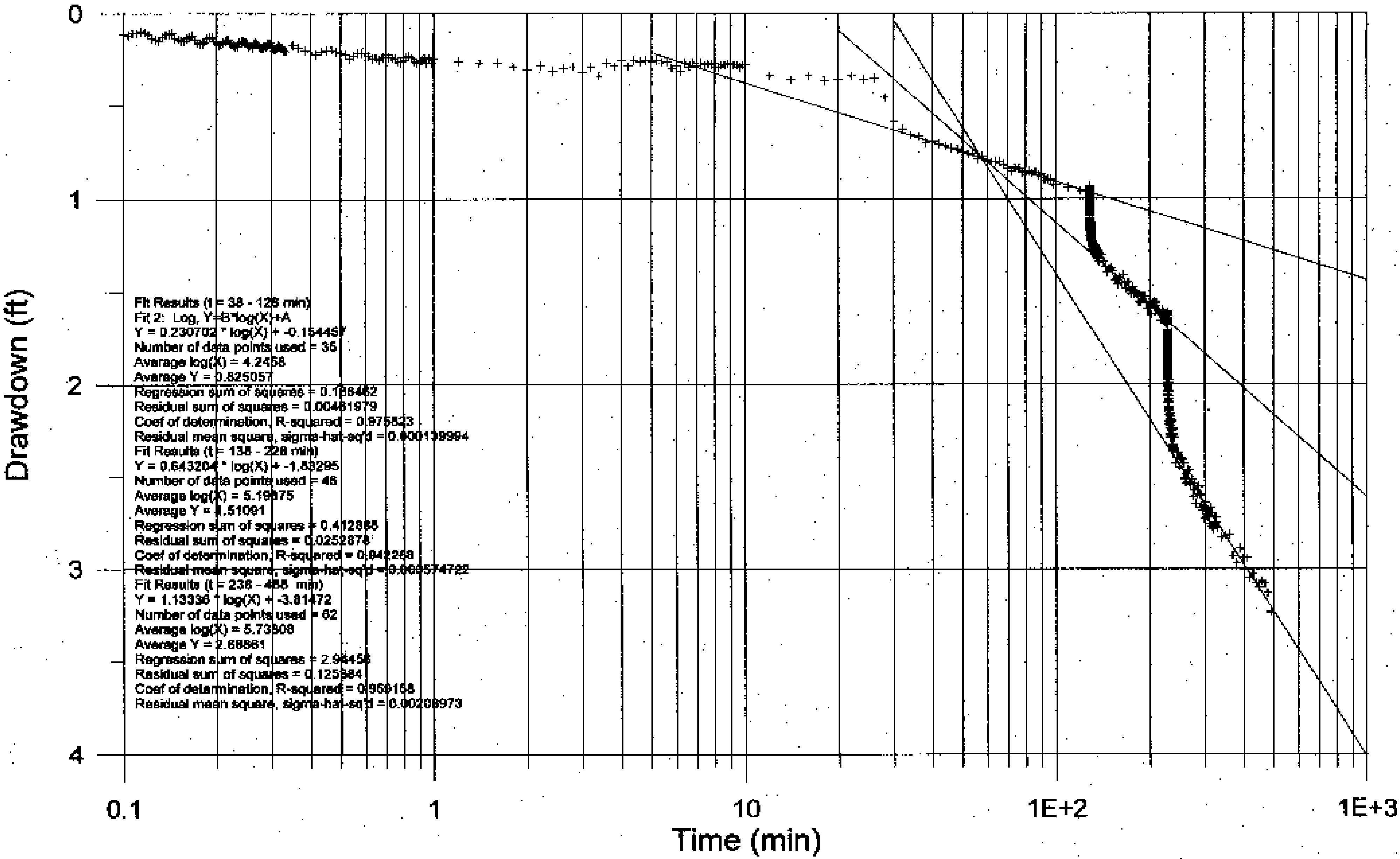
APPENDIX C
Aquifer Testing Graphs and Calculations

Figure C.1 - Pre-test Water Levels



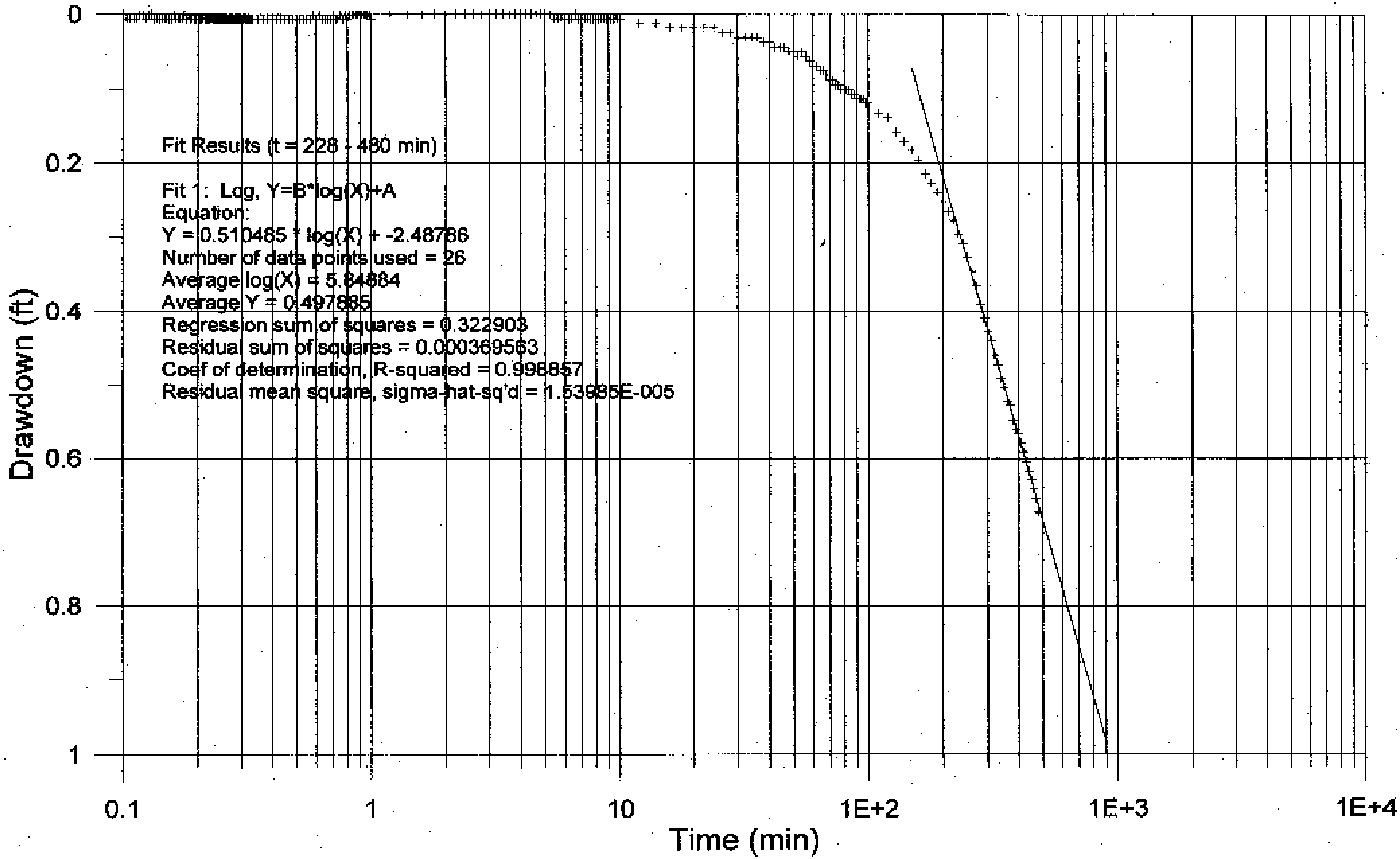
u:\chempump\chemstep\swl\swl.grf

Figure C.2 - MW-3028 Step Pumping (Q = 6.3/10.6/15.5/23.0 gpm, r = 0 ft)



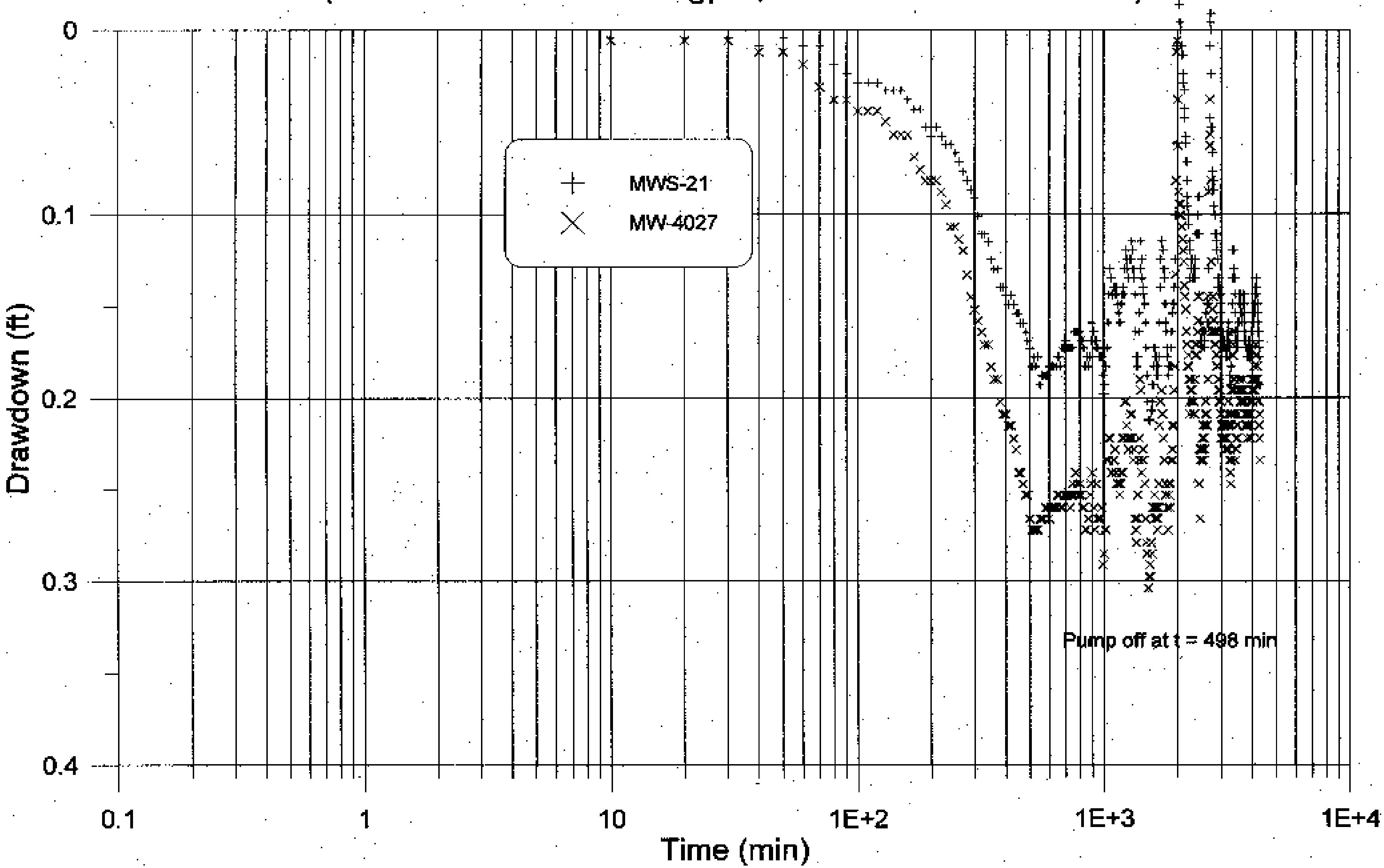
u:\chempump\chemstep\step3028\3028stp.grf

Figure C.3 - MW-2037 Step Pumping (Q = 6.3/10.6/15.5/23.0 gpm, r = 159.5 ft)



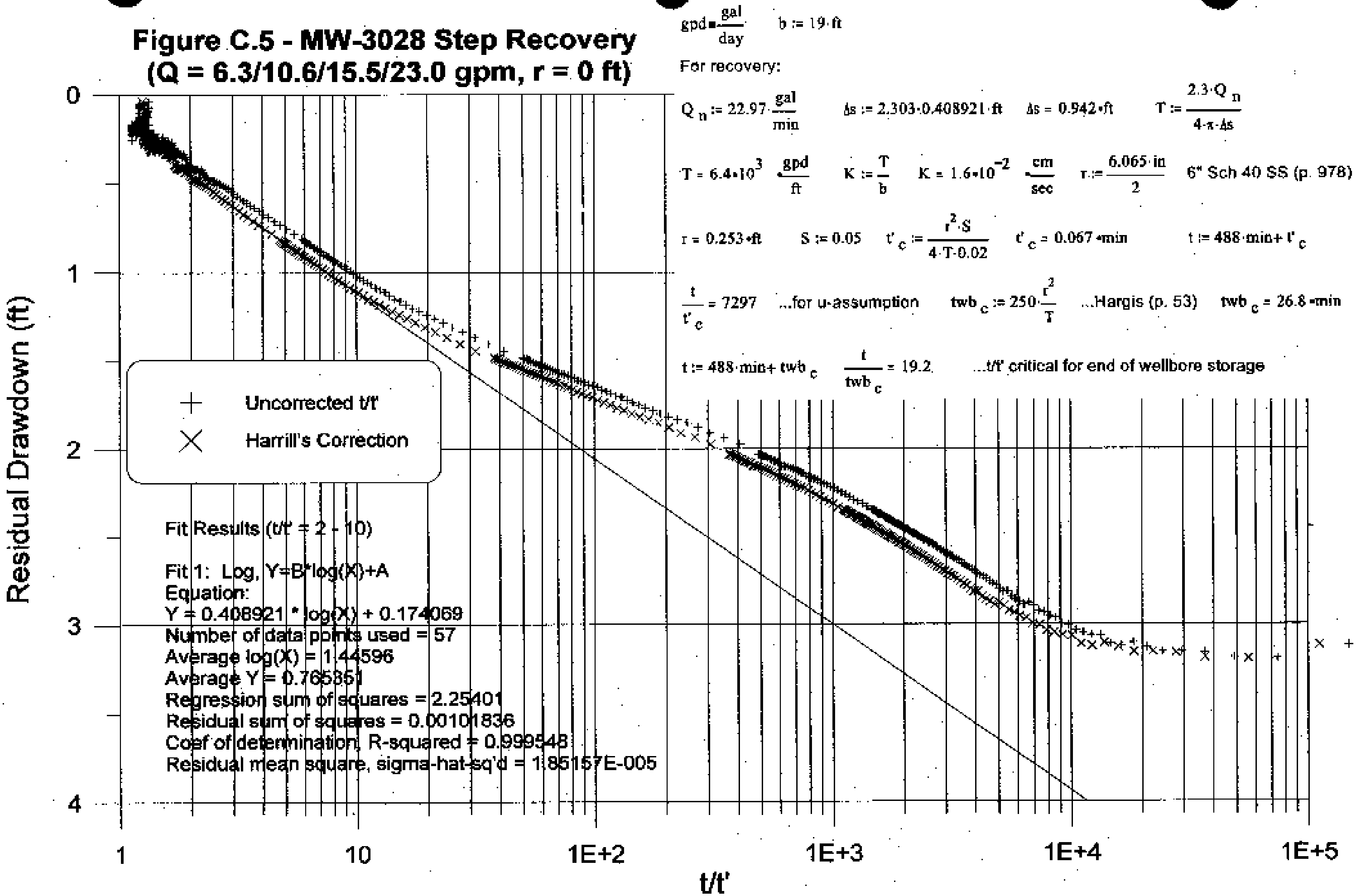
u:\chempump\chemstep\stepobs\2037stp.grf

Figure C.4 - MWS-21 and MW-4027 Step Pumping
(Q = 6.3/10.6/15.5/23.0 gpm, r = 188.9 ft and 204.5 ft)



u:\chempump\chemstep\stepobs\21&4027stp.grf

Figure C.5 - MW-3028 Step Recovery
(Q = 6.3/10.6/15.5/23.0 gpm, r = 0 ft)



u:\chempump\chemstep\step3028\3028recstp.grf

Figure C.6 - MW-3028 (Q = 31 gpm, r = 0 ft, dtw(0) = 41.00' toc)

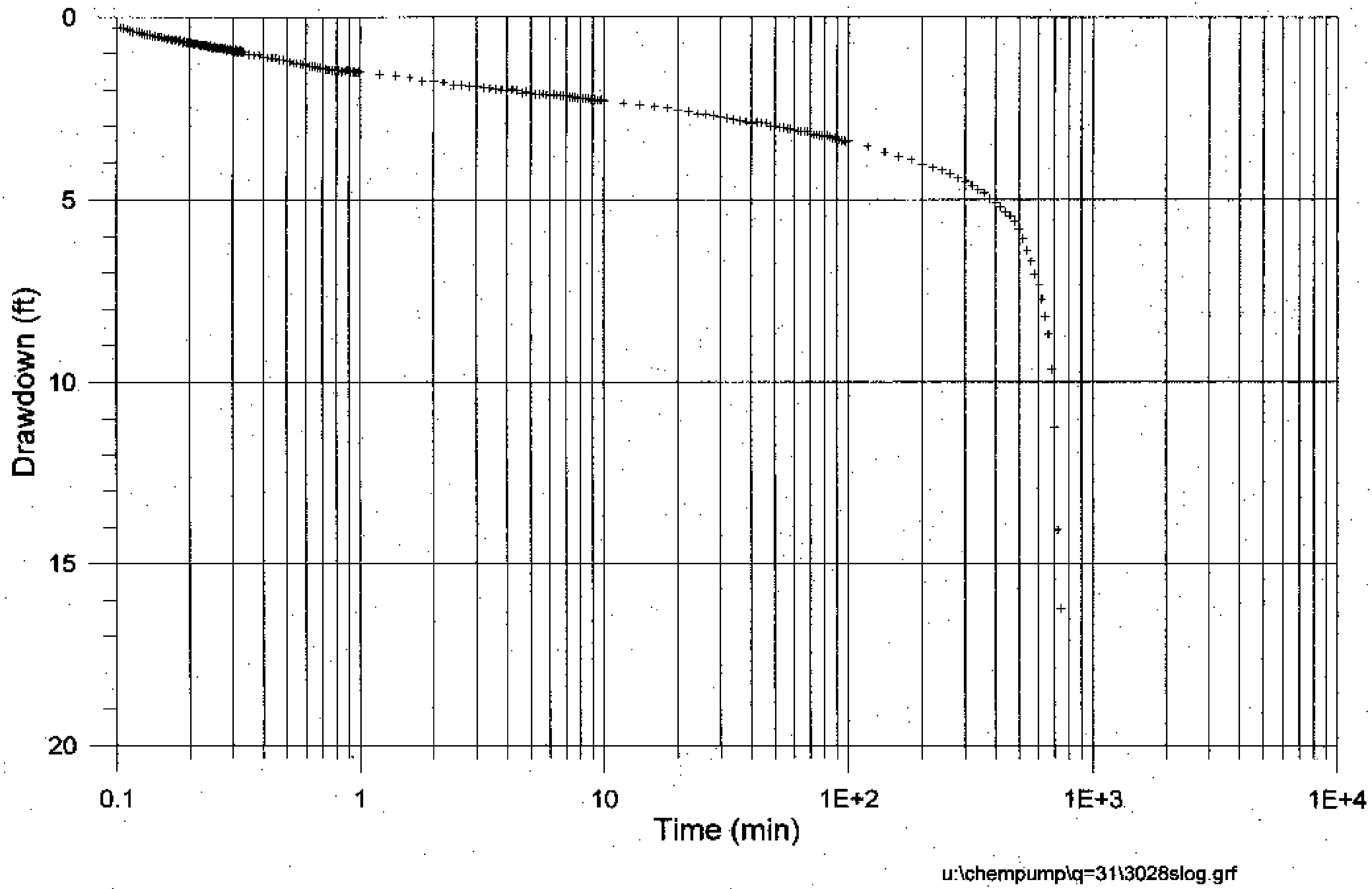
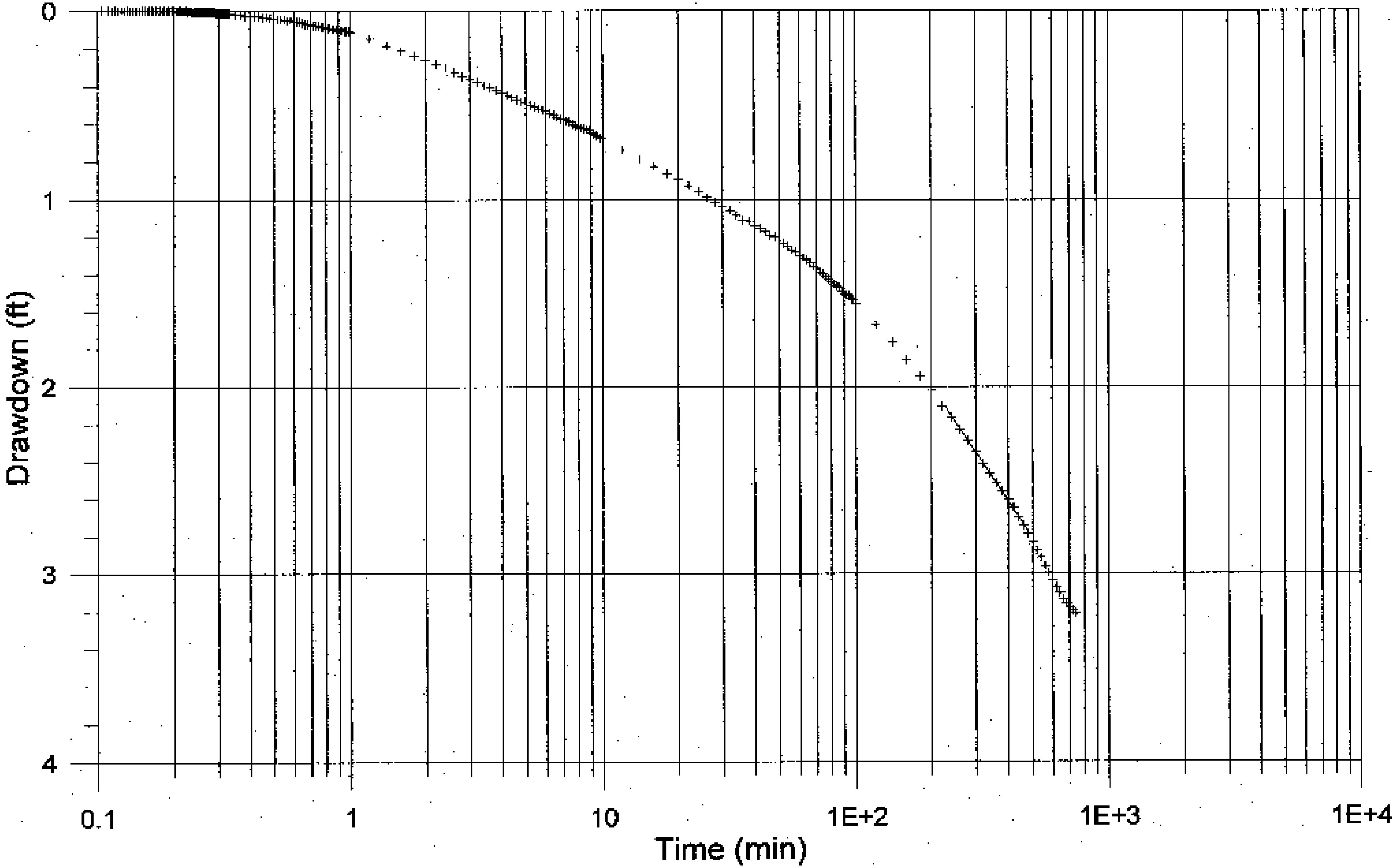
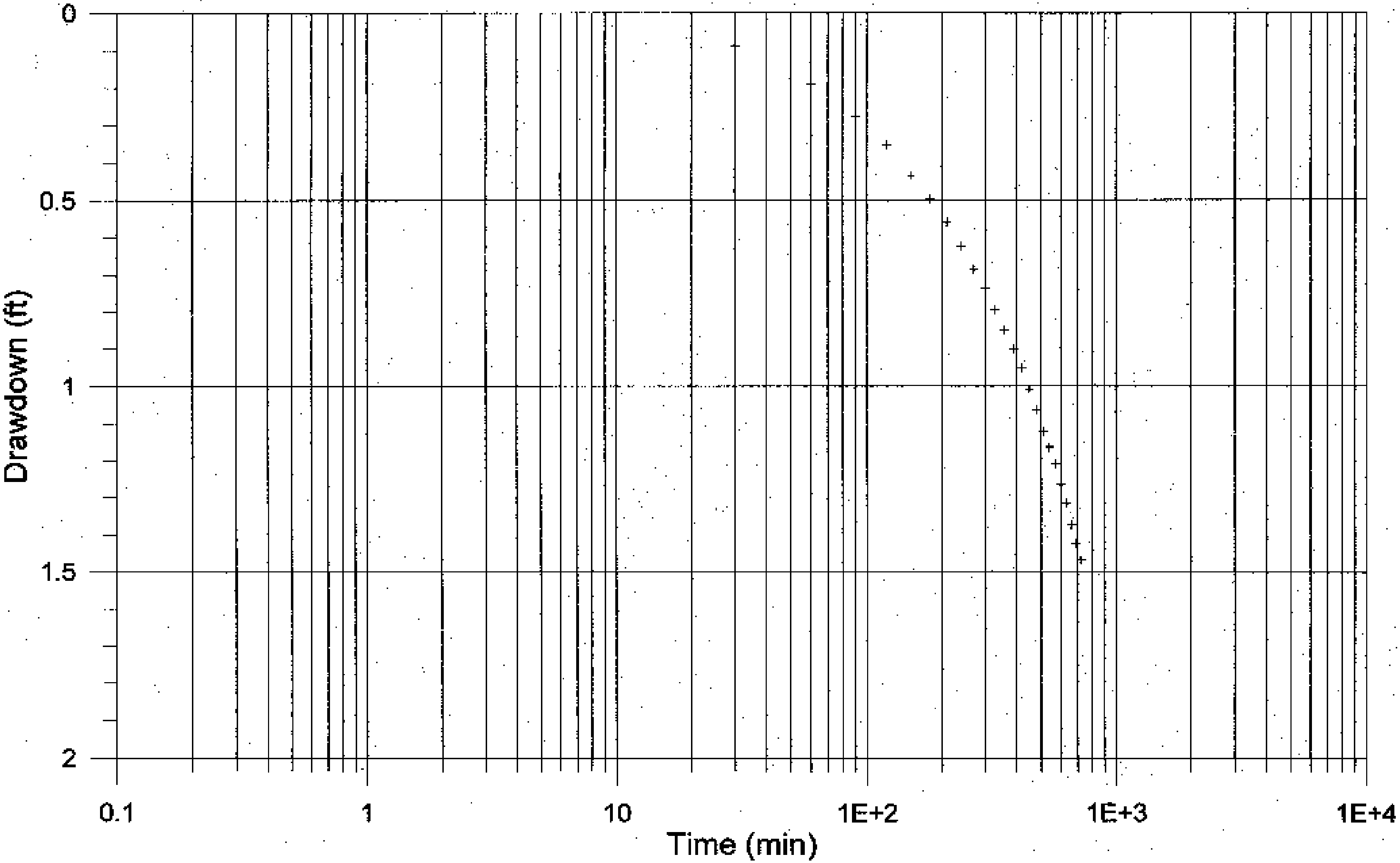


Figure C.7 - MW-3029 (Q = 31 gpm, r = 46.5 ft)



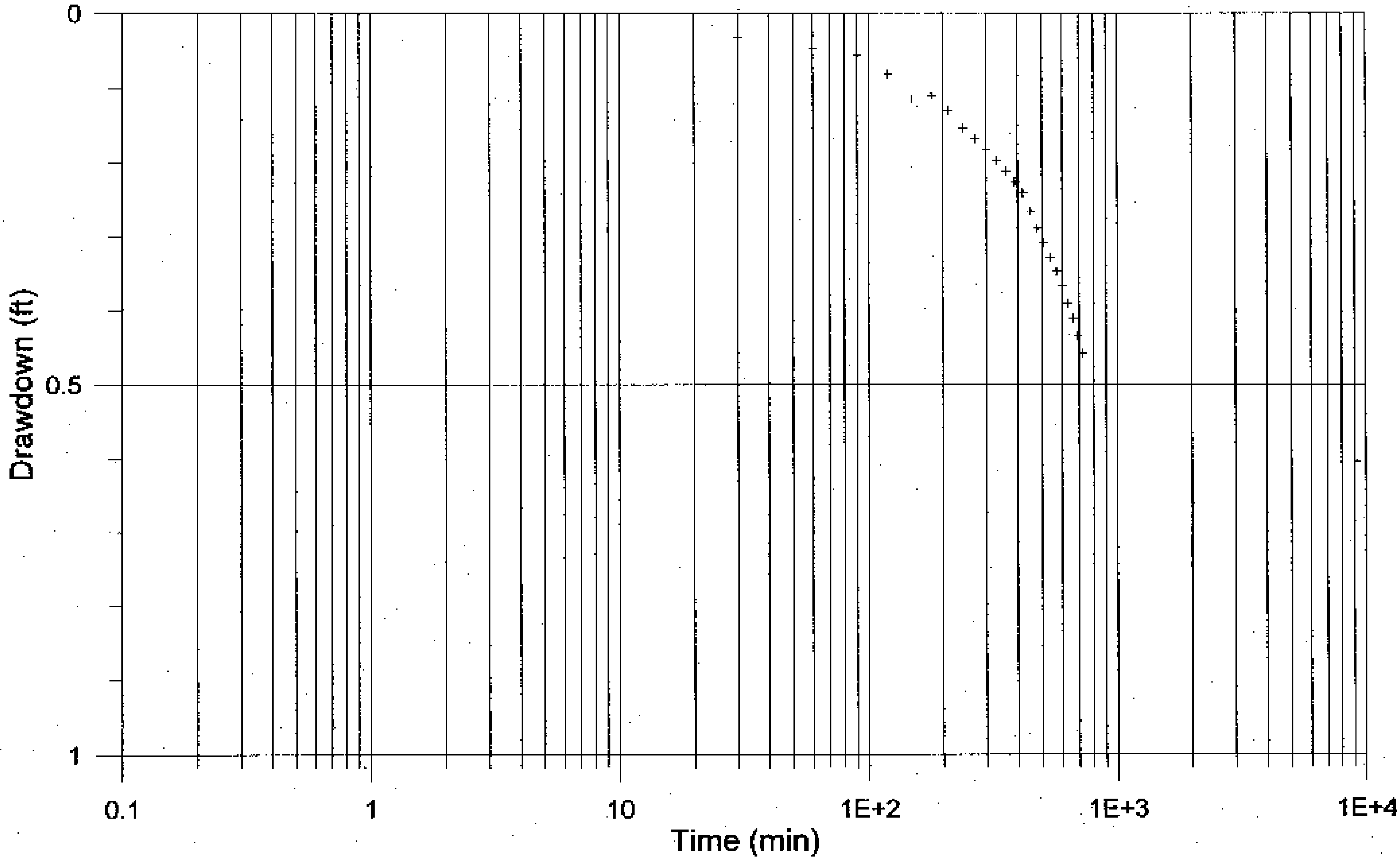
u:\chempump\q=31\3029slog.grf

Figure C.8 - MW-2037 (Q = 31 gpm, r = 159.5 ft)



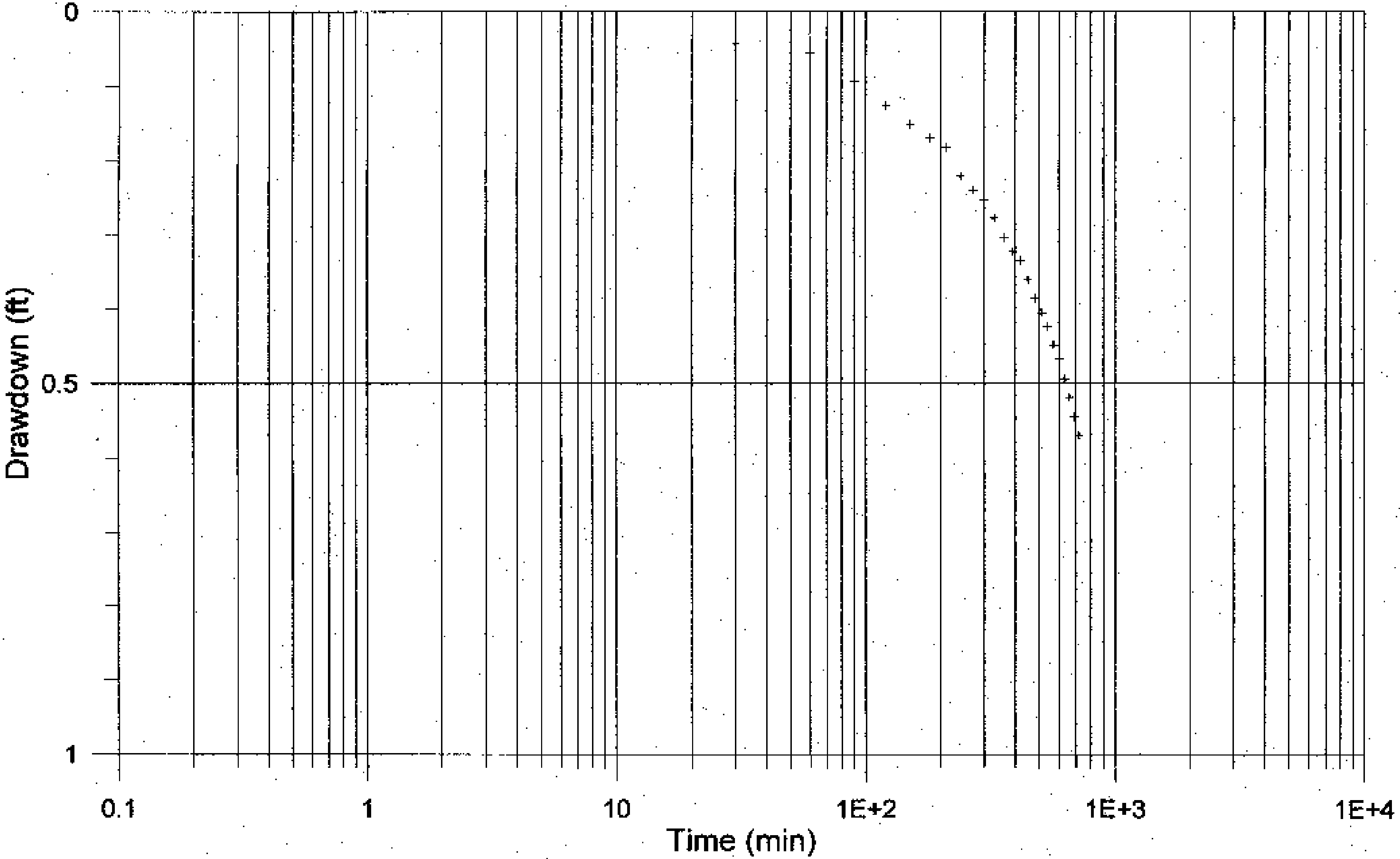
u:\chempump\q=31\2037slog.grf

Figure C.9 - MW-S21 (Q = 31 gpm, r = 188.9 ft)



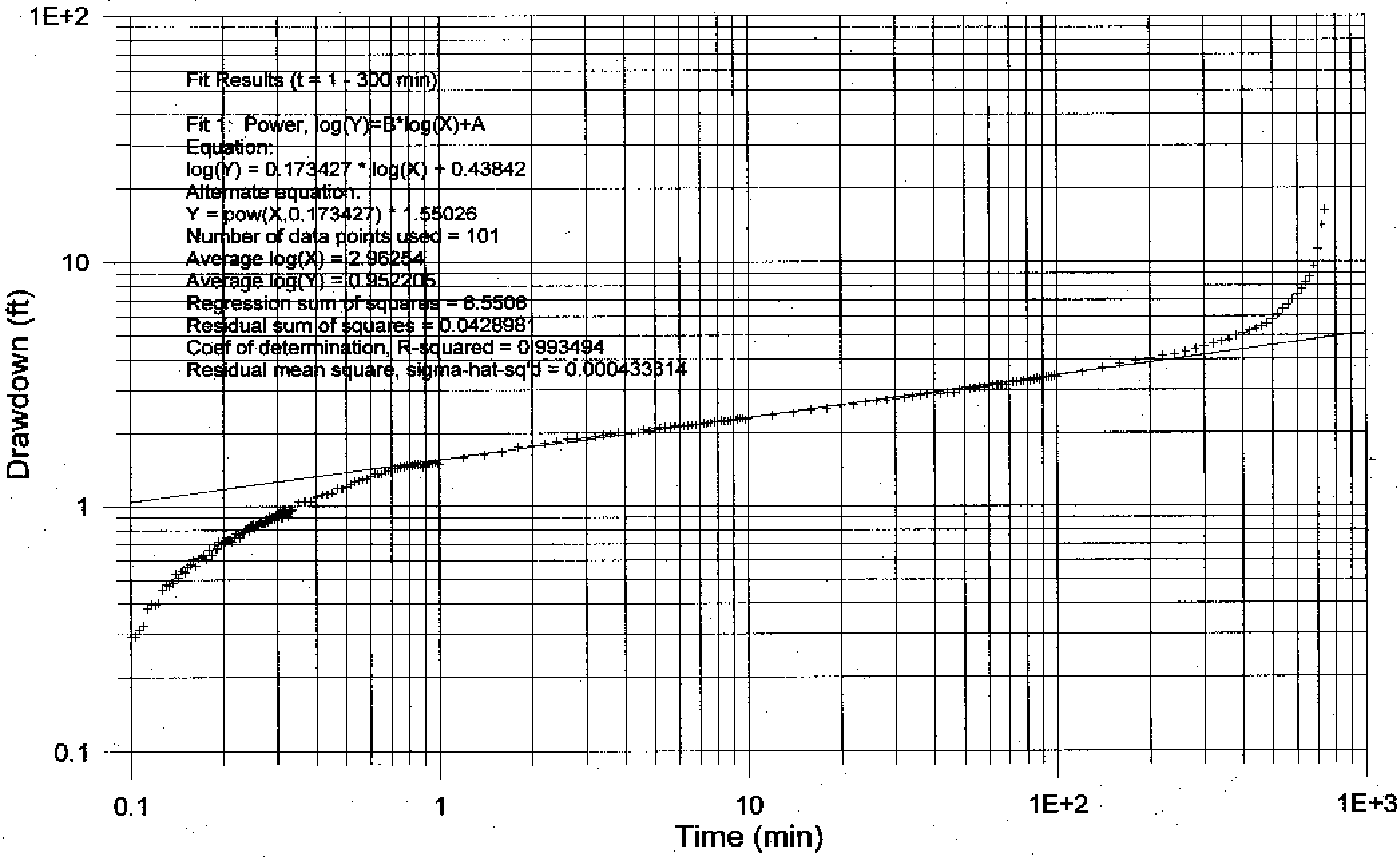
u:\chempump\q=31\mw21slog.grf

Figure C.10 - MW-4027 (Q = 31 gpm, r = 204.5 ft)



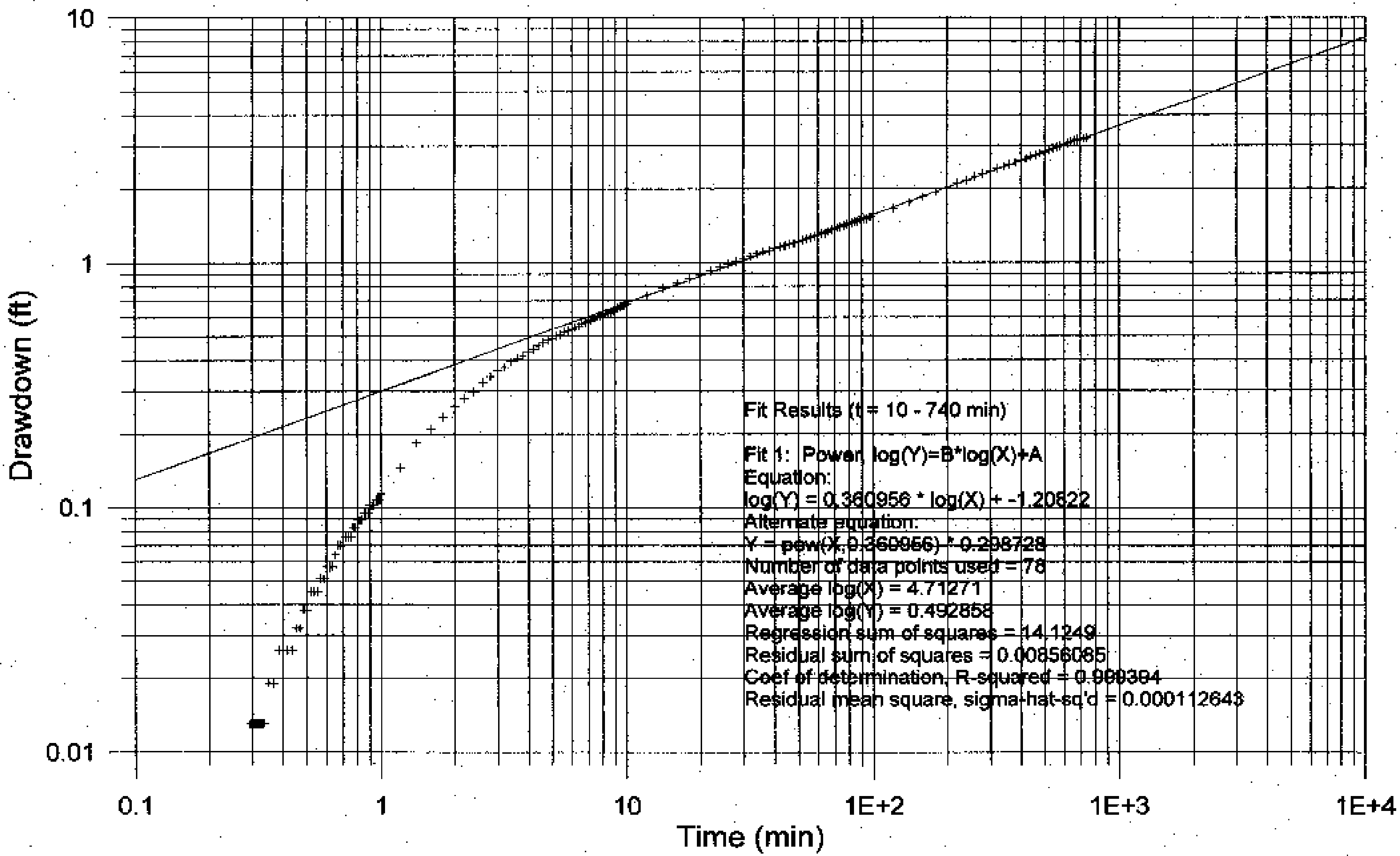
u:\chempump\q=31\mw4027slog.grf

Figure C.11 - MW-3028 (Q = 31 gpm, r = 0 ft)



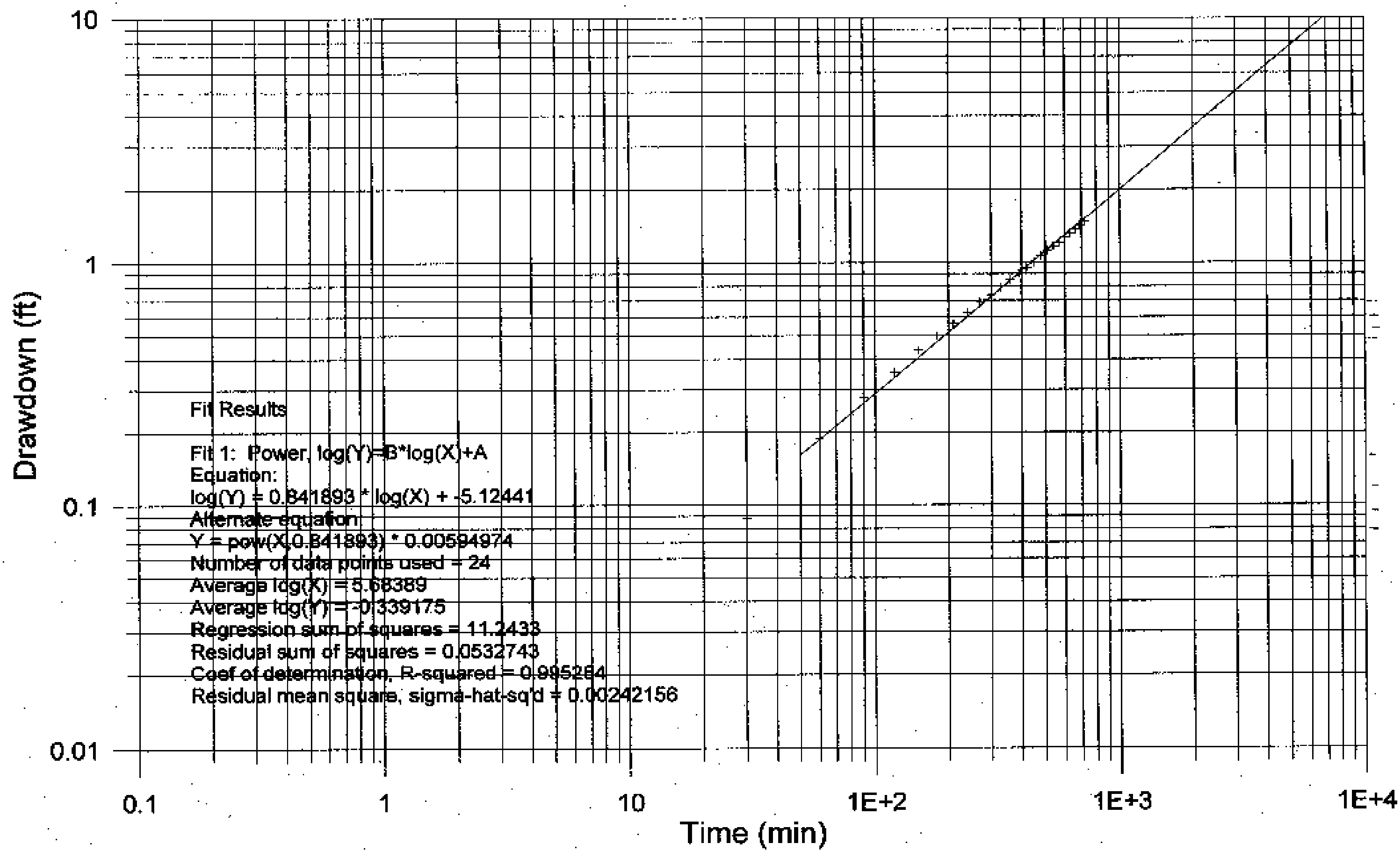
u:\chempump\q=31\3028-3x5.grf

Figure C.12 - MW-3029 (Q = 31 gpm, r = 46.5 ft)



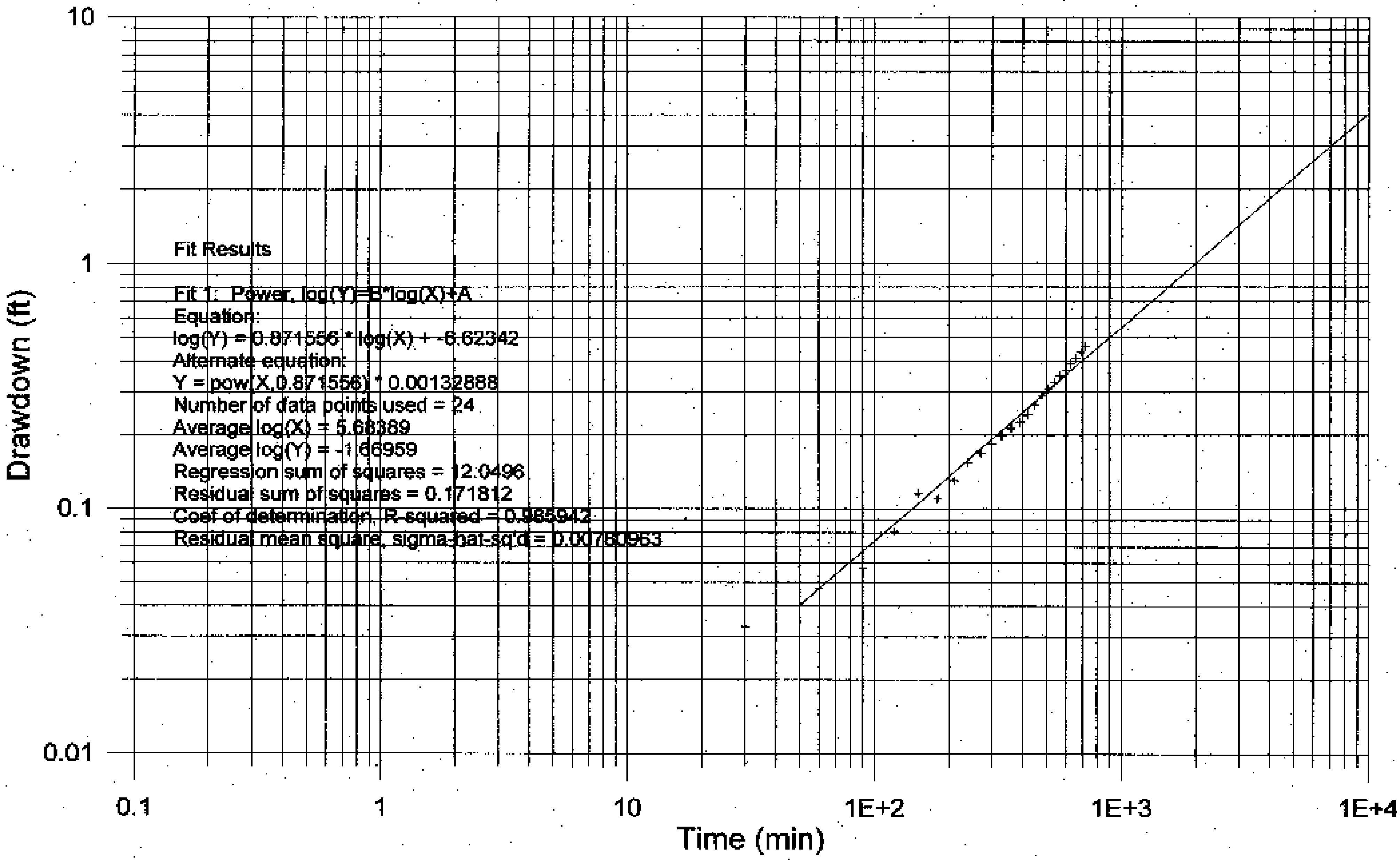
u:\chempump\q=31\3029-3x5.grf

Figure C.13 - MW-2037 (Q = 31 gpm, r = 159.5 ft)



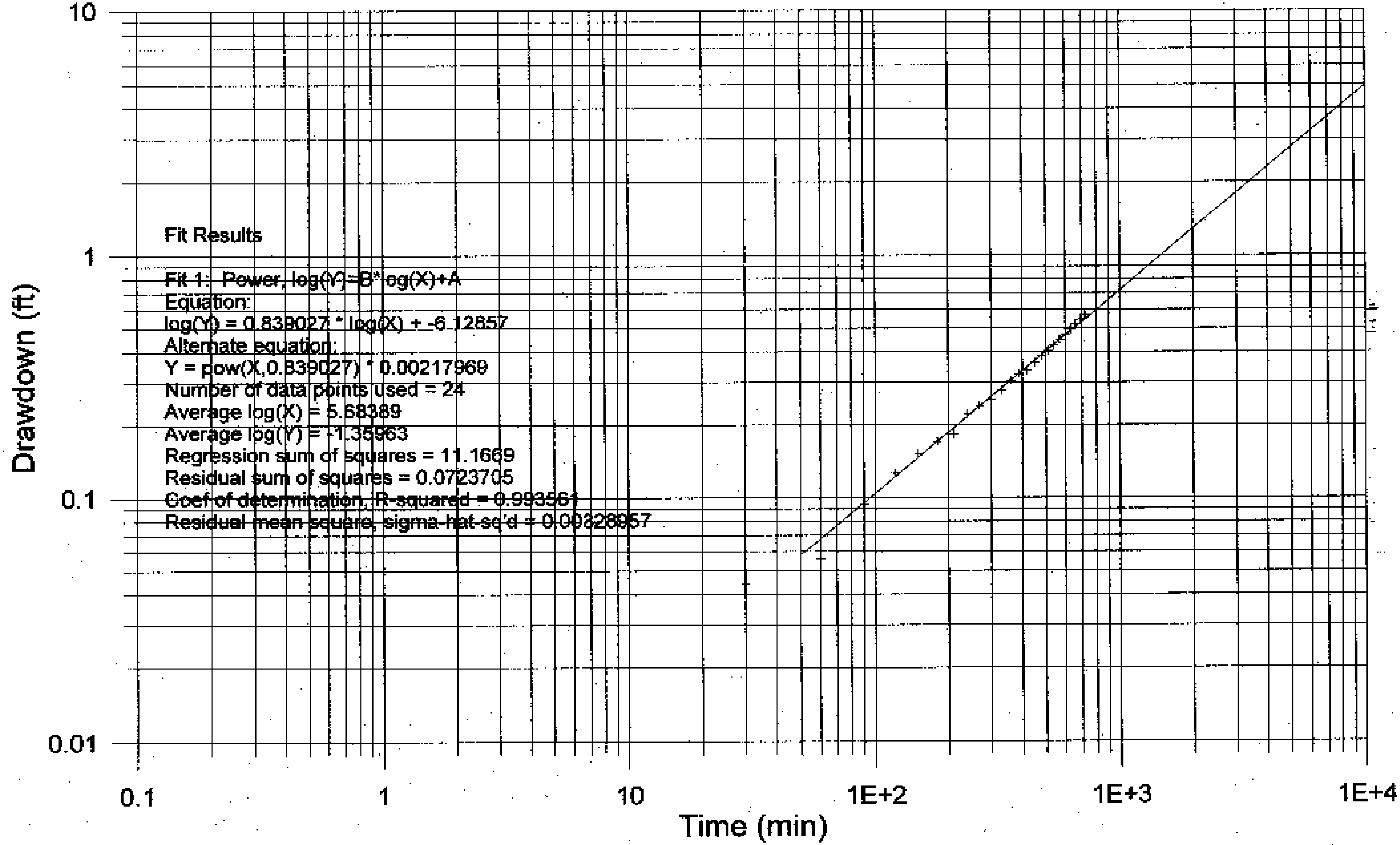
u:\chempump\q=31\2037-3x5.grf

Figure C.14 - MW-S21 (Q = 31 gpm, r = 188.9 ft)



u:\chempump\q=31\mw21-3x5.grf

Figure C.15 - MW-4027 (Q = 31 gpm, r = 204.5)



u:\chempump\q=31\4027-3x5.grf

Figure C.16 - Theis Solution Type Curve

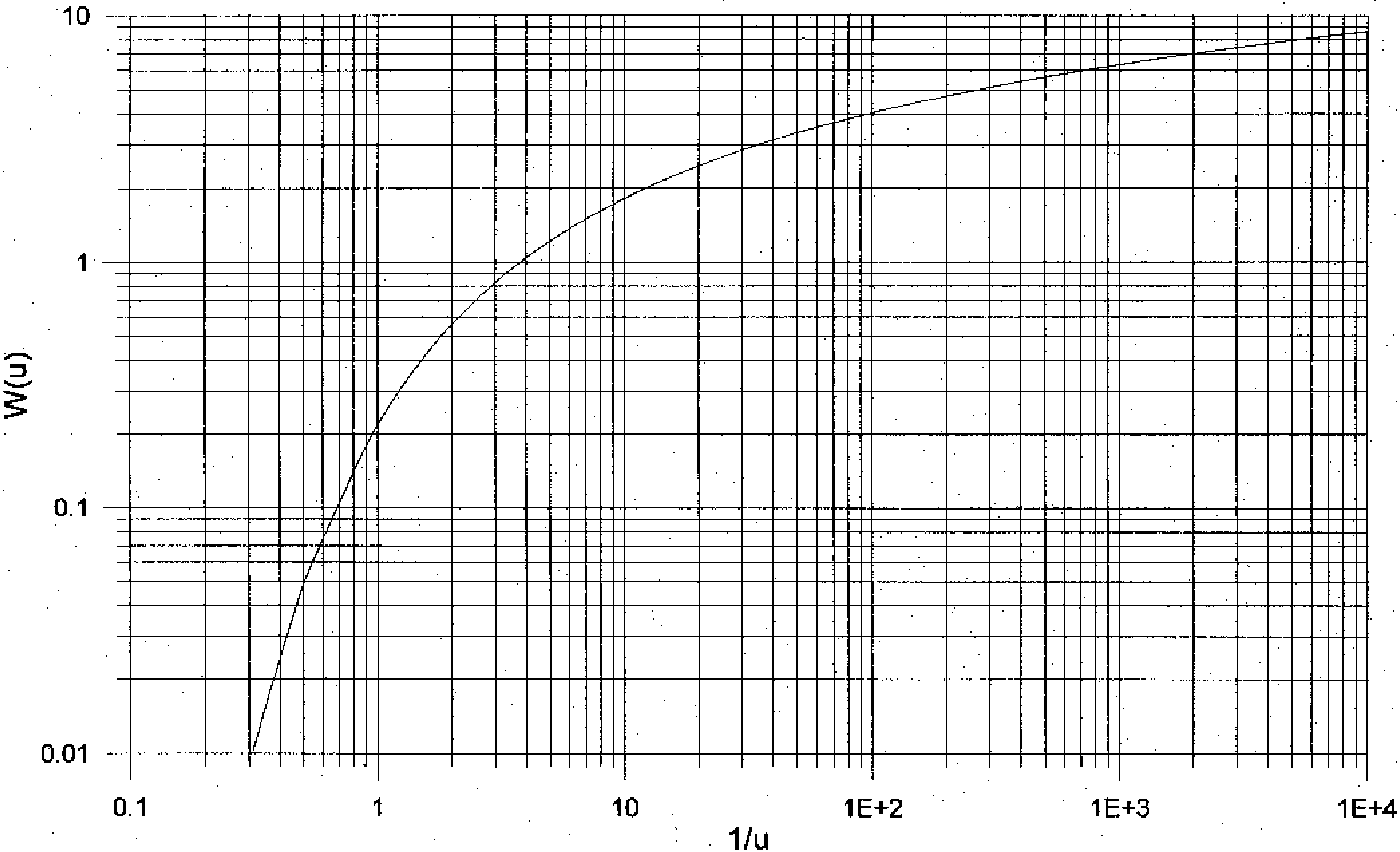


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Figure C.17 - MW-3028 (Q = 10.7 gpm, r = 0 ft)

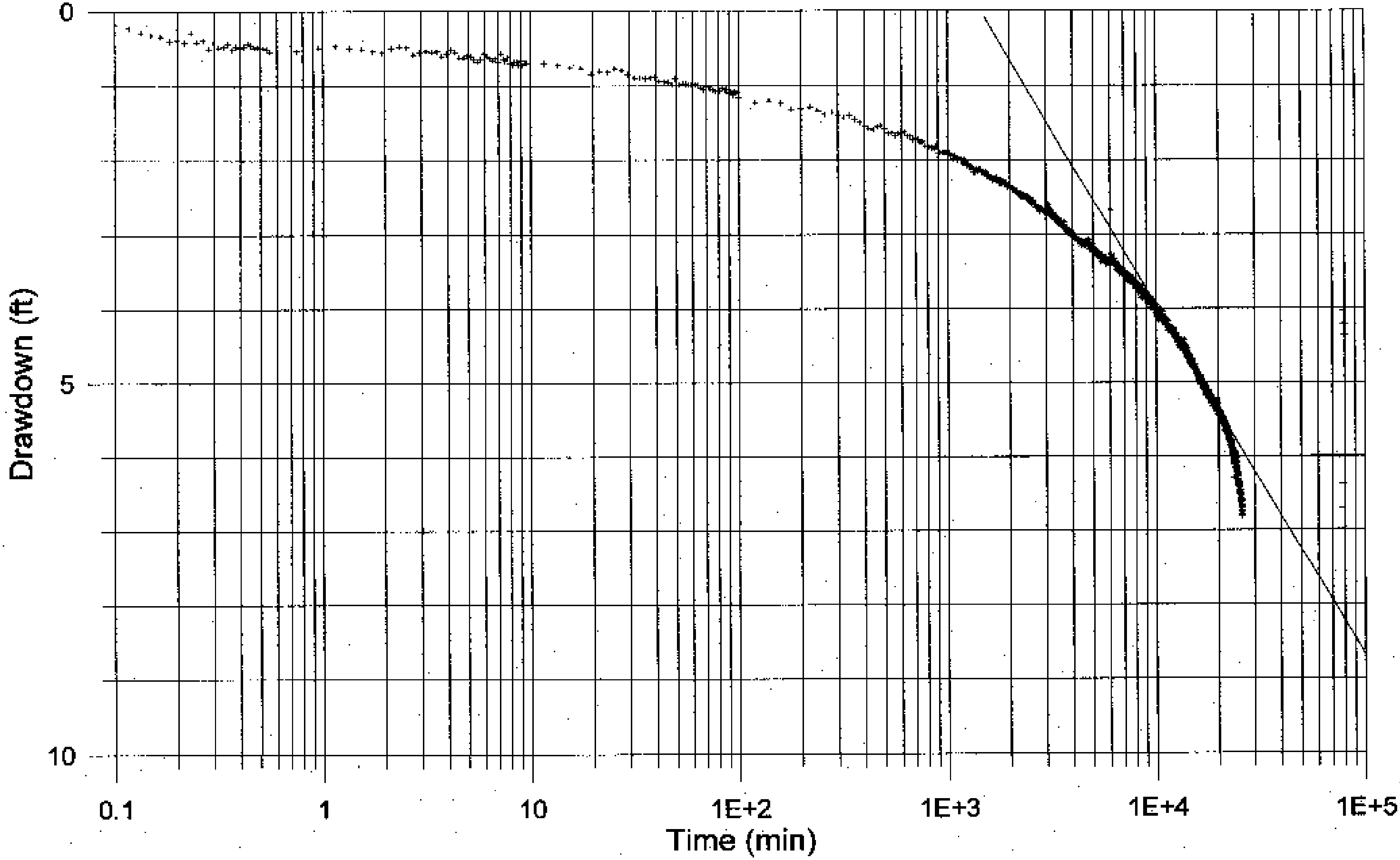

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Figure C.18 - MW-4028 (Q = 10.7 gpm, r = 32.2 ft)

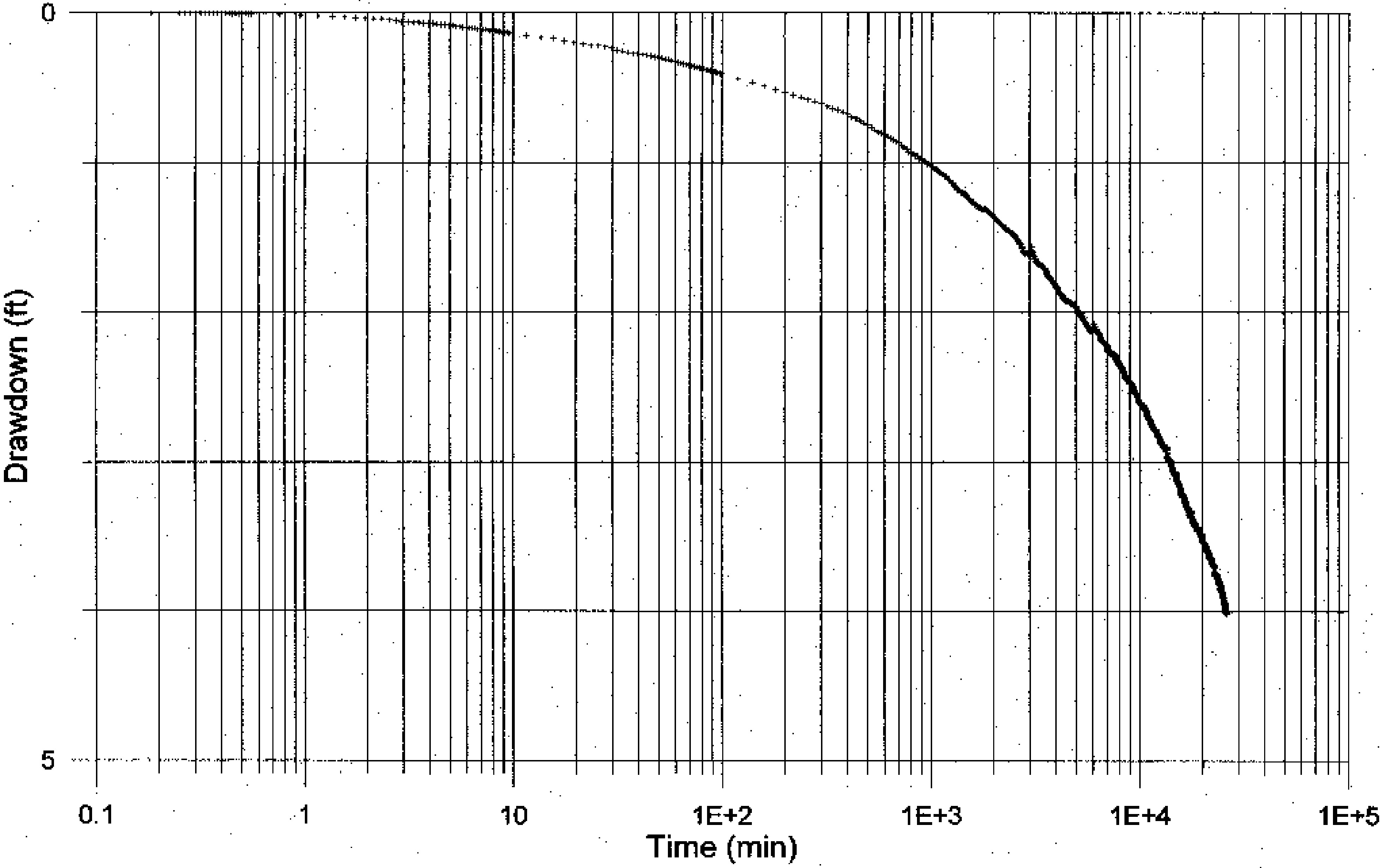

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Figure C.19 - MW-3029 (Q = 10.7 gpm, r = 46.5 ft)

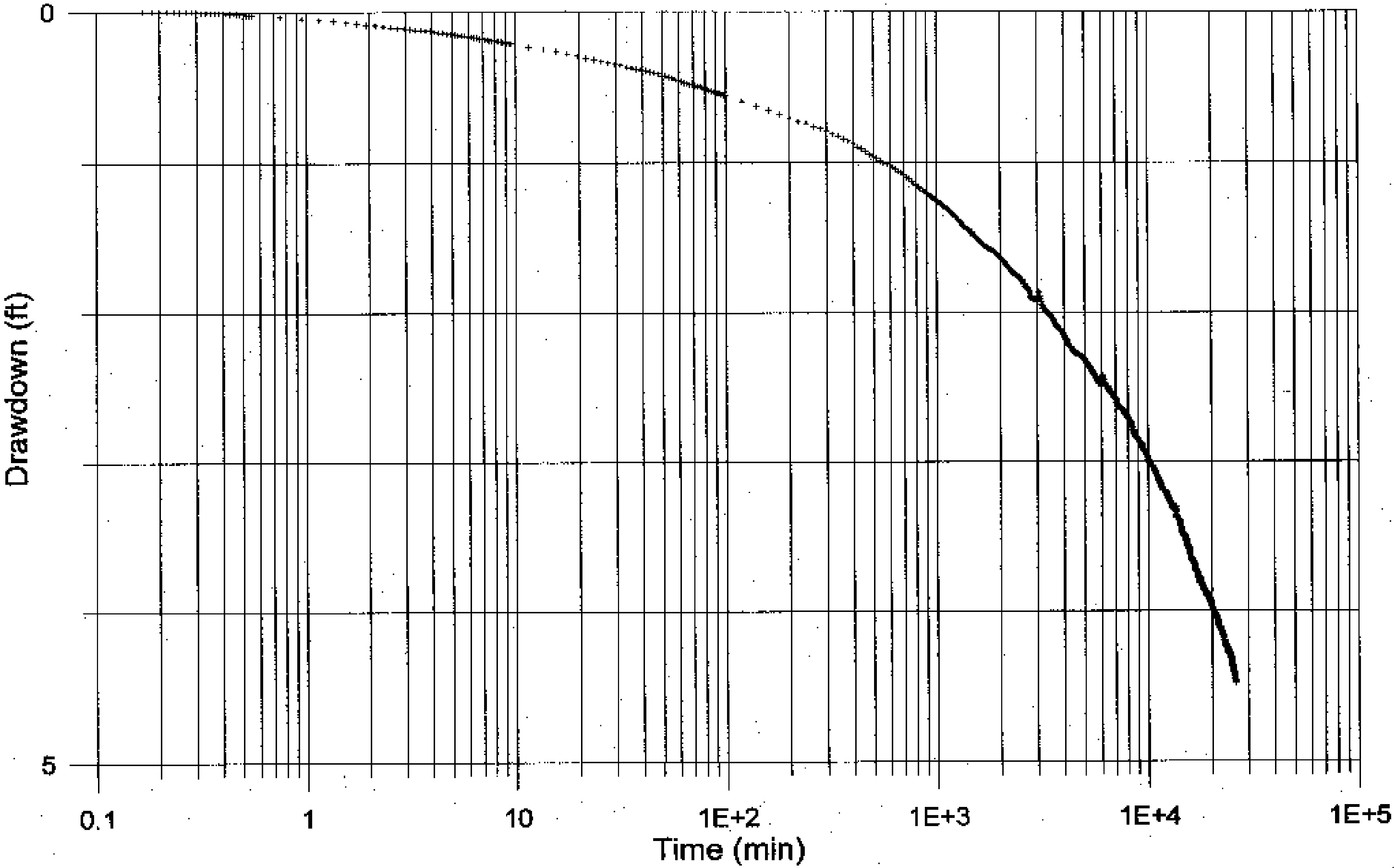

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Figure C.20 - MW-2037 (Q = 10.7 gpm, r = 159.5 ft)

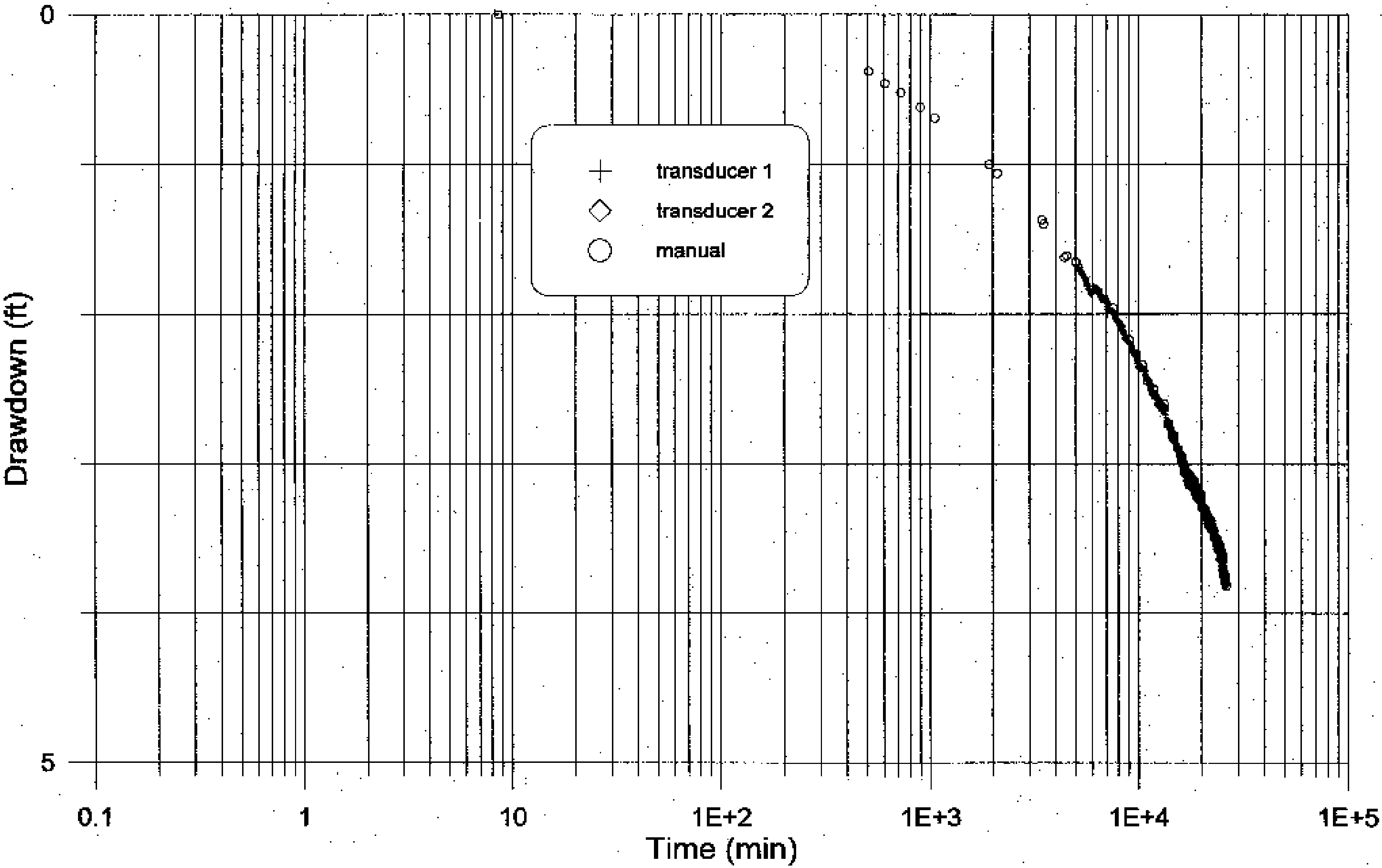

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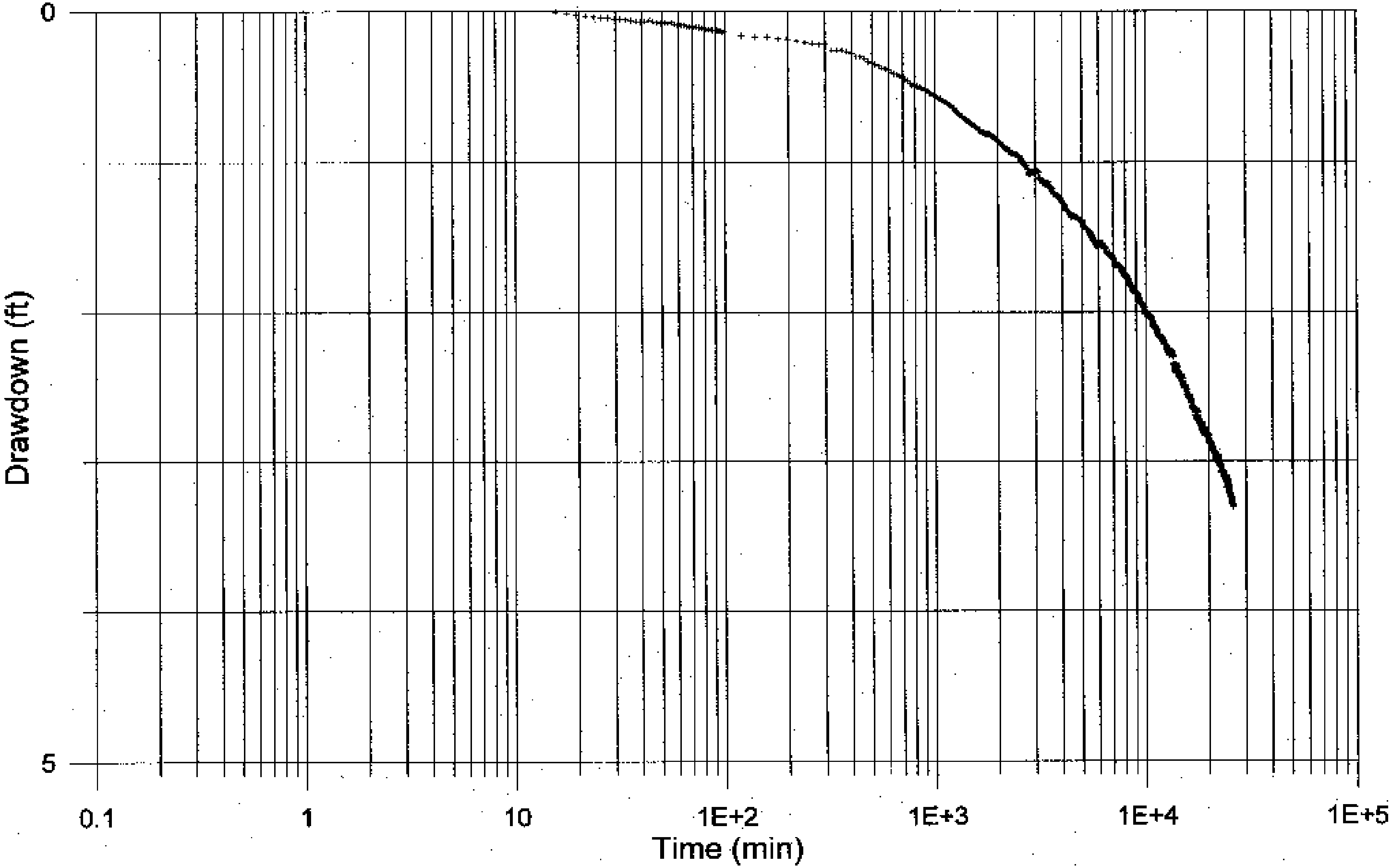
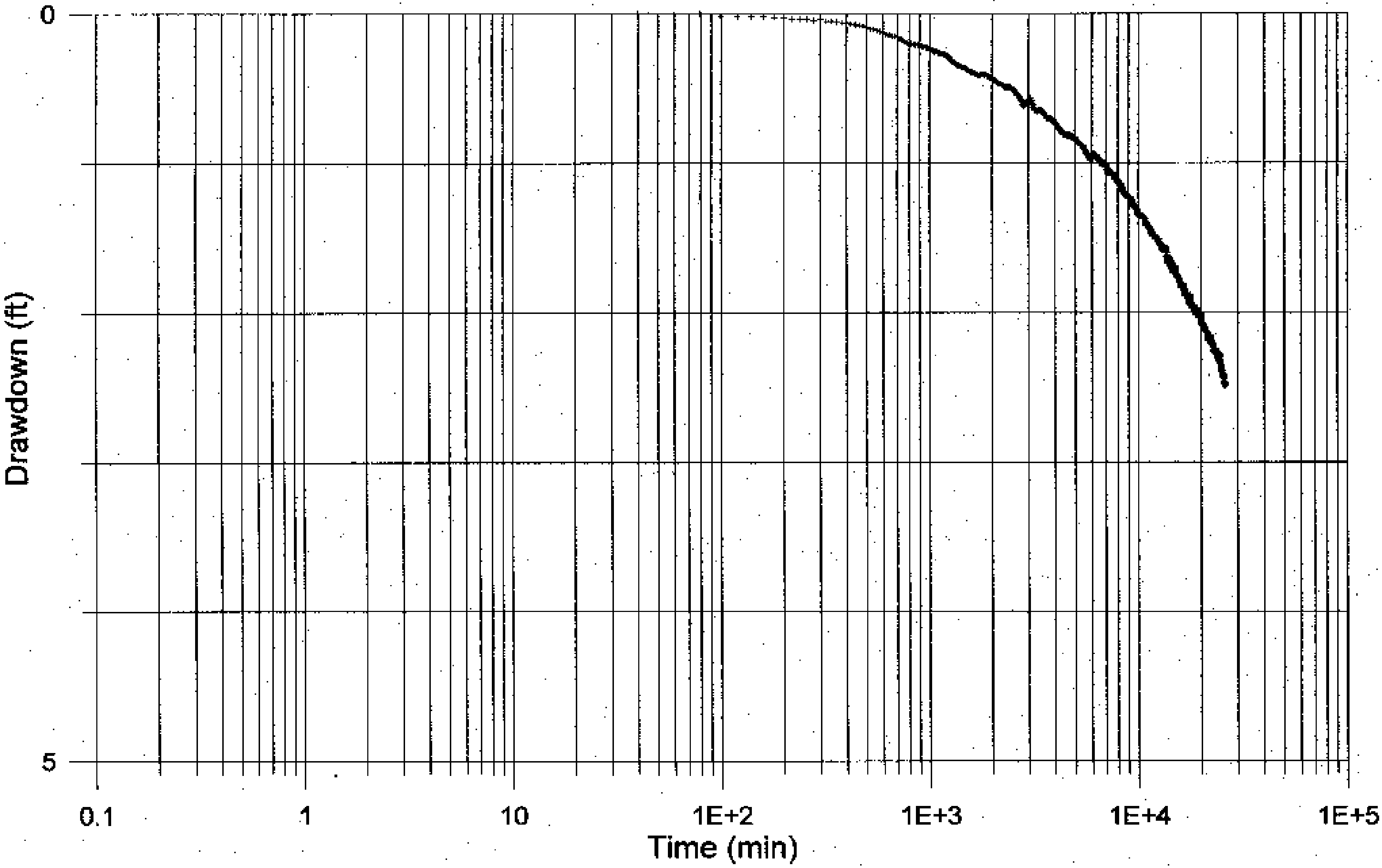
Figure C.21 - MW-4029 (Q = 10.7 gpm, r = 161.2 ft)



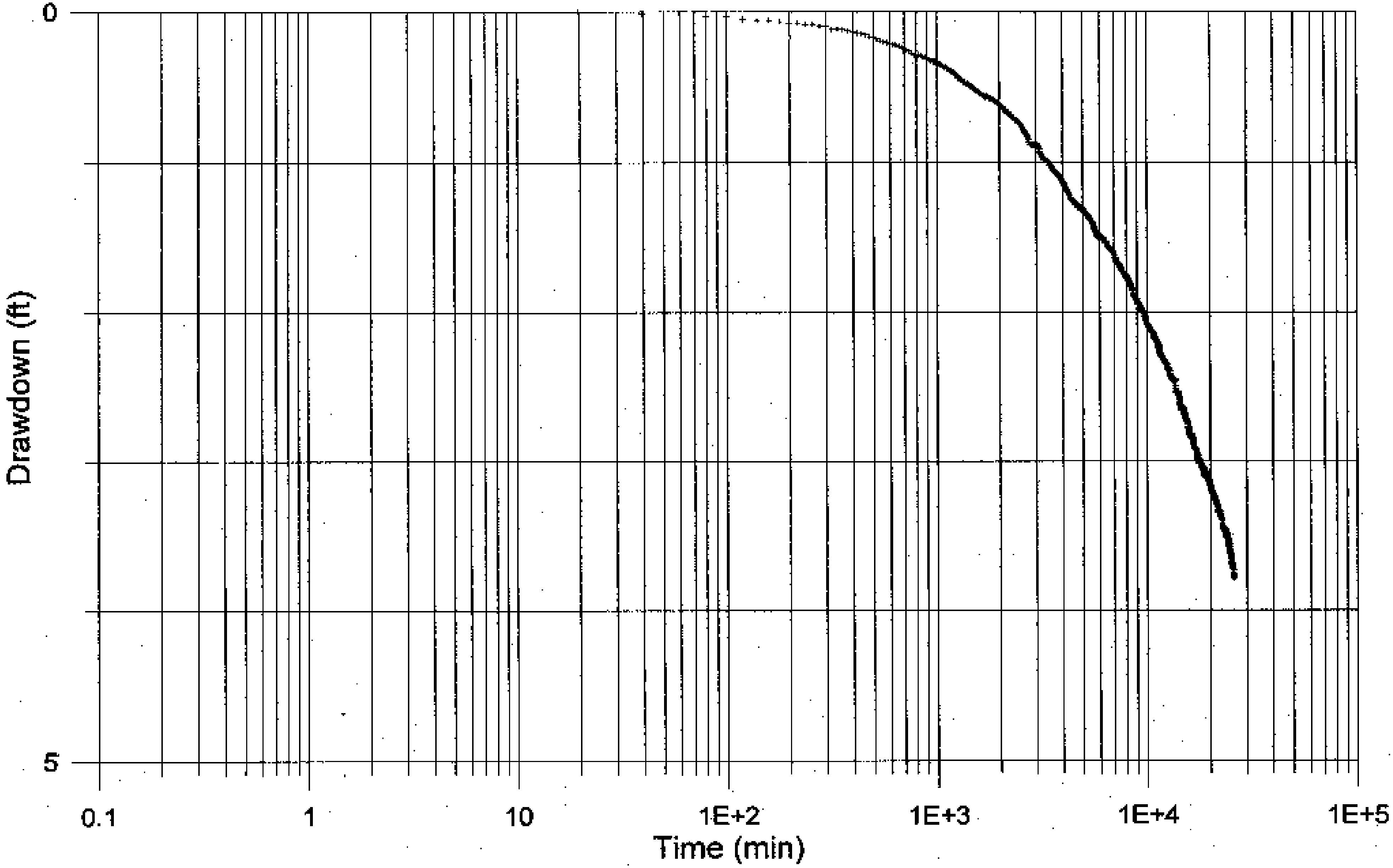
u:\chempump\longterm\4029pump.grf

Figure C.22 - MWS-21 (Q = 10.7 gpm, r = 188.9 ft)



u:\chempump\longterm\s21pump.grf

Figure C.23 - MW-4027 (Q = 10.7 gpm, r = 204.5 ft)



u:\chempump\longterm\4027pump.grf

Figure C.24 - MW-2036 (Q = 10.7 gpm, r = 479.9 ft)

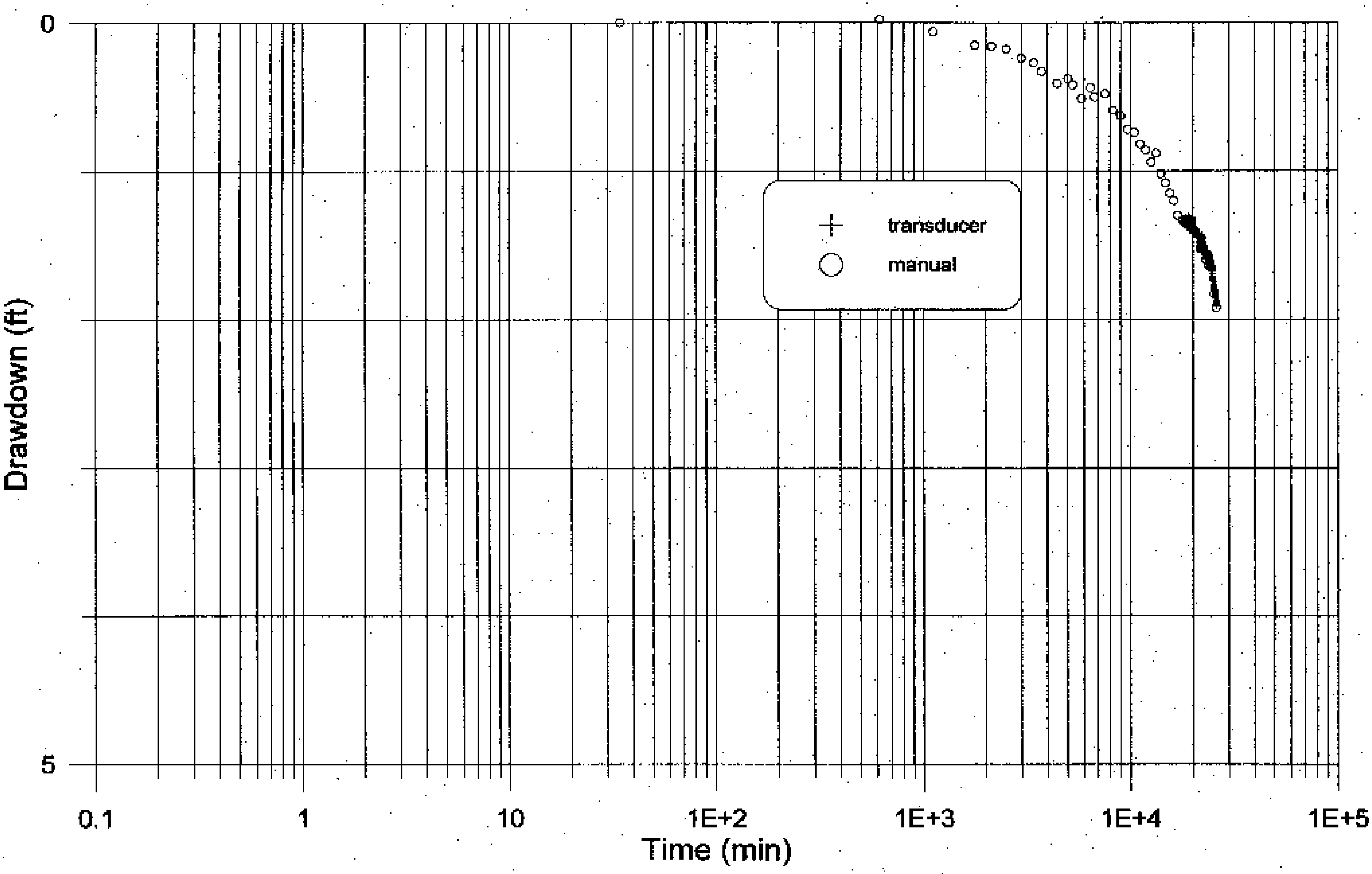


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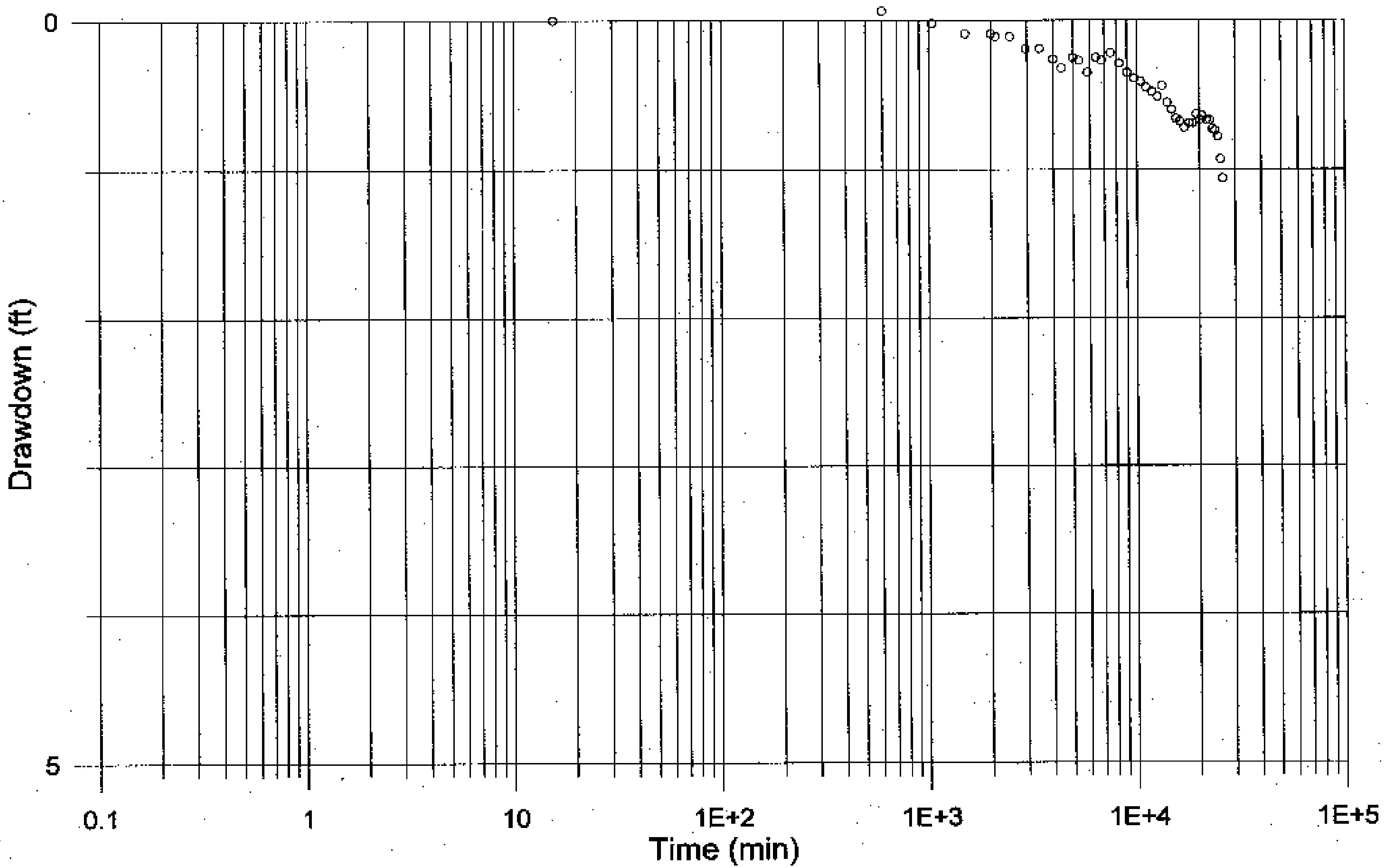
Figure C.25 - MW-2038 (Q = 10.7 gpm, r = 598.2 ft)



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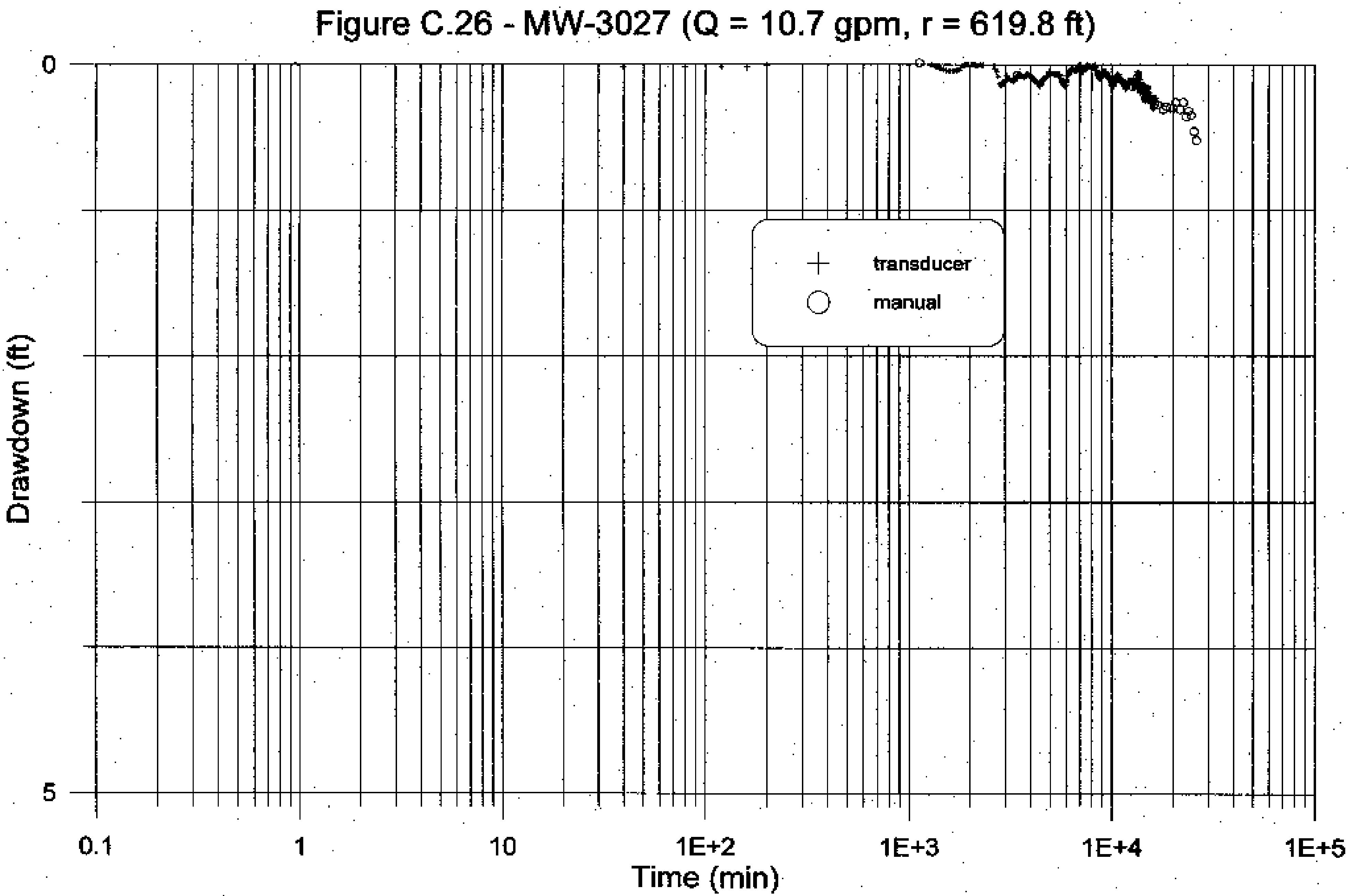

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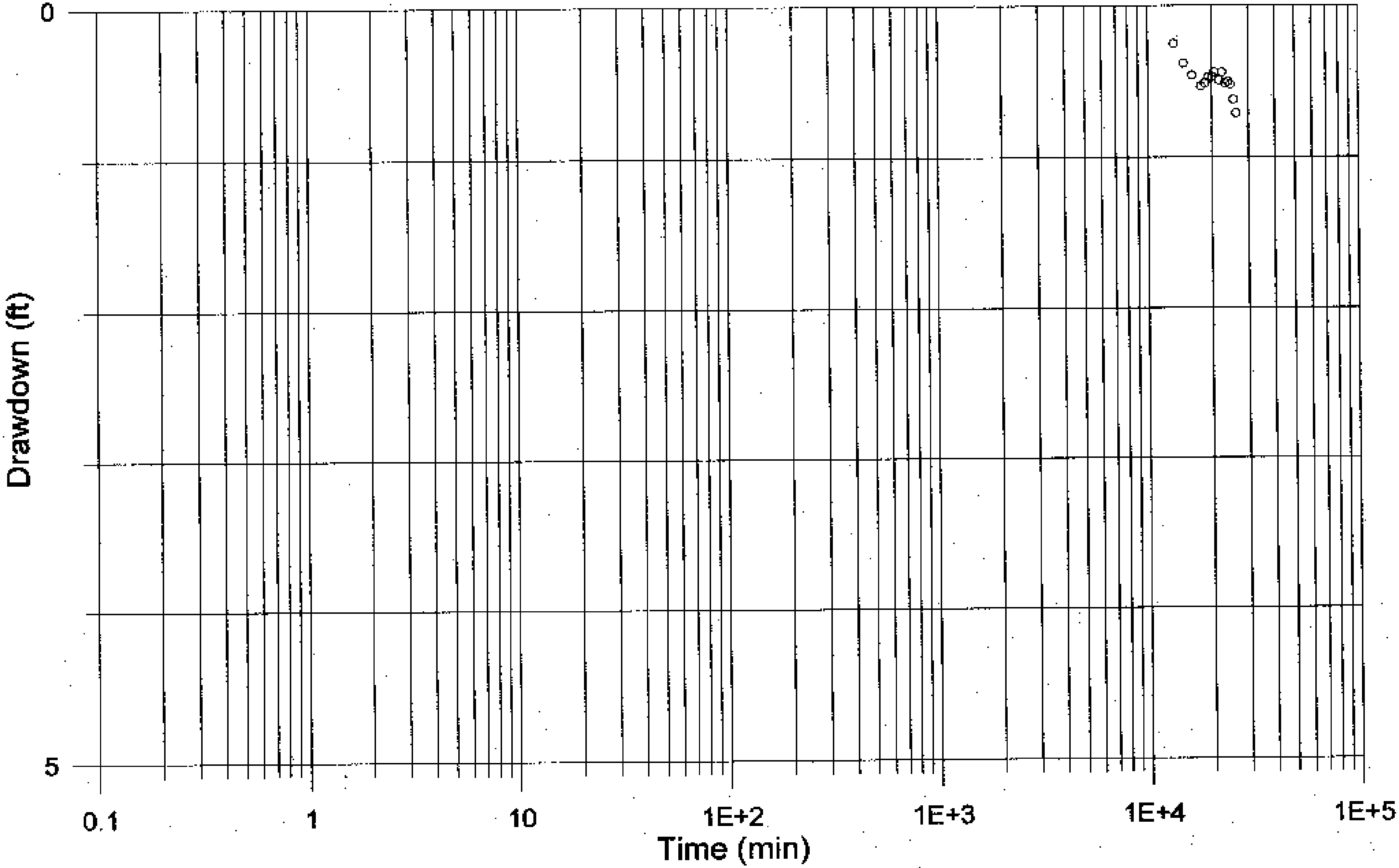
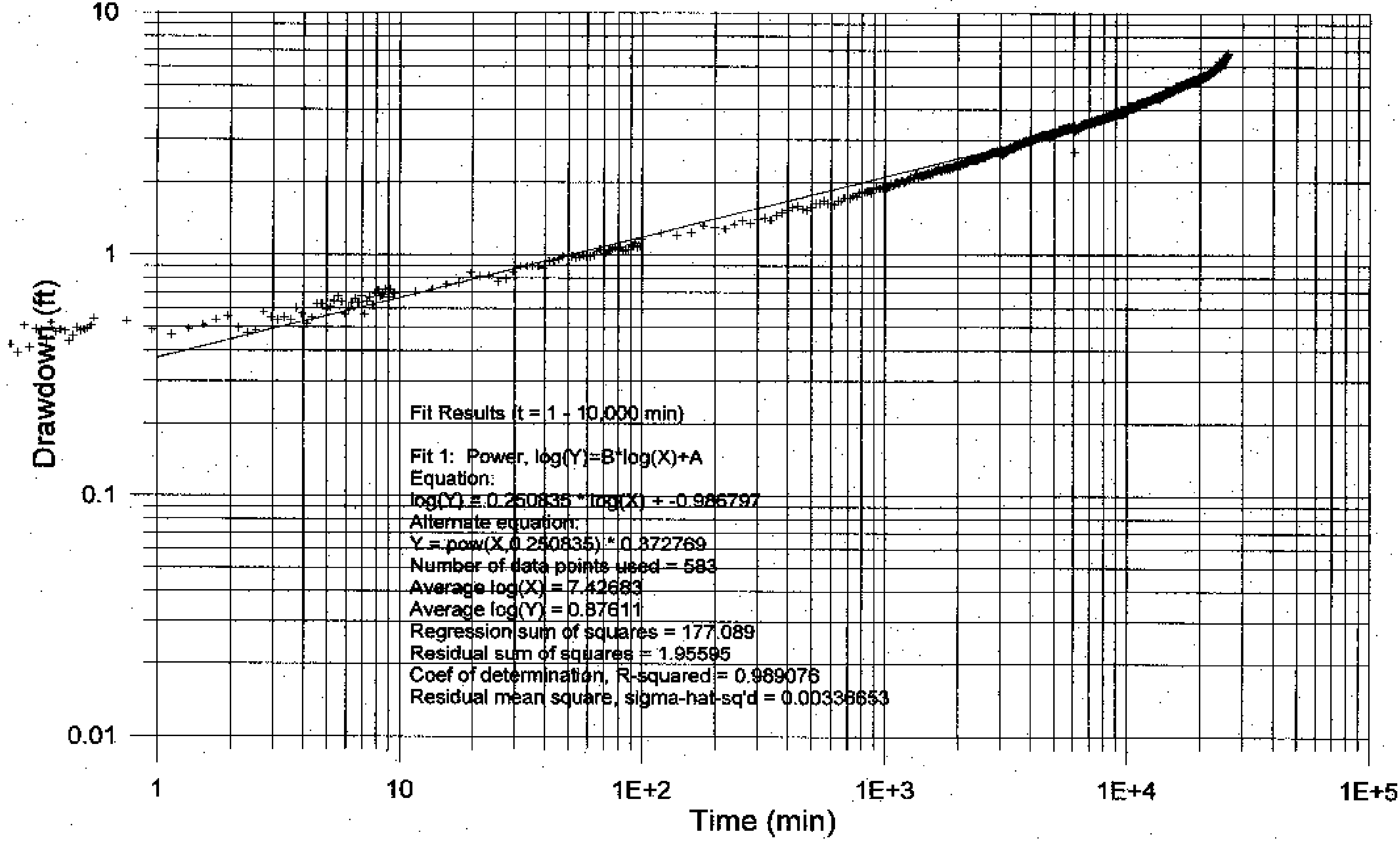
Figure C.27 - MW-3026 (Q = 10.7 gpm, r = 621.9 ft)
Unweathered Retrofit Well



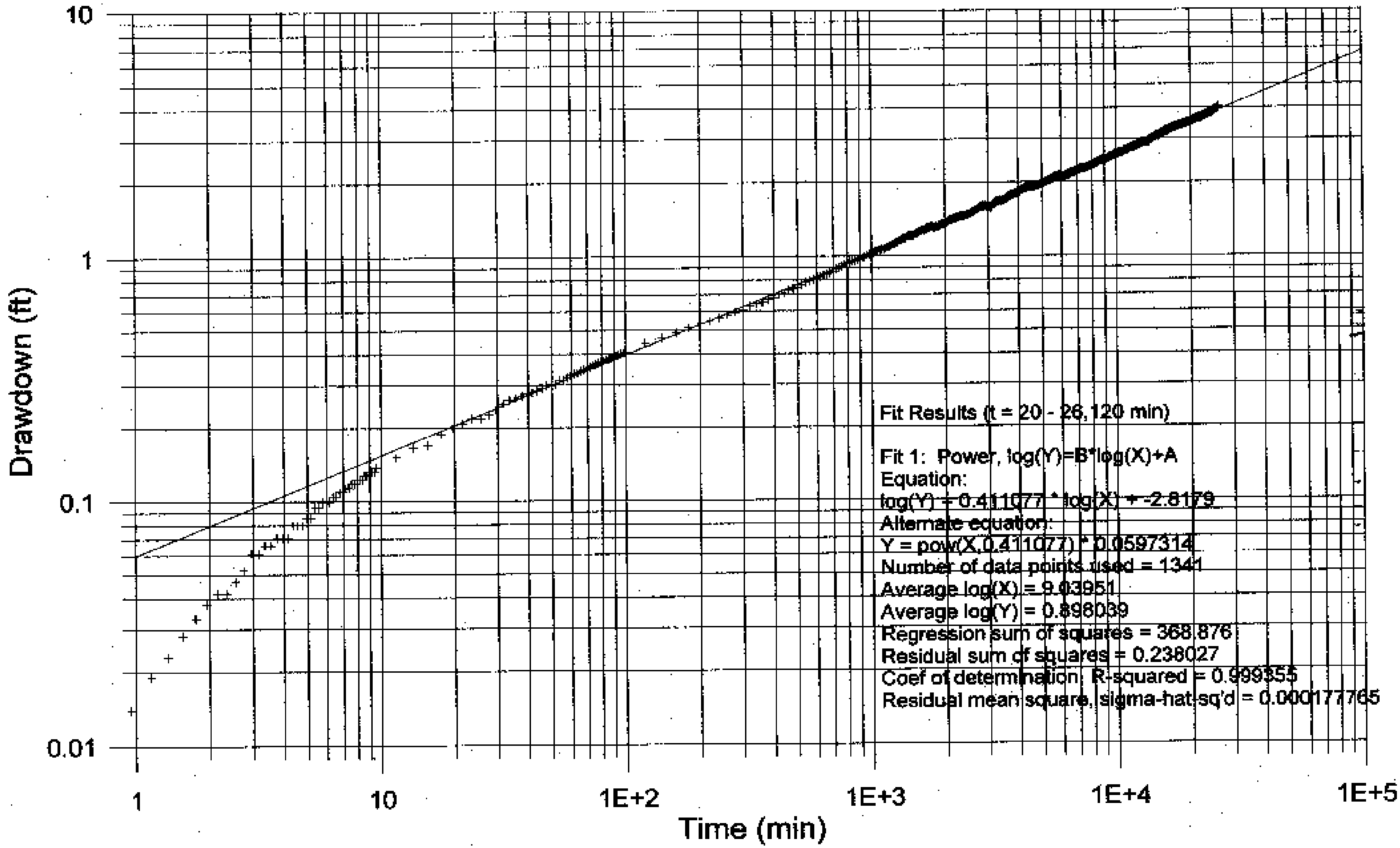
u:\chempump\longterm\3026pump.grf

Figure C.28 - MW-3028 (Q = 10.7 gpm, r = 0 ft)



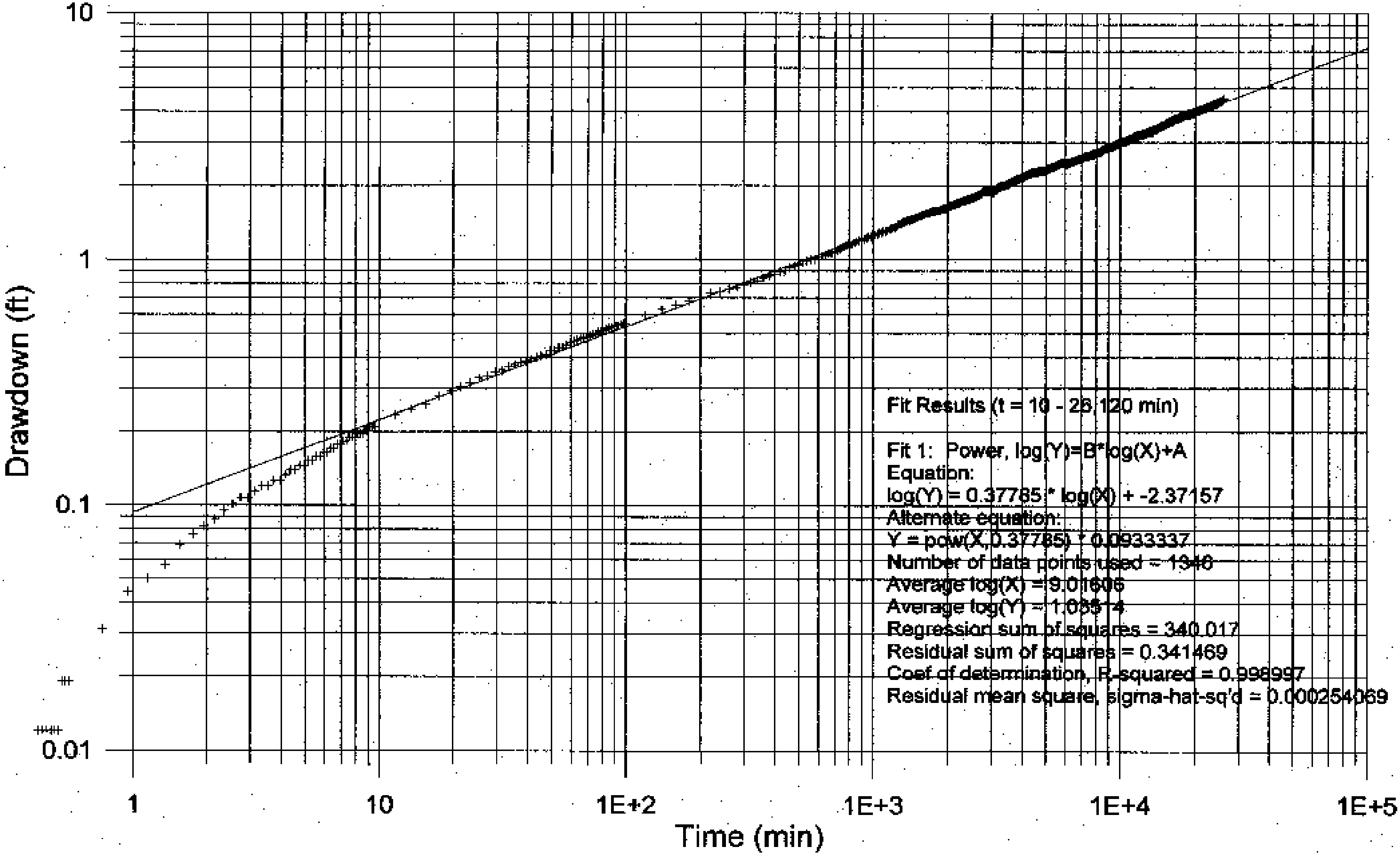
u:\chempump\longterm\3028l3x5.grf

Figure C.29 - MW-4028 (Q = 10.7 gpm, r = 32.2 ft)



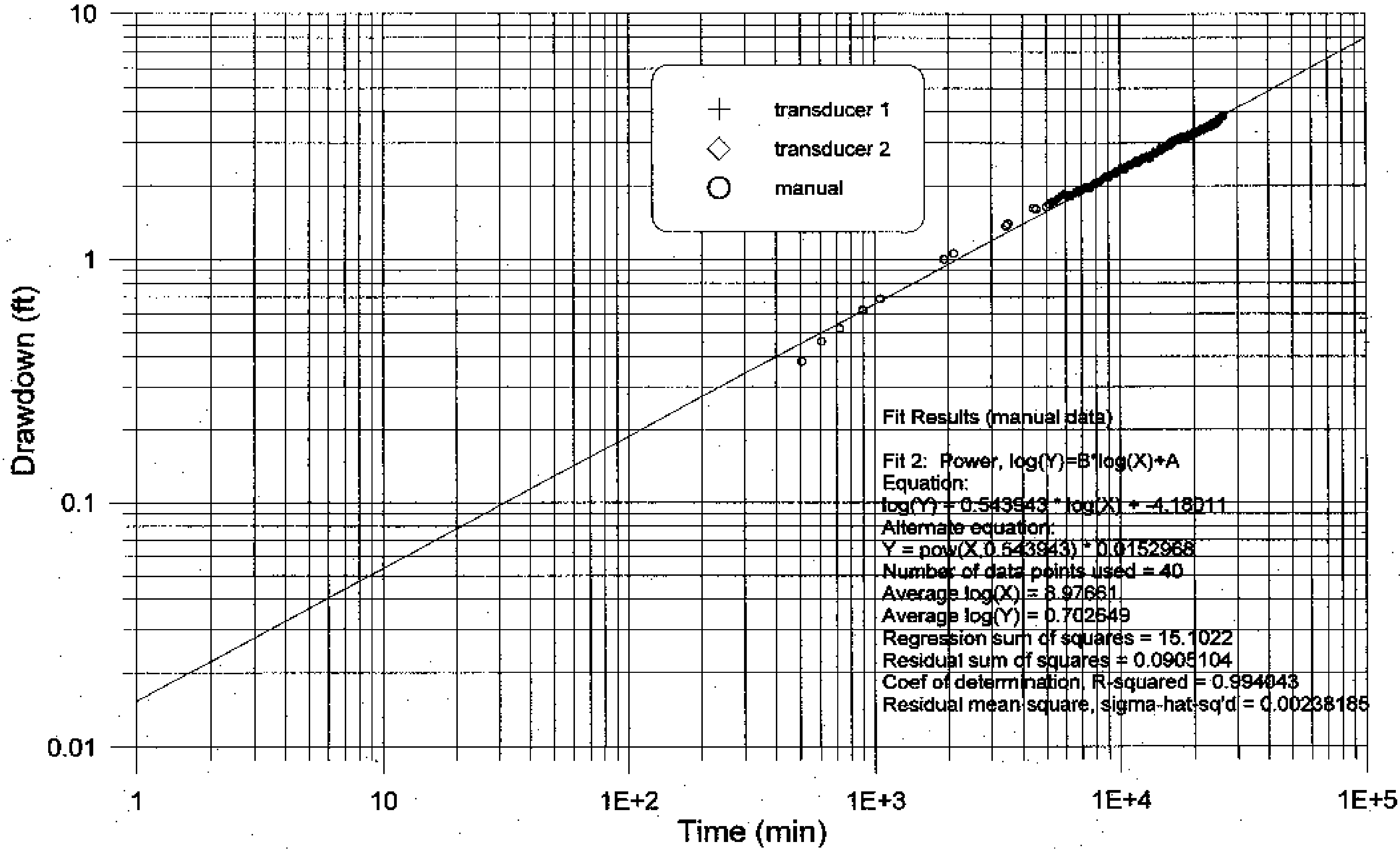
u:\chempump\longterm\4028l3x5.grf

Figure C.30 - MW-3029 (Q = 10.7 gpm, r = 46.5 ft)



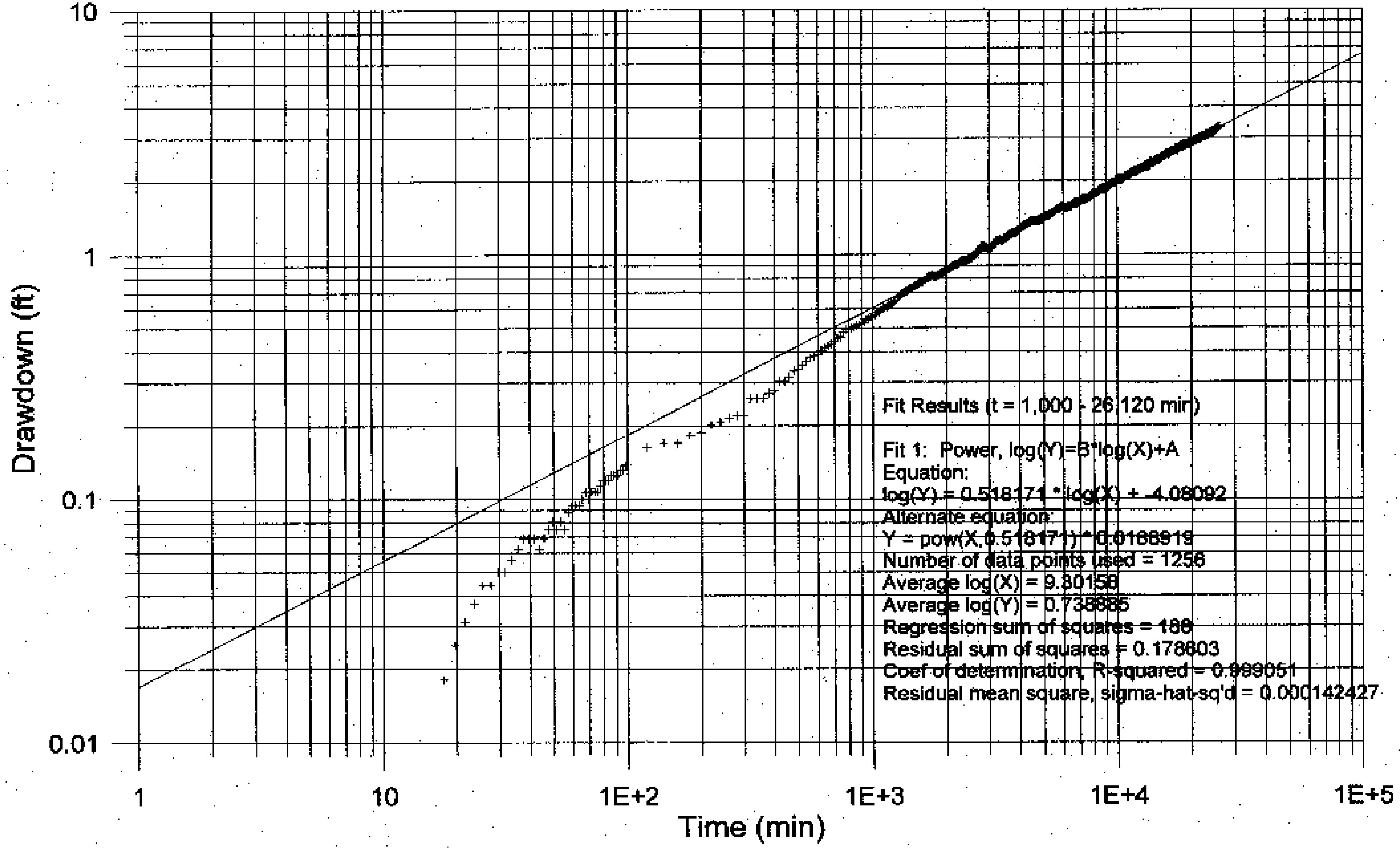
u:\chempump\longterm\3029l3x5.grf

Figure C.31 - MW-2037 (Q = 10.7 gpm, r = 159.5 ft)



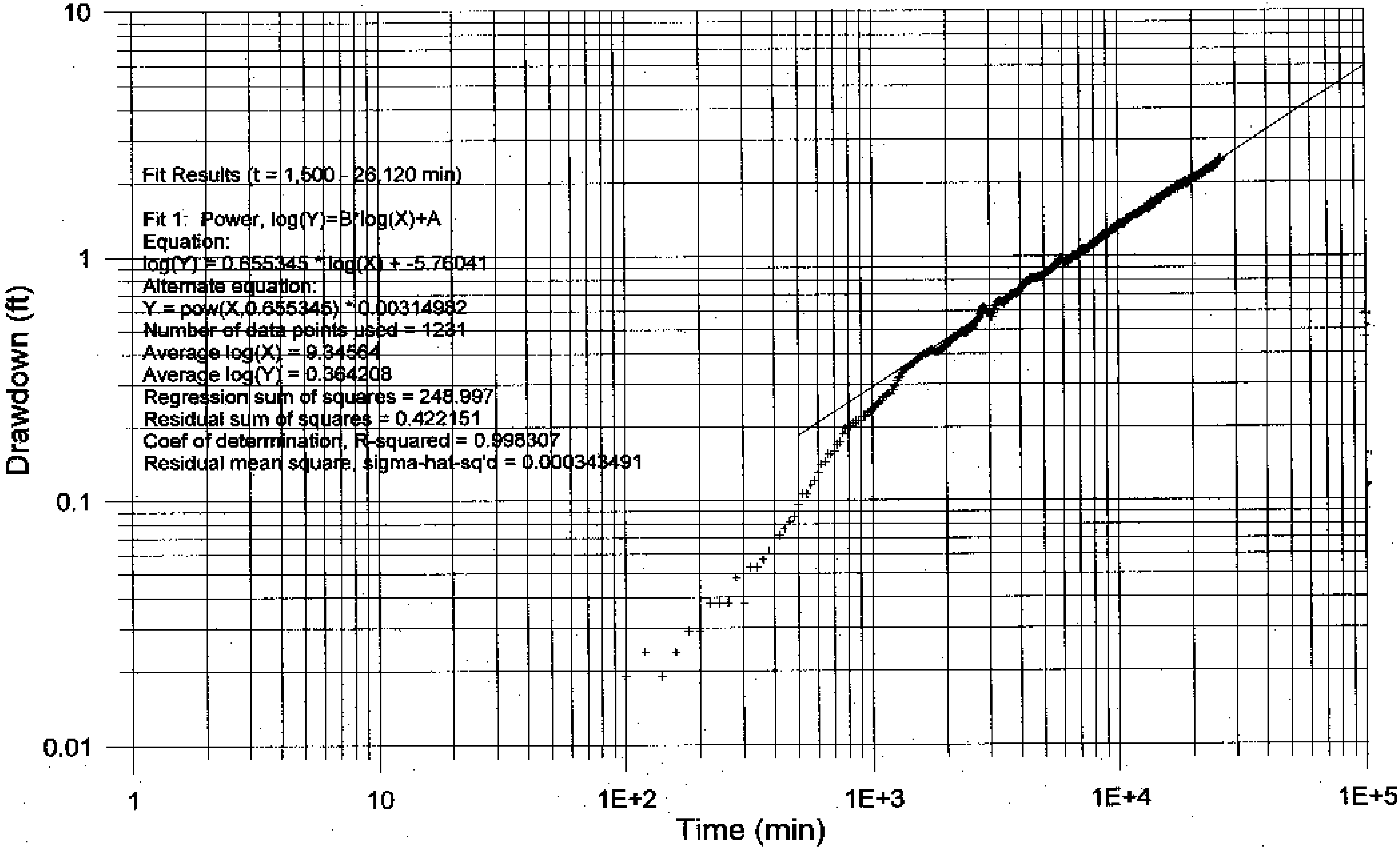
u:\chempump\longterm\2037l3x5.grf

Figure C.32 - MW-4029 (Q = 10.7 gpm, r = 161.2 ft)



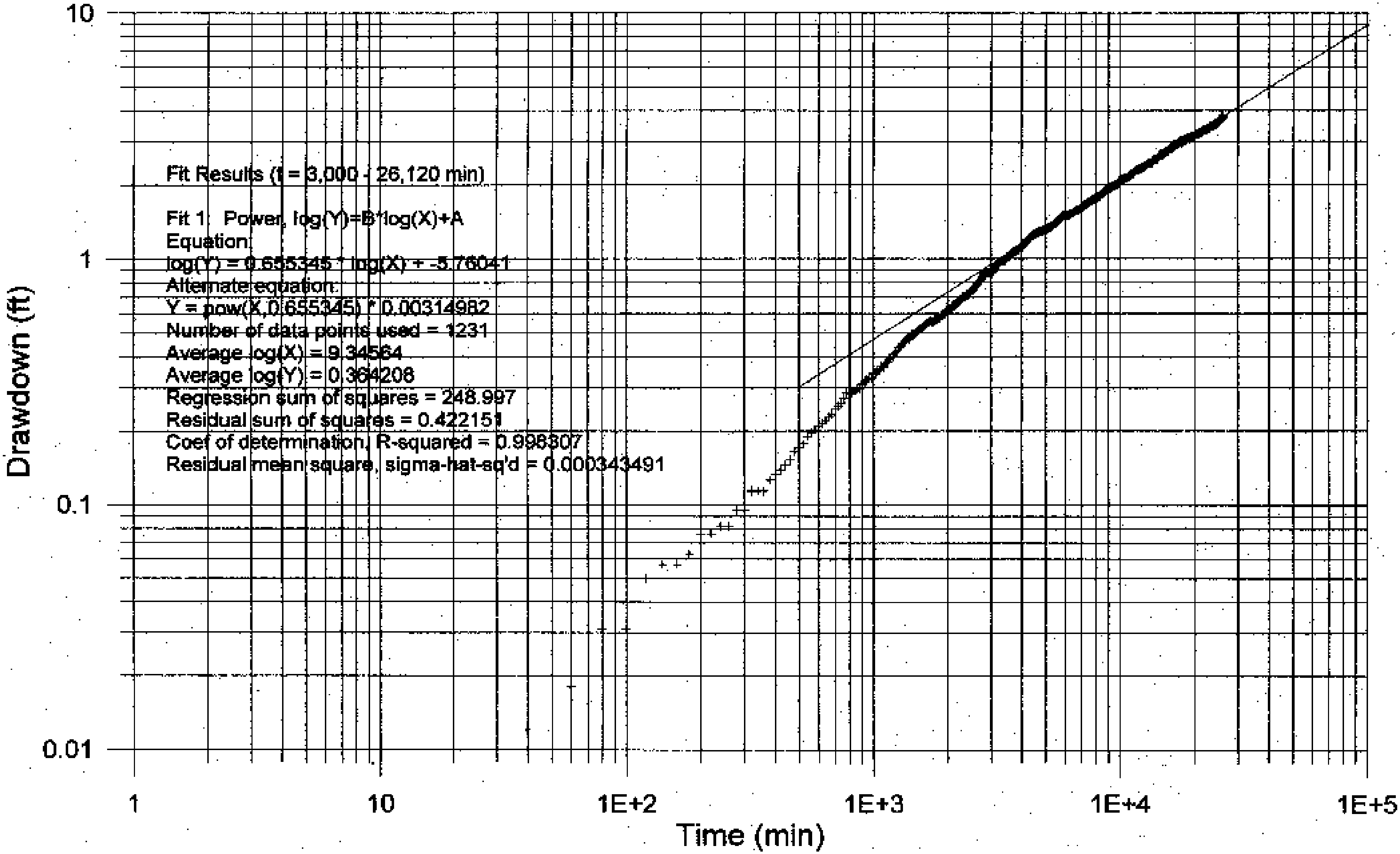
u:\chempump\longterm\4029l3x5.grf

Figure C.33 - MWS-21 (Q = 10.7 gpm, r = 188.9 ft)



u:\chempump\longterm\s21l3x5.grf

Figure C.34 - MW-4027 (Q = 10.7 gpm, r = 204.5 ft)



u:\chempump\longterm\4027l3x5.grf

Figure C.35 - MW-2036 (Q = 10.7 gpm, r = 479.9 ft)

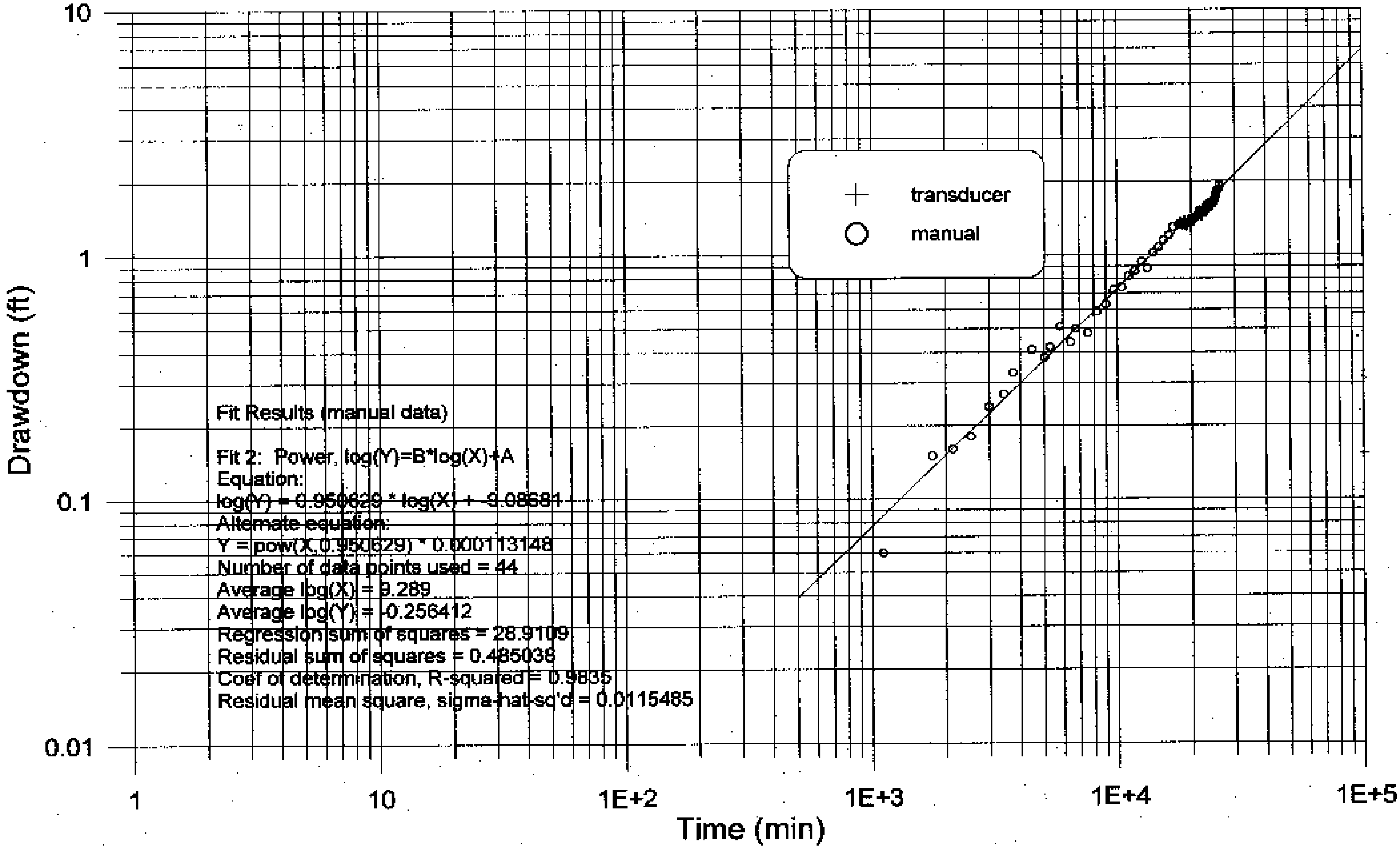


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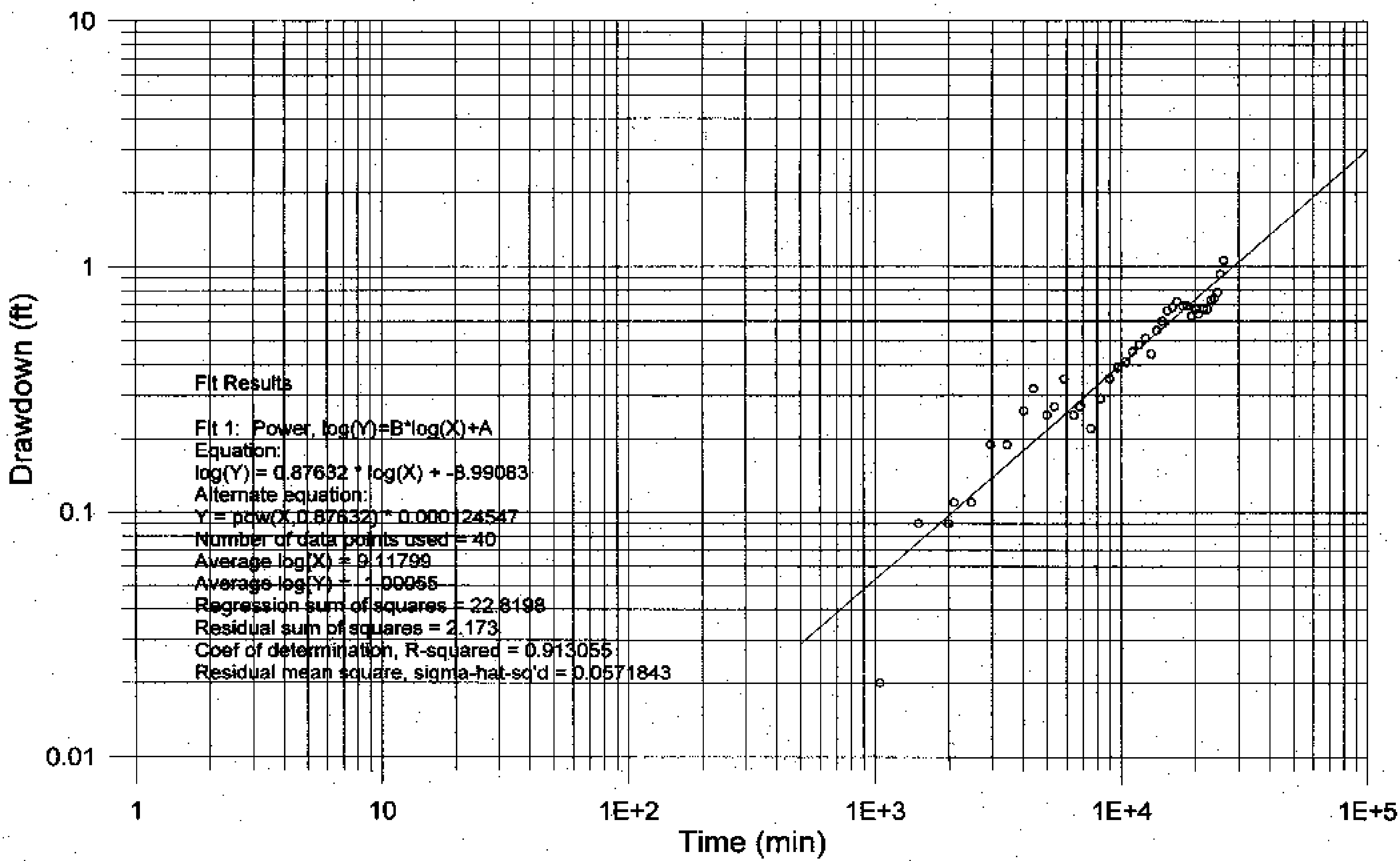
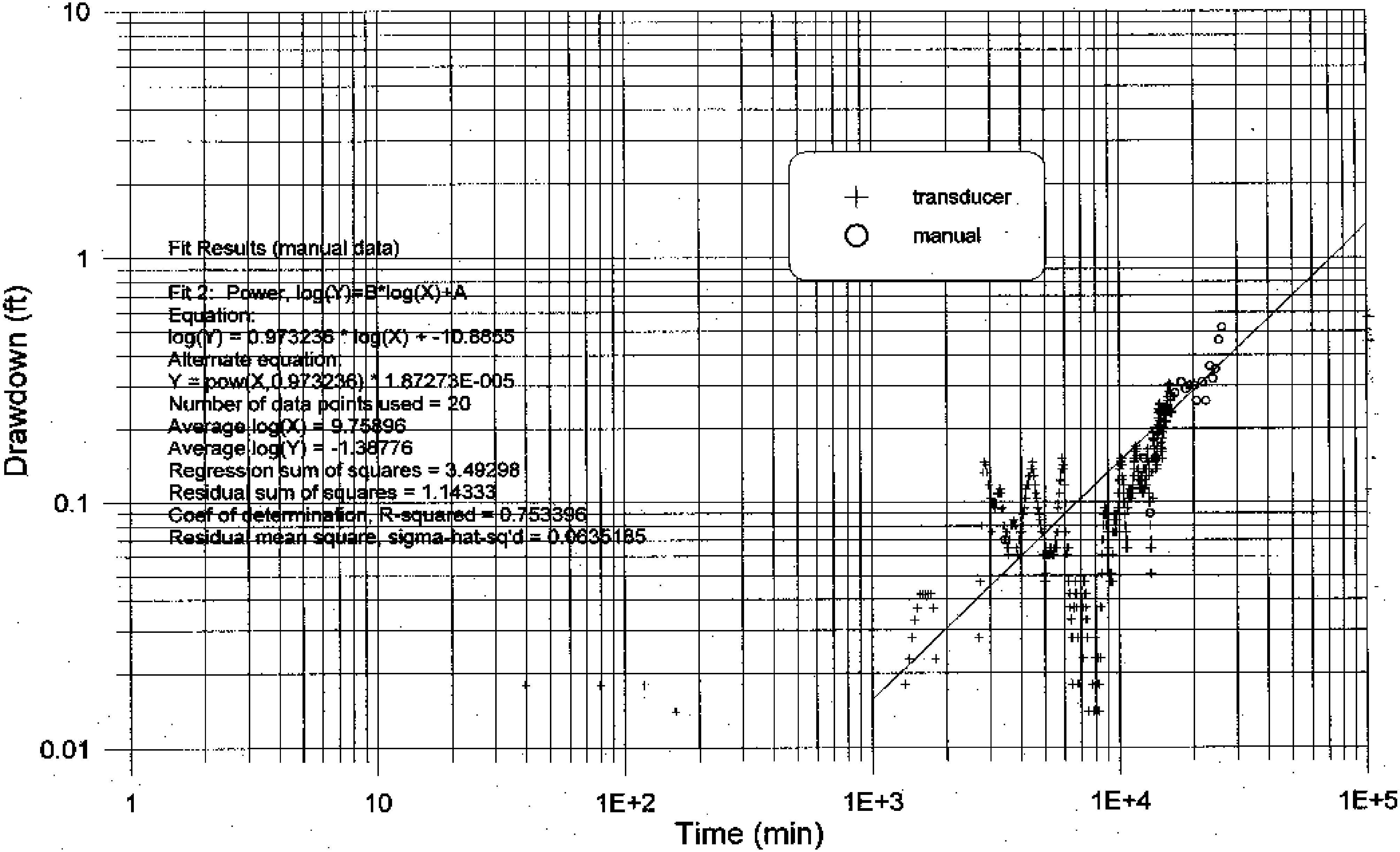
Figure C.36 - MW-2038 (Q = 10.7 gpm, r = 598.2 ft)



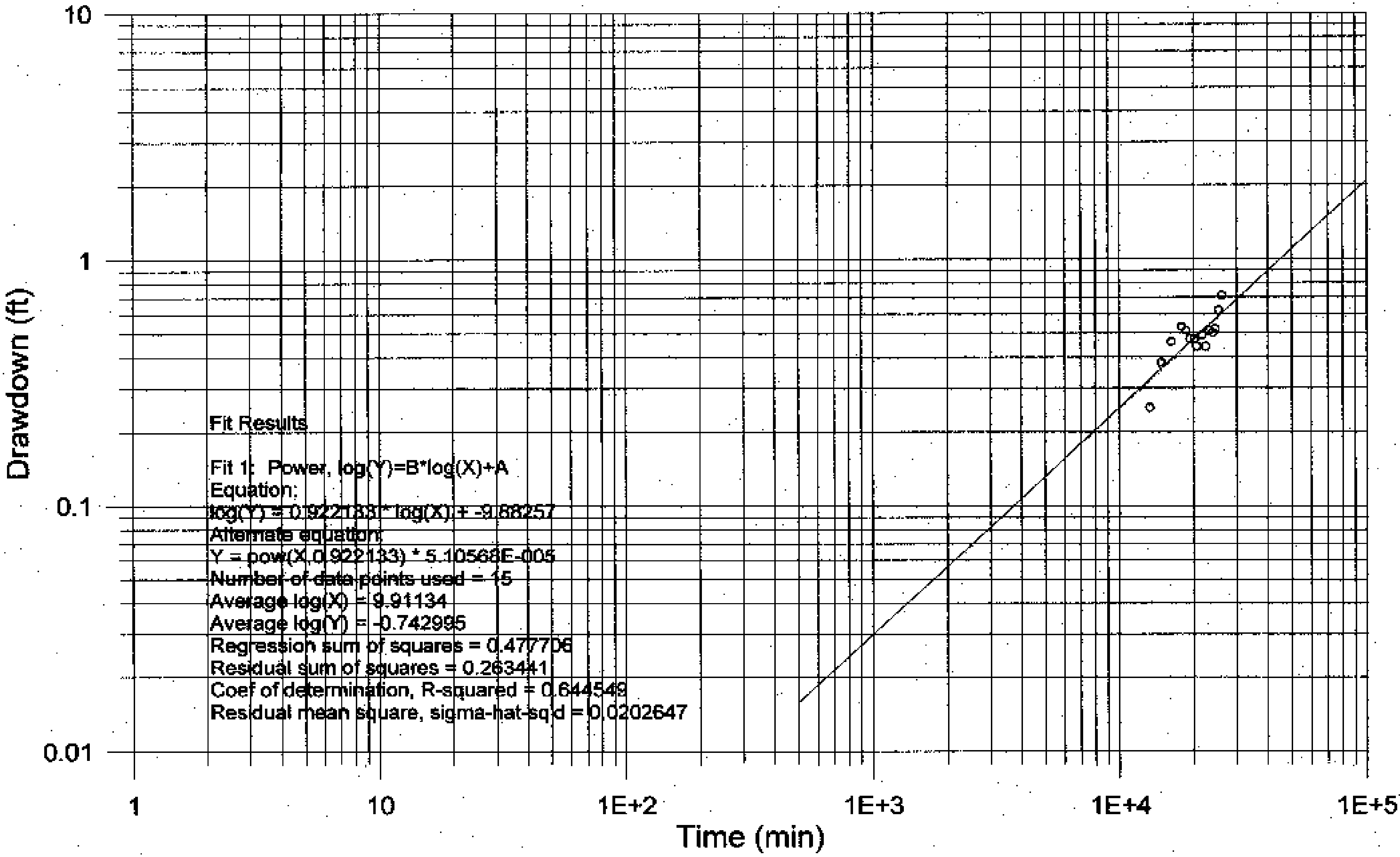
u:\chempump\longterm\2038l3x5.grf

Figure C.37 - MW-3027 (Q = 10.7 gpm, r = 619.8 ft)



u:\chempump\longterm\3027l3x5.grf

Figure C.38 - MW-3026 (Q = 10.7 gpm, r = 621.9 ft)
Unweathered Retrofit Well



u:\chempump\longterm\3026l3x5.grf

Figure C.39 - Pumping Well Type Curve for Early and Medium Pumping Times

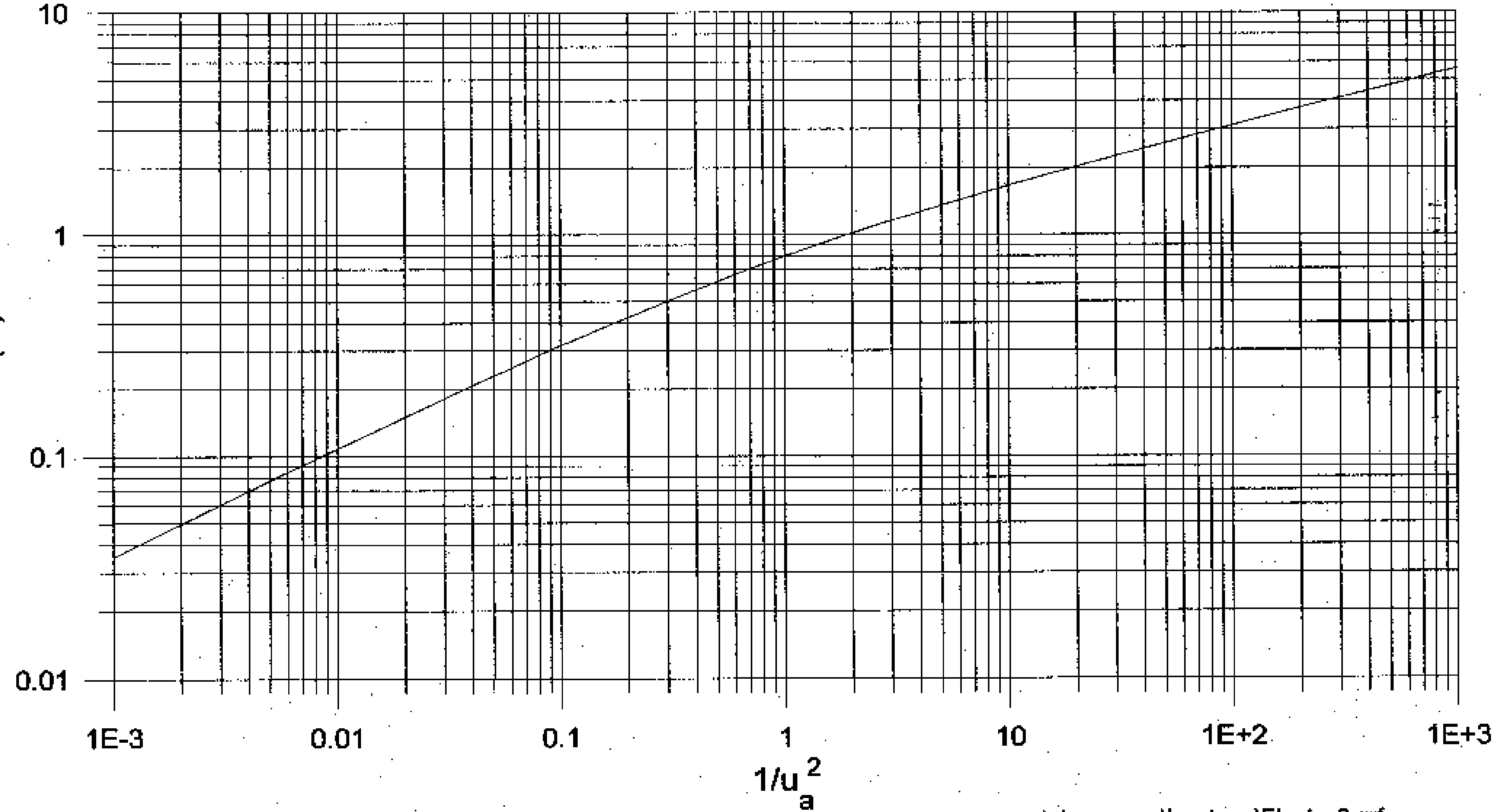


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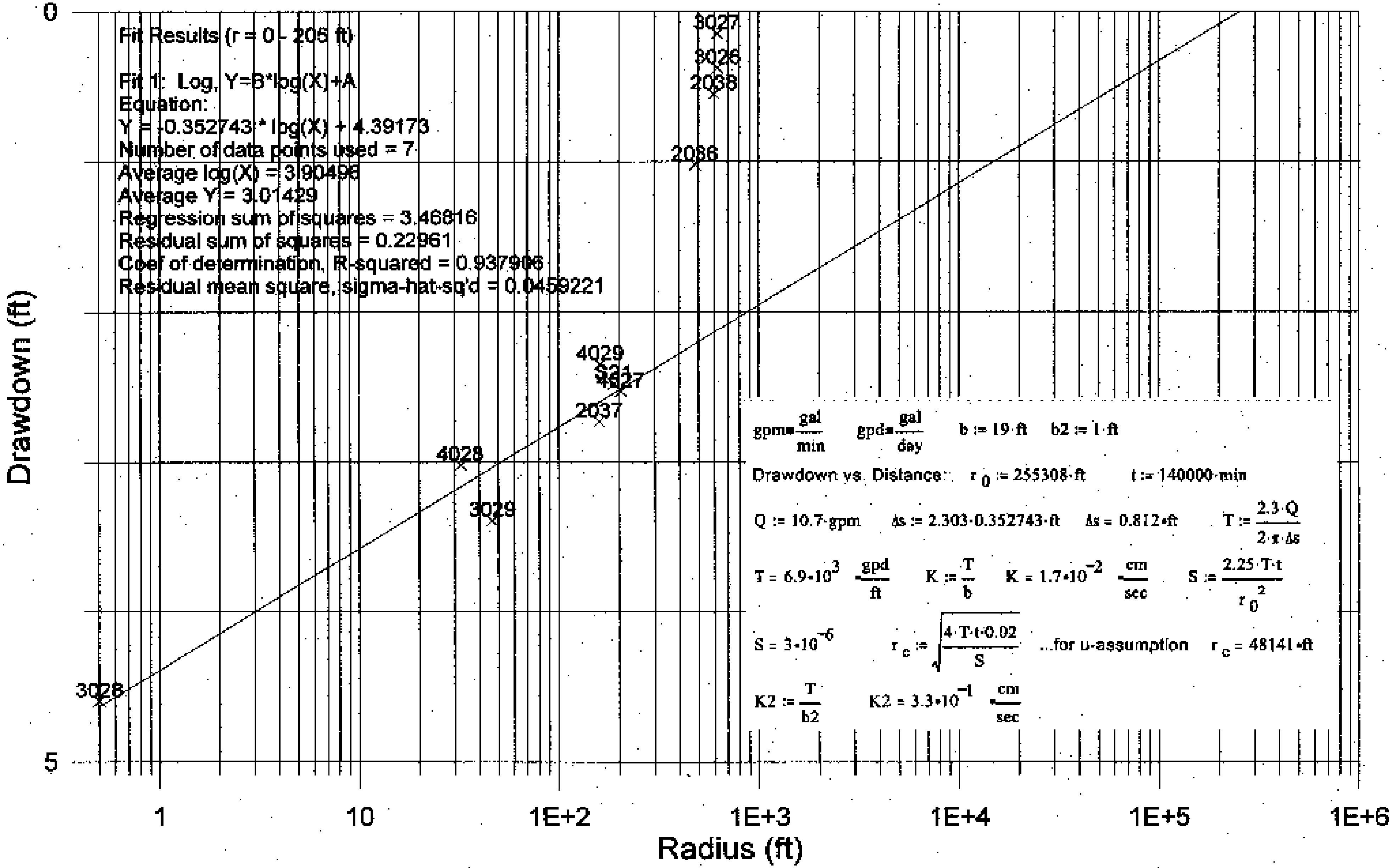
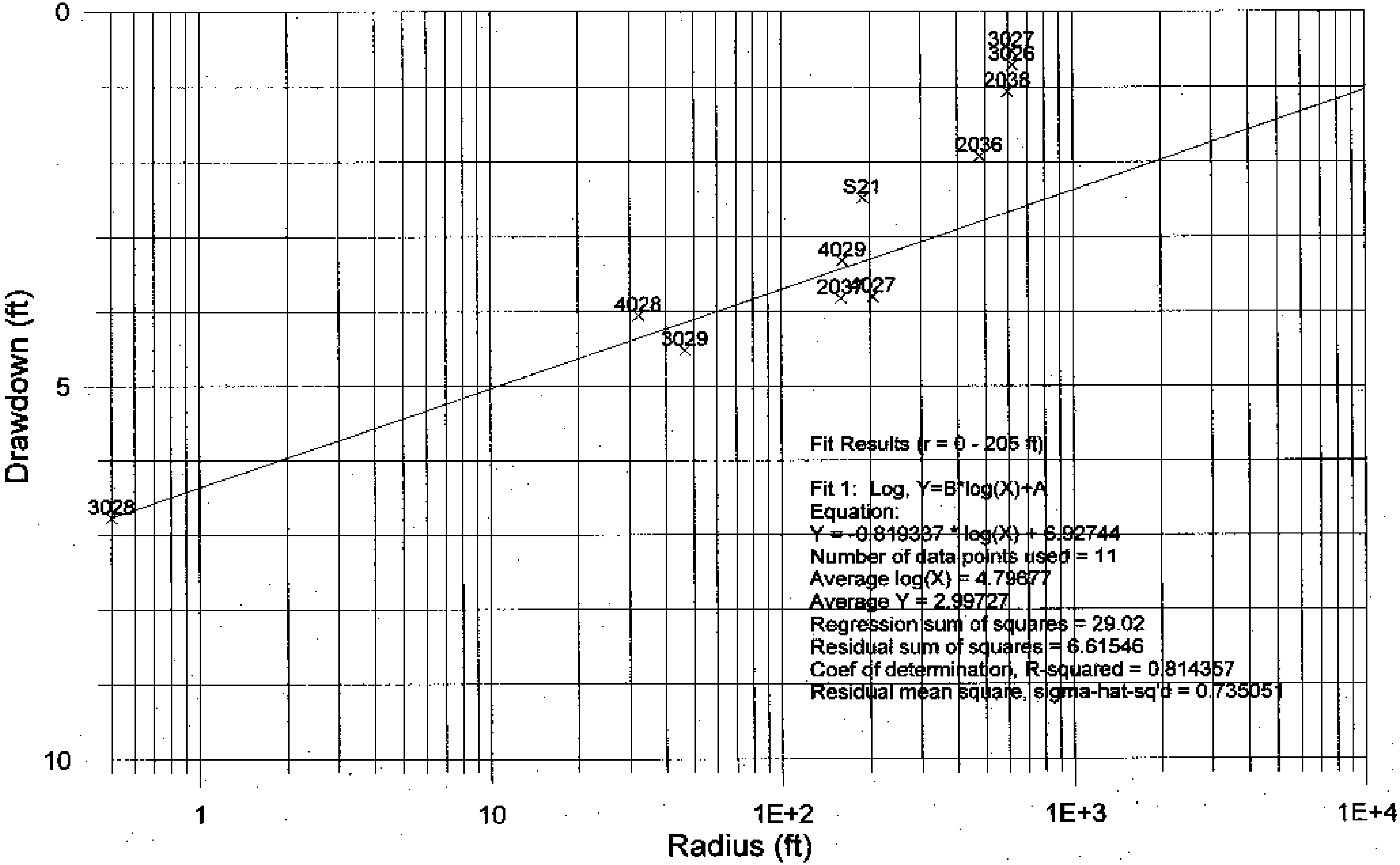
Figure C.40 - Drawdown vs. Distance (Q = 10.7 gpm, 7/23/98))



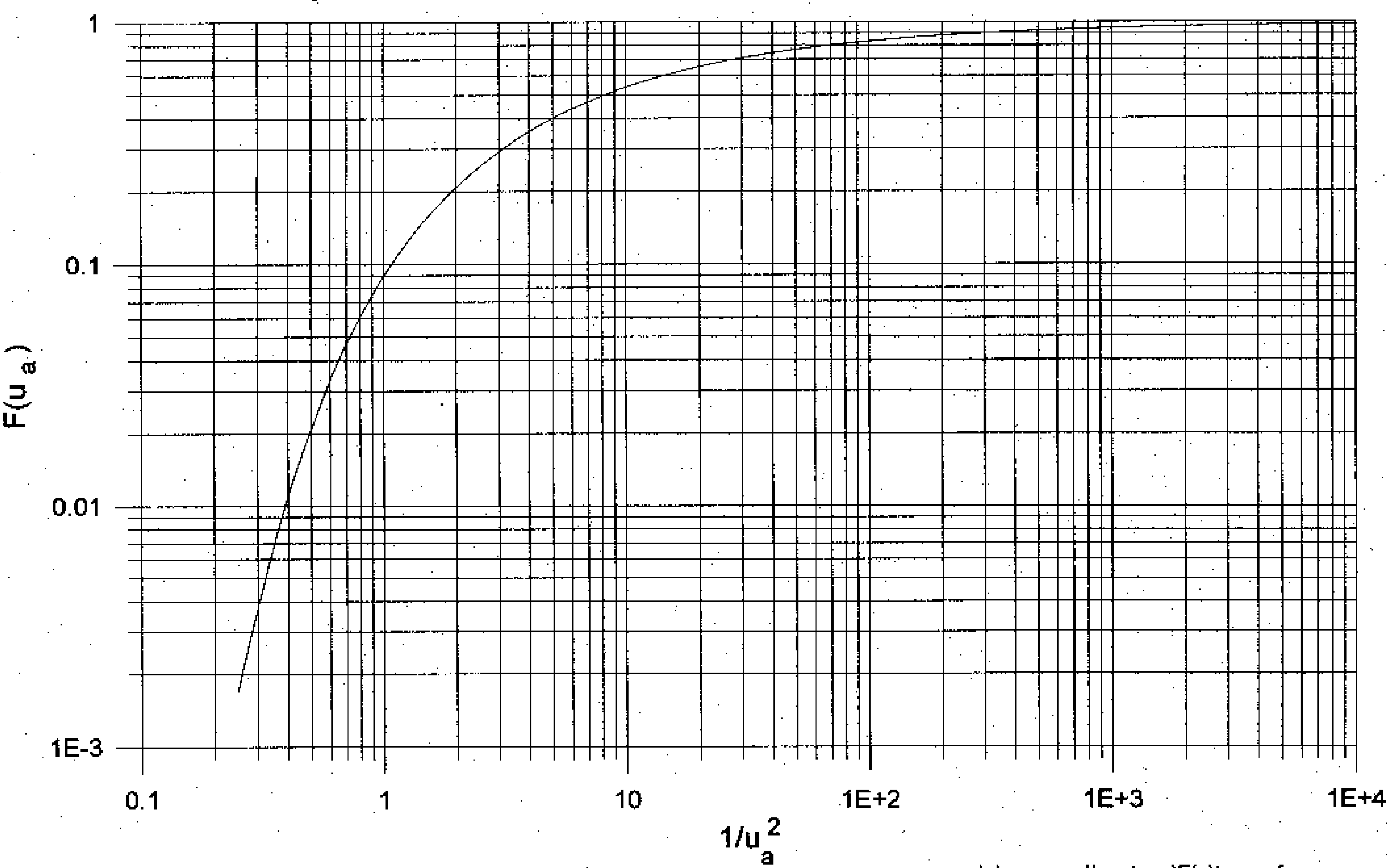
u:\chempump\longterm\dist-723.grf

Figure C.41 - Drawdown vs. Distance (Q = 10.7 gpm, 7/31/98))



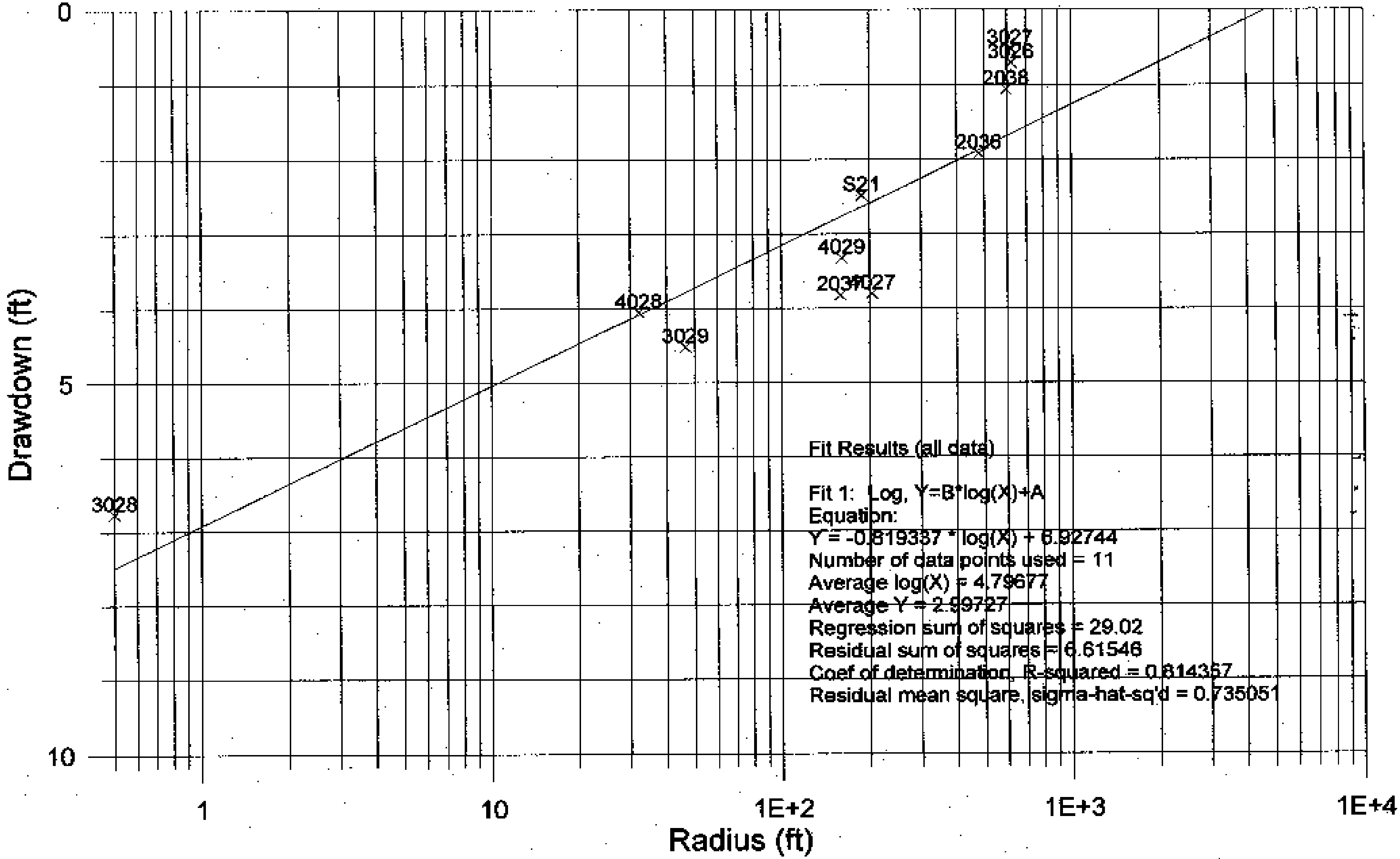
u:\chempump\longterm\dist-731.grf

Figure C.42 - Drawdown Ratio Type Curve for Wells in Aquifer



u:\chempump\longterm\F(u)type.grf

Figure C.43 - Drawdown vs. Distance (Q = 10.7 gpm, 7/31/98))



u:\chempump\longterm\dist731b.grf

Figure C.44 - Drawdown vs. t/r^2

u:\champump\longtermt-r2-5x7.grf

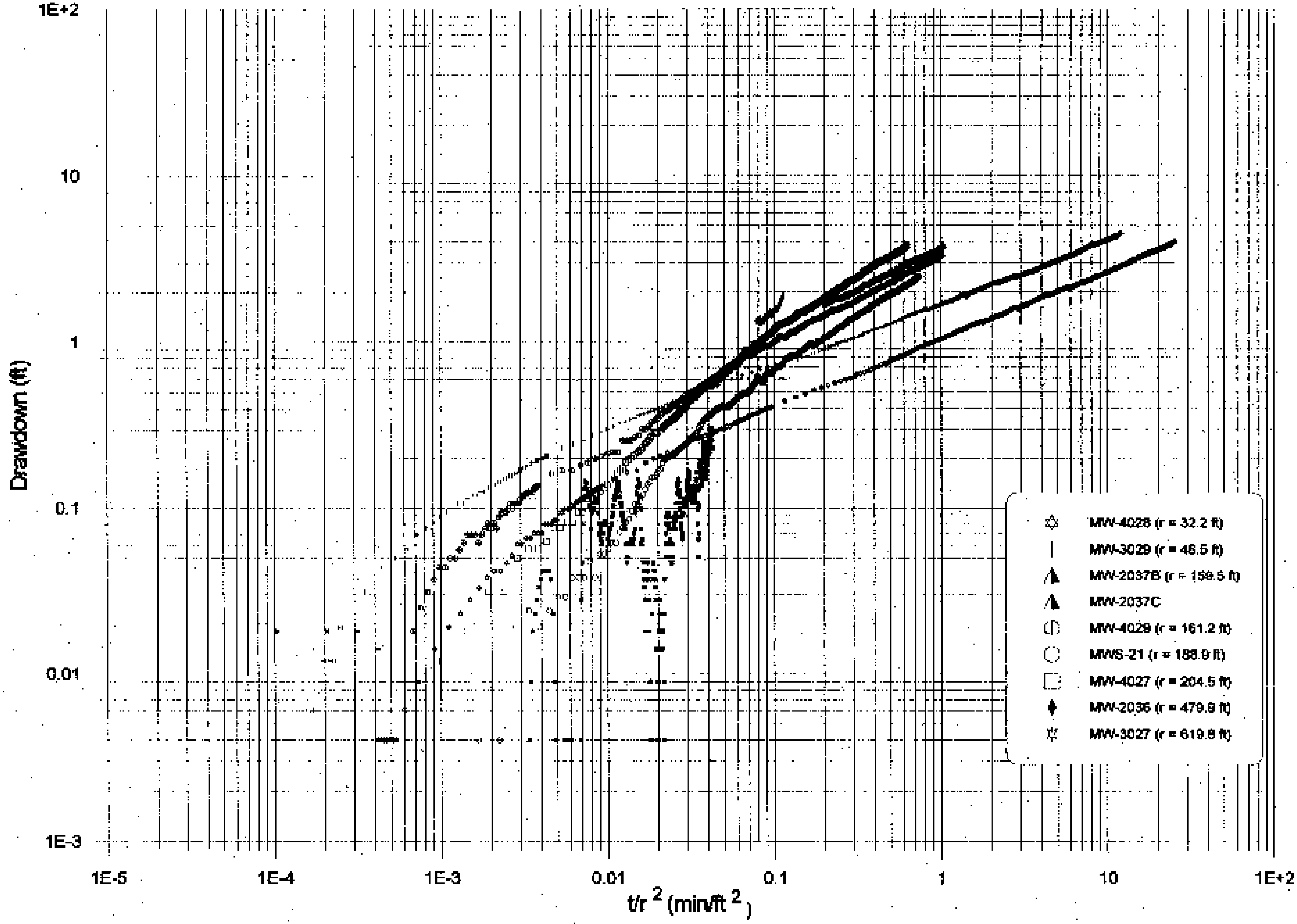
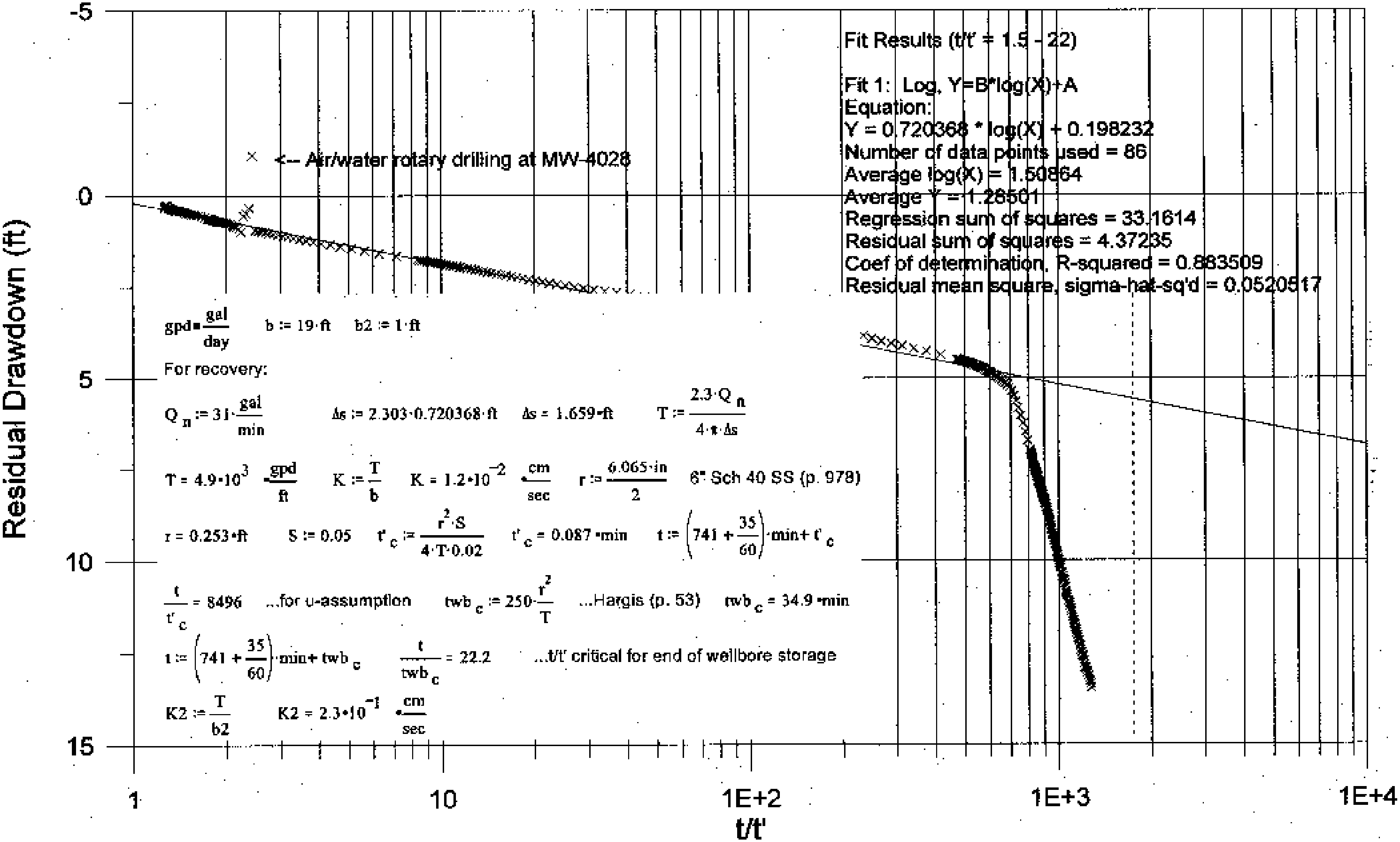
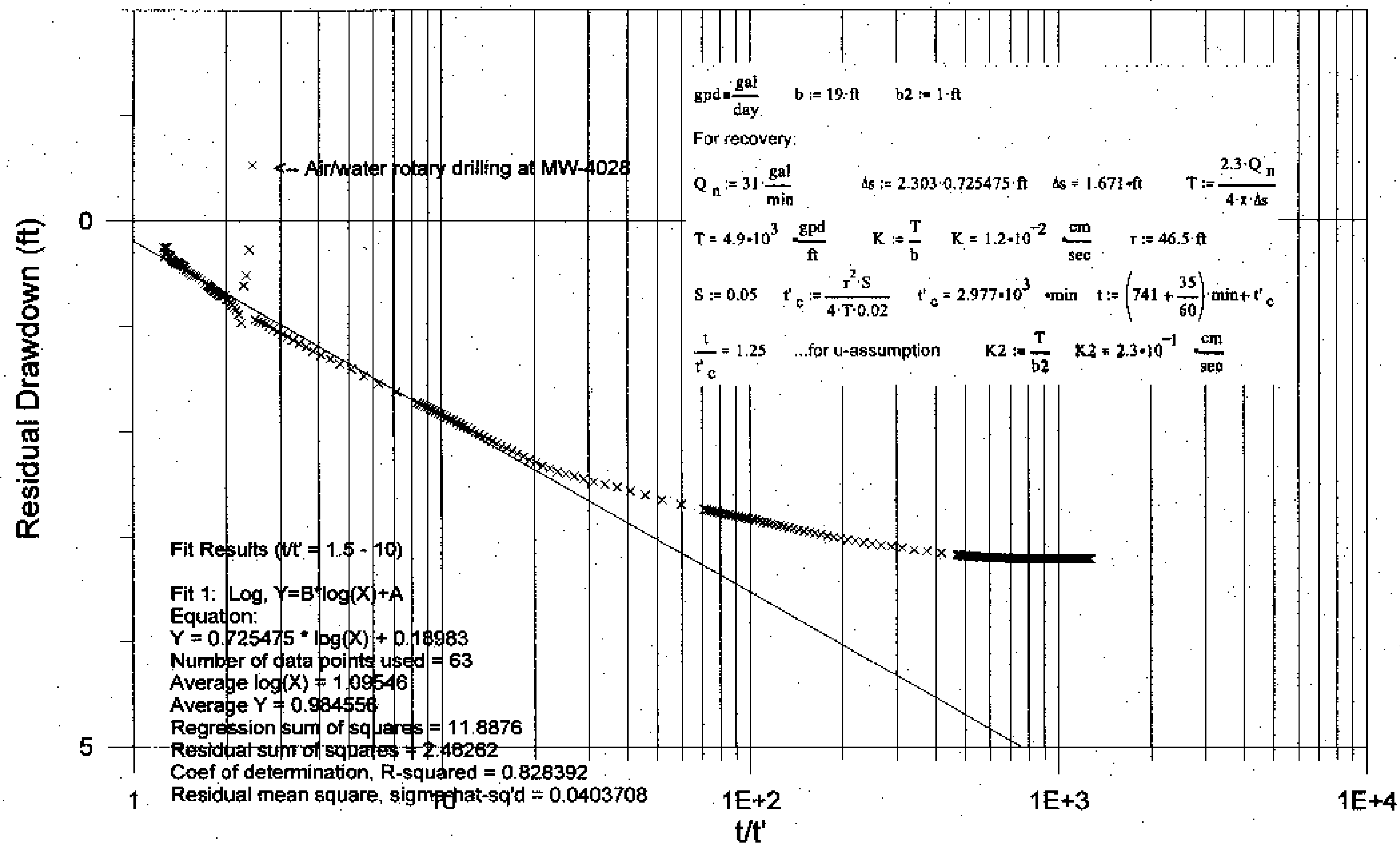


Figure C.45 - MW-3028 Recovery (Q = 31 gpm, r = 0 ft)



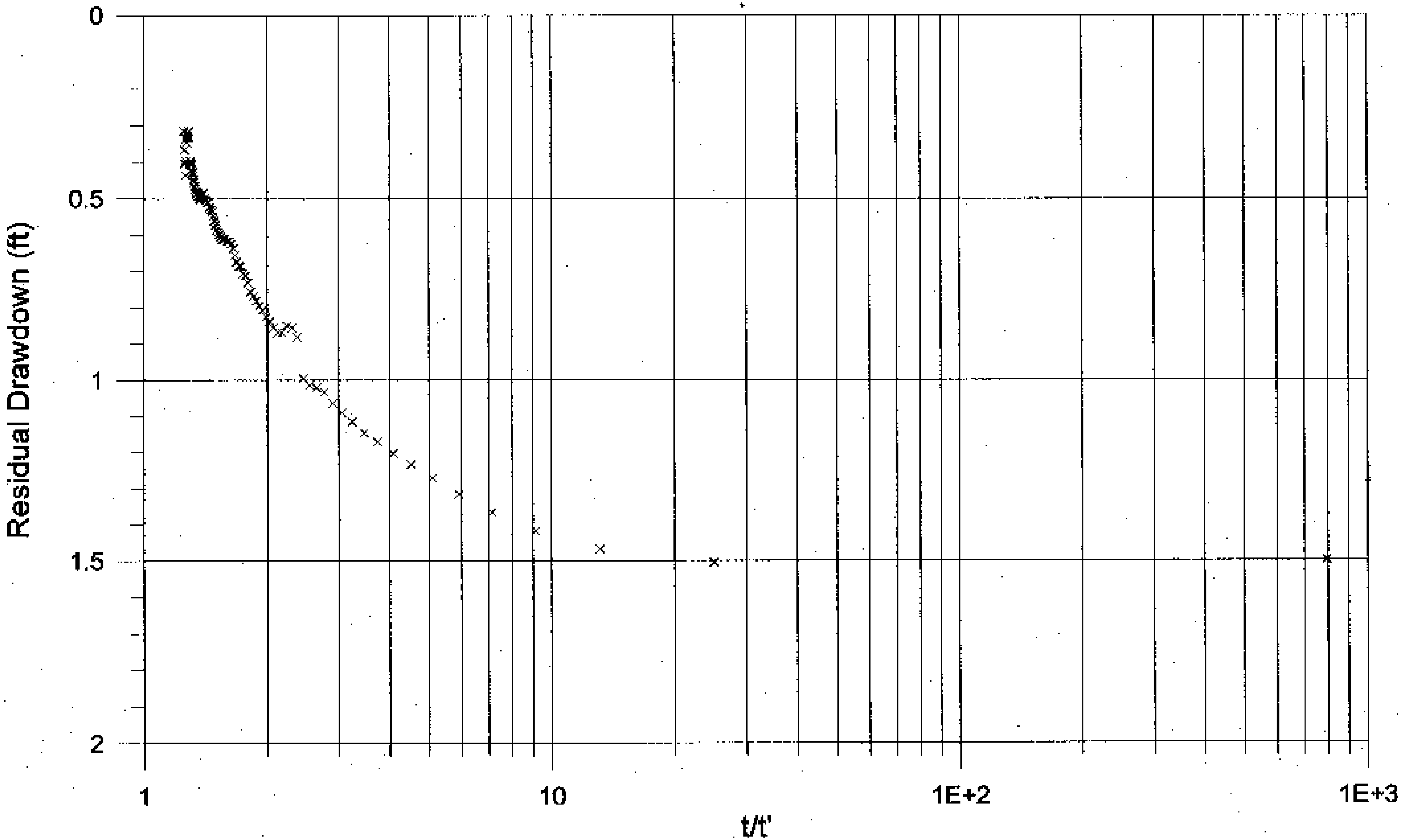
u:\chempump\q=31\3028-rec.grf

Figure C.46 - MW-3029 Recovery (Q = 31 gpm, r = 46.5 ft)



u:\chempump\q=31\3029-rec.grf

Figure C.47 - MW-2037 Recovery (Q = 31 gpm, r = 159.5 ft)



u:\chempump\q=31\2037-rec.grf

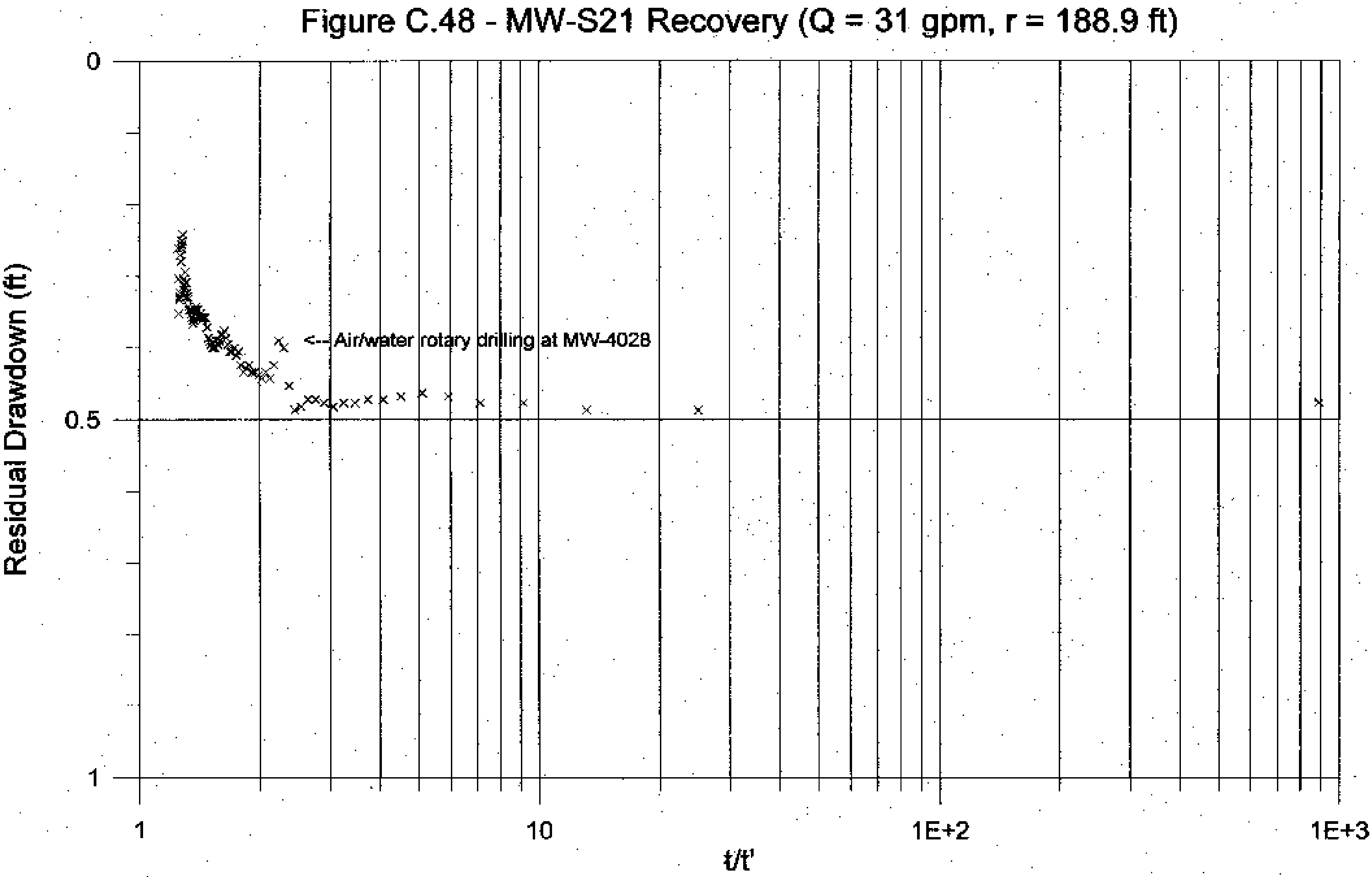
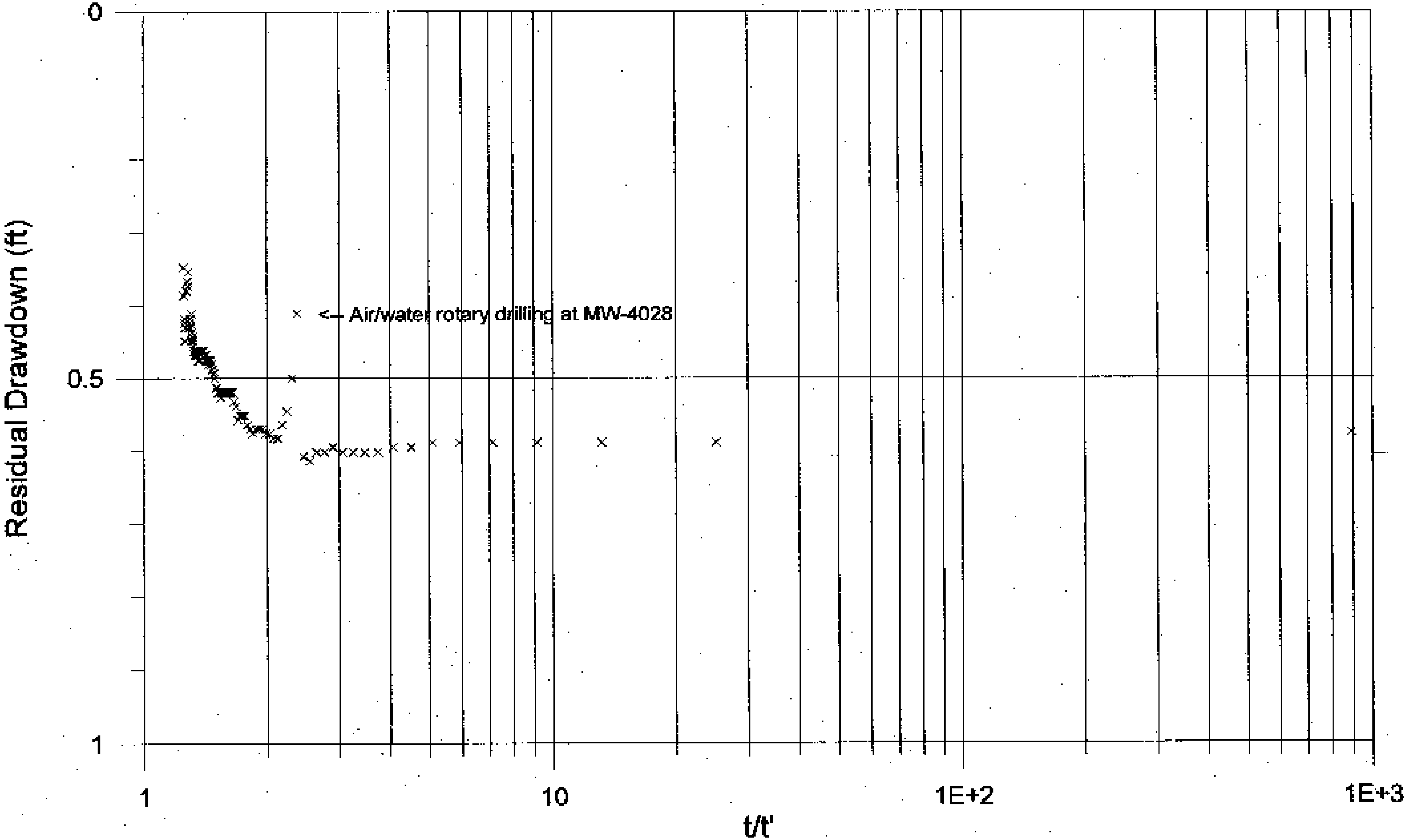


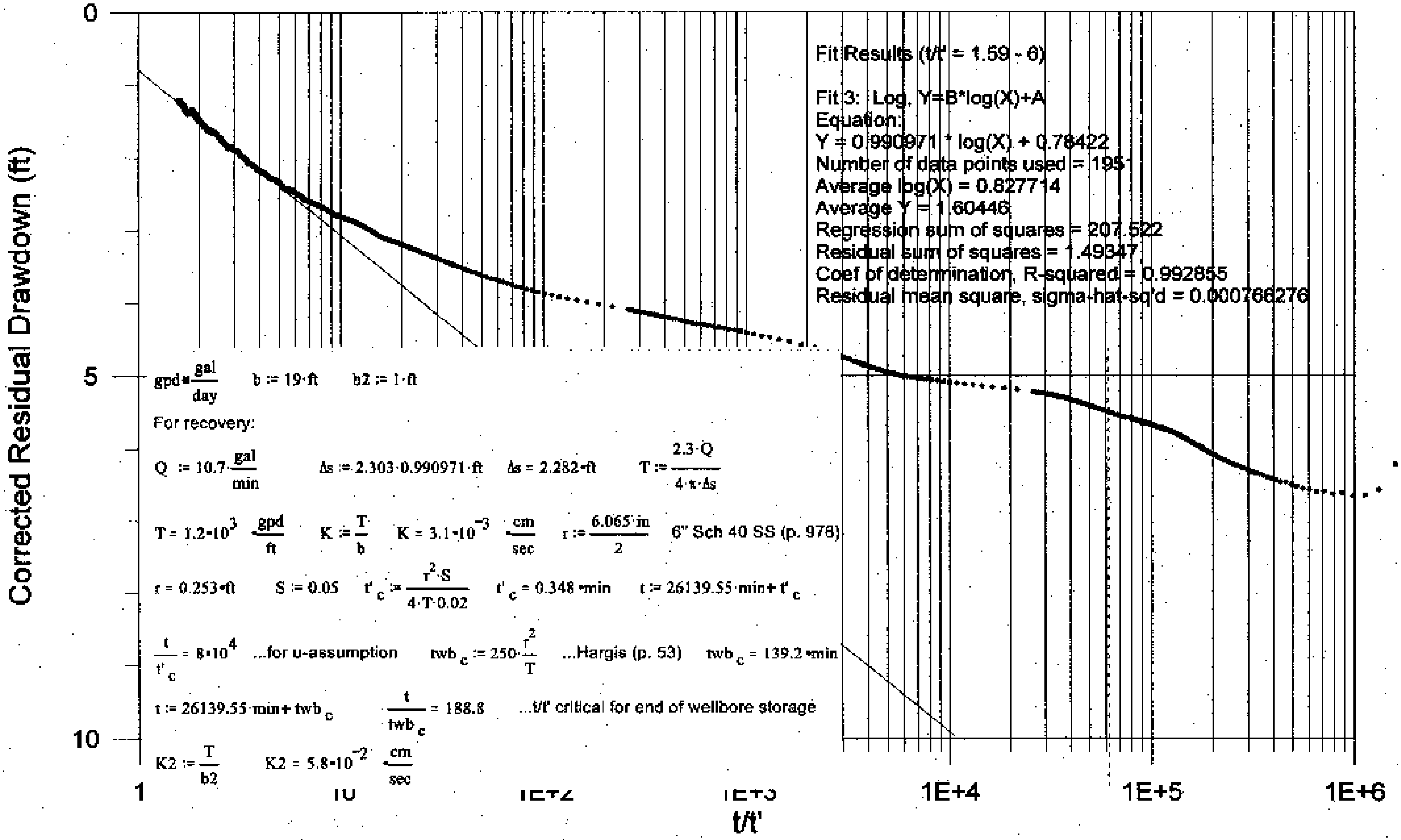
Figure C.48 - MW-S21 Recovery (Q = 31 gpm, r = 188.9 ft)
Residual Drawdown (ft)
0
0.5
1
1
10
1E+2
1E+3
t/t'
<-- Air/water rotary drilling at MW-4028
u:\chempump\q=31\mw21-rec.grf

Figure C.49 - MW-4027 Recovery (Q = 31 gpm, r = 204.5 ft)



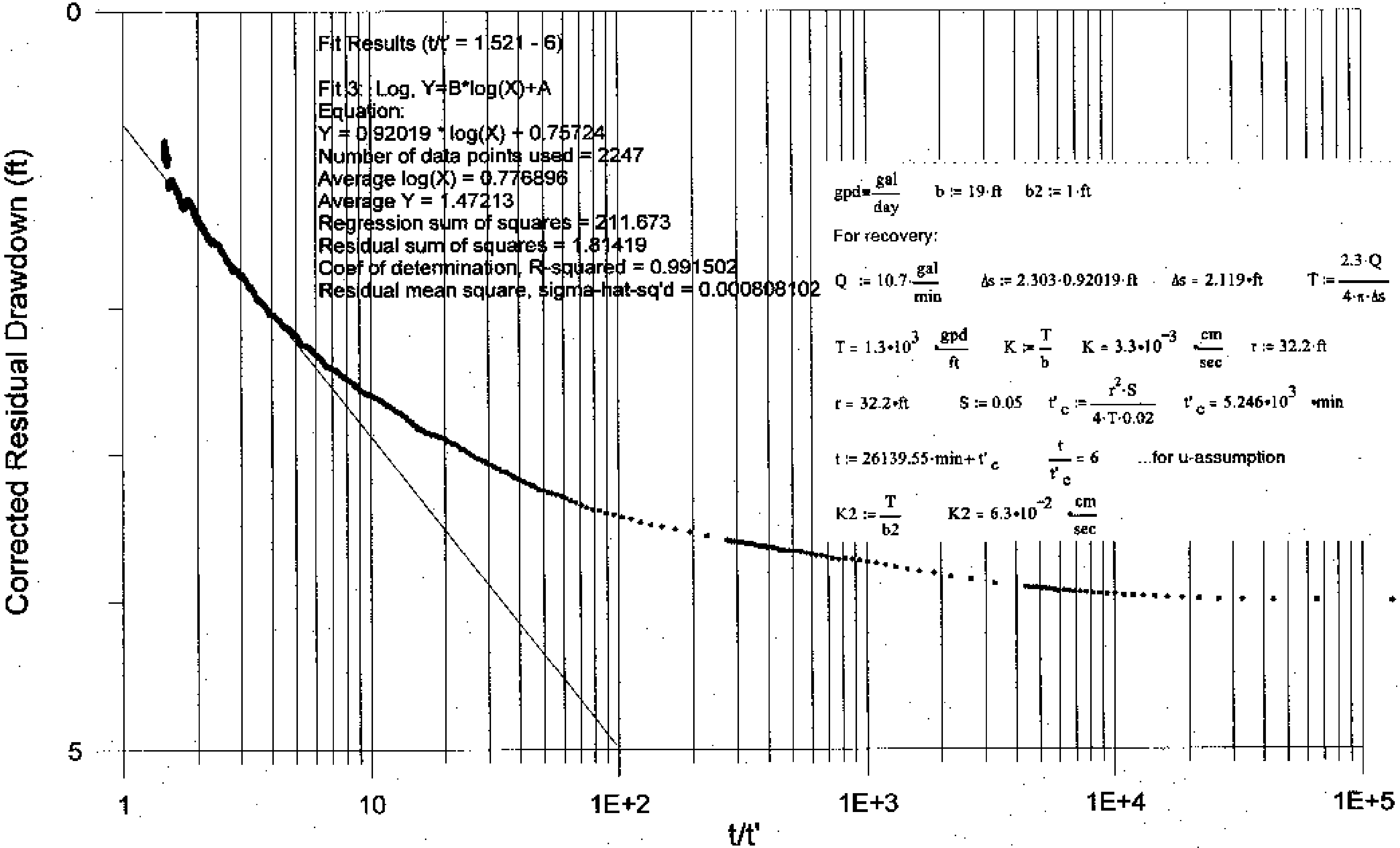
u:\chempump\q=31\4027-rec.grf

Figure C.50 - MW-3028 Recovery (Q = 10.7 gpm, r = 0 ft)



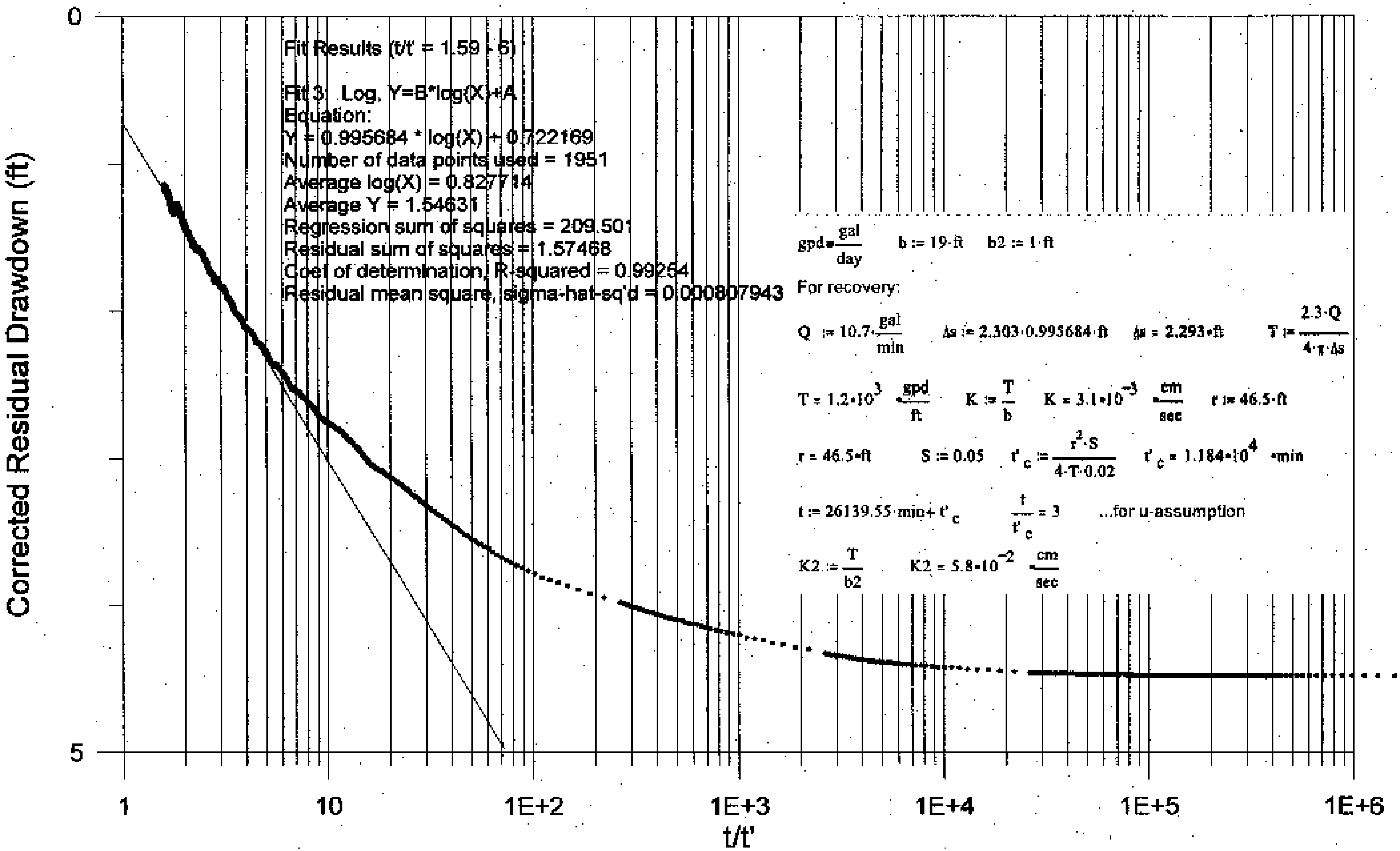
u:\chempump\longterm\rcvrgrfs\3028lrec.grf

Figure C.51 - MW-4028 Recovery (Q = 10.7 gpm, r = 32.2 ft)



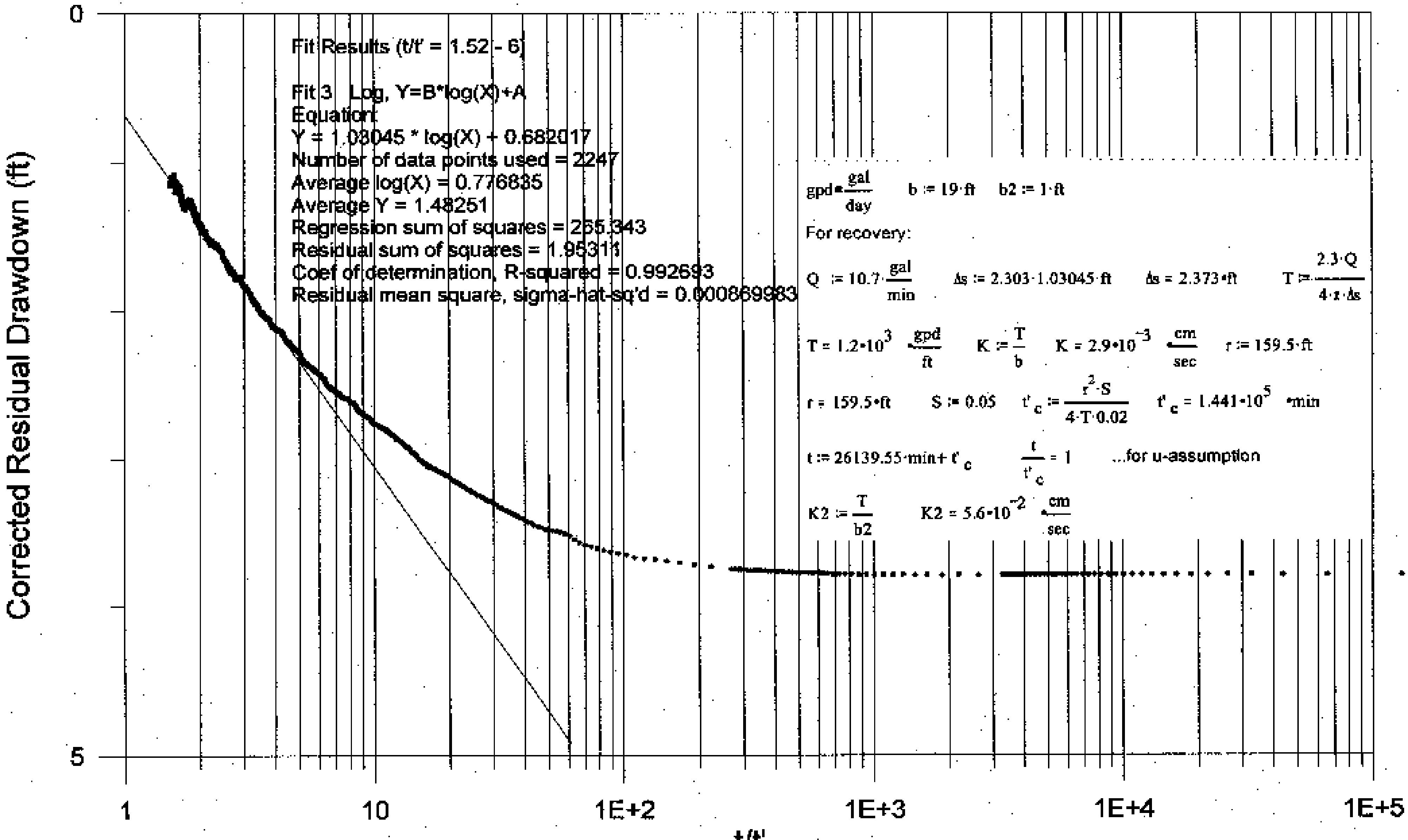
u:\chempump\longterm\rcvrgrfs\4028lrec.grf

Figure C.52 - MW-3029 Recovery (Q = 10.7 gpm, r = 46.5 ft)



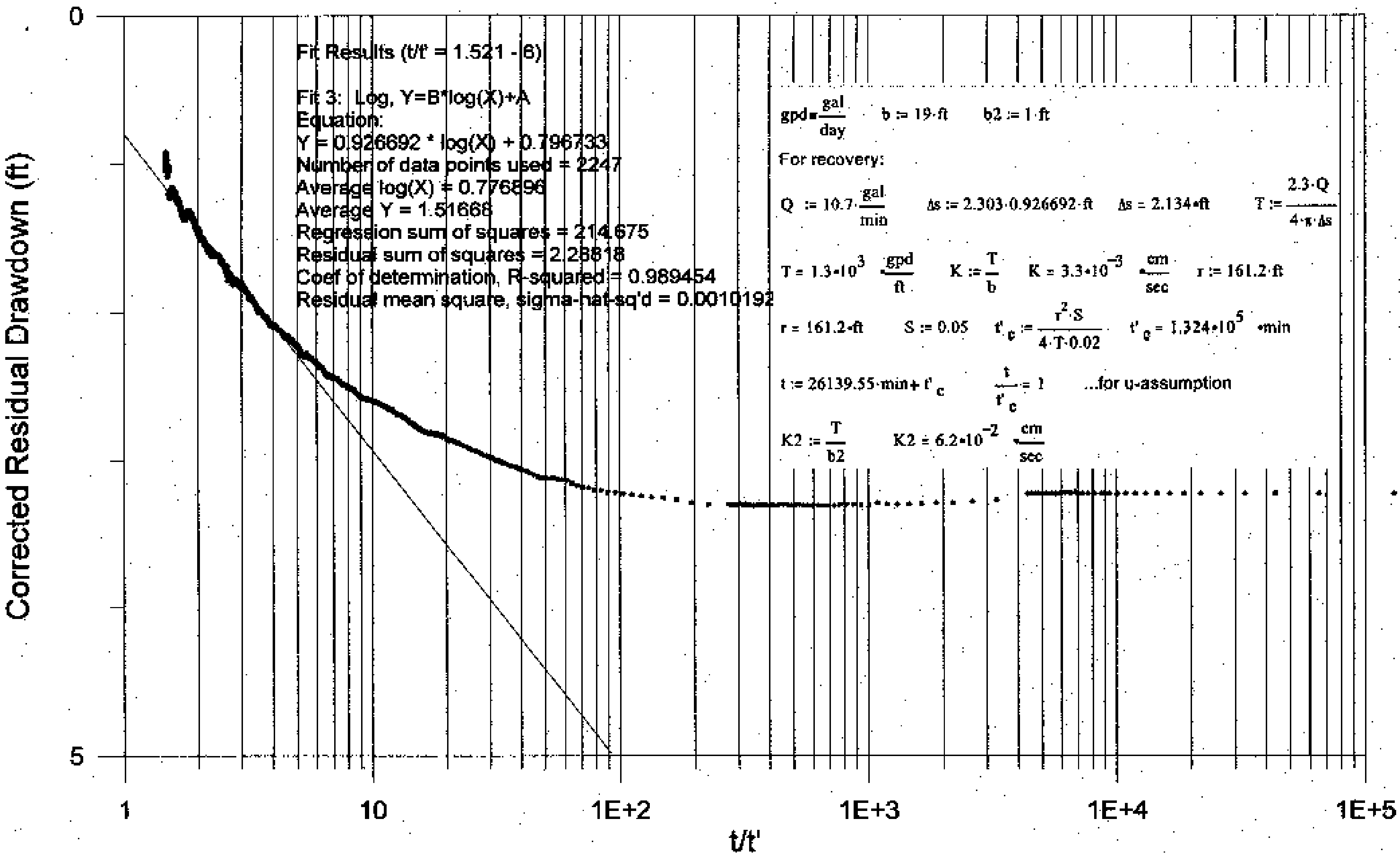
u:\chempump\longterm\rcvrgrfs\3029lrec.grf

Figure C.53 - MW-2037 Recovery (Q = 10.7 gpm, r = 159.5 ft)



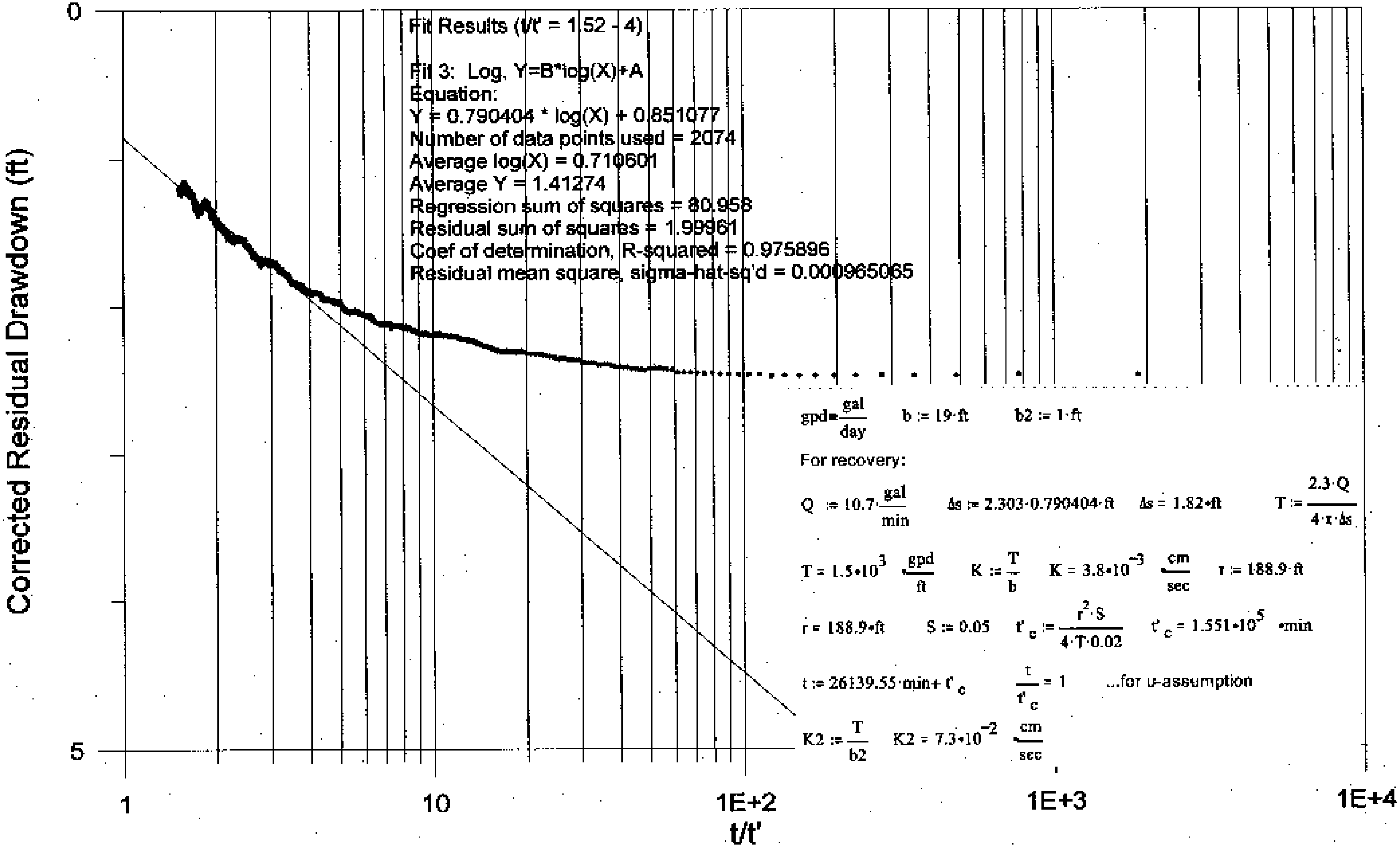
u:\chempump\longterm\rcvrgrfs\2037lrec.grf

Figure C.54 - MW-4029 Recovery (Q = 10.7 gpm, r = 161.2 ft)



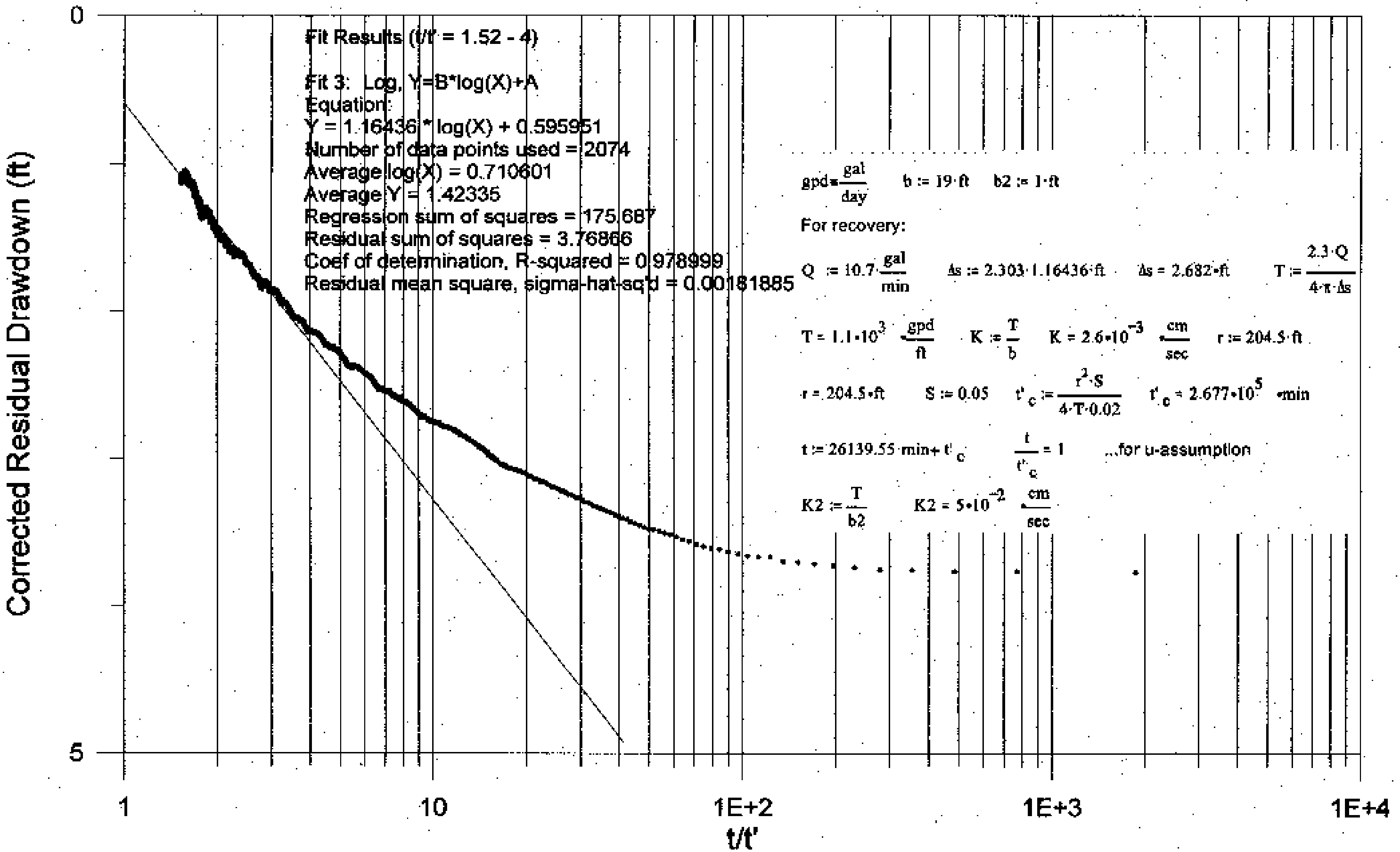
u:\chempump\longterm\rcvrgrfs\4029lrec.grf

Figure C.55 - MWS-21 Recovery (Q = 10.7 gpm, r = 188.9 ft)



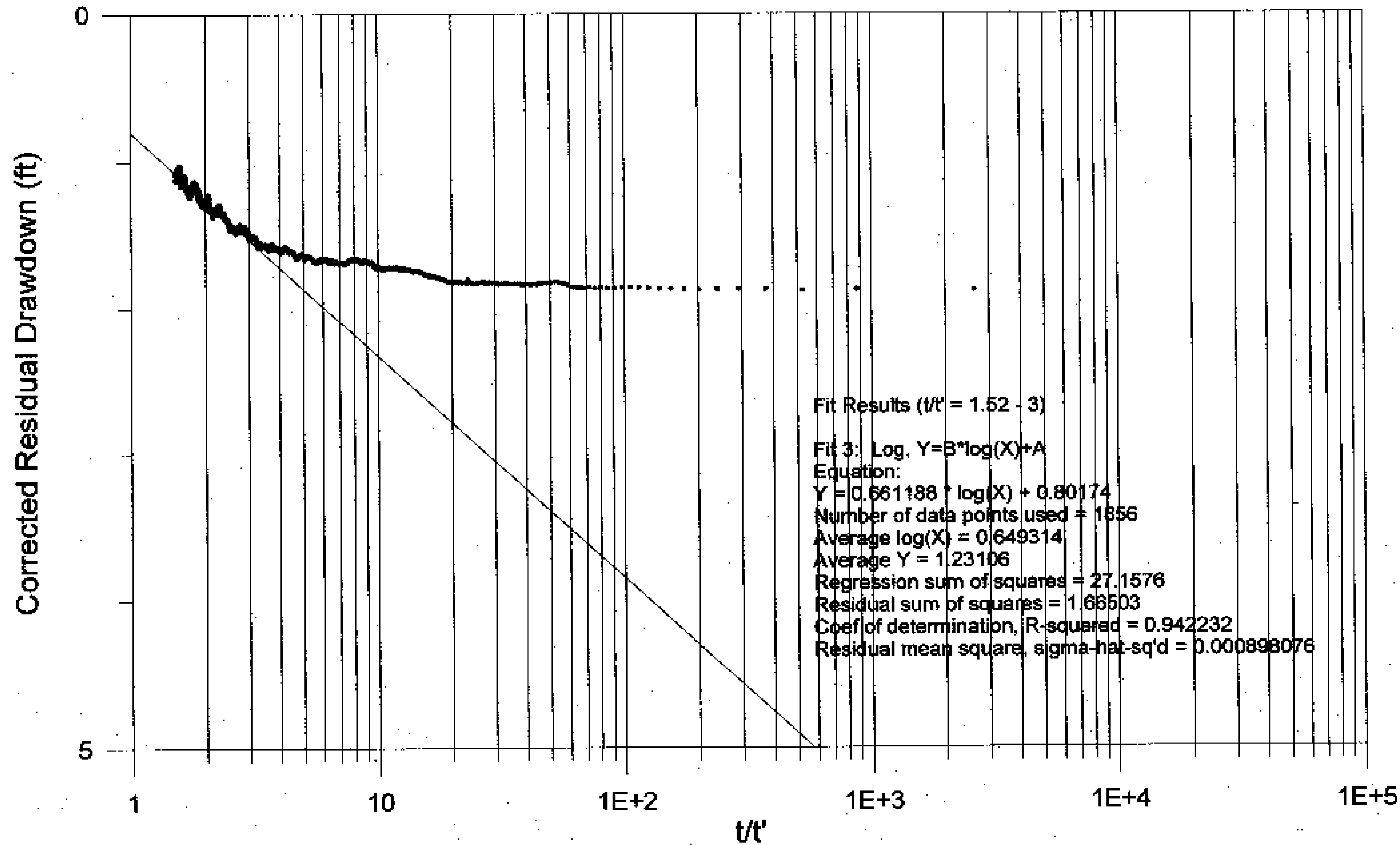
u:\chempump\longterm\rcvrgrfs\s21lrec.grf

Figure C.56 - MW-4027 Recovery (Q = 10.7 gpm, r = 204.5 ft)



u:\chempump\longterm\rcvrgrfs\40271rec.grf

Figure C.57 - MW-2036 Recovery (Q = 10.7 gpm, r = 479.9 ft)



u:\chempump\longterm\rcvrgrfs\2036lrec.grf

Figure C.58 - Drawdown Type Curve for Wells in the Pumped Dike

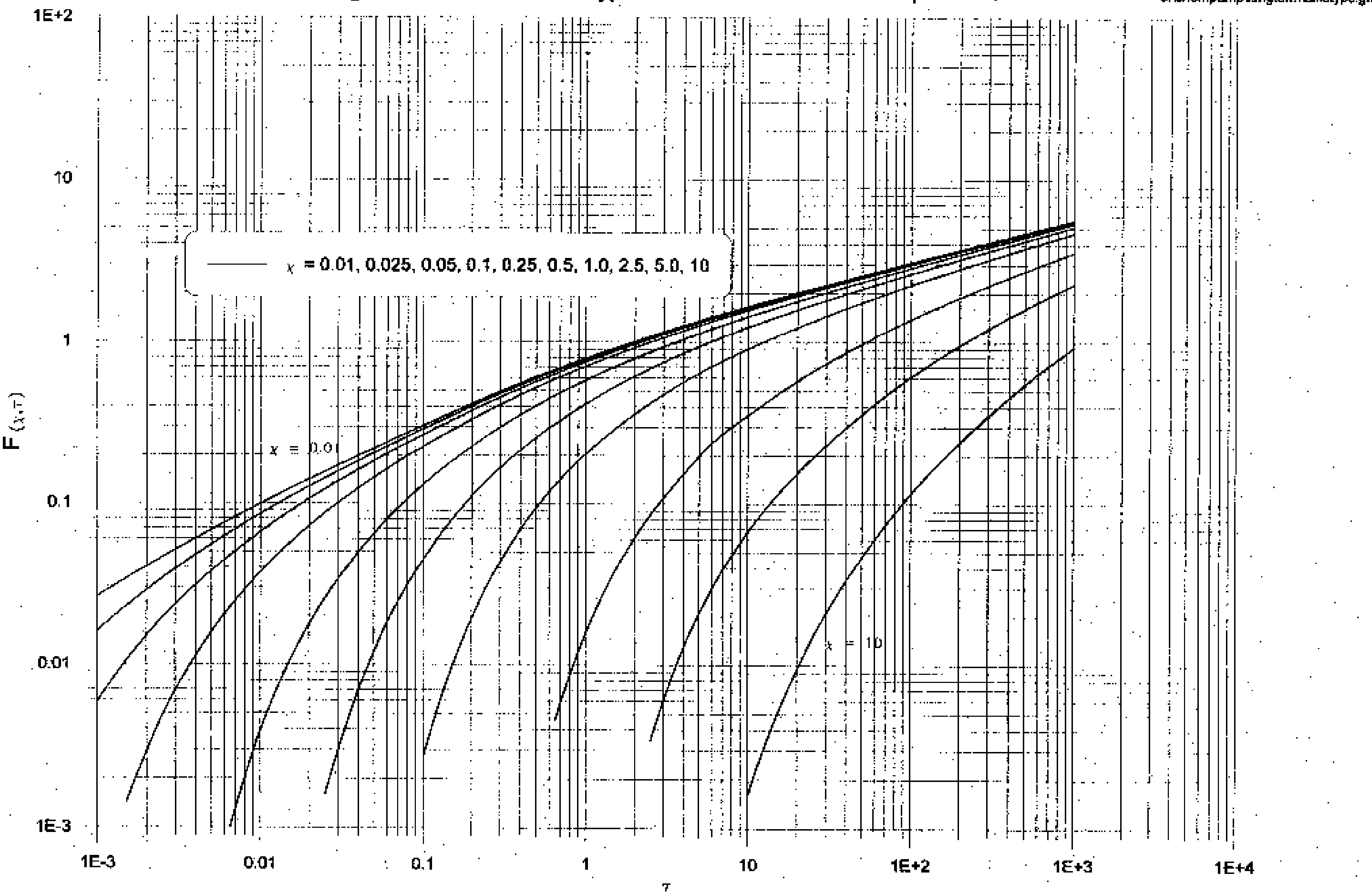
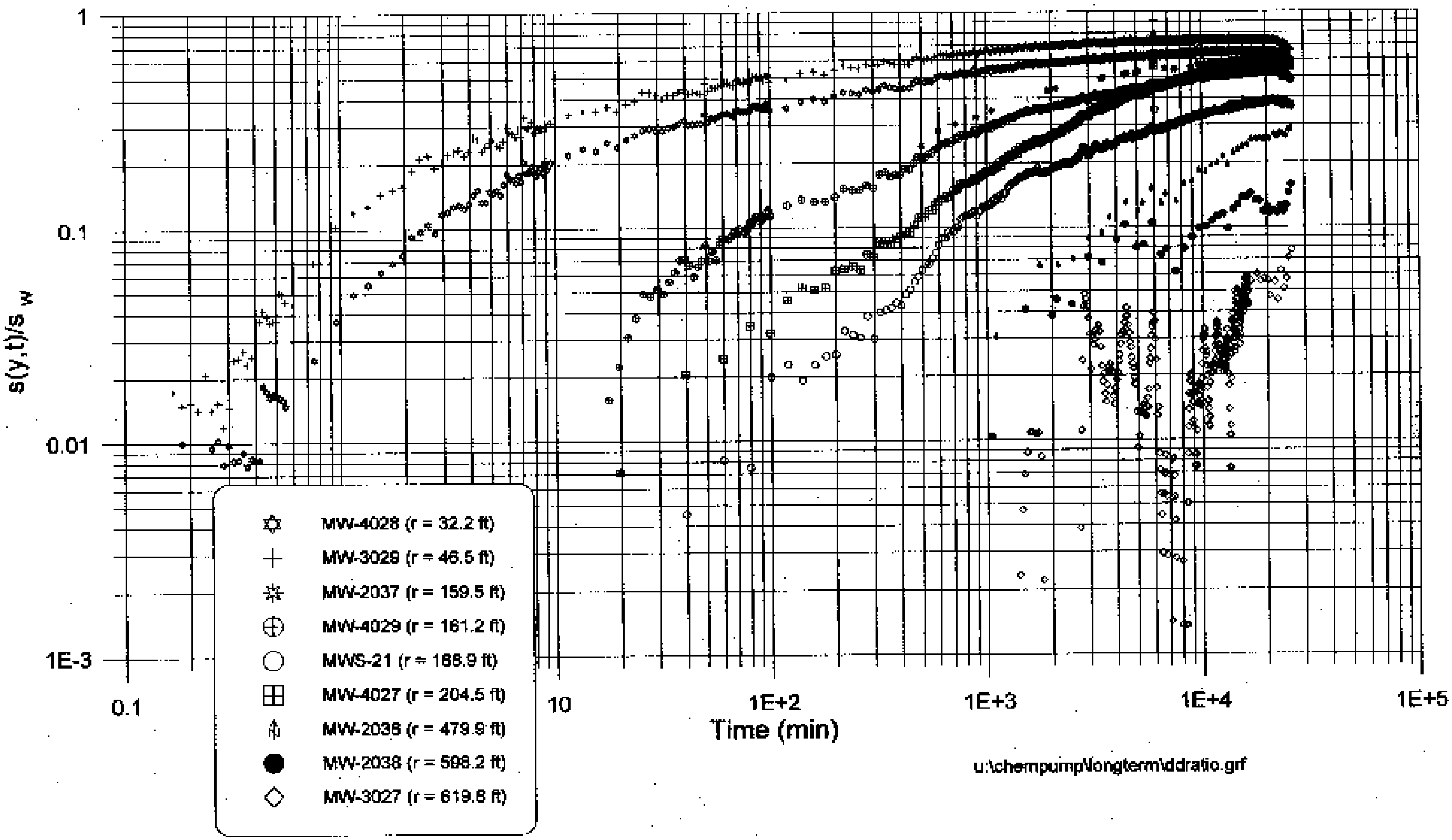


Figure C.59 - Drawdown Ratio vs. Time



Step-Drawdown Calculations

Adapted from Birsoy and Summers (1980)—*Ground Water*, v. 18, no. 2, pp. 137-146

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$ $b := 19 \cdot ft$ $bb := 1 \cdot ft$ ...range of saturated screened intervals

$Q := \begin{bmatrix} 6.3 \\ 10.57 \\ 15.46 \\ 22.97 \end{bmatrix} \cdot gpm$ ...discharge rates $ts := \begin{bmatrix} 0 \\ 28 \\ 128 \\ 228 \end{bmatrix} \cdot min$ ...time at start of step $te := \begin{bmatrix} 28 \\ 128 \\ 228 \\ 488 \end{bmatrix} \cdot min$ ...time at end of step

A := READPRN("3028stps.prn") ...input data file

$t := A^{\langle 2 \rangle} \cdot min$ ...time

$s := A^{\langle 4 \rangle} \cdot ft$ ...drawdown

$step := A^{\langle 6 \rangle}$ ...step number

$nsteps := max\left(A^{\langle 6 \rangle}\right)$ $nsteps = 4$

$minstep := min\left(A^{\langle 6 \rangle}\right)$ $minstep = 1$

```
x(step, thres) := | i ← 1
                  | break if max(step) ≤ thres
                  | while step_i ≤ thres
                  |   i ← i + 1
                  | i
```

...determine number of the first data for step 2

$x(step, 1) = 196$

$j := 2 .. x(step, 1) - 1$ $\beta_j := 1$ ...adjustment factor = 1 for first step

$j := x(step, 1) .. rows(A)$

$$\beta_j := \prod_{i=1}^{step_j - 1} \left(\frac{t_j - ts_i}{t_j - te_i} \right)^{\frac{Q_i}{Q_{step_j}}}$$

...adjustment factor for subsequent steps

$j := 2 .. rows(A)$

$at_j := \beta_j \cdot \left(t_j - ts_{step_j}\right)$ ...adjusted time $dat := \frac{at}{min}$ $lat_j := log\left(dat_j\right)$ ...log adjusted time

$sQ_j := \frac{s_j}{Q_{step_j}}$ $sQJ_j := \frac{s_j - \frac{(s_j)^2}{2 \cdot b}}{Q_{(step_j)}}$ ...s/Q and s/Q with Jacob's correction applied (Ref. #2)

$$B := augment\left[augment\left[augment\left[augment\left(augment(A,\beta), \frac{at}{min}\right), \frac{sQ}{\left(\frac{ft}{gpm}\right)}\right], \frac{sQJ}{\left(\frac{ft}{gpm}\right)}\right], lat\right]$$

$i := minstep .. nsteps$

$j := 2 .. rows(B)$

$n_i := \sum_j 1 \cdot (B_{j,6} = i)$ $n = \begin{bmatrix} 194 \\ 39 \\ 230 \\ 246 \end{bmatrix}$ $\sum_i n_i + 1 = 710$ $rows(B) = 710$ ...count data for each step and verify total

$ne_i := \left(\sum_{i=1}^{i} n_i \right) + 1$ $ne = \begin{bmatrix} 195 \\ 234 \\ 464 \\ 710 \end{bmatrix}$ ...ending row for each step

$nb_i := ne_i - n_i + 1$ $nb = \begin{bmatrix} 2 \\ 196 \\ 235 \\ 465 \end{bmatrix}$ ...beginning row for each step

$S1 := submatrix(B, nb_1 + 1, ne_1, 1, 11)$ WRITEPRN("STP13028.prn") := S1 ...write data out to external file

$t_{172} = 7.2 \cdot min$ ...end of wellbore storage = 27 min and 7.2 min = minimum time for corr. coef. >= 0.9 (see below)

$S1B := submatrix(B, 172, ne_1, 1, 11)$

$S2 := submatrix(B, nb_2, ne_2, 1, 11)$ WRITEPRN("STP23028.prn") := S2

$S3 := submatrix(B, nb_3, ne_3, 1, 11)$ WRITEPRN("STP33028.prn") := S3

$S4 := submatrix(B, nb_4, ne_4, 1, 11)$ WRITEPRN("STP43028.prn") := S4

$s1 := slope\left(S1^{\langle 11 \rangle}, S1^{\langle 9 \rangle}\right)$ $s1 = 0.017$ ...slope of line relating s/Q to log adjusted time in ft/gpm

$s1B := slope\left(S1B^{\langle 11 \rangle}, S1B^{\langle 9 \rangle}\right)$ $s1B = 0.034$ ...slope of line after wellbore storage effects

$s2 := slope(S2^{<11>}, S2^{<9>})$ $s2 = 0.034$

$s3 := slope(S3^{<11>}, S3^{<9>})$ $s3 = 0.032$

$s4 := slope(S4^{<11>}, S4^{<9>})$ $s4 = 0.038$

$savg := \frac{s1B + s2 + s3 + s4}{nsteps}$ $savg = 0.035$ ...average slope

$b1 := intercept(S1^{<11>}, S1^{<9>})$ $b1 = 0.035$ $b1B := intercept(S1B^{<11>}, S1B^{<9>})$ $b1B = 0.013$

$b2 := intercept(S2^{<11>}, S2^{<9>})$ $b2 = 0.018$ ...y value at adjusted time = 1, log adjusted time = 0

$b3 := intercept(S3^{<11>}, S3^{<9>})$ $b3 = 0.032$

$b4 := intercept(S4^{<11>}, S4^{<9>})$ $b4 = 0.033$

$bavg := \frac{b1B + b2 + b3 + b4}{nsteps}$ $bavg = 0.024$

$r1 := corr(S1^{<11>}, S1^{<9>})$ $r1 = 0.943$ $r1B := corr(S1B^{<11>}, S1B^{<9>})$ $r1B = 0.9$

$r2 := corr(S2^{<11>}, S2^{<9>})$ $r2 = 0.987$ ...correlation coefficients

$r3 := corr(S3^{<11>}, S3^{<9>})$ $r3 = 0.986$

$r4 := corr(S4^{<11>}, S4^{<9>})$ $r4 = 0.989$

$T := \frac{2.3}{4 \cdot \pi \cdot savg \cdot \frac{ft}{gpm}}$ $T = 7.6 \cdot 10^{3} \frac{gpd}{ft}$ ...best estimate transmissivity

$K := \frac{T}{b}$ $K = 1.9 \cdot 10^{-2} \frac{cm}{sec}$ ...best estimate hydraulic conductivity $K2 := \frac{T}{bb}$ $K2 = 3.6 \cdot 10^{-1} \frac{cm}{sec}$

$T1 := \frac{2.3}{4 \cdot \pi \cdot s1 \cdot \frac{ft}{gpm}}$ $T1 = 1.6 \cdot 10^{4} \frac{gpd}{ft}$ $K1 := \frac{T1}{b}$ $K1 = 3.9 \cdot 10^{-2} \frac{cm}{sec}$

$T1B := \frac{2.3}{4 \cdot \pi \cdot s1B \cdot \frac{ft}{gpm}}$ $T1B = 7.7 \cdot 10^{3} \frac{gpd}{ft}$ $K1B := \frac{T1B}{b}$ $K1B = 1.9 \cdot 10^{-2} \frac{cm}{sec}$

$T2 := \frac{2.3}{4 \cdot \pi \cdot s2 \cdot \frac{ft}{gpm}}$ $T2 = 7.7 \cdot 10^{3} \frac{gpd}{ft}$ $K2 := \frac{T2}{b}$ $K2 = 1.9 \cdot 10^{-2} \frac{cm}{sec}$

$$T3 := \frac{2.3}{4\cdot\pi\cdot s3\cdot\frac{ft}{gpm}} \qquad T3 = 8.3\cdot10^{3}\,\frac{gpd}{ft} \qquad K3 := \frac{T3}{b} \qquad K3 = 2.1\cdot10^{-2}\,\frac{cm}{sec}$$

$$T4 := \frac{2.3}{4\cdot\pi\cdot s4\cdot\frac{ft}{gpm}} \qquad T4 = 7\cdot10^{3}\,\frac{gpd}{ft} \qquad K4 := \frac{T4}{b} \qquad K4 = 1.7\cdot10^{-2}\,\frac{cm}{sec}$$

Check K estimate using recovery data (Refs. #3 and #4):

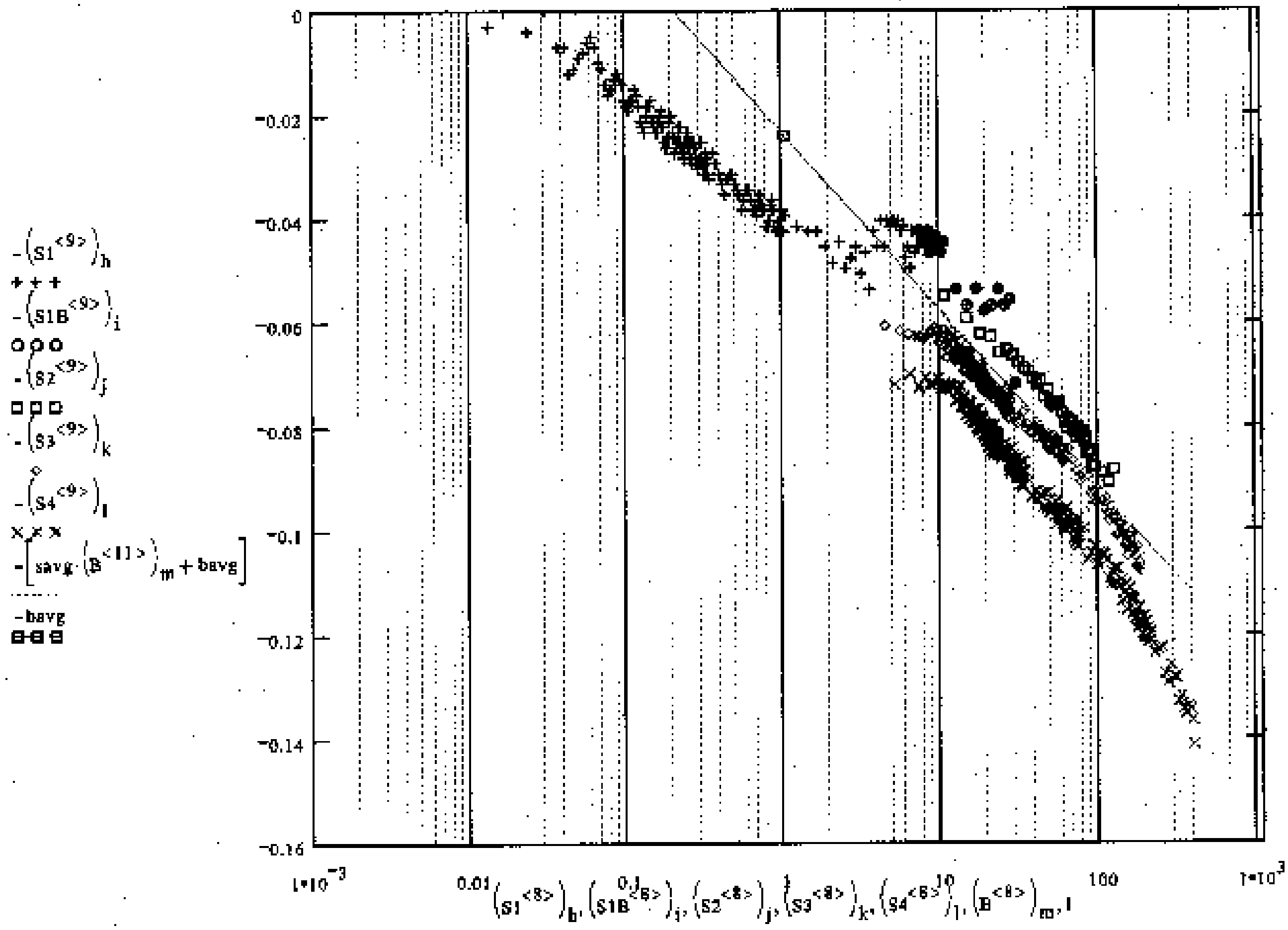
$Q_n := 22.97\cdot\frac{gal}{min}$ $\quad \Delta s := 2.303\cdot0.408921\cdot ft$ (see plot) $\qquad \Delta s = 0.942\cdot ft \qquad T := \frac{2.3\cdot Q_n}{4\cdot\pi\cdot\Delta s}$

$T = 6.4\cdot10^{3}\,\frac{gpd}{ft} \qquad K := \frac{T}{b} \qquad K = 1.6\cdot10^{-2}\,\frac{cm}{sec} \qquad r := \frac{6.065\cdot in}{2}$ 2" Sch 40 SS (Ref. #5, p. 977)

$r = 0.253\cdot ft \qquad S := 0.05 \qquad t'_c := \frac{r^2\cdot S}{4\cdot T\cdot 0.02} \qquad t'_c = 0.067\cdot min \qquad t := 488\cdot min + t'_c$

$\frac{t}{t'_c} = 7297$ ...for u-assumption $\qquad twb_c := 250\cdot\frac{r^2}{T}$ ...Hargis (Ref.#3, p. 53) $\qquad twb_c = 26.8\cdot min$

$t := 488\cdot min + twb_c \qquad \frac{t}{twb_c} = 19.2$ ...t/t' critical for end of wellbore storage h := 1.. rows(S1)   i := 1.. rows(S1B)   j := 1.. rows(S2)   k := 1.. rows(S3)   l := 1.. rows(S4)   m := 2.. rows(B)



+++ Step 1
ooo Step 1 after wellbore storage
□□□ Step 2
◇ Step 3
××× Step 4
······ average fit
⊟⊟⊟ x,y=1,-bavg

raw time, actual time, drawdown, -drawdown, barometric pressure,
step, adjustment factor, s/Q, s/Q w/ Jacob's correction, log adjusted time

"B=......

MW-4028:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 0.21 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 4.1 \cdot min$ $x := 32.2 \cdot ft$ $\chi := 2.5$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 1.79 \cdot 10^{3} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 9.5 \cdot 10^{3} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 2.3 \cdot 10^{-2} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 4.5 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 3.3 \cdot 10^{-2} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 2.2 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 1.1 \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 7.37 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\ 2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 2.06$

MW-3029a:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 0.28 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 12 \cdot min$ $x := 46.5 \cdot ft$ $\chi := 1.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 4.84 \cdot 10^{3} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 2.6 \cdot 10^{4} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 6.4 \cdot 10^{-2} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 1.2 \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 2 \cdot 10^{-2} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 1.3 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 1.4 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 7.09 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot {s_w}^2}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 1.98$

MW-3029b:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 0.18 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 1.4 \cdot min$ $x := 46.5 \cdot ft$ $\chi := 2.5$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 3.01 \cdot 10^{3} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 1.6 \cdot 10^{4} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 4 \cdot 10^{-2} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 7.5 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 9.1 \cdot 10^{-3} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 6 \cdot 10^{-4}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 2.4 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 5.86 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\ 2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 1.64$

MW-2037:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 1.7\cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 910\cdot min$ $x := 159.5\cdot ft$ $\chi := 2.5$ $Q := 10.7\cdot gpm$

Assume:

$Wd := 50\cdot ft$ $b := 19\cdot ft$ $b2 := 1\cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q\cdot F(\chi,\tau)\cdot x}{2\cdot s(x,t)\cdot \chi}$ $WdTd = 1.09\cdot 10^{3} \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 5.8\cdot 10^{3} \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 1.4\cdot 10^{-2} \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 2.7\cdot 10^{-1} \frac{cm}{sec}$

$WdSd := \frac{Q\cdot F(\chi,\tau)\cdot \chi\cdot t}{2\cdot s(x,t)\cdot x\cdot \tau}$ $WdSd = 1.8\cdot 10^{-1} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 1.2\cdot 10^{-2}$

$ScTc := \frac{Q^2\cdot F(\chi,\tau)^2\cdot \chi^2\cdot \tau}{14\cdot s(x,t)^2\cdot x^2\cdot \tau}$ $ScTc = 1.5\cdot 10^{-1} \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99\cdot ft$ $t := 4000\cdot min$

$w1 := WdTd\cdot\sqrt{ScTc}$ $w1 = 1.68\cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2\cdot\sqrt{t}}{7.5\cdot s_w^{\,2}}$ $w2 = 3.58\cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 0.47$

MW-4029:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 0.38 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 19 \cdot min$ $x := 161.2 \cdot ft$ $\chi := 5.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 2.47 \cdot 10^{3} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 1.3 \cdot 10^{4} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 3.2 \cdot 10^{-2} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 6.2 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 3.4 \cdot 10^{-2} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 2.2 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 2.5 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 4.85 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\,2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 1.35$

MWS-21a:

$gpm = \frac{gal}{min}$ $gpd = \frac{gal}{day}$

Given:

$s(x,t) := 1.4 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 510 \cdot min$ $x := 188.9 \cdot ft$ $\chi := 5.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 7.87 \cdot 10^{2} \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 4.2 \cdot 10^{3} \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 1 \cdot 10^{-2} \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 2 \cdot 10^{-1} \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 2.1 \cdot 10^{-1} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 1.4 \cdot 10^{-2}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 3.6 \cdot 10^{-1} \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 1.85 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\,2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 0.52$

MWS-21b:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 1.0 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 55 \cdot min$ $x := 188.9 \cdot ft$ $\chi := 10.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 5.51 \cdot 10^{2} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 2.9 \cdot 10^{3} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 7.2 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 1.4 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 6.3 \cdot 10^{-2} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 4.2 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 3 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 1.19 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\,2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 0.33$

MW-4027a:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 0.95 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 31 \cdot min$ $x := 204.5 \cdot ft$ $\chi := 10.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,\tau) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 6.28 \cdot 10^{2} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 3.3 \cdot 10^{3} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 8.2 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 1.6 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,\tau) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 3.5 \cdot 10^{-2} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 2.3 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 1.6 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 9.91 \cdot 10^{-6} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\,2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 0.28$

MW-4027b:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

Given:

$s(x,t) := 2.0 \cdot ft$ $F(\chi,\tau) := 1$ $\tau := 10$ $t := 410 \cdot min$ $x := 204.5 \cdot ft$ $\chi := 5.0$ $Q := 10.7 \cdot gpm$

Assume:

$Wd := 50 \cdot ft$ $b := 19 \cdot ft$ $b2 := 1 \cdot ft$ ...width of dike and range of saturated thicknesses

Calculate Hydraulic Properties:

$WdTd := \frac{Q \cdot F(\chi,t) \cdot x}{2 \cdot s(x,t) \cdot \chi}$ $WdTd = 5.96 \cdot 10^{2} \cdot \frac{m^3}{day}$ $Td := \frac{WdTd}{Wd}$ $Td = 3.2 \cdot 10^{3} \cdot \frac{gpd}{ft}$

$Kd := \frac{Td}{b}$ $Kd = 7.8 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $Kd2 := \frac{Td}{b2}$ $Kd2 = 1.5 \cdot 10^{-1} \cdot \frac{cm}{sec}$

$WdSd := \frac{Q \cdot F(\chi,t) \cdot \chi \cdot t}{2 \cdot s(x,t) \cdot x \cdot \tau}$ $WdSd = 1.1 \cdot 10^{-1} \cdot m$ $Sd := \frac{WdSd}{Wd}$ $Sd = 7.2 \cdot 10^{-3}$

$ScTc := \frac{Q^2 \cdot F(\chi,\tau)^2 \cdot \chi^2 \cdot t}{14 \cdot s(x,t)^2 \cdot x^2 \cdot \tau}$ $ScTc = 1.2 \cdot 10^{-1} \cdot \frac{m^2}{day}$

Check with Pumping Well:

$s_w := 2.99 \cdot ft$ $t := 4000 \cdot min$

$w1 := WdTd \cdot \sqrt{ScTc}$ $w1 = 8.13 \cdot 10^{-6} \cdot m^4 \cdot s^{-1.5}$ $w2 := \frac{Q^2 \cdot \sqrt{t}}{7.5 \cdot s_w^{\,2}}$ $w2 = 3.58 \cdot 10^{-5} \cdot m^4 \cdot s^{-1.5}$

$\frac{w1}{w2} = 0.23$

APPENDIX D
Groundwater Quality Analytical and Quality Control Data

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
GW-3028-070198-02	3028	07/01/98	NITRATE-N	253		0.7	MG/L		*	0000	000
GW-3028-070198-02	3028	07/01/98	IRON	430		5.0	UG/L		*	0000	000
GW-3028-070198-02	3028	07/01/98	MANGANESE	25.7		0.68	UG/L		*	0000	000
GW-3028-070198-02	3028	07/01/98	URANIUM, TOTAL	0.996	0.0133	0.064	PCI/L		*	0000	000
GW-3028-073198-1240	3028	07/31/98	URANIUM, TOTAL	0.880	0.018	0.677	PCI/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,1,1-TRICHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,1,1-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,1,1-TRICHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,1,1-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,1,1-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,1,2,2-TETRACHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,1,2,2-TETRACHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,1,2,2-TETRACHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,1,2,2-TETRACHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,1,2,2-TETRACHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,1,2-TRICHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,1,2-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,1,2-TRICHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,1,2-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,1,2-TRICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,1-DICHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,1-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,1-DICHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,1-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,1-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,1-DICHLOROETHENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,1-DICHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,1-DICHLOROETHENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,1-DICHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,1-DICHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,2-DICHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,2-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,2-DICHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,2-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,2-DICHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,2-DICHLOROETHENE (TOTAL)	(8.0)		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,2-DICHLOROETHENE (TOTAL)	(15)		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	1,2-DICHLOROETHENE (TOTAL)	(9.0)		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,2-DICHLOROETHENE (TOTAL)	(13)		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,2-DICHLOROETHENE (TOTAL)	(16)		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	1,2-DICHLOROPROPANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	1,2-DICHLOROPROPANE	ND		50	UG/L		*	0000	000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	OCD_Q
GW-3028-061998-ST2	3028	06/19/98	1,2-DICHLOROPROPANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	1,2-DICHLOROPROPANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	1,2-DICHLOROPROPANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	2-BUTANONE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	2-BUTANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	2-BUTANONE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	2-BUTANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	2-BUTANONE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	2-HEXANONE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	2-HEXANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	2-HEXANONE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	2-HEXANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	2-HEXANONE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	4-METHYL-2-PENTANONE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	4-METHYL-2-PENTANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	4-METHYL-2-PENTANONE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	4-METHYL-2-PENTANONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	4-METHYL-2-PENTANONE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	ACETONE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	ACETONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	ACETONE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	ACETONE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	ACETONE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	BENZENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	BENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	BENZENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	BENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	BENZENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	BROMODICHLOROMETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	BROMODICHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	BROMODICHLOROMETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	BROMODICHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	BROMODICHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	BROMOFORM	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	BROMOFORM	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	BROMOFORM	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	BROMOFORM	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	BROMOFORM	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	BROMOMETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	BROMOMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	BROMOMETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	BROMOMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	BROMOMETHANE	ND		50	UG/L		*	0000	000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
GW-3028-061098	3028	06/10/98	CARBON DISULFIDE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CARBON DISULFIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CARBON DISULFIDE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CARBON DISULFIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CARBON DISULFIDE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CARBON TETRACHLORIDE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CARBON TETRACHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CARBON TETRACHLORIDE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CARBON TETRACHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CARBON TETRACHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CHLOROBENZENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CHLOROBENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CHLOROBENZENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CHLOROBENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CHLOROBENZENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CHLOROETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CHLOROETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CHLOROETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CHLOROFORM	(3.0)		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CHLOROFORM	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CHLOROFORM	(3.0)		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CHLOROFORM	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CHLOROFORM	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CHLOROMETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CHLOROMETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	CIS-1,3-DICHLOROPROPENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	CIS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	CIS-1,3-DICHLOROPROPENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	CIS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	CIS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	DIBROMOCHLOROMETHANE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	DIBROMOCHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	DIBROMOCHLOROMETHANE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	DIBROMOCHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	DIBROMOCHLOROMETHANE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	ETHYL BENZENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	ETHYL BENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	ETHYL BENZENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	ETHYL BENZENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	ETHYL BENZENE	ND		50	UG/L		*	0000	000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
GW-3028-061998-ST1	3028	06/19/98	LIMONENE (TIC)	26			UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	METHYLENE CHLORIDE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	METHYLENE CHLORIDE	130		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	METHYLENE CHLORIDE	38		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	METHYLENE CHLORIDE	72		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	METHYLENE CHLORIDE	84		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	STYRENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	STYRENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	STYRENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	STYRENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	STYRENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TETRACHLOROETHENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TETRACHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	TETRACHLOROETHENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TETRACHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TETRACHLOROETHENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TETRACHLOROETHENE (PCE)	ND		12	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TETRACHLOROETHENE (PCE)	(6.0)		25	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-070198-01	3028	07/01/98	TETRACHLOROETHENE (PCE)	21.0		6.7	UG/L		*	0000	000
GW-3028-070198-02	3028	07/01/98	TETRACHLOROETHENE (PCE)	(6.8)		10.0	UG/L		*	0000	000
GW-3028-070198-03	3028	07/01/98	TETRACHLOROETHENE (PCE)	ND		10.0	UG/L		*	0000	000
GW-3028-070698	3028	07/06/98	TETRACHLOROETHENE (PCE)	ND		6.7	UG/L		*	0000	000
GW-3028-071498-1010	3028	07/14/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-071498-1810	3028	07/14/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-071598-0210	3028	07/15/98	TETRACHLOROETHENE (PCE)	ND		25	UG/L		*	0000	000
GW-3028-072098-1430	3028	07/20/98	TETRACHLOROETHENE (PCE)	1.2		0.50	UG/L		*	0000	000
GW-3028-072198-0230	3028	07/21/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072198-1430	3028	07/21/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072298-0230	3028	07/22/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072298-1410	3028	07/22/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072398-0230	3028	07/23/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072798-1425	3028	07/27/98	TETRACHLOROETHENE (PCE)	(1.0)		5.0	UG/L		*	0000	000
GW-3028-072898-0956	3028	07/28/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-072998-1115	3028	07/29/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-073098-0940	3028	07/30/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-073198-1240	3028	07/31/98	TETRACHLOROETHENE (PCE)	ND		5.0	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TOLUENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TOLUENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	TOLUENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TOLUENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TOLUENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TRANS-1,3-DICHLOROPROPENE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TRANS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000

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GW-3028-061998-ST2	3028	06/19/98	TRANS-1,3-DICHLOROPROPENE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TRANS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TRANS-1,3-DICHLOROPROPENE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TRICHLOROETHENE	390		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TRICHLOROETHENE	490		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	TRICHLOROETHENE	470		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TRICHLOROETHENE	510		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TRICHLOROETHENE	640		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	TRICHLOROETHENE (TCE)	420		12	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	TRICHLOROETHENE (TCE)	470		25	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	TRICHLOROETHENE (TCE)	530		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	TRICHLOROETHENE (TCE)	530		25	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	TRICHLOROETHENE (TCE)	480		25	UG/L		*	0000	000
GW-3028-070198-01	3028	07/01/98	TRICHLOROETHENE (TCE)	403		6.7	UG/L		*	0000	000
GW-3028-070198-02	3028	07/01/98	TRICHLOROETHENE (TCE)	532		10.0	UG/L		*	0000	000
GW-3028-070198-03	3028	07/01/98	TRICHLOROETHENE (TCE)	517		10.0	UG/L		*	0000	000
GW-3028-070698	3028	07/06/98	TRICHLOROETHENE (TCE)	543		6.7	UG/L		*	0000	000
GW-3028-071498-1010	3028	07/14/98	TRICHLOROETHENE (TCE)	420		25	UG/L		*	0000	000
GW-3028-071498-1810	3028	07/14/98	TRICHLOROETHENE (TCE)	350		25	UG/L		*	0000	000
GW-3028-071598-0210	3028	07/15/98	TRICHLOROETHENE (TCE)	510		25	UG/L		*	0000	000
GW-3028-072098-1430	3028	07/20/98	TRICHLOROETHENE (TCE)	410		20.0	UG/L		*	0000	000
GW-3028-072198-0230	3028	07/21/98	TRICHLOROETHENE (TCE)	380		10	UG/L		*	0000	000
GW-3028-072198-1430	3028	07/21/98	TRICHLOROETHENE (TCE)	400		10	UG/L		*	0000	000
GW-3028-072298-0230	3028	07/22/98	TRICHLOROETHENE (TCE)	380		10	UG/L		*	0000	000
GW-3028-072298-1410	3028	07/22/98	TRICHLOROETHENE (TCE)	370		10	UG/L		*	0000	000
GW-3028-072398-0230	3028	07/23/98	TRICHLOROETHENE (TCE)	390		10	UG/L		*	0000	000
GW-3028-072798-1425	3028	07/27/98	TRICHLOROETHENE (TCE)	580		25	UG/L		*	0000	000
GW-3028-072898-0956	3028	07/28/98	TRICHLOROETHENE (TCE)	600		25	UG/L		*	0000	000
GW-3028-072998-1115	3028	07/29/98	TRICHLOROETHENE (TCE)	510		25	UG/L		*	0000	000
GW-3028-073098-0940	3028	07/30/98	TRICHLOROETHENE (TCE)	580		25	UG/L		*	0000	000
GW-3028-073198-1240	3028	07/31/98	TRICHLOROETHENE (TCE)	590		25	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	VINYL CHLORIDE	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	VINYL CHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	VINYL CHLORIDE	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	VINYL CHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	VINYL CHLORIDE	ND		50	UG/L		*	0000	000
GW-3028-061098	3028	06/10/98	XYLENES, TOTAL	ND		20	UG/L		*		000
GW-3028-061998-ST1	3028	06/19/98	XYLENES, TOTAL	ND		50	UG/L		*	0000	000
GW-3028-061998-ST2	3028	06/19/98	XYLENES, TOTAL	ND		25	UG/L		*	0000	000
GW-3028-061998-ST3	3028	06/19/98	XYLENES, TOTAL	ND		50	UG/L		*	0000	000
GW-3028-061998-ST4	3028	06/19/98	XYLENES, TOTAL	ND		50	UG/L		*	0000	000
GW-4027-061098	4027	06/10/98	1,1,1-TRICHLOROETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,1,2,2-TETRACHLOROETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,1,2-TRICHLOROETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,1-DICHLOROETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,1-DICHLOROETHENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,2-DICHLOROETHANE	ND		10	UG/L		*		000

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GW-4027-061098	4027	06/10/98	1,2-DICHLOROETHENE (TOTAL)	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	1,2-DICHLOROPROPANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	2-BUTANONE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	2-HEXANONE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	4-METHYL-2-PENTANONE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	ACETONE	10		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	BENZENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	BROMODICHLOROMETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	BROMOFORM	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	BROMOMETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CARBON DISULFIDE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CARBON TETRACHLORIDE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CHLOROBENZENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CHLOROETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CHLOROFORM	(2.0)		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CHLOROMETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	CIS-1,3-DICHLOROPROPENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	DIBROMOCHLOROMETHANE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	ETHYL BENZENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	METHYLENE CHLORIDE	(2.0)		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	STYRENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	TETRACHLOROETHENE	19		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	TETRACHLOROETHENE (PCE)	23		1.0	UG/L		*		000
GW-4027-061098	4027	06/10/98	TOLUENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	TRANS-1,3-DICHLOROPROPENE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	TRICHLOROETHENE	(3.0)		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	TRICHLOROETHENE (TCE)	4.0		1.0	UG/L		*		000
GW-4027-061098	4027	06/10/98	VINYL CHLORIDE	ND		10	UG/L		*		000
GW-4027-061098	4027	06/10/98	XYLENES, TOTAL	ND		10	UG/L		*		000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
MW-S003-070698	S003	07/06/98	TETRACHLOROETHENE (PCE)	ND		1.0	UG/L		*	0000	000
MW-S003-070698	S003	07/06/98	TRICHLOROETHENE (TCE)	ND		1.0	UG/L		*	0000	000
MW-S004-070698	S004	07/06/98	TETRACHLOROETHENE (PCE)	ND		1.0	UG/L		*	0000	000
MW-S004-070698	S004	07/06/98	TRICHLOROETHENE (TCE)	(0.69)		1.0	UG/L		*	0000	000
MW-S021-070698	S021	07/06/98	TRICHLOROETHENE (TCE)	182		2.5	UG/L		*	0000	000
MW-S112-070698	S112	07/06/98	TETRACHLOROETHENE (PCE)	ND		1.0	UG/L		*	0000	000
MW-S112-070698	S112	07/06/98	TRICHLOROETHENE (TCE)	ND		1.0	UG/L		*	0000	000
MW-S021-070698	S021	07/06/98	TETRACHLOROETHENE (PCE)	ND		2.5	UG/L		*	0000	000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
SP-6301-070698-L	6301	07/06/98	TETRACHLOROETHENE (PCE)	ND		1.0	UG/L		*	0000	000
SP-6301-070698-L	6301	07/06/98	TRICHLOROETHENE (TCE)	ND		1.0	UG/L		*	0000	000

WSSRAP_ID	LOCATI	DATE_SAM	PARAMETER	CONC	ERR	DL	UNITS	VER_QU	VAL_QUAL	REV_QU	QCD_Q
GW-3028-072098-1430-MD	3028	07/20/98	TETRACHLOROETHENE (PCE)	360		10	UG/L		*	0000	100
GW-3028-072098-1430-MS	3028	07/20/98	TETRACHLOROETHENE (PCE)	390		10	UG/L		*	0000	100
GW-3028-072098-1430-MD	3028	07/20/98	TRICHLOROETHENE (TCE)	730		20	UG/L		*	0000	100
GW-3028-072098-1430-MS	3028	07/20/98	TRICHLOROETHENE (TCE)	790		20	UG/L		*	0000	100