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Summary of Three Dimensional Pump Testing of a Fractured Rock Aquifer in the Western Siberian Basin (U)

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Summary

A group of scientists from the Savannah River Technology Center and Russia successfully completed a 17 day field investigation of a fractured rock aquifer at the MAYAK PA nuclear production facility in Russia. The test site is located in the western Siberian Basin near the floodplain of the Mishelyak river. The fractured rock aquifer is composed of porphyrites, tuff, tuffbreccia and lava and is overlain by 0.5 - 12 meters of elluvail and alluvial sediments. The Joint Coordinating Committee for Environmental Remediation and Waste Management (JCCEM) sponsored the field research and is composed of the United States Department of Energy (USDOE) Office of Technology Development and the Russian Ministry of Atomic Energy (MINATOM).

A network of 3 uncased wells (176, 1/96, and 2/96) was used to conduct the tests. Wells 176 and 2/96 were used as observation wells and the centrally located well 1/96 was used as the pumping well. Six packers were installed and inflated in each of the observation wells at a depth of up to 85 meters. The use of 6 packers in each well resulted in isolating 7 zones for monitoring. The packers were inflated to different pressures to accommodate the increasing hydrostatic pressure. A straddle packer assembly was installed in the pumping well to allow testing of each of the individual zones isolated in the observation wells. A constant rate pumping test was run on each of the 7 zones. Appendix The results of the pumping tests are included in Appendix A.

The test provided new information about the nature of the fractured rock aquifers in the vicinity of the Mishelyak river and will be key information in understanding the behavior of contaminants originating from process wastes discharged to Lake Karachi. Results from the tests will be analyzed to determine the hydraulic properties of different zones within the fractured rock aquifer and to determine the most cost effective clean-up approach for the site.

Appendix A

Results from Three Dimensional Pump Testing of a Fractured Rock Aquifer in the Western Siberian Basin

TECHNICAL REPORT

on joint Russian-American field studies performed from August, 31 through September, 15 1996 in the area of "Mayak" PA site

(in accordance with contract #4 dated November, 15 1995 "Multi-Packer Well Investigation)

"Investigation of Filtration Properties of the Fractured Water-bearing Horizons with Test Pumping using the Multipacker System"

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Introduction

This report was prepared by the group of Russian and American experts on the preliminary results of joint multipacker tests which were held on September, 1-15 1996 in the territory of "Mayak" PA. The field test site is located 3 km to the South from the lake Karachai within the frontal part of the contaminant plume. The recognized importance of these works resulted from preliminary investigation that determined contaminated water discharge in the vicinity of the Mishelyak River.

The works were held in accordance with the Technical Task agreed by the both sides and signed by the head of the MINATOM Department Dr. E.Mikerin within the frameworks of Agreement on Using Atomic Energy in the peaceful purposes and within the frameworks of Memorandum between the US Department of Energy and Russian MINATOM (JCCEM).

The purpose of the works was to determine the properties of fractured rocks including the interrelation of different types of fractures for studying the discharge conditions for underground water to the vicinity of the Mishelyak River. The main task for studies is to receive the calculation parameters for fracturing characteristics, to determine vertical and horizontal anisotropy of fractured rock mass, and prevailing directions of regional fracturing.

Studies included the following activities:

- drilling of two monitoring wells;
- cluster pumping test from well 1/96 for determining the hydrological parameters for the whole zone;
- borehole geophysical studies including telephotometry, electric logging, caliper logging, resistivity logging and gamma-ray logging.
- analysis and processing of geophysical studies results and choice of intervals for packer installation in the central and monitoring wells;
- installation of two packer assemblies into two monitoring wells;
- pumping tests from the zones isolated with packers from the central well;
- water sampling during pumping and chemical and radiochemical water analysis including express analysis on nitrate-ion concentrations.

Cooperative studies were held by experts from PSA "Hydrospetsgeologia"< PA "Mayak" and group of experts from SRL, PNL, EML.

In this report, the brief description of the field studies including methods used, equipment and procedure of field tests and preliminary results are performed. The final report will be prepared later after detailed data processing and after all data from chemical and radiochemical analysis are received.

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1. Statement of the Task

Lake Karachai is situated between the rivers Techa and Mishelyak. Since 1952 this lake has been used for the storage of liquid radioactive waste. Technological waste which infiltrates from the lake into the water-bearing horizon is the main source of water contaminated with radionuclides and chemical components and has a higher density than natural water. Because of gravitation effects, the dense solution moves to the bottom of the aquifer system (70-100 m) and migrates to the north and to the south according to the flow structure toward the the places of underground water discharge.

The progress of the contaminant plume flow has been traced since 1962 with the help of a monitoring well network in which interval water sampling is performed (Figure 1.1). The resulting chemical concentration data allows estimates of the velocity of contaminant flow, structure of the contaminant plume in the vertical section borders of distribution, etc.

In 1994 a group of Russian and American scientists conducted a series of experiments to evaluate compare the sampling method traditionally used by Russian scientists at Lake Karachai with methods traditionally used in the United States. The results of the 1994 sampler comparison showed that the Russian and American sampling methods provided similar results.

Following the 1994 study it was proposed to conduct a multipacker test to study the possibility of contaminated water discharge into open drainage system. Complicated hydrological and geological conditions and peculiarities of the processes controlling the migration of high density solutions do not allow the use of analytical methods to predict distribution of contamination. As a result it was proposed to try to estimate mechanism of possible contaminated water discharge by natural methods based on the interval estimation of the hydraulic conductivty of fractured rocks at the Lake Karachai site.

A team of Russian scientists from "Mayak" PA, PSA "Hydrospetsgeologia" and American scientists from the Savannah River Laboratory conducted multipacker tests at the Lake Karachai site in Septenber of 1996. The American side shipped equipment to Russia for the multipacker experiments.

When planning this experiment, Russian and American scientists proposed these field studies to allow evaluation of vertical and horizontal water transmission properties of the bed rocks for the first time. The studies were proposed at a site in the flow path in the prevailing direction of the regional fracturing. The resulting parameters will assist in determining the direction of the underground contaminated water flow in the vicinity of the river Mishelyak and their possible discharge into the open drainage system.

2. Brief Geological and Hydrogeological Characteristics of the Field Test Site

The test well cluster is situated close to the floodplain of the river Mishelyak. The upper part of the section is composed of delluvial, alluvial and elluvial sediments, which are represented mainly by loam, sandy loam with gravel and rock fragments. The thickness of these deposits ranges from 0.5 to 12 m. Below 12m, porphyrites, tuffs and tuffbreccia and lava occur. The rocks are massive, locally foliated or fractured, with quartz, calcite and chlorite-filled veins. The fracturing is more intensive in the upper part of the section and is caused by two reasons: weathering processes and tectonics.

The aquifers are composed of fractured zones of volcanic and metamorphic rocks of Paleozoic, typical of the Urals as well as the test site. Underground water in these zones is unconfined and the water table occurs at the depth from 0.1 to 3.5 m. Hydraulic properties of the aquifer are non-homogeneous. Tranmissivity coefficient is 20-100 m^2/day. The calculated transmissivity determined on data of cluster pumping test (well 1/96) is 102 m^2/day and hydraulic diffusivity is $2.3 \cdot 10^5$ m^2/day.

3. Methods

Selection of intervals for monitoring and pumping

The intervals selected for monitoring in wells 176 and 2/96, and the intervals selected for pumping in well 1/96 were determined jointly by the Russian and American scientists. The criteria used to identify zones of interest included the geophysical logs (e.g., resistivity and caliper logs), borehole photography, and results from previous pumping and borehole contaminant distribution studies. Based on these criteria approximately five to nine zones of interest were initially identified with particular emphasis on active hydrologic zones and depths where plume transport has been measured. With six packers, we isolated seven intervals (five between the packers, another above the top packer and another below the lowest packer). For clarity, these zones were identified as A, B, C, ... G. In the monitoring wells, the zones are contiguous and are separated by the glands of the packer. The packers occupy approximately 1 meter and provide a positive seal against the borehole wall. A straddle packer assembly was used for the pumping well. This assembly allowed isolation of a pumping zone from the zones above and below as needed. The length of the assembly was adjusted for each pumping zone to match the agreed depths.

Initial depth selections were made for the central pumping well (1/96). Figure 3.1 summarizes the depth selections for well 1/96 along with key geophysical data. Following selection of the intervals for the central well, the depth selections for the monitoring wells (176 and 2/96) were then made using the same criteria and comparing to the central well for consistency. Finally, the core from well 1/96 was examined as a final check on the depths selected. The multipacker installations and depths of all zones are shown in Table 3.1.

Equipment Installation

Multipacker system in observation wells

Six inflatable packers were installed in each of the 2 observation wells (176 and 2/96) at the Lake Karachai field test site. The packer assembly consisted of packers, in-line adapters, solid nipples, steel pipe, and slotted pipe (Figure 3.2). In-line adapters and slotted pipe were used to pass tubing through the packers from one zone to another. Solid nipples were placed just above the in-line adapters in each zone to isolate one zone from another. In order to account for the increasing submergence of the packers different inflation pressures were used for selected packers (Table 3.1). Pressure was measured in each of the zones using pressure transducers. The pressure transducers were connected to the zones using color coded 1/4" nylon pressure transfer lines filled with water.

Each pressure transfer line was filled with water by immersing the lower end of the tube into the zone to be monitored and using a vacuum to lift the formation water to the surface. After the water had been lifted to the surface the top end of the tube was placed in a bucket of water to establish a siphon from the bucket down into the zone. When enough water had been siphoned to remove all of the air from the line a pressure transducer was connected to the pressure transfer line inside the bucket to ensure that no air was inside the pressure transfer line.

Straddle packer in Pumping Well

A straddle packer assembly was used to pump water from each of the zones isolated in the monitoring wells. The straddle packer assembly was constructed using packers, slotted pipe, solid nipple, and a pump shroud (Figure 3.3) and installed in the pumping well 1/96. Slotted pipe and in-line adapters were used to pass tubing through the packers from one zone to another. Pressure was monitored above the pumping zone, in the sampling zone, and below the sampling zone using pressure transfer lines and pressure transducers as described above. Solid nipples were placed just above the in-line adapters in each zone to isolate one zone from another.

A pump shroud was connected above the straddle packer assembly to isolate the pump from the top zone. A 3/4 hp submersible pump (AppendixIII) was installed in the pump shroud and was capable of pumping over 60 L/min. The pump shroud forced upward flow across the pump motor resulting in convection cooling of the motor. Packers in the straddle packer assembly were inflated to varying pressures to account for the increasing submergence of the packers.

Static Tests

A static test was performed on well 176 to measure natural fluctuations in water levels in each of the zones. The static test was conducted by installing and inflating a multipacker assembly in well 176. Following installation of the multipacker assembly, the water level in each of the zones was monitored and recorded using pressure transducers and data loggers. The data logger was programmed to measure and record water levels at a constant time interval. In addition to monitoring water levels a barometer was connected to measure barometric pressure.

Pumping/Recovery Tests

Pumping tests were conducted on each of the zones listed in Table 3.2. A step drawdown test was conducted on each zone to determine the optimum pumping rate for each zone. During the step drawdown test the drawdown was monitored in the pumping well while the pumping rate was being increased. The pumping rate that produced the most drawdown while maintaining a water level above the submersible pump was used for the constant rate pumping test. Following the short control test, the water levels were allowed to recover prior to additional testing.

A constant rate pumping test was run on each zone until the water level in the pumping and observation wells approached steady state. Water produced during each was collected in a tank prior to discharge. Water levels were monitored for 30 minutes prior to each pumping test, during the pumping test, and during the recovery period following termination of the pumping test. Figures 3.4 and 3.5 are examples of the drawdown curves for the pumping/recovery test.

Water levels were monitored and recorded using pressure transducers and data loggers. The data loggers were programmed to read drawdown at a prescribed interval and to record the level only if it had changed a specified amount from the previous reading. If the drawdown did not change within a specified number of readings the drawdown was also recorded to prevent storing empty files for a test. The "event" programming of the data loggers allowed each entire test (background data through the recovery period) to be logged with one program.

Water Sampling/Analysis during Interval Pumping

During pumping out from every interval isolated with packers sampling of the pumped water was done. Water samples (10 L) were taken in the beginning and at the end of every pumping. Samples for express analysis on nitrate-ion content were taken at specified time intervals during the test.

There was used the samplig method which was applied before: using the multipacker system. Sampling time for express analyses was determined with taking into account the volume of water in the isolated well interval and the flow rate. Water samples were generally taken every 1,2.5, 5, 10, 20, 30, 45, 60 min after pumping beginning and then every 30 min.

Samples express analysis on nitrate-ion content were held with the use of ion-selective electrodes in the field laboratory directly after sampling. Water samples for chemical and radiochemical analysis were given to CPL "Mayak" PA. Results will be given to the American side after all the analysis is completed and will be given in the final report.

4. Preliminary Results

Pumping tests for eight zones were attempted using the methods described above and seven tests were successfully completed, Table 4.1. A test could not be completed in Zone G due to it's very low hydraulic conductivity. Pumping rates in the Zones A - F varied from 0.6 to 75 L/min depending on the zone.

Hydrologic Response

A static test was conducted on well 176 for ~ 24 hours and on well 2/96 for ~ 3 hours . The static tests were short due to a limited amount of time for the field works. Following inflation of the packers, pressures in each zone rapidly increase and then decrease to their "shut-in" pressure, Figures 4.1 and 4.2. In well 176, Zones A,B,C, and E rapidly approach their shut-in pressure, Zone D fluctuates around an average shut-in pressure and, Zones F and G gradually move toward a shut-in pressure. Note that Zone G is approximately 300m longer in well 176 than in well in 2/96. In general, the static pressures are consistent with those predicted by the regional and local hydrologic conceptual models. Vertical flow potentials in the borehole are generally upward in 2/96 from all zones toward Zones A and B. In well 176, vertical flow potentials are generally upward toward zones A and B with some flow toward the high permeability zone E and with a potential toward the underpressurized Zone G. Zone G had a very low hydraulic conductivity, however, suggesting that downward flow toward Zone G and below is not significant in regional flow regime, rather, flow occurs at shallow and intermediate depths and is controlled by the River Mishelyak with possible migration underneath at intermediate depth. Confirmations of the potentials and high precision vertical borehole flowmeter data in these and the surrounding wells would allow clear confirmation of the regional and subregional flow vectors suggested by the static tests.

The results in Figure 4.3 illustrate the typical response of the central pumping well 1/96 during a test. Note that the pressure above and below the straddle packer assembly are relatively constant and do not appear to be directly affected during pumping, this suggests that the packers have a good seal -- even under the influence of large drawdowns during pumping. Water level changes due to pumping varied depending on the zone being pumped, Table 4.1 and Figures 4.4 and 4.5. In most cases the zone being pumped in well 1/96 had the largest response in the monitoring wells. However, for two cases in well 2/96 (Zone A and B tests) the largest response was in a zone below the pumping zone. This can be more clearly seen in Figures 4.6 and 4.7. Since the selected intervals for the monitoring zones in 2/96 were already set below the other two wells, this suggests that the fracture connections may have a downward trend between the pumping well and well 2/96. Well 2/96 had more drawdown during pumping than well 176 for all tests except when Zone D was pumped, Table 4.2.

The specific capacity for each zone in the pumping well was calculated using the final drawdown in the pumping zone, Table 4.1. The lack of casing and screen in the well and the relatively low pumping rates minimize the head loss due to the entry of water into the well and as a result the specific capacity of each zone is a good indicator of the relative hydraulic conductivity of the zones. The highest specific capacities (39.5 L/min/m) are found in zones E and F. Above and below these high capacity zones, in zone D and in the deepest zone (G), the lowest specific capacities were measured -- 0.047 and <0.003 L/min/m, respectively. Overlying zone D, the rock exhibited intermediate specific capacities, 1.3 L/min/m (Zones A and B) and 0.32 L/min/m (Zone C). As a check on quality and consistency, the sum of the specific capacities in the individual zones (82 L/min/m) should approximately equal the specific capacity measured when all zones were pumped simultaneously (84.7 L/min/m). The close agreement indicates high quality and consistent results. Similarly, the sum of the nitrate concentrations weighted using the specific capacity (4903 mg/L) should approximately equal the nitrate concentration measured when pumping all zones simultaneously (4624 mg/L). This provides evidence that the chemical analysis was also of high quality and consistency. The nitrate results are discussed in more detail below.

Interval Sampling of the Well 1/96

Change of nitrate-ion concentrations during pumping from the intervals isolated with packers from well 1/96 are given in Appendix A and on Figure 4.8. From the figure, we can see that stabilization of nitrate-ion content in the samples from zones A, B and C is observed in 10-15 min. after pumping beginning. Maximum nitrate-ion concentrations in the intervals A and B are measured at 5 minutes. Concentrations then decline to the stable values. Such changes may be related to the fact that the sampled zones are characterized by relatively small fracturing and capacity. Average values of the pumping flow rate of zones A and B are 9 and 7.5 L/min, respectively. As a result, groundwater flow into the well may be delayed because of reduced permeability in the immediate vicinity of the borehole. Increase of the component content in the pre-well zone relatively the real concentrations in the layer water is possible because of exchange and nitrate accumulation in this zone. During pumping from the isolated interval in the first minutes, water flow from the pre-well zone takes place with relatively high nitrate-ion content followed by the inflow of the layer water into the well. This results in stabilization on the real concentration values (Figure 4.8).

While pumping from the interval B such effect is not observed because of the presence of the zones with intensive rock fracturing. This also results in increased groundwater influx - 13 L/min.

Interval D is characterized by very low hydraulic conductivity. Flow rate varied within the limits 0.6 - 0.7 L/min. Chart of the nitrate-ion concentration change during pumping shows the same effect of delay of the layer water influx in the well. Time of the delay is increased because of the low hydraulic conductivity of the sampled interval.

Intervals E and F are characterized with maximum hydraulic conductivities and pumping flow rates of 75 L/min. that is why the layer water influx into these intervals is observed in 2.5 - 5 min. after beginning of the pumping (stable nitrate-ion concentrations).

After interval pumping the pumping of the whole borehole 1/96 was performed without isolation with packers with the constant flow rate of 75 L/min. According to the samples express-analysis data taken during pumping from the borehole at the beginning the increase of nitrate-ion concentration is observed and, then, stabilization at relatively small concentrations, as happened while pumping from the zones A and C In this case the reason may be in concentration "accumulation" in the well after contaminated water influx during pumping from the zones E and F. Following decrease of nitrate-ion concentrations, probably, is related to influx of the less contaminated water from the upper intervals. In the whole significant nitrate-ion concentrations in water samples taken during the test are explained by the fact that the main input into the sum water influx along the well shaft is carried from the zones E and F. In these zones the contaminant flow with the highest nitrates content was observed at pumping.

Comparison of the nitrate-ion concentrations in all the tested zones indicates that when the depth is increased the initial and stable component concentrations are increased as well. This accounts for the fact that the main contaminated flow occurs on the depth of 50 to 75-80 m, which corresponds to the representations on vertical hydrochemical zonation of contaminated water because of high density of solutions which migrate from the lake Karachai.

Discussion

The entire program of testing was completed on schedule. The equipment used for testing was of high quality and facilitated the transfer of technology from between the Russian and American delegations participating in the testing. Results of the testing show that a multipacker assembly can be used to simultaneously isolate seven zones in a single borehole for hydraulic testing. Pump testing using the multipacker assemblies in observation wells 176 and 2/96, and a straddle packer assembly in the central pumping well 1/96 produced data useful for evaluating the hydraulic properties and connection of the zones of fractured rock present at the Lake Karachai site.

Drawdown was observed in both observation wells (176, and 2/96) when pumping the central well (1/96) suggesting lateral connection in the general direction of the regional strike and dip of fractures. When the multipackers were in place to isolate the observation zones, 2/96 exhibited more drawdown than 176 which may indicate a higher transmissivity in the direction of dip of the fractures.

The drawdown data from the observation intervals (Zones A - G) isolated with the multipacker systems in wells 176 and 2/96, combined with the drawdown and contaminant concentration data from zones in the pumping well (1/96), provide important indications of the dynamics of water flow at the field site.

In general, groundwater at the site is moving in the fractured rock through the unified aquifer. Water in this aquifer flows in two distinct intervals. These active intervals are separated by rocks of low lateral hydraulic conductivity, but which provide substantial vertical (or steeply dipping) hydraulic connection between the intervals. The shallow interval consists of observation zones A-C and the deeper interval consists of zones E-F. Zone D acts as a leaky aquitard between these aquifer intervals and the entire system is underlain by a massive body of rock (zone G) that generally does not participate in the active hydrologic system.

Examination the borehole telephotometry and the gross distribution of fractures in the core material from well 1/96 supports this general conceptual model. The core material and borehole photos from zones A, B, and C show that the fractures are dominated by horizontal and subhorizontal dipping fractures that provide pathways for groundwater migration. In contrast. Zone D is cut by a very high angle fracture across the entire interval. The rare subhorizontal fractures in Zone D have been healed. Zones E and F are again dominated by subhorizontal fractures. The interval from 56-67m (Zone F) shows evidence of relatively intense alteration perhaps indicating the presence of a preferred fluid migration pathway. Zone G is cut by numerous subhorizontal fractures that are sealed by secondary minerals suggesting that it is a relatively impermeable zone. More detailed study of these features may provide additional details regarding the hydrodynamic regime

In order to better define natural flow patterns long term monitoring (e.g., months) of shut-in pressure using a multipacker assembly and high sensitivity borehole flow meter tests should be conducted. Long term monitoring of shut-in pressure will provide valuable information on the hydraulic gradient in and between fracture zones. The hydraulic gradient information can then be used to prepare piezometric maps, identify flow patterns, prepare boundary conditions for numerical modeling, and calibrate/validate modeling results.

A high sensitivity borehole flow meter uses an electromagnetic flow meter to measure water flowrate and can be used to measure groundwater flow in boreholes with a resolution of ~1 mL/min. The results of ambient borehole flow meter logging are used to determine the direction and rate of natural groundwater flow in the borehole. Following ambient borehole flow meter measurements a dynamic tests is performed using a borehole flow meter and a submersible pump. The results from both the ambient and dynamic borehole flow meter tests are combined to prepare a detailed log (~ 50 cm intervals) of the relative hydraulic conductivity of the hydrogeologic profile. The hydrogeologic log is valuable information for the modeling of groundwater flow and contaminant transport.

Similar to the long term monitoring of shut in pressures, the high sensitivity borehole flow meter would be most useful if used in key wells along the entire flow transect to allow mapping of the hydrologic properties of the fractured rock system. Importantly, the high sensitivity borehole flow meter is relatively inexpensive and rapid to deploy and collect information. Thus, seven or more wells could be logged in a reasonable joint field program.

5. Conclusions and Recommendations

Joint Russian-American field tests using the multipacker assemblies for well sampling allowed to estimate for the first time the interrelation of the of different fractures of Paleozoic water-bearing horizon within the borders of the river Mishelyak in the place of discharge of contaminated underground water discharge from the Lake Karachai. Obtained data will further allow to determine fracture parameters and to verify physical model of the contaminated water discharge process into vicinity of the Mishelyak River.

During scientific discussions on these works and during preparation of the report there were determined the following statements on possible ways of our cooperation:

1. to combine joint final report and publish articles in 1996-97 on the results of field studies performed at "Mayak" PA site in 1996;
2. to continue joint field studies in the vicinity of the Mishelyak River including:
   a) multipacker test situated at one more site with the aim of spatial confirmation of the data obtained;
   b) to study parameters of hydraulic resistance and sorption capacities of the bed sediments which determine the delay in the process of contaminated water discharge into the Mishelyak River;
3. to work on the joint methods for the field tests and data processing for studies of facilities that may impact ecological conditions in similar geological and hydrogeological settings.
4. to use the high sensitivity borehole flowmeter

Data obtained in the result of proposed field tests will allow to determine migration conditions and contaminated water discharge in the vicinity of the Mishelyak River and, also, to estimate characteristics of fracture rocks which determine filtration capacities of the water-bearing horizon within the borders of the discharge site. Using this information in numeric modeling of contamination migration we will be able to give true estimation of the substance amount discharged into the open drainage system and this will exceed the reliability of the forecasted calculations of the possible countermeasures on contamination localization.

Table 3.1 Details of multipacker installation in wells 176 and 2/96

Monitoring Well 176(Elevation 246.58 m)

ZONE	Top of Packer depth (m)	Zone Interval depth (m)	Inflation Pressure
Zone A	18.7	0 to 18.7	85 psi
Zone B	31.2	19.7 to 31.2	85 psi
Zone C	41.9	32.2 to 41.9	130 psi
Zone D	48	42.9 to 48.0	130 psi
Zone E	56.6	49.0 to 56.6	130 psi
Zone F	81.3	57.6 to 81.3	195 psi
Zone G	--	82.3 to 400	--

Monitoring Well 2/96 (Elevation 246.27 m)

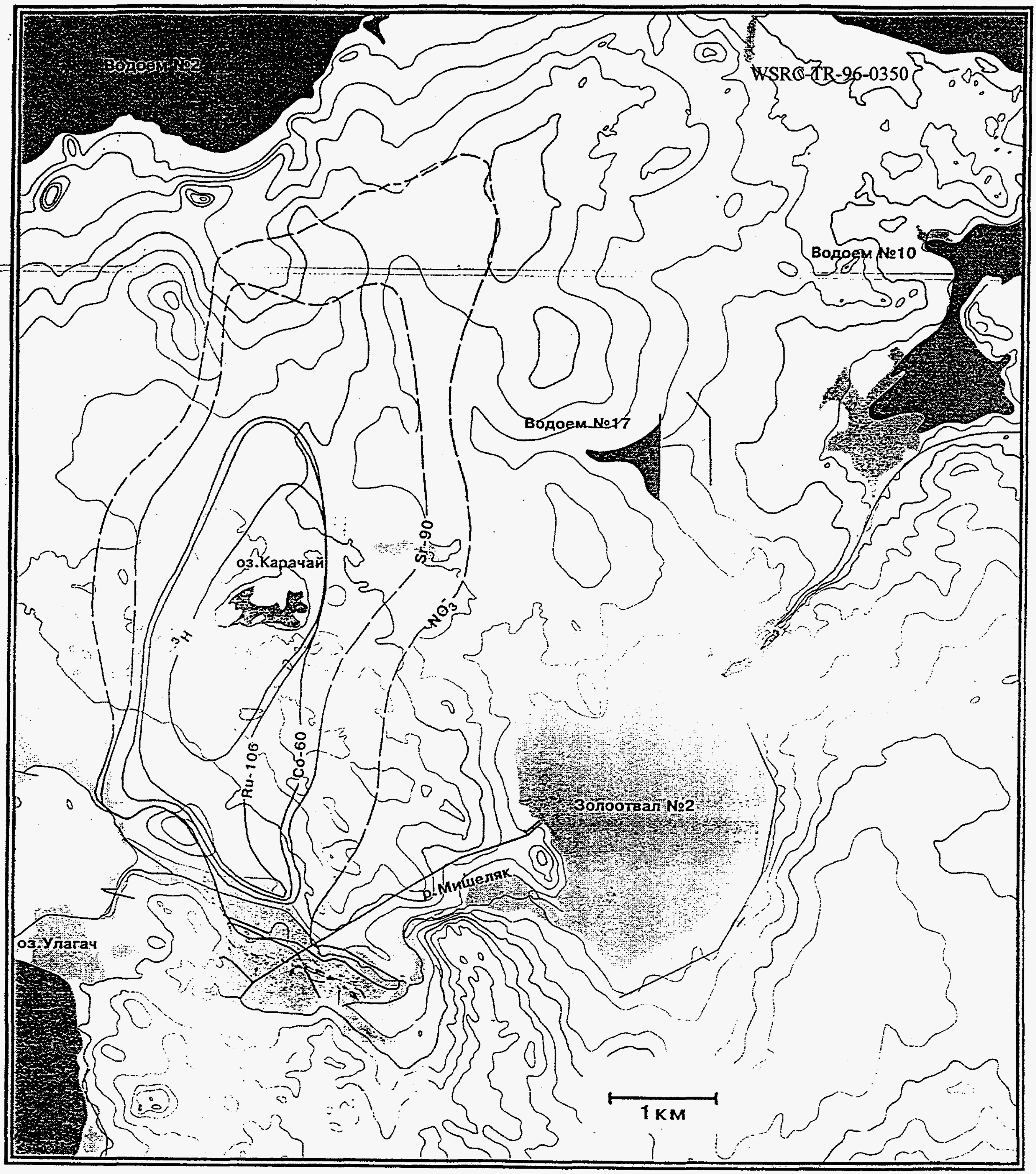
ZONE	Top of Packer depth (m)	Zone Interval depth (m)	Inflation Pressure
Zone A	19.21	0 to 19.21	85 psi
Zone B	31.91	20.21 to 31.91	85 psi
Zone C	41.41	32.91 to 41.41	130 psi
Zone D	49.91	42.41 to 49.91	130 psi
Zone E	59.41	50.91 to 59.41	130 psi
Zone F	78.55	60.41 to 78.55	195 psi
Zone G	--	79.55 to 105	--

Table 3.2 Zones and Final Pumping Results for Well 1/96

Zone pumped	Q L/min	final dH m	Q/dH	final NO_3 mg/L
A (0 -19 m)	8.82	6.8	1.3	536
B (20.9 - 32.2 m)	12.5	9.7	1.3	1096
C (32.3 - 41.5 m)	7.5	23.4	0.32	1380
D (42.5 - 47.5 m)	0.63	13.5	0.047	1928
E (49.0 - 54.0 m)	75	1.9	39.5	4217
F (55.4 - 75.9 m)	75	1.9	39.5	5888
G (79.0 - 99.6 m)	*< 0.1*	*> 35*	*< 0.003*	*no sample*
all zones	75	0.9	84.7	4624

Table 4.1 Summary of all steady state drawdown (meters) results from in observation wells 176 and 2/96

	176							2/96						
zone pumped	A	B	C	D	E	F	G	A	B	C	D	E	F	G
196 A	0.058	0.052	0.000	0.000	0.000	0.000	0.000	0.049	0.060	0.035	0.000	0.011	0.009	0.000
196 B	0.048	0.065	0.025	0.030	0.025	0.025	0.000	0.040	0.075	0.100	0.040	0.034	0.025	0.015
196 C	0.020	0.040	0.046	0.030	0.016	0.016	0.000	0.020	0.030	0.087	0.020	0.020	0.014	0.005
196 D	0.000	0.000	0.005	0.020	0.007	0.004	0.000	0.000	0.000	0.000	0.010	0.002	0.005	0.000
196 E	0.060	0.080	0.120	0.290	0.490	0.440	0.020	0.050	0.070	0.130	0.680	0.630	0.470	0.230
196 F	0.073	0.075	0.120	0.240	0.490	0.960	0.090	0.040	0.040	0.110	0.320	0.430	1.240	0.440
196 G	--	--	--	--	--	--	--	--	--	--	--	--	--	--
all zones	0.080	0.100	0.125	0.280	0.480	0.610	0.047	0.070	0.090	0.130	0.470	0.510	0.720	0.290



Ореолы загрязнения подземных вод на 1994 год в изолиниях ПДК и $ДК_Б$ основных компонентов-загрязнителей

Figure 1.1 Map of the study area showing Lake Karochai and the extent of groundwater contamination (plume boundaries represent permissible limits)

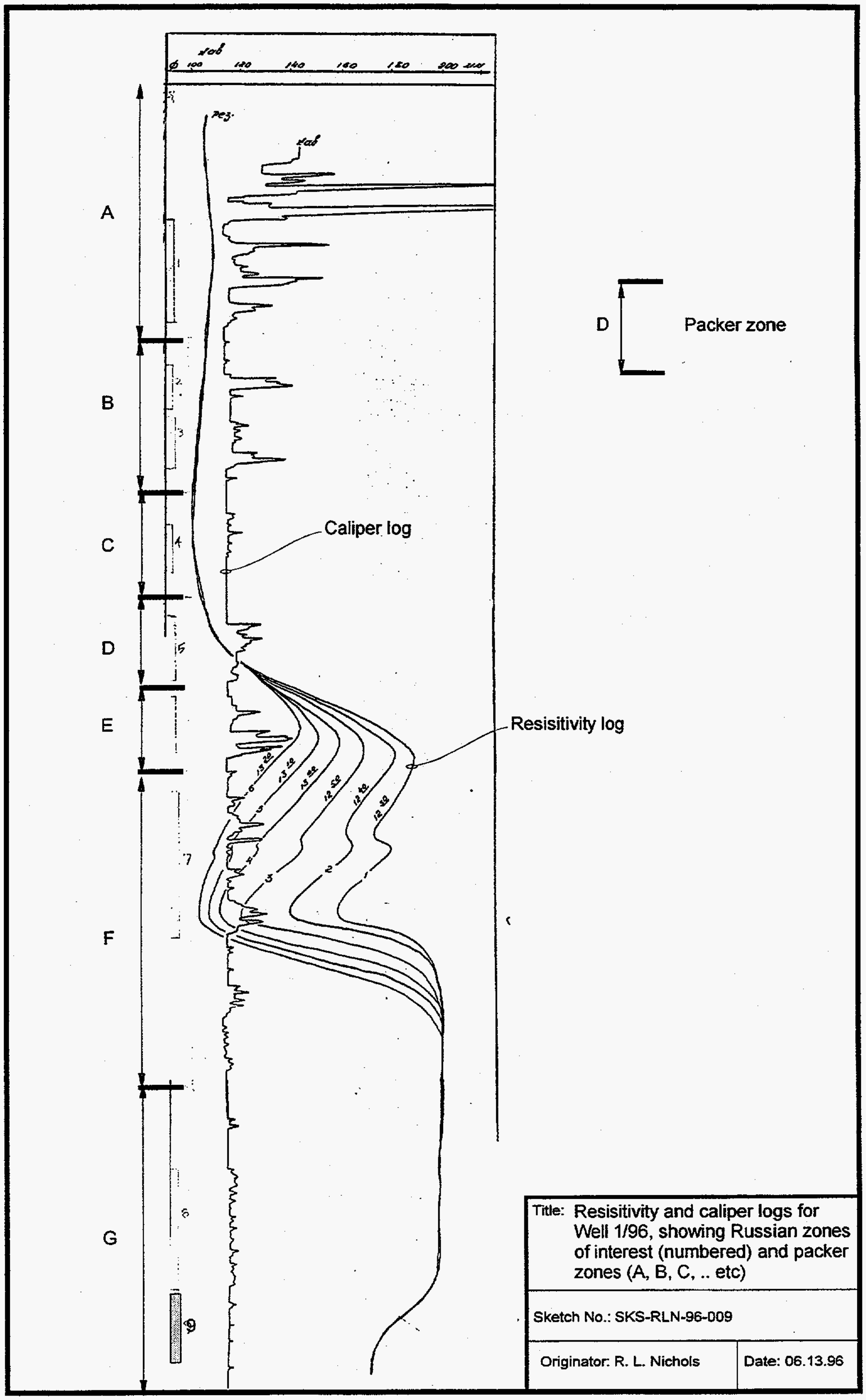


Figure 3.1 Resistivity and caliper logs for well 1/96 showing test zones A through G.

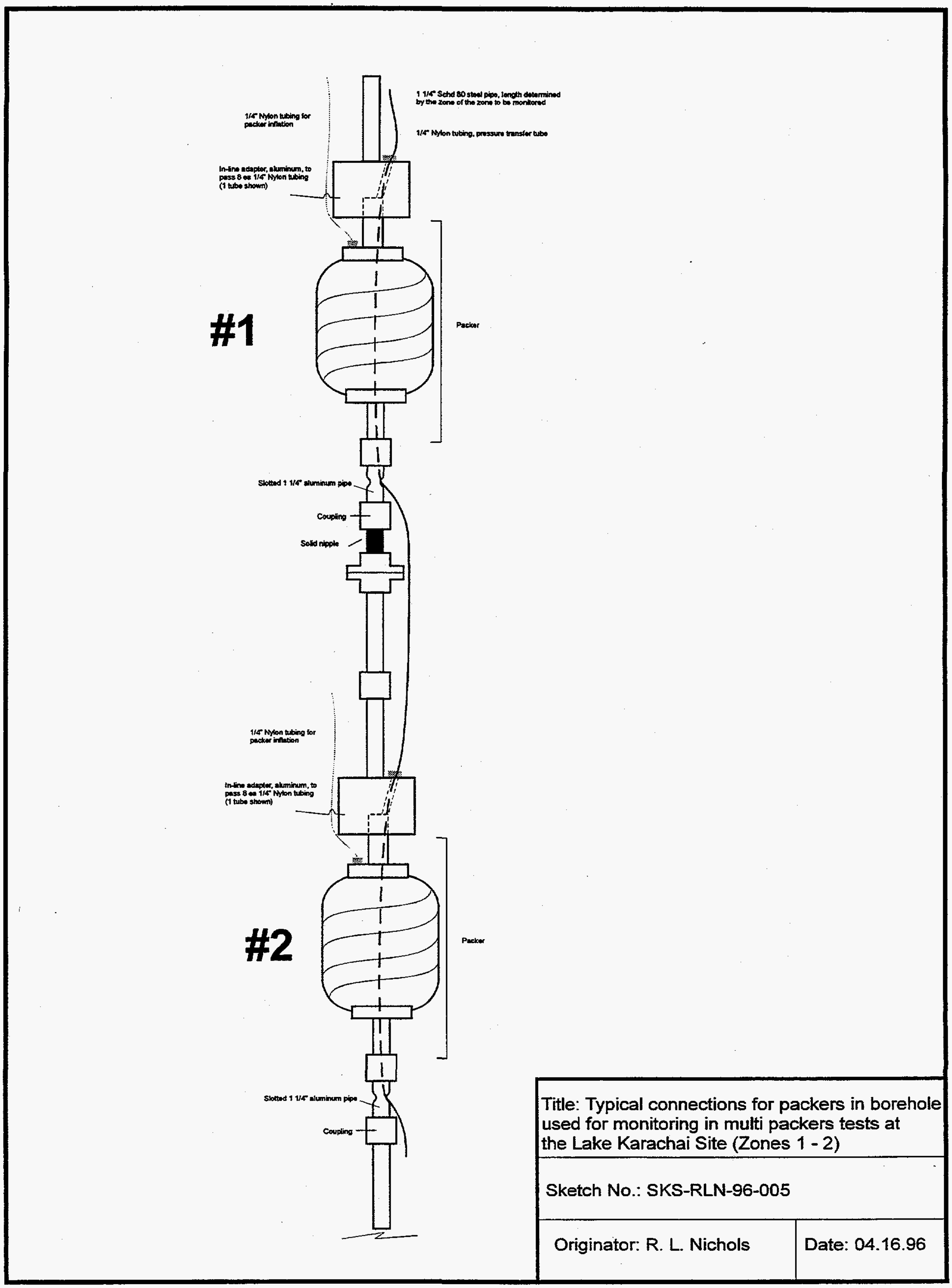
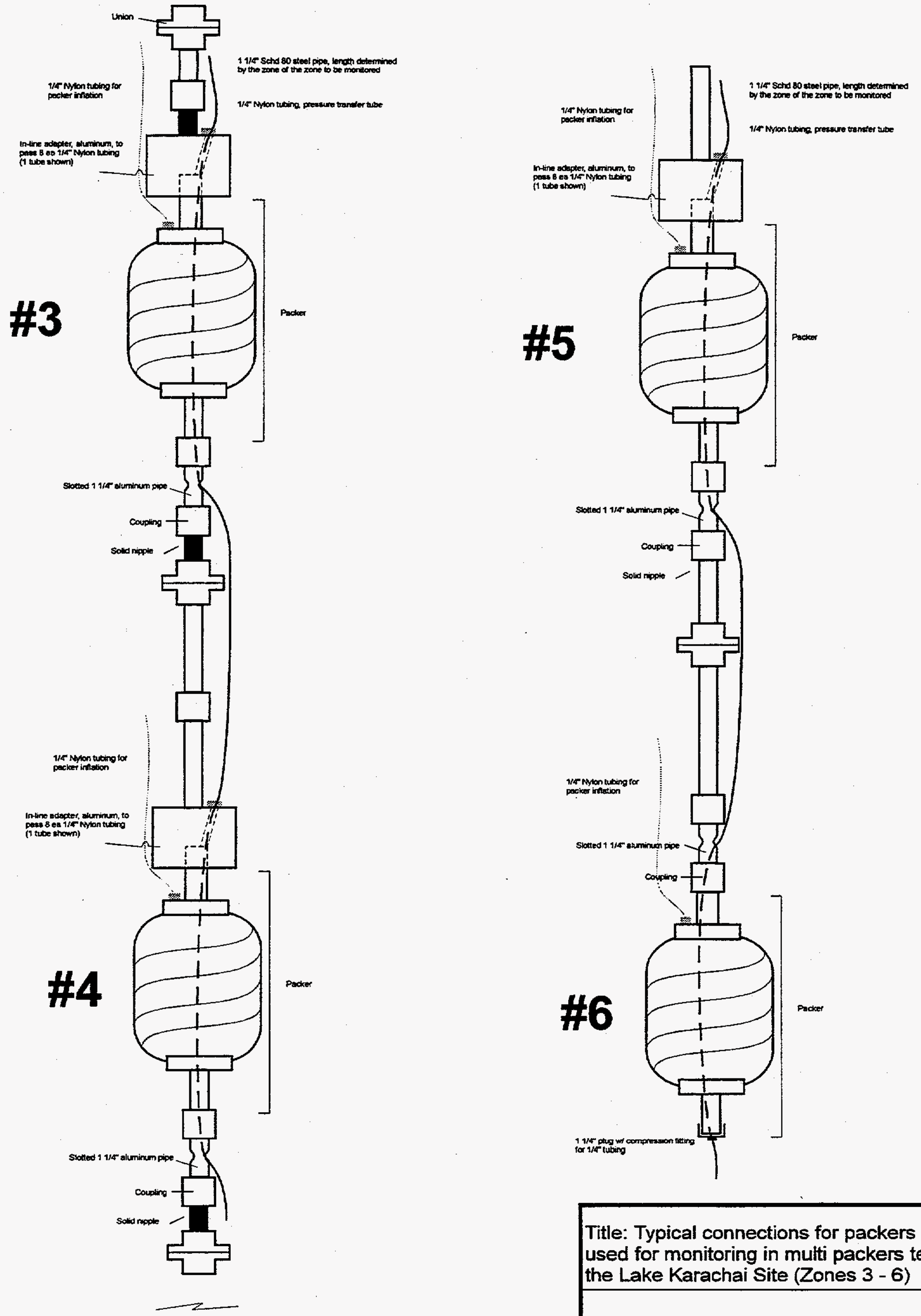


Figure 3.2 Schematic drawing of multipacker assembly for observation wells 176 and 2/96.



Title: Typical connections for packers in borehole used for monitoring in multi packers tests at the Lake Karachai Site (Zones 3 - 6)	
Sketch No.: SKS-RLN-96-004	
Originator: R. L. Nichols	Date: 04.16.96

Figure 3.2 contined Schematic drawing of multipacker assembly for observation wells 176 and 2/96.

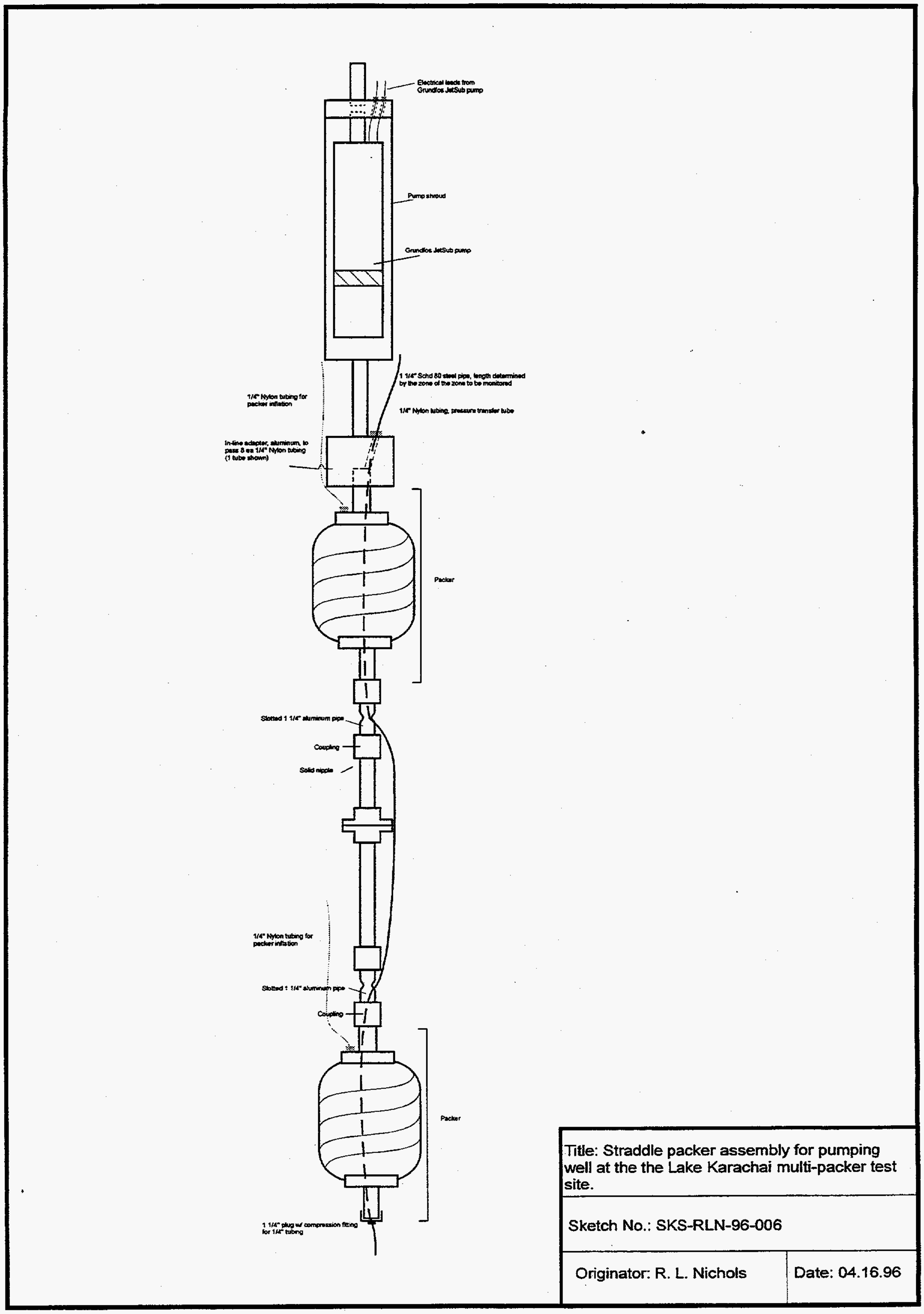


Figure 3.3 Schematic drawing of straddle packer assembly for pumping well 1/96.

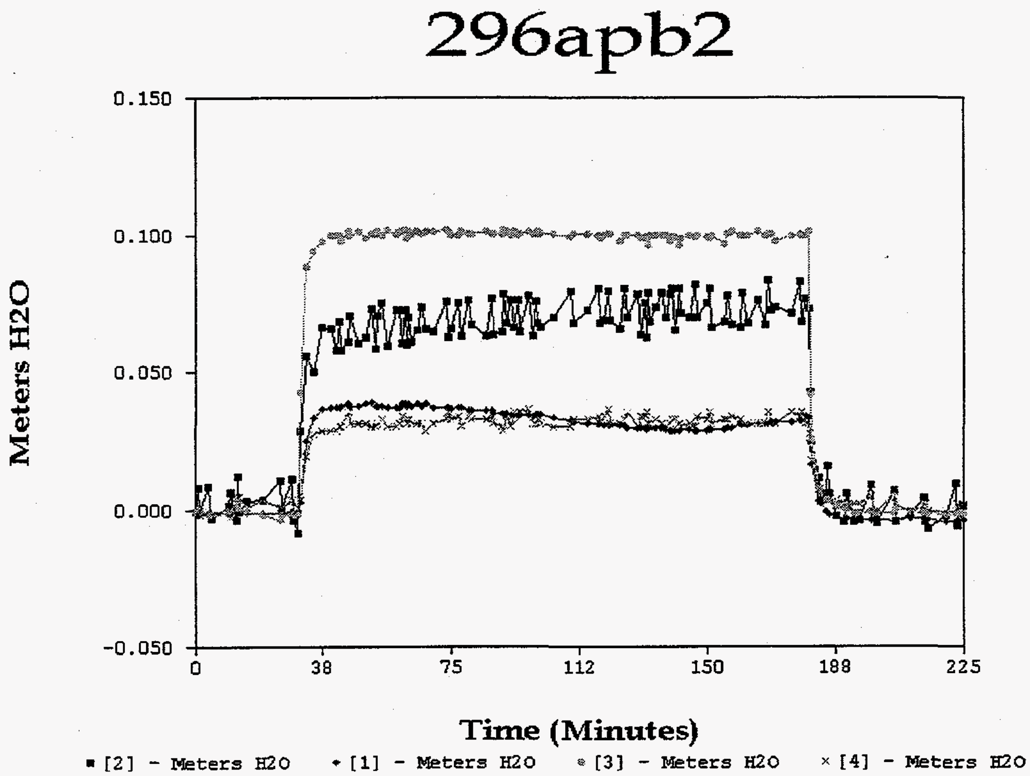


Figure 3.4 Drawdown vs time for observation well 2/96, zones A [1], B [2], C [3], and D [4], while pumping well 1/96 zone B at 12.5 L/min.

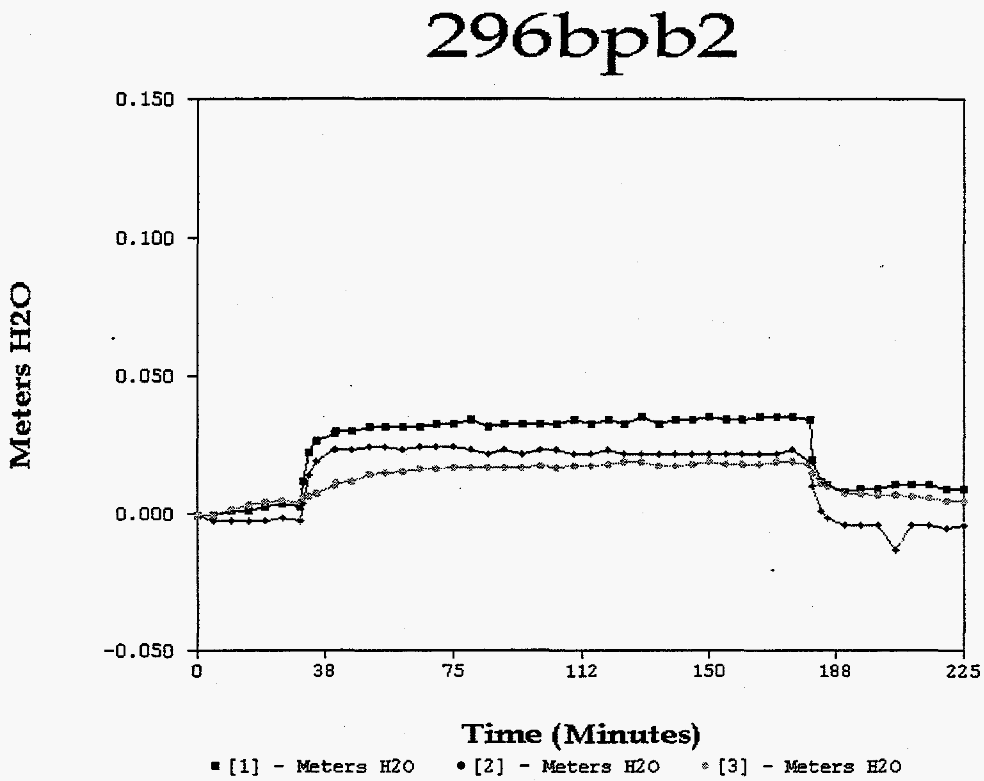


Figure 3.5 Drawdown vs time for observation well 2/96, zones E [1], F [2], and G [3] while pumping well 1/96 zone B at 12.5 L/min.

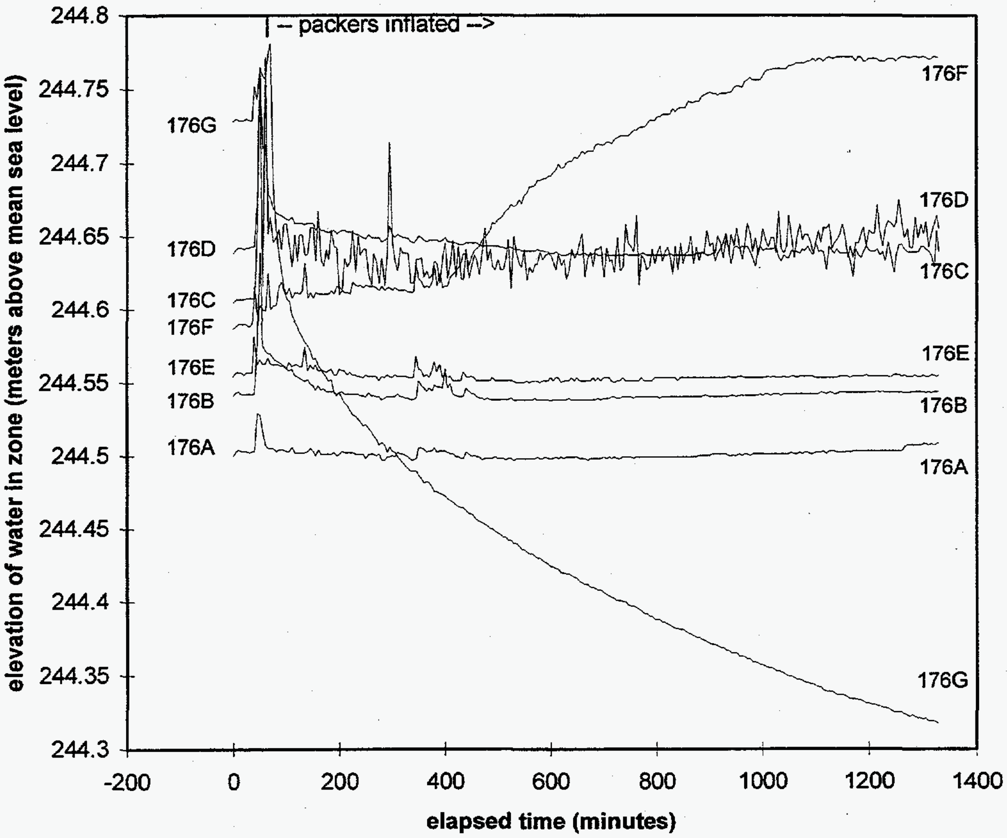


Figure 4.1 Results of static test for well 176.

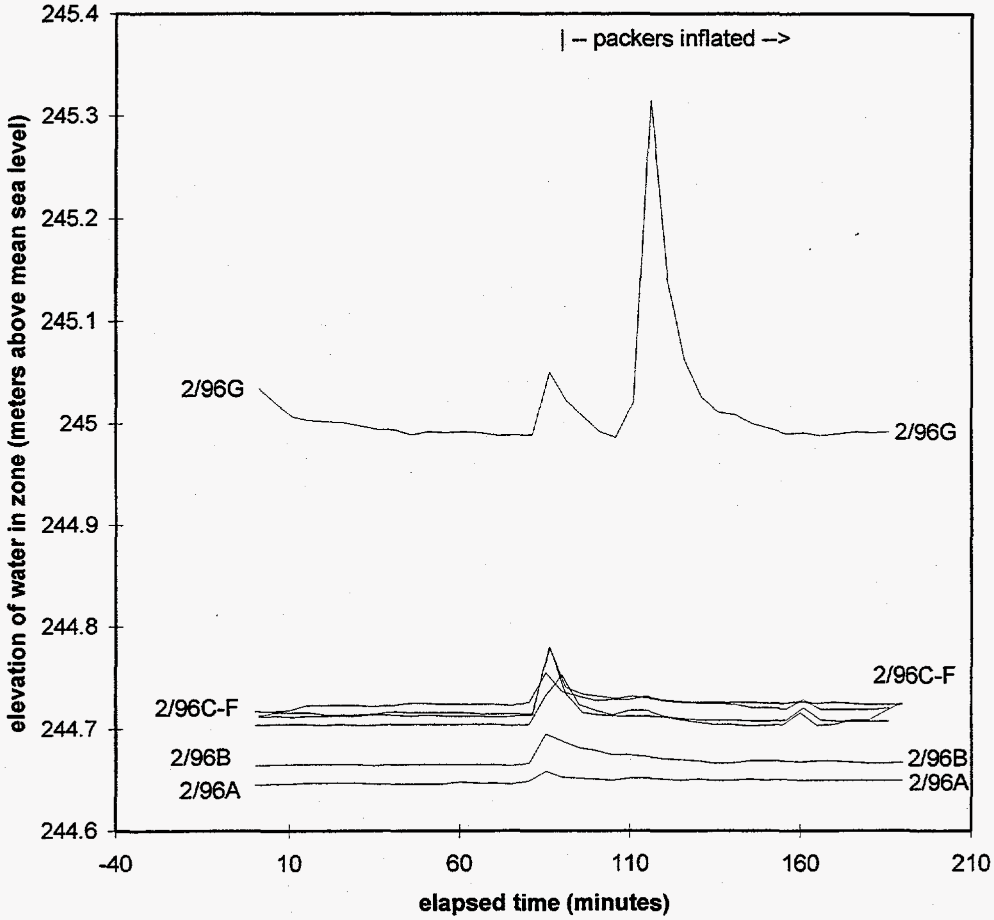


Figure 4.2 Results of static test for well 2/96.

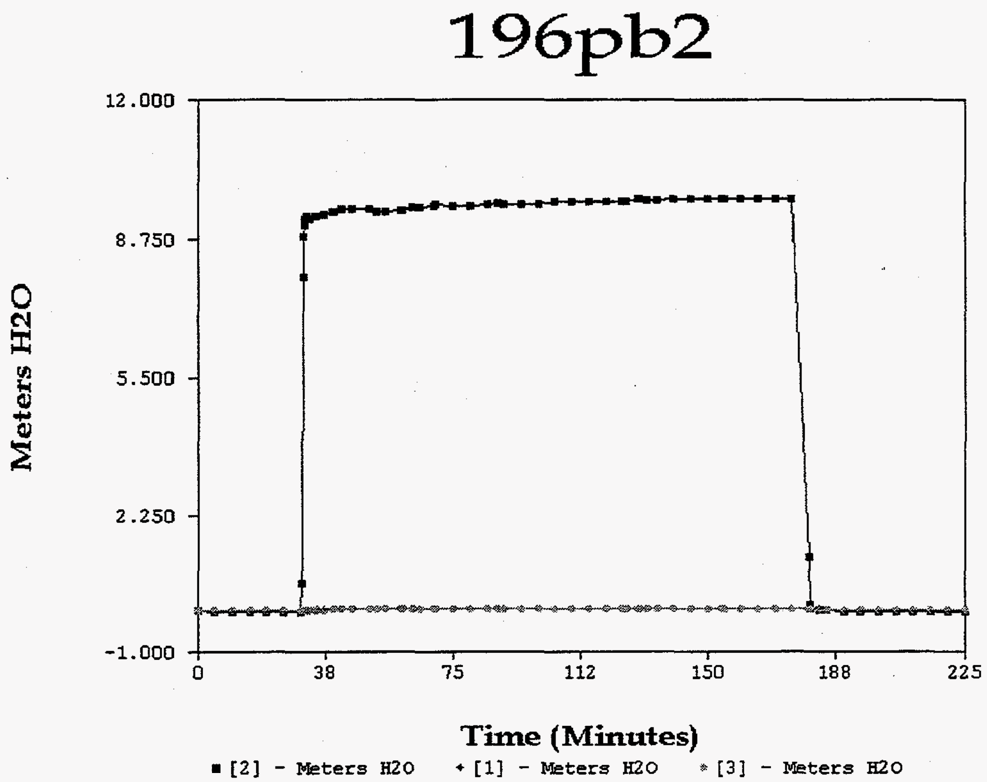


Figure 4.3 Drawdown vs time for pumping well 1/96, zones A [1], B [2], and C-G [3] while pumping well 1/96 zone B at 12.5 L/min.

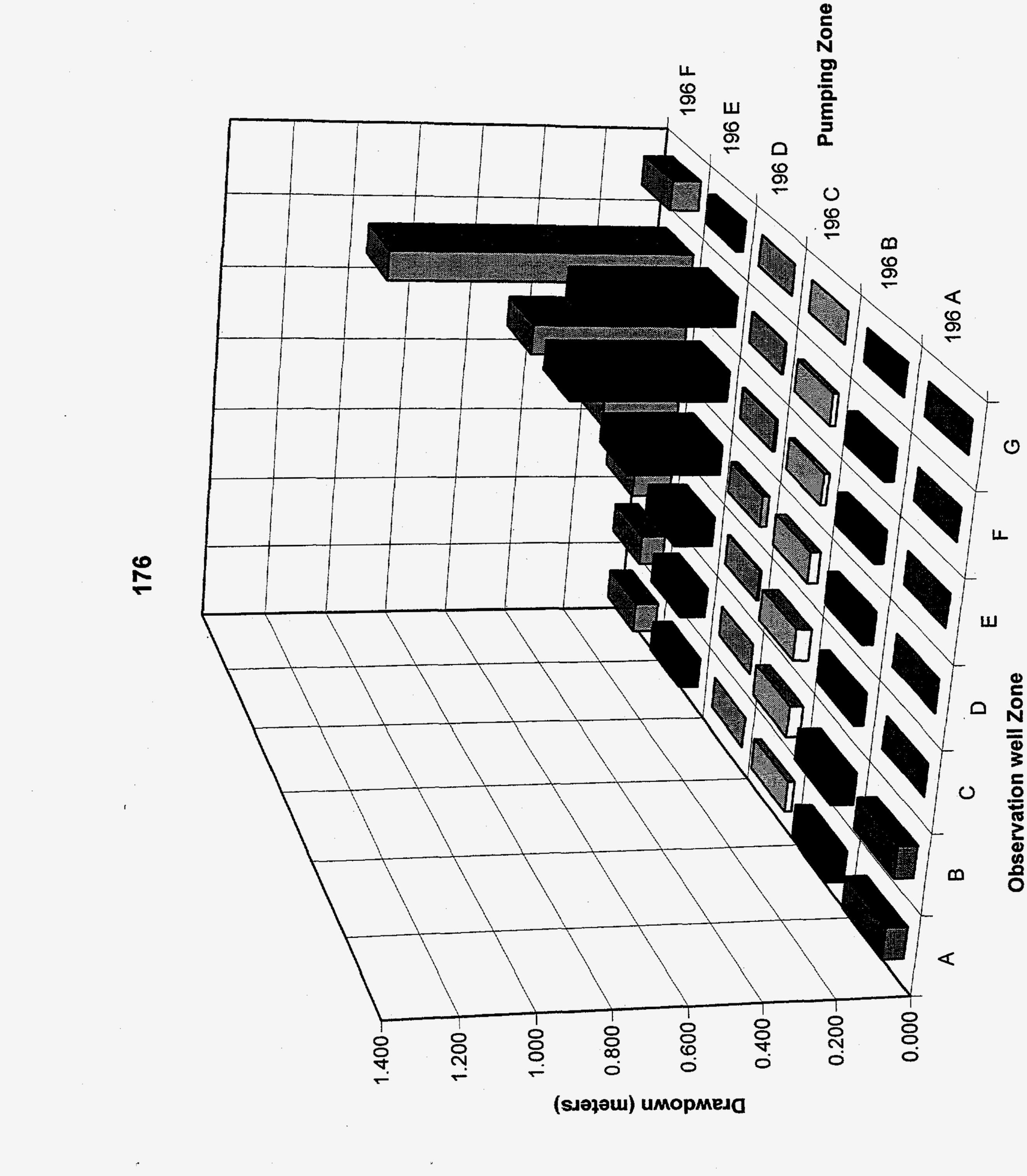


Figure 4.4. Summary diagram of steady state drawdowns for observation well 176

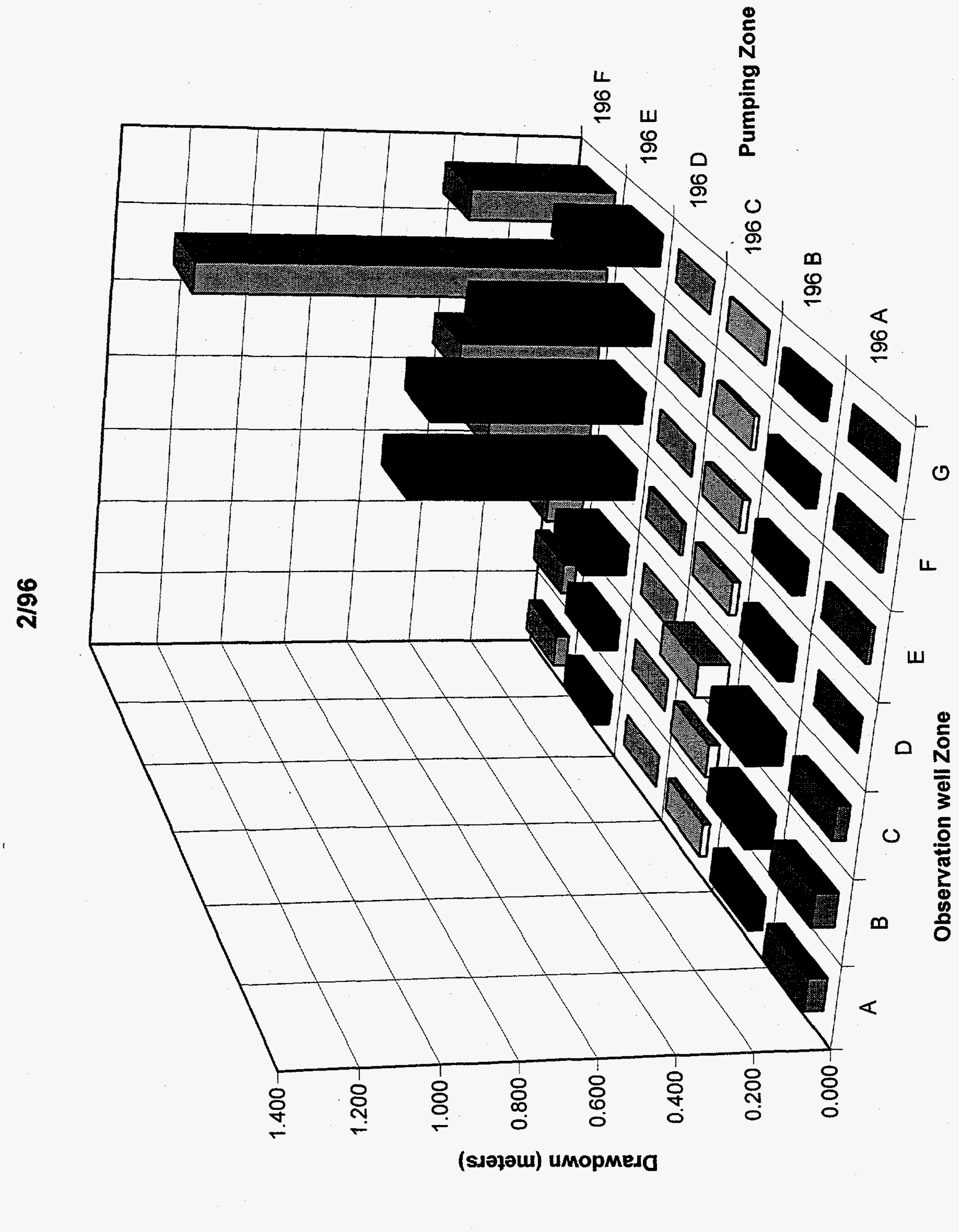


Figure 4.5. Summary diagram of steady state drawdowns for observation well 2/96

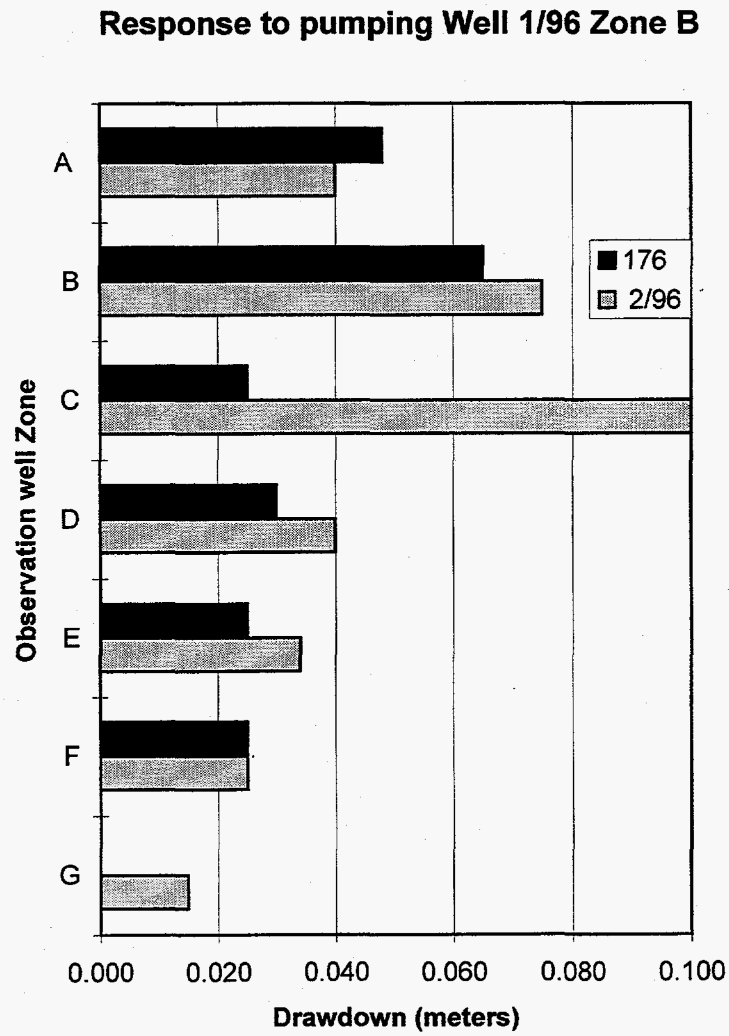


Figure 4.6. Comparison of steady state drawdown in wells 176 and 2/96 while pumping well 1/96 zone B.

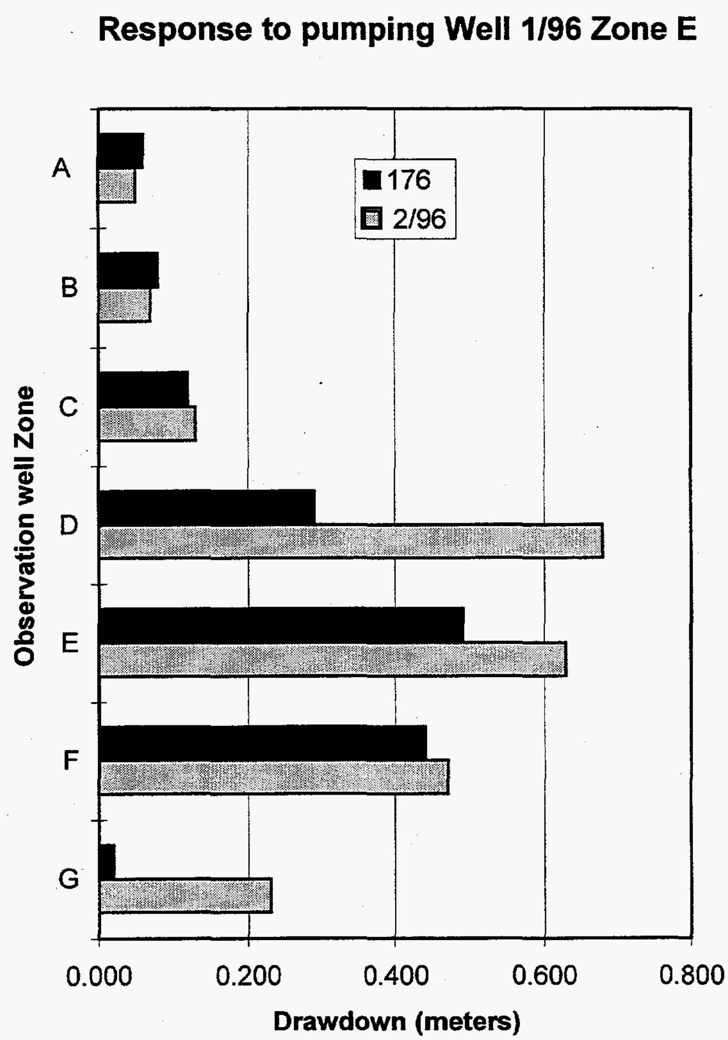


Figure 4.7. Comparison of steady state drawdown in wells 176 and 2/96 while pumping well 1/96 zone E.

Концентрация нитрат-иона (мг/л) в воде из скважины 1/96 при поинтервальных откачках

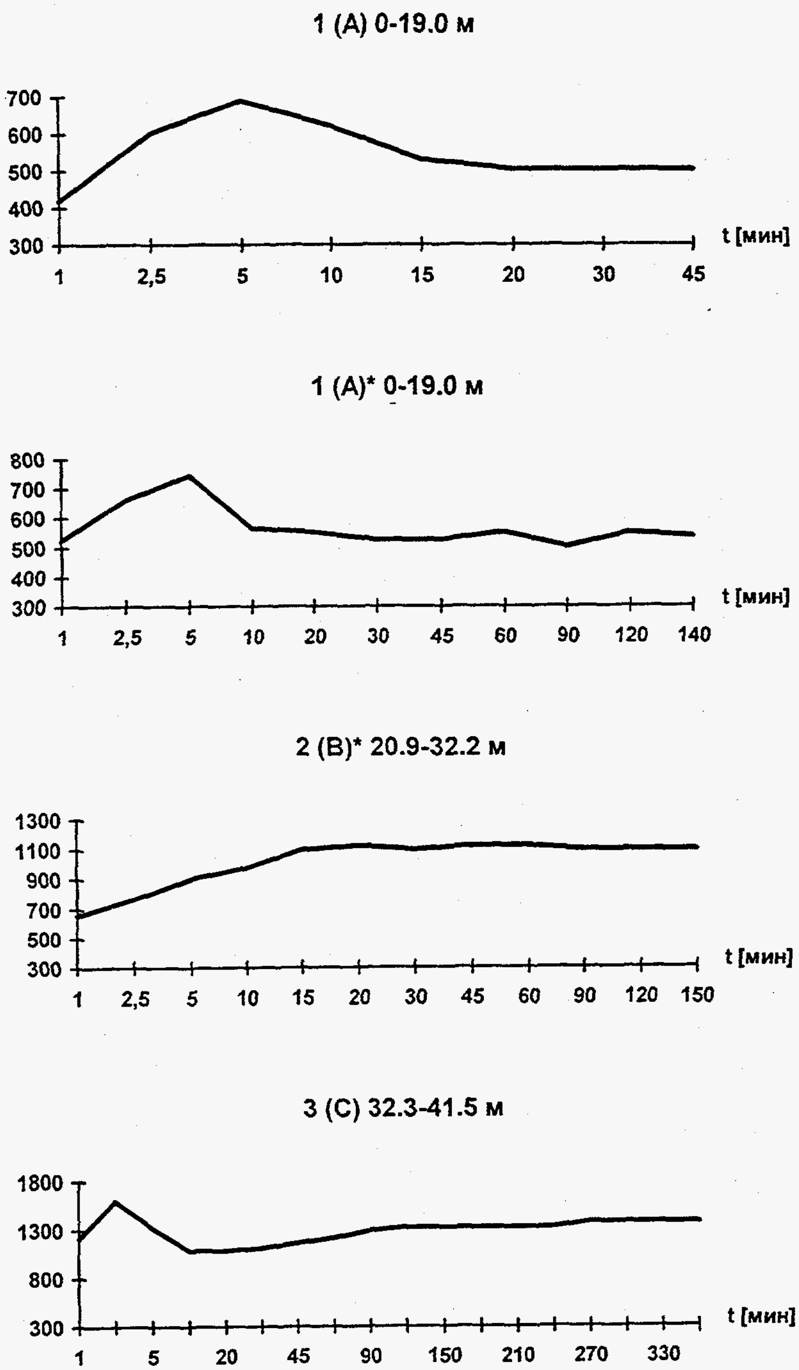
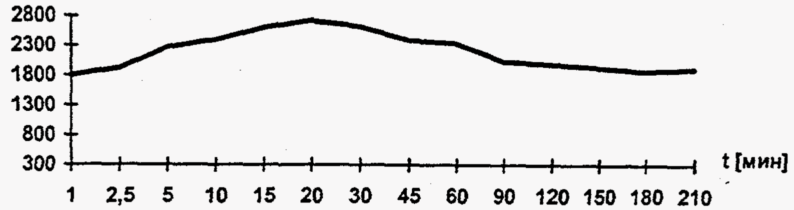


Figure 4.8 Nitrate ion concentration (mg/L) in water pumped from intervals in the central well 1/96

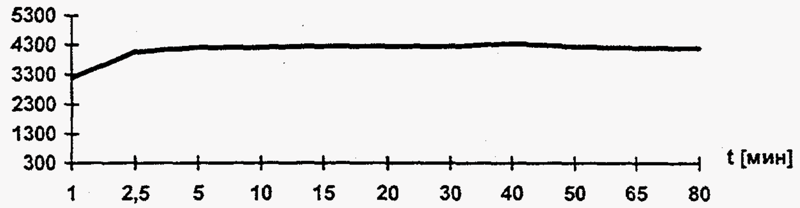
Концентрация нитрат-иона (мг/л) в воде из скважины 1/96 при поинтервальных откачках

(продолжение)

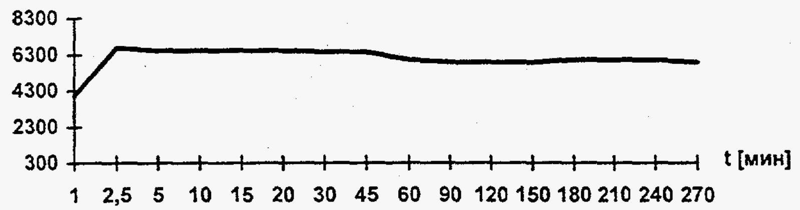
4 (D) 42.5-47.5 м



5 (E) 49.0-54.0 м



6 (F) 55.4-75.9 м



без пакеров

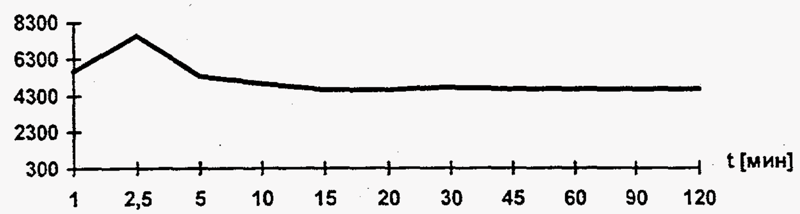


Figure 4.8 (continued) Nitrate ion concentration (mg/L) in water pumped from intervals in the central well 1/96

Appendix A

Flowrate and NO3 data for pumping tests

Zone Pumped	Sample Number	Elapsed Time (min)	Flow Rate L/sec (L/min)	NO3 mg/L
Zone A	1-1	1	0.154 (9.23)	418
	1-2	2.5	--	602
	1-3	5	--	690
test stopped	1-4	10	0.147 (8.82)	620
repeated	1-5	15	--	530
below	1-6	20	--	502
	1-7	30	0.147 (8.82)	502
	1-8	45	0.147 (8.82)	502
Zone A	1-1	1	0.154 (9.23)	526
0.0 - 19.0 m	1-2	2.5	--	662
	1-3	5	--	743
	1-4	10	0.154 (9.23)	564
	1-5	20	--	551
	1-6	30	0.152 (9.12)	526
	1-7	45	0.15 (9.0)	526
	1-8	60	0.147 (8.82)	551
	1-9	90	0.15 (9.0)	502
	1-10	120	0.147 (8.82)	550
	1-11	140	0.147 (8.82)	536
Zone B	2-1	1	--	1213
test stopped	2-2	2.5	--	1213
repeated	2-3	5	0.0637 (3.8)	1199
below	2-4	10	--	1081
Zone B	2-1	1	0.213 (12.78)	653
20.9 - 32.2 m	2-2	2.5	--	767
	2-3	5	0.213 (12.78)	902
	2-4	10	0.222 (13.3)	977
	2-5	15	0.213 (12.78)	1096
	2-6	20	--	1122
	2-7	30	0.213 (12.78)	1096
	2-8	45	0.215 (12.9)	1122
	2-9	60	0.213 (12.78)	1122
	2-10	90	0.213 (12.78)	1096
	2-11	120	0.208 (12.5)	1096
	2-12	150	0.208 (12.5)	1096

Zone Pumped	Sample Number	Elapsed Time (min)	Flow Rate L/sec (L/min)	NO3 mg/L
Zone C 32.3 - 41.5 m	3-1	1	0.1205 (7.23)	1213
	3-2	2.5	--	1603
	3-3	5	0.125 (7.5)	1318
	3-4	10	0.1283 (7.7)	1084
	3-5	20	0.125 (7.5)	1084
	3-6	30	0/118 (7.1)	1109
	3-7	45	0.125 (7.5)	1161
	3-8	60	0.125 (7.5)	1216
	3-9	90	--	1288
	3-10	120	0.125 (7.5)	1318
	3-11	150	--	1318
	3-12	180	0.125 (7.5)	1318
	3-13	210	--	1318
	3-14	240	0.125 (7.5)	1318
	3-15	270	--	1380
	3-16	300	0.125 (7.5)	1380
	3-17	330	--	1380
	3-18	360	0.125 (7.5)	1380
Zone D 42.5 –47.5	4-1	1	--	1799
	4-2	2.5	--	1928
	4-3	5	0.0105 (0.63)	2265
	4-4	10	--	2399
	4-5	15	--	2600
	4-6	20	--	2723
	4-7	30	0.0167 (0.7)	2630
	4-8	45	0.0105 (0.67)	2399
	4-9	60	0.0101 (0.61)	2344
	4-10	90	--	2042
	4-11	120	0.0105 (0.63)	1995
	4-12	150	--	1950
	4-13	180	0.0105 (0.63)	1884
	4-14	210	0.0105 (0.63)	1928
Zone E 49.0-54.0 m	5-1	1	--	3199
	5-2	2.5	1.25 (75)	4074
	5-3	5	--	4217
	5-4	10	1.25 (75)	4217
	5-5	15	1.25 (75)	4266
	5-6	20	1.25 (75)	4266
	5-7	30	1.25 (75)	4266
	5-8	40	1.25 (75)	4365
	5-9	50	1.25 (75)	4266
	5-10	65	1.25 (75)	4217
	5-11	80	1.25 (75)	4217

Zone Pumped	Sample Number	Elapsed Time (min)	Flow Rate L/sec (L/min)	NO3 mg/L
Zone F 55.4 - 75.9 m	6-1	1	1.25 (75)	4027
	6-2	2.5	--	6683
	6-3	5	1.25 (75)	6531
	6-4	10	--	6531
	6-5	15	--	6531
	6-6	20	--	6531
	6-7	30	1.25 (75.0)	6456
	6-8	45	1.11 (67.0)	6456
	6-9	60	1.11 (67.0)	6026
	6-10	90	1.25 (75.0)	5888
	6-11	120	1.25 (75.0)	5888
	6-12	150	1.11 (67.0)	5888
	6-13	180	1.11 (67.0)	6026
	6-14	210	1.11 (67.0)	6026
	6-15	240	1.11 (67.0)	6026
	6-16	270	1.11 (67.0)	5888
All Zones 0.0 - 105 m	7-1	1	1.25 (75.0)	5623
	7-2	2.5	1.25 (75.0)	7586
	7-3	5	1.25 (75.0)	5370
	7-4	10	1.25 (75.0)	4954
	7-5	15	1.25 (75.0)	4954
	7-6	20	1.25 (75.0)	4954
	7-7	30	1.25 (75.0)	4732
	7-8	45	1.25 (75.0)	4624
	7-9	60	1.25 (75.0)	4624
	7-10	90	1.25 (75.0)	4624
	7-11	120	1.25 (75.0)	4624

Appendix B

Drawdown curves for all zones from all tests

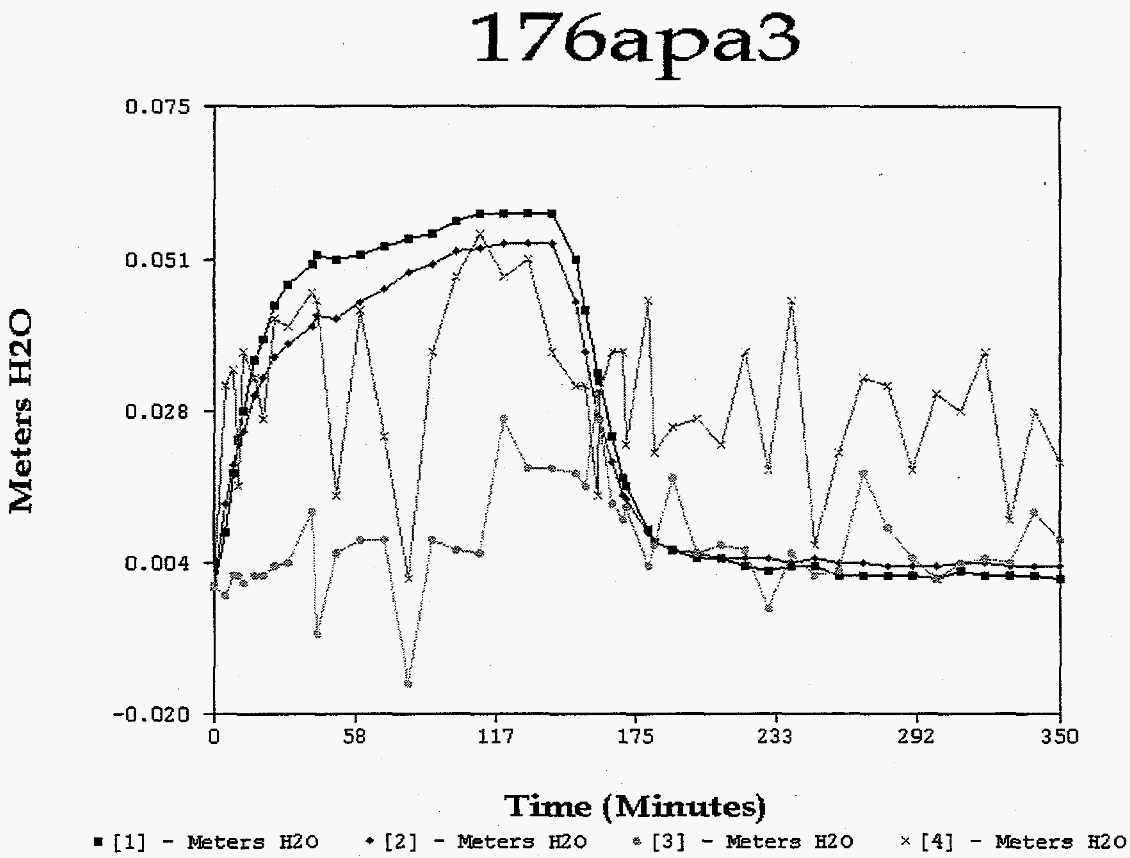


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone A at 8.82 L/min.

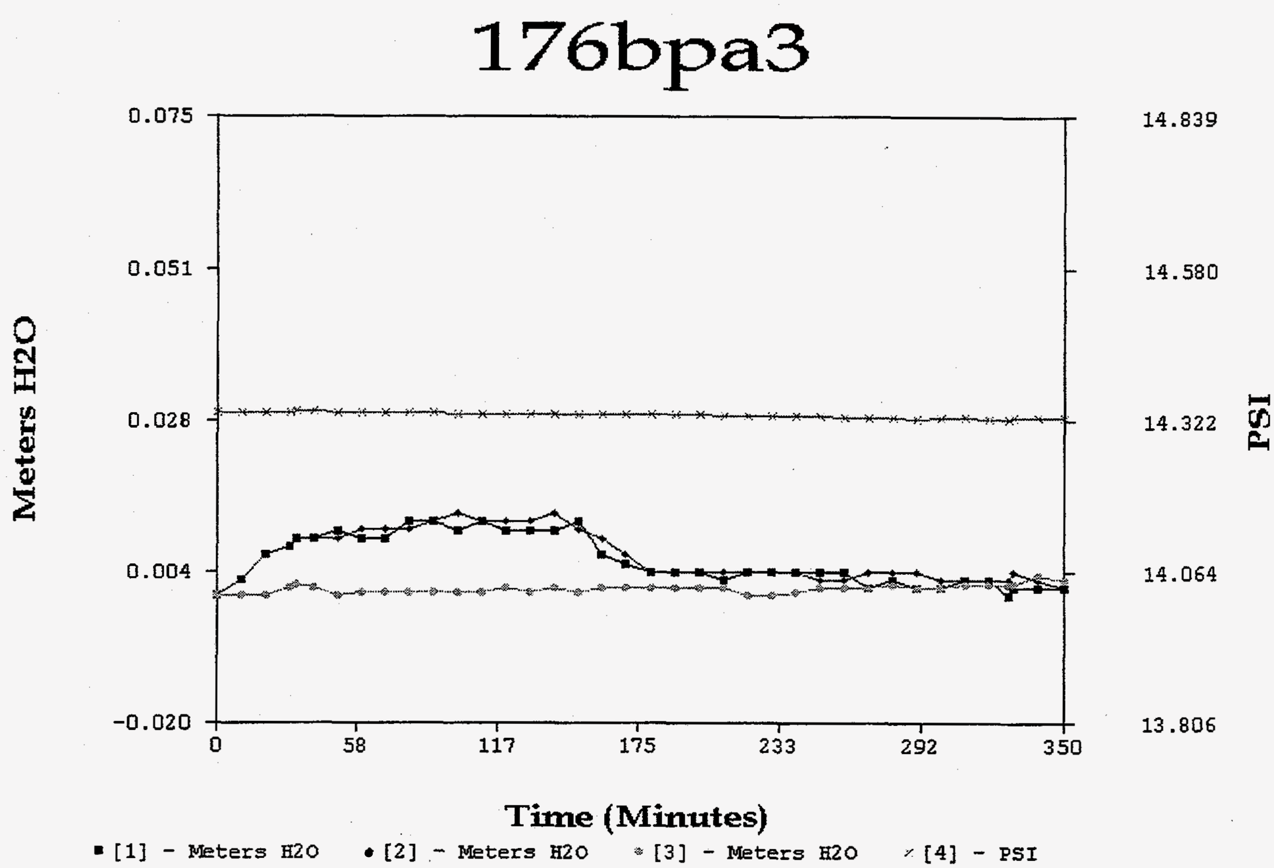


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3] and barometer [4], while pumping well 1/96 zone A at 8.82 L/min.

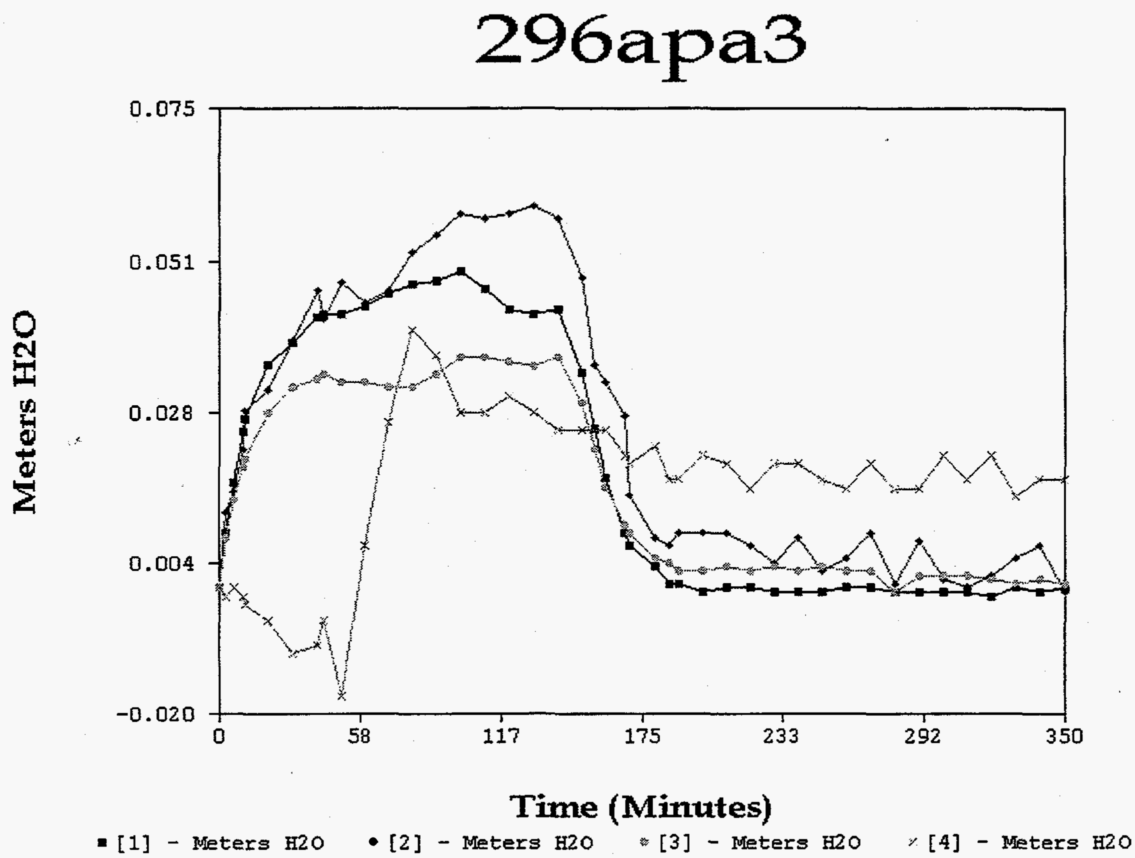


Figure Drawdown vs. time for observation well 2/96, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone A at 8.82 L/min.

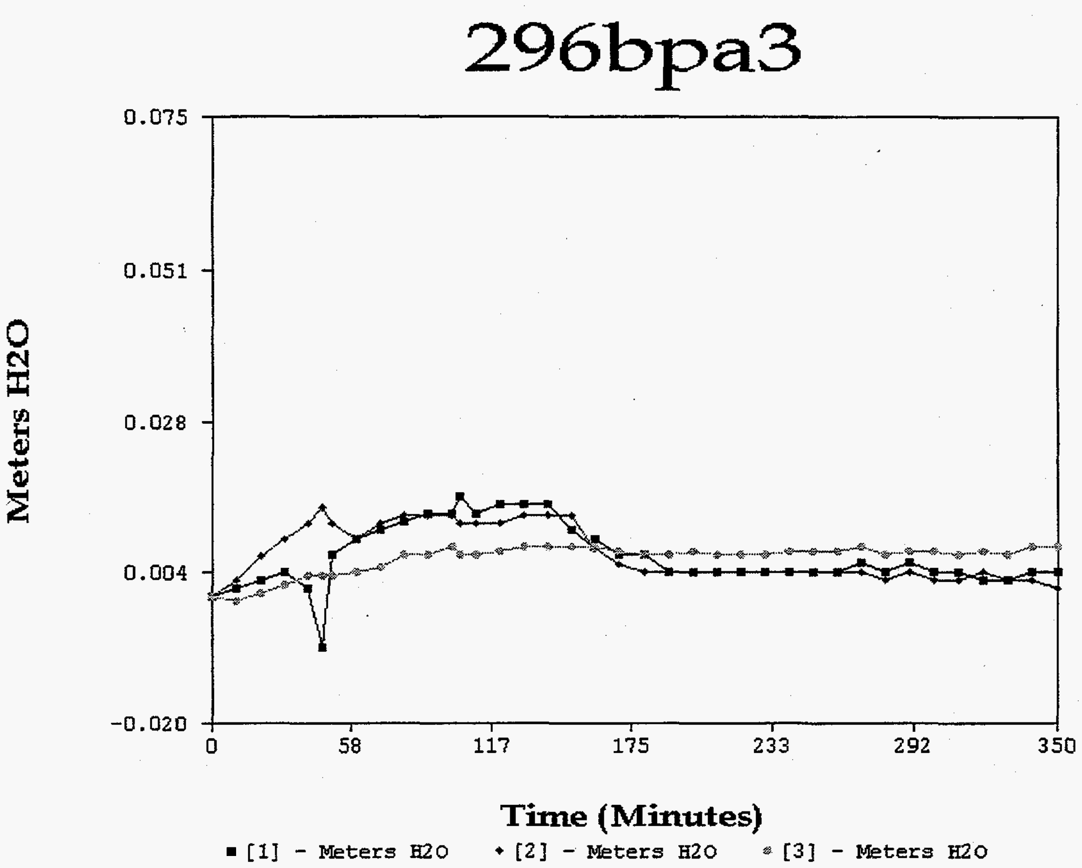


Figure Drawdown vs. time for observation well 296, zones E [1], F [2], G [3], while pumping zone A in well 1/96 at 8.82 L/min.

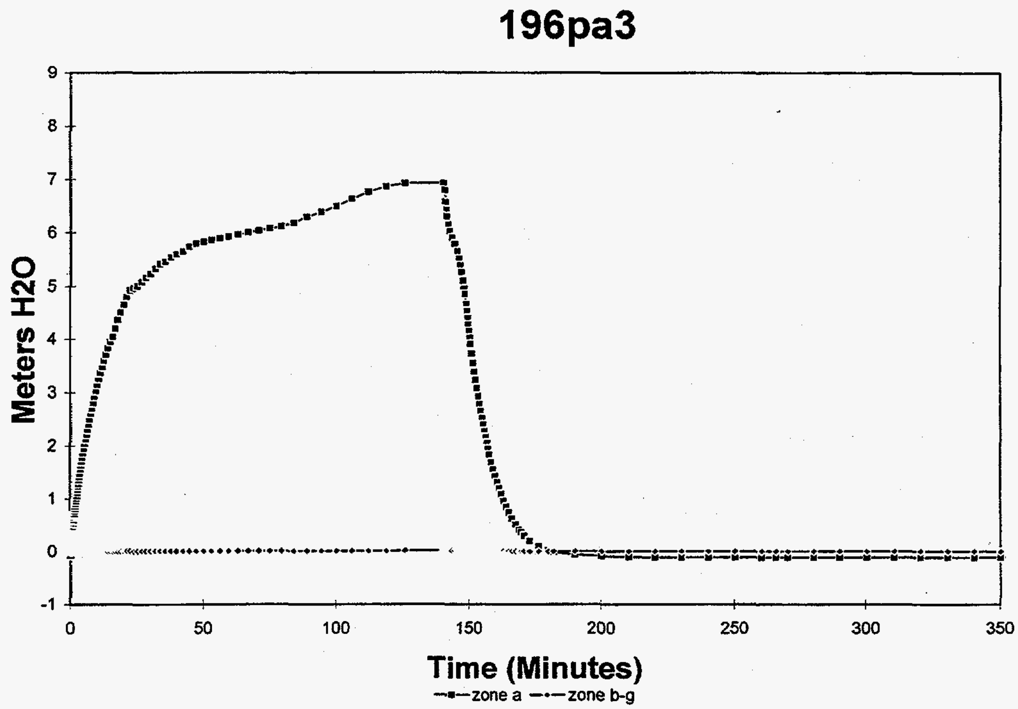


Figure Drawdown vs. time for pumping well 196, zones A [1], and B-G [2],, while pumping at 8.82 L/min.

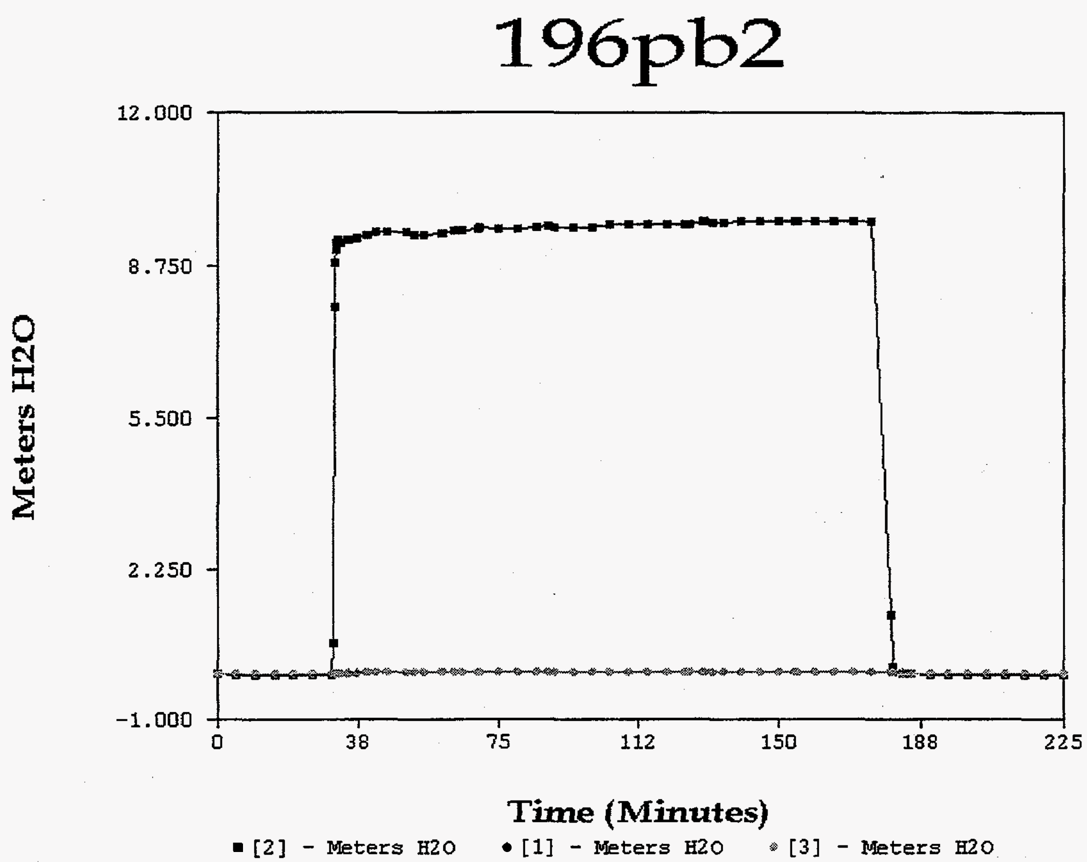


Figure 4.3 Drawdown vs. time for pumping well 196, zones A [1], B [2], and C-G [3], while pumping at 12.5 L/min.

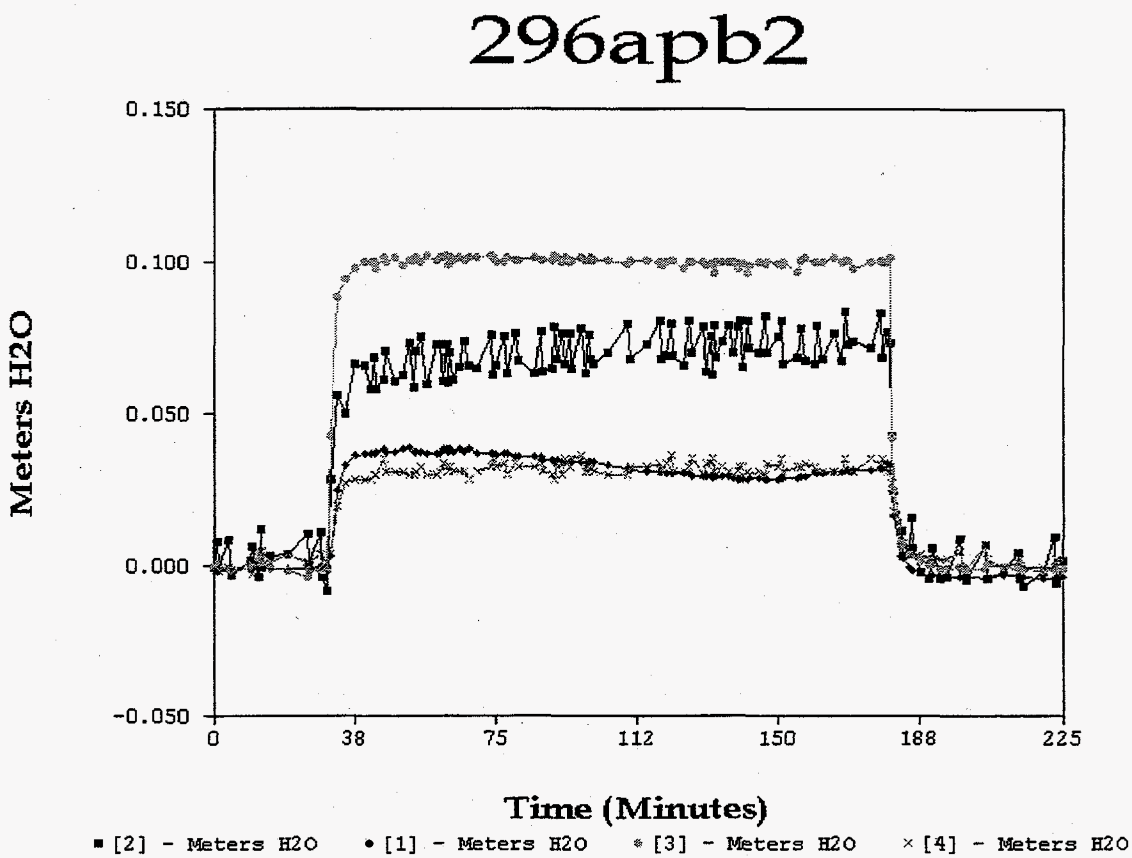


Figure 3.4 Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone B at 12.5 L/min.

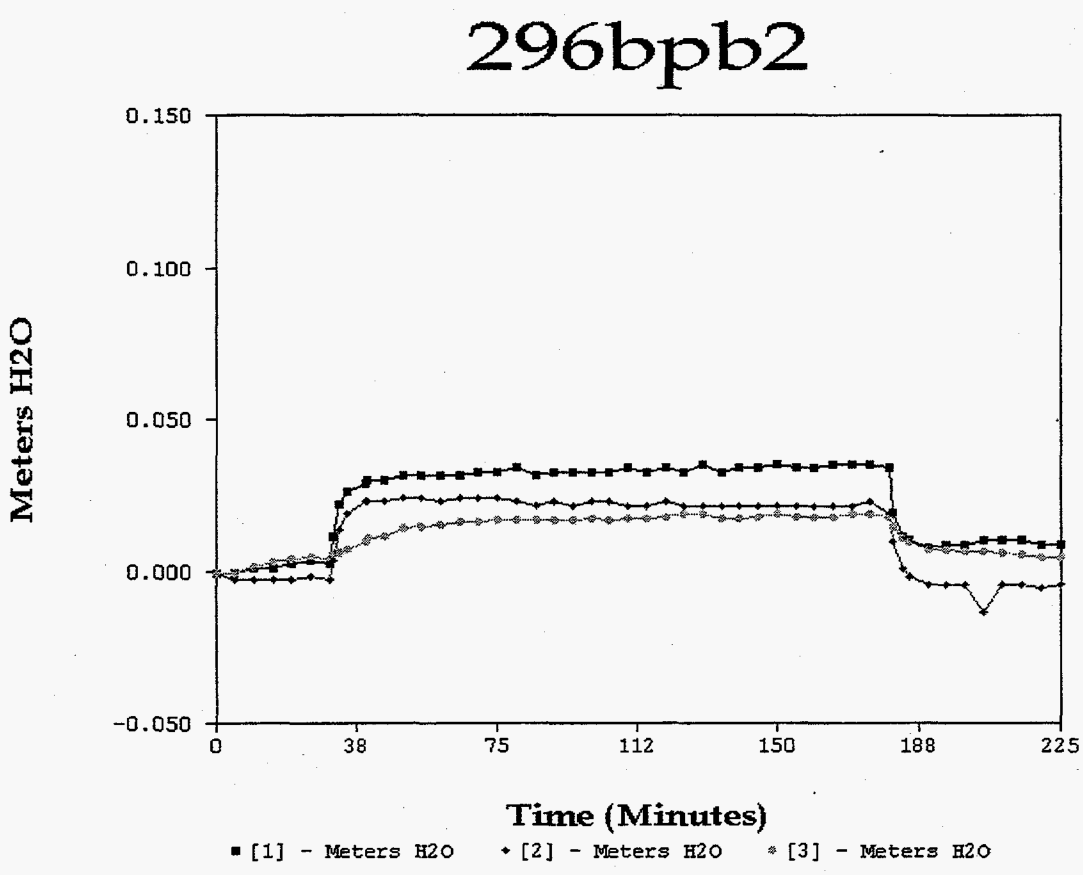


Figure 3.5 Drawdown vs. time for observation well 296, zones E [1], F [2], G [3], while pumping zone B in well 1/96 at 12.5 L/min.

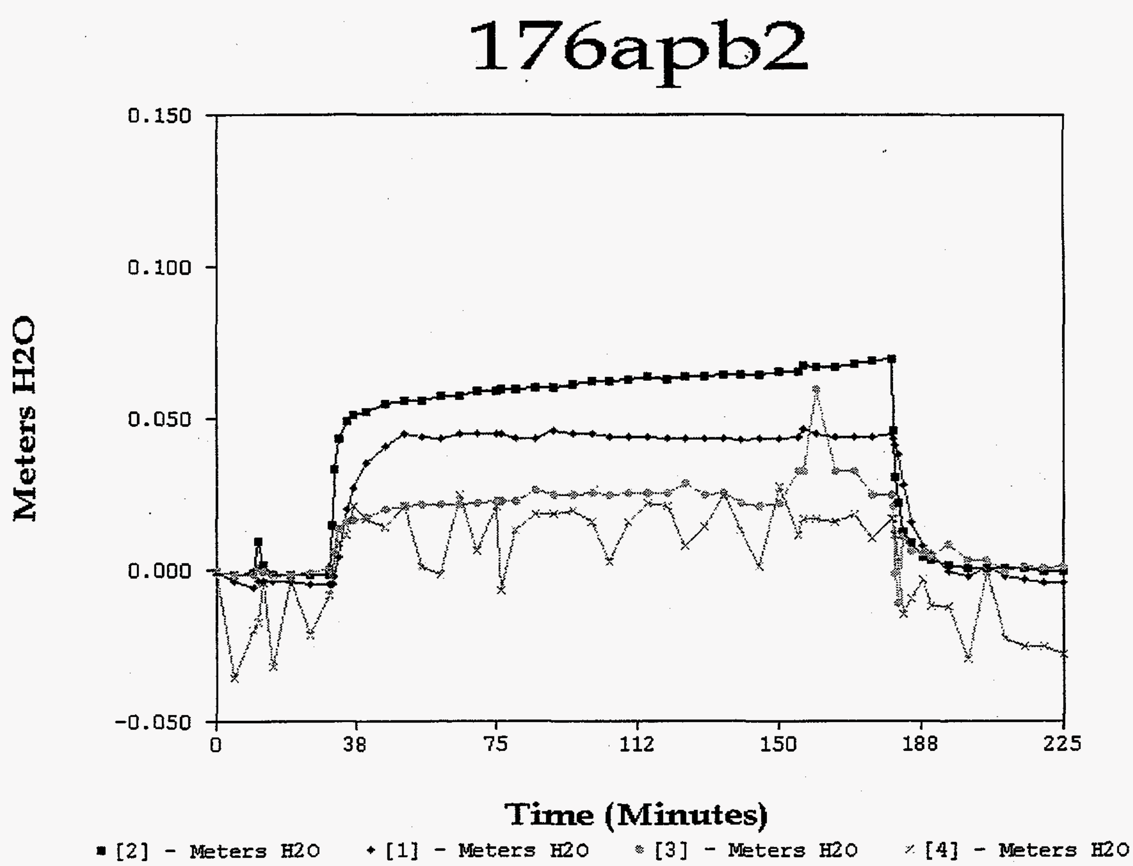


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone B at 12.5 L/min.

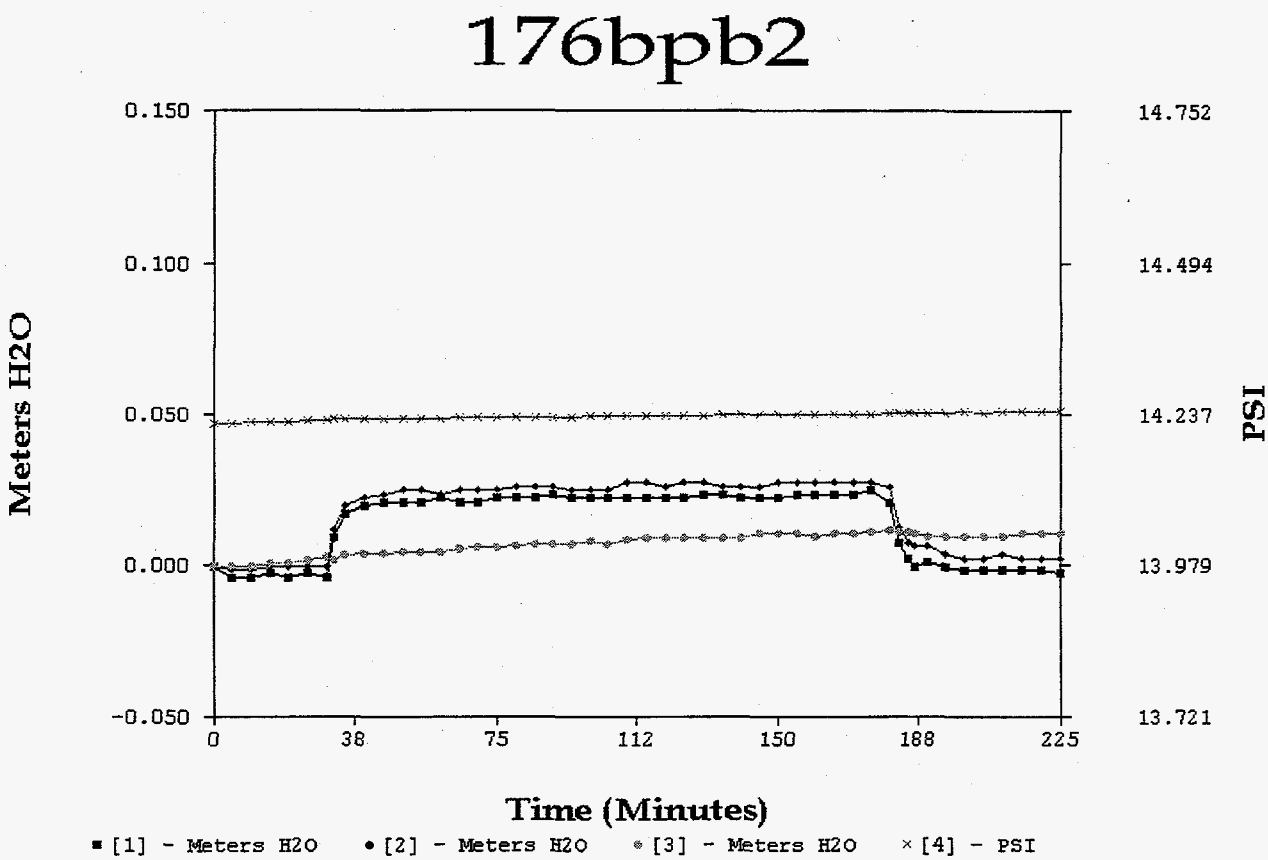


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3] and barometer [4], while pumping well 1/96 zone B at 12.5 L/min.

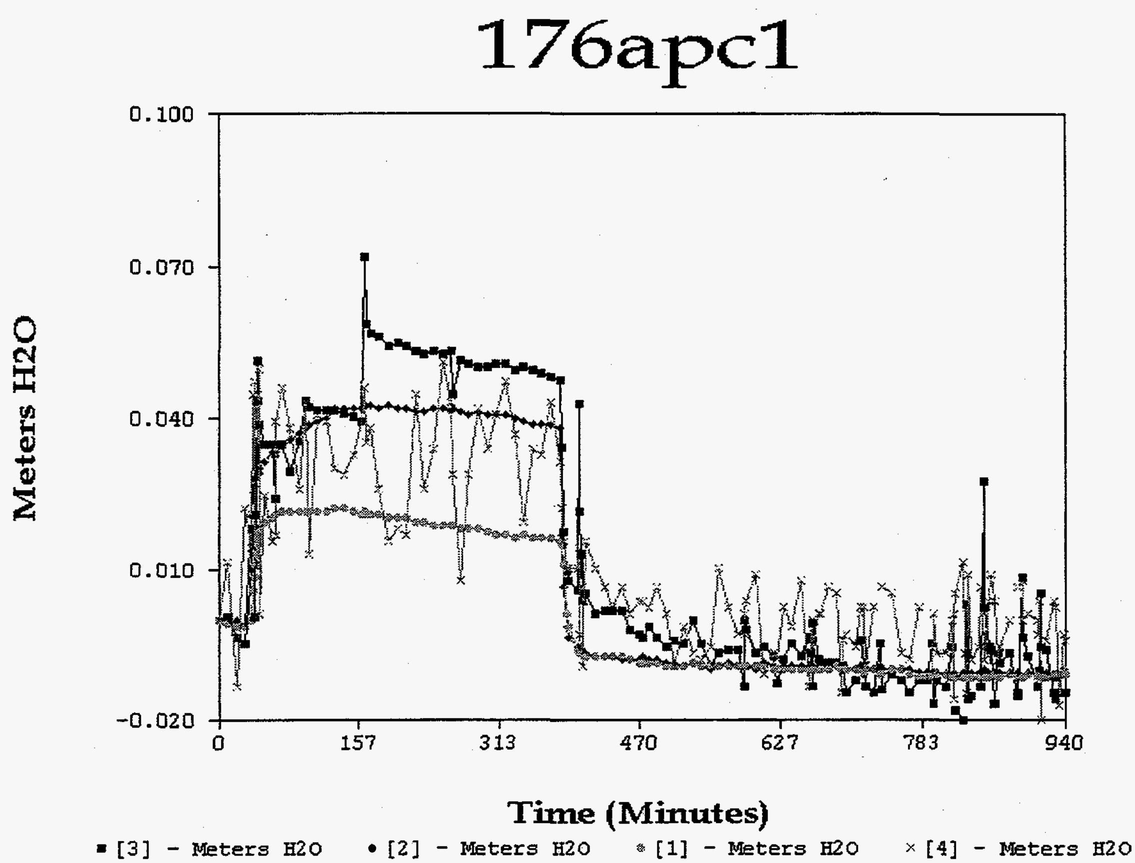


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone C at 7.5 L/min.

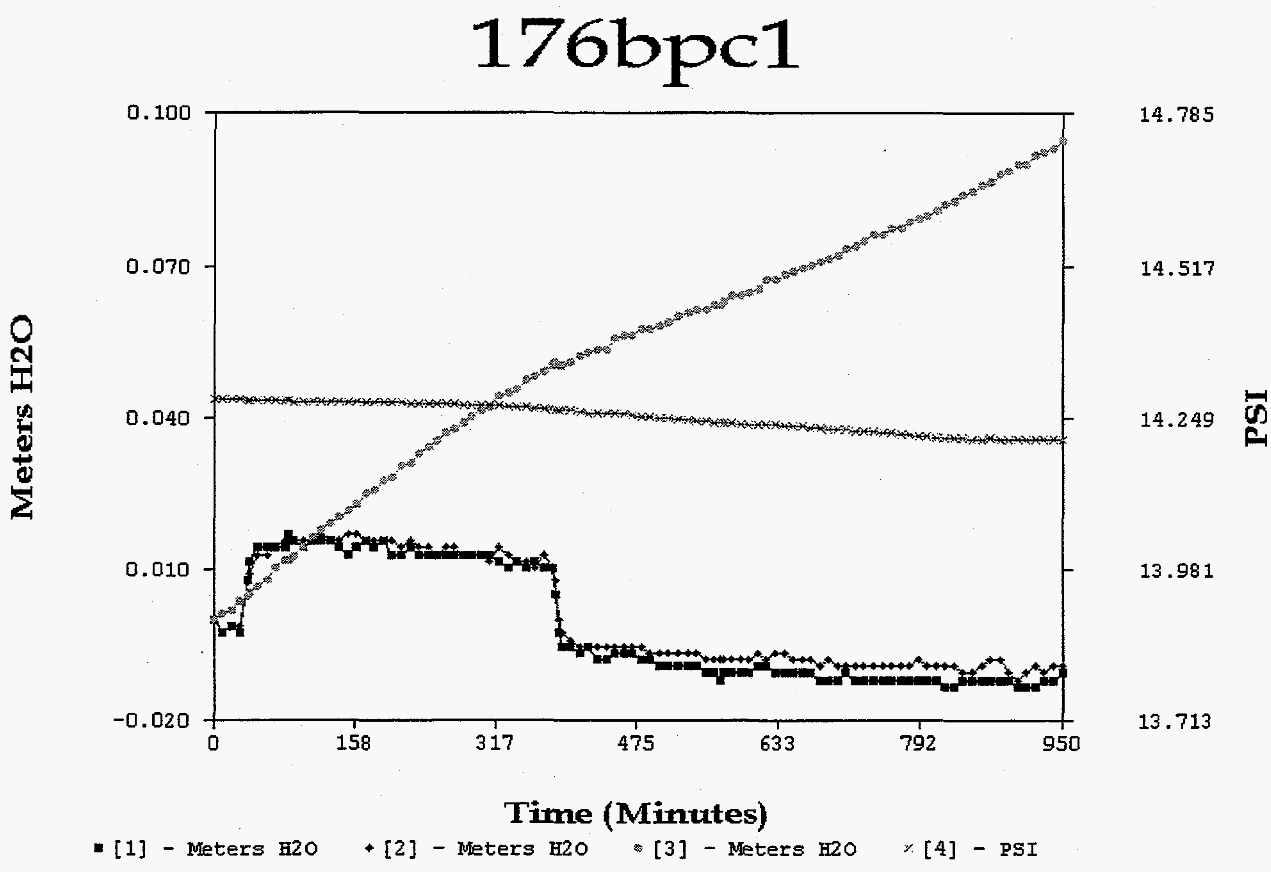


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3] and barometer [4], while pumping well 1/96 zone C at 7.5 L/min.

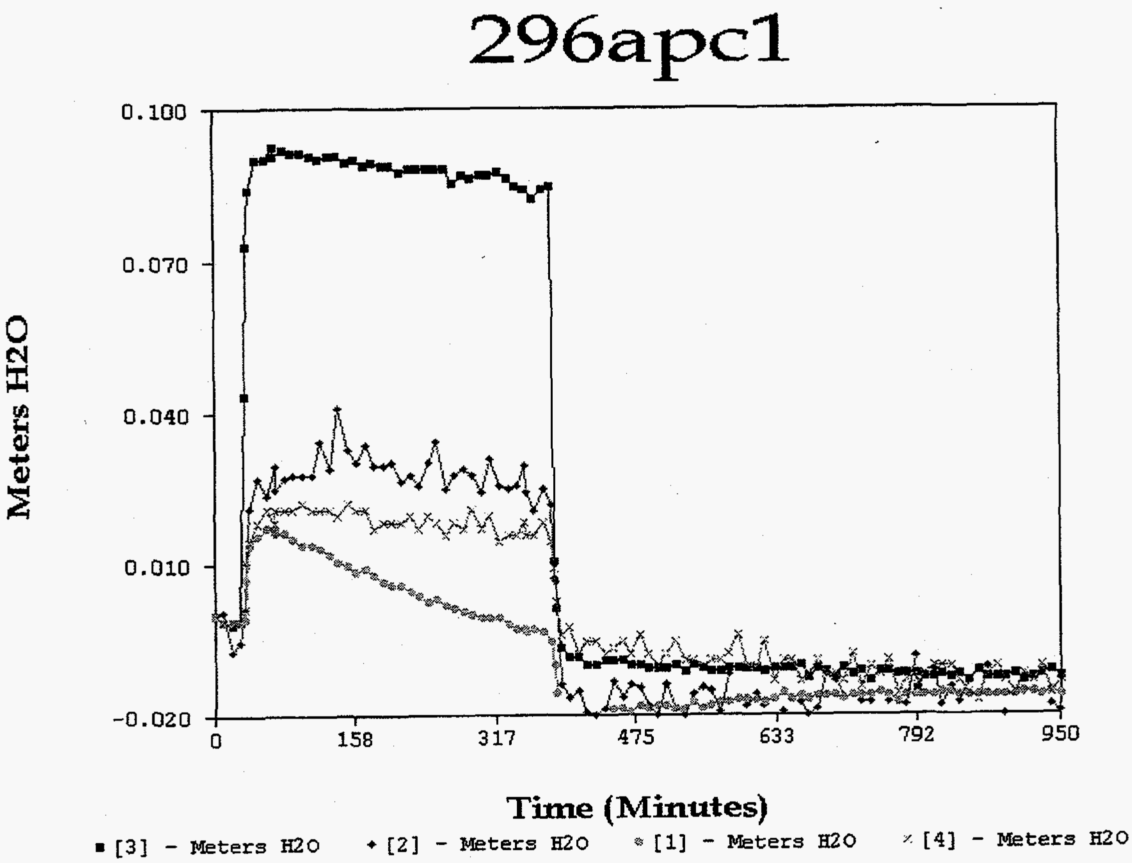


Figure Drawdown vs. time for observation well 2/96, zones A [1], B [2], C [3] and D[4], while pumping well 1/96 zone C at 7.5 L/min.

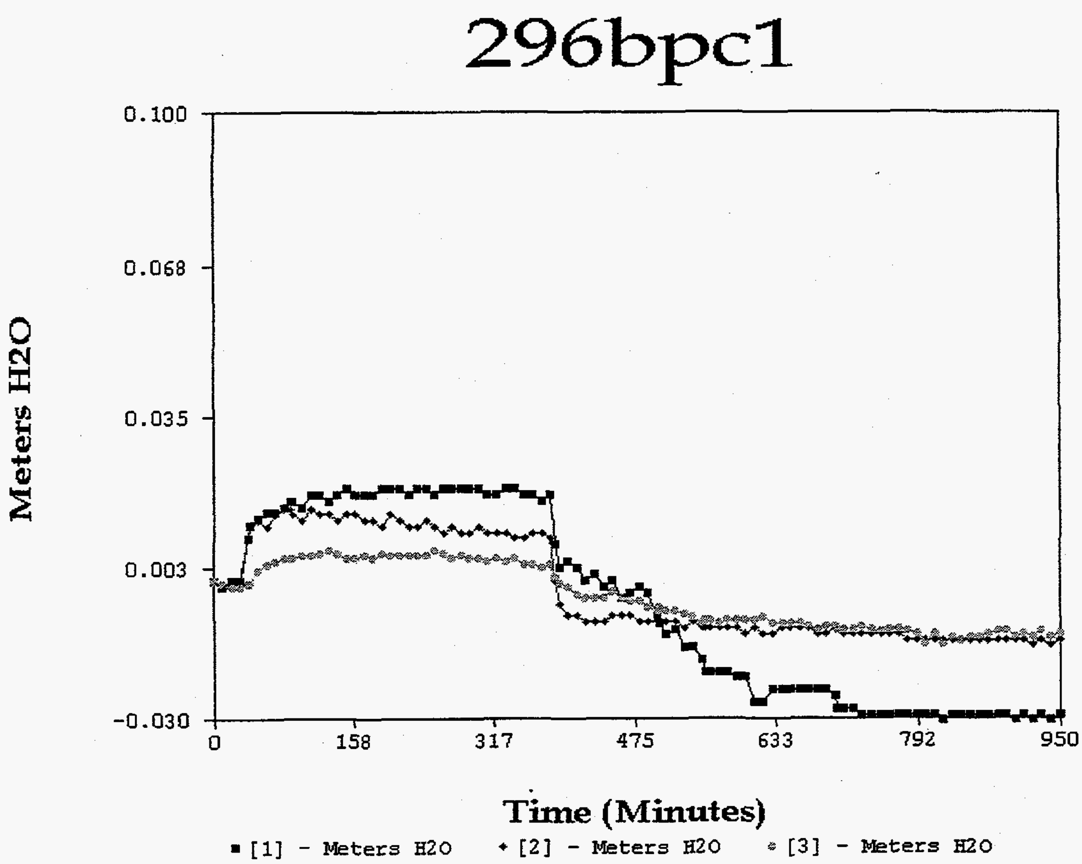


Figure Drawdown vs. time for observation well 296, zones E [1], F [2], G [3], while pumping zone C in well 1/96 at 7.5 L/min.

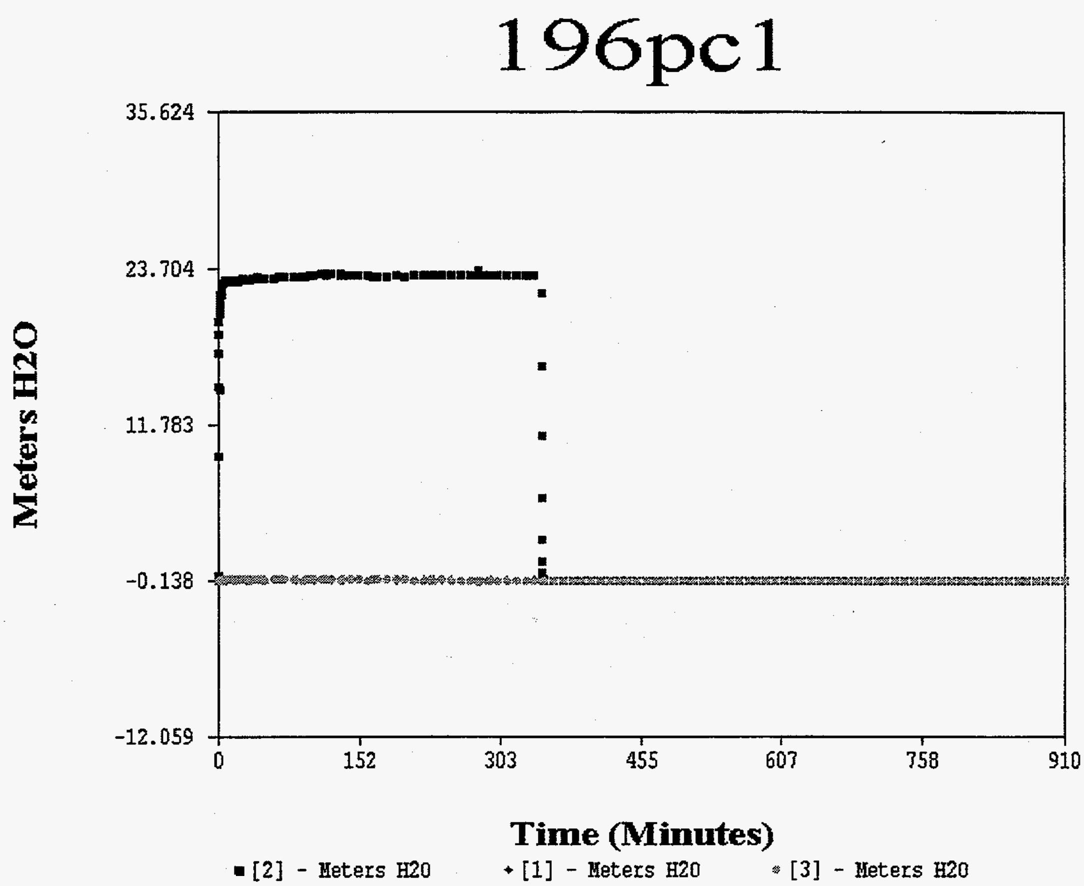


Figure Drawdown vs. time for pumping well 196, zones A-B [1], C [2], and D-G [3], while pumping at 7.5 L/min.

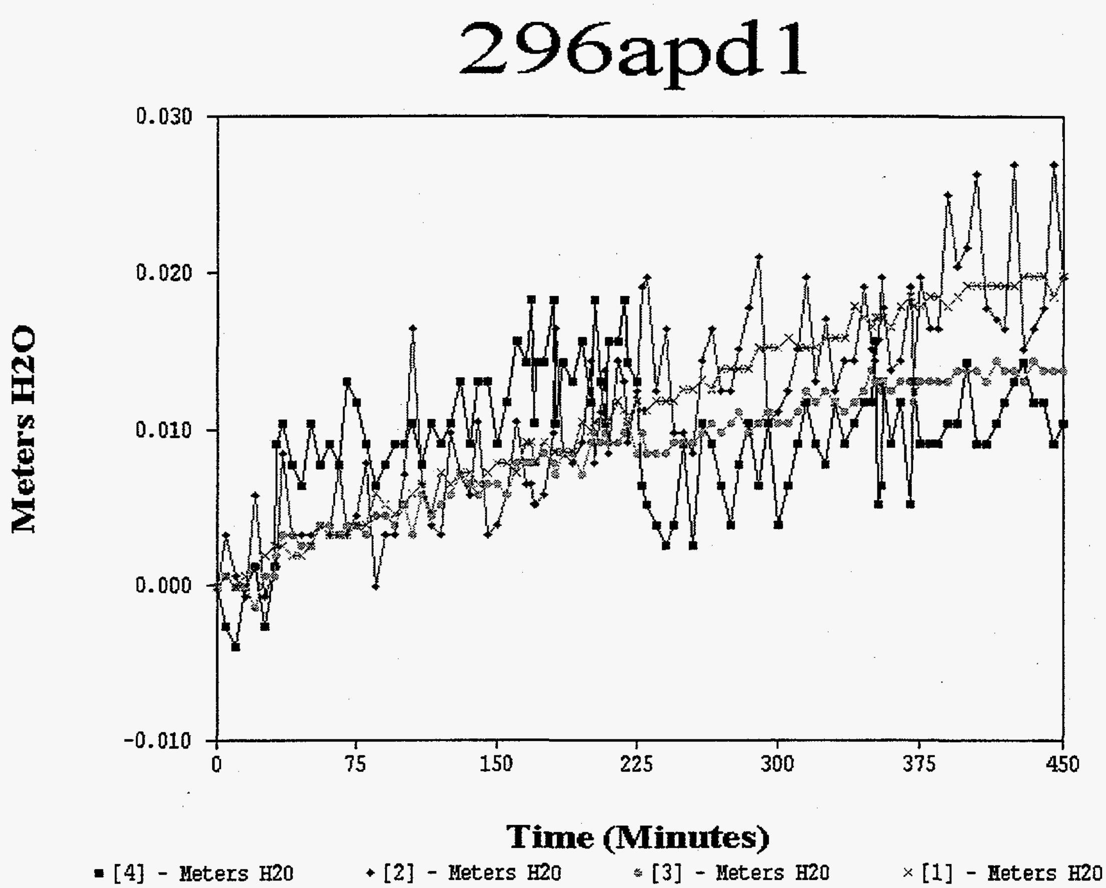


Figure Drawdown vs. time for observation well 2/96, zones A [1], B [2], C [3] and D[4], while pumping well 1/96 zone D at 0.63 L/min.

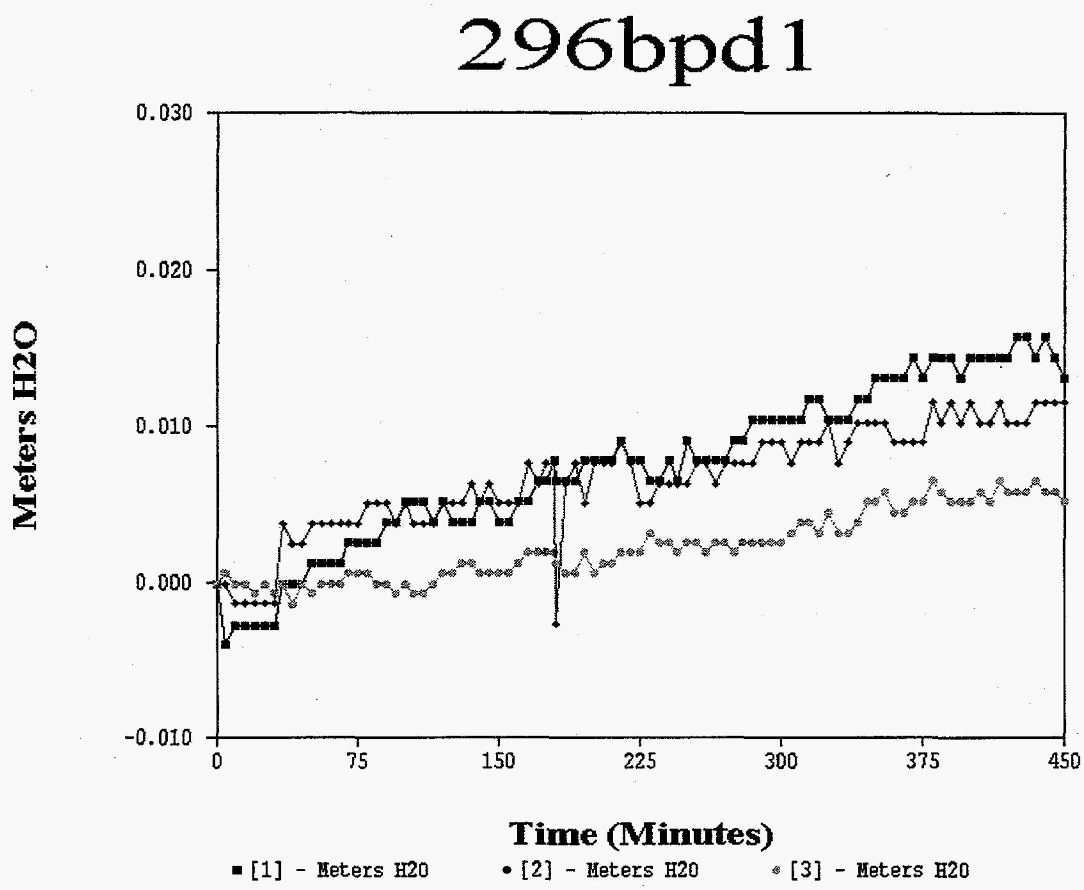


Figure Drawdown vs. time for observation well 296, zones E [1], F [2], G [3], while pumping zone D in well 1/96 at 0.63 L/min.

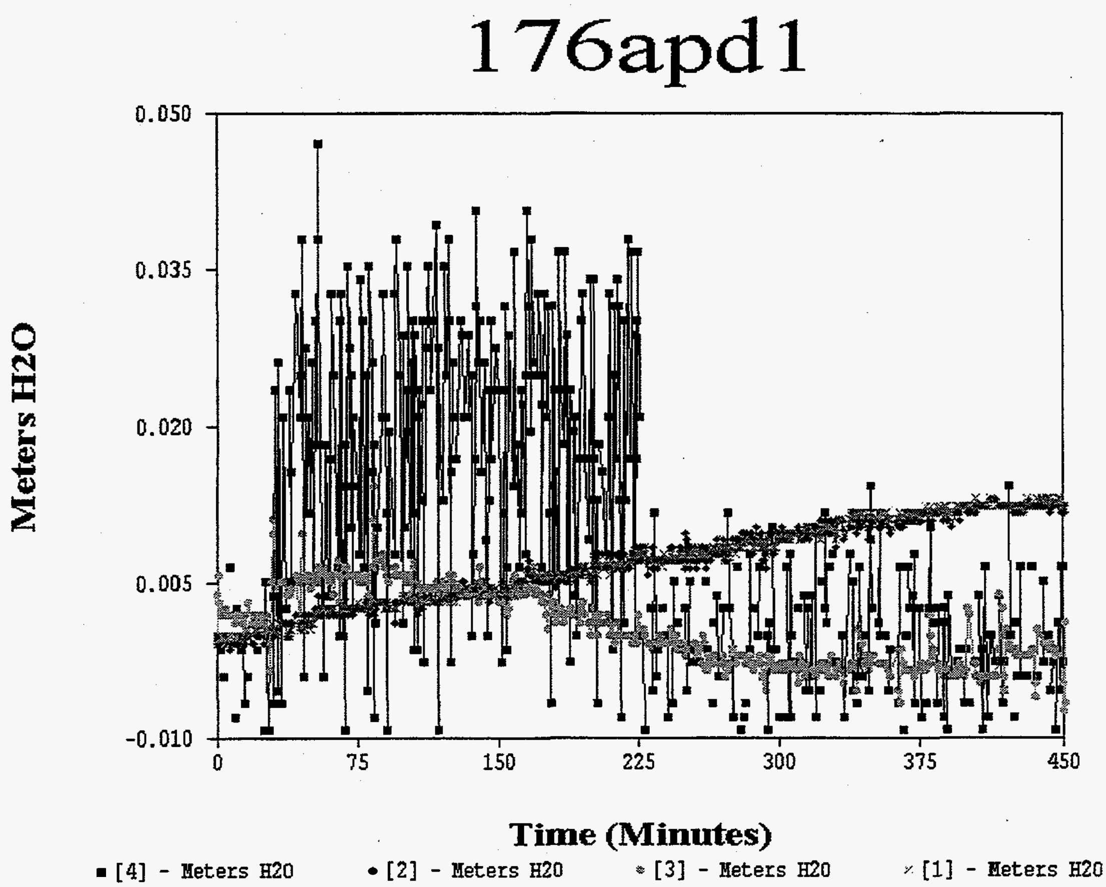


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone D at 0.63 L/min.

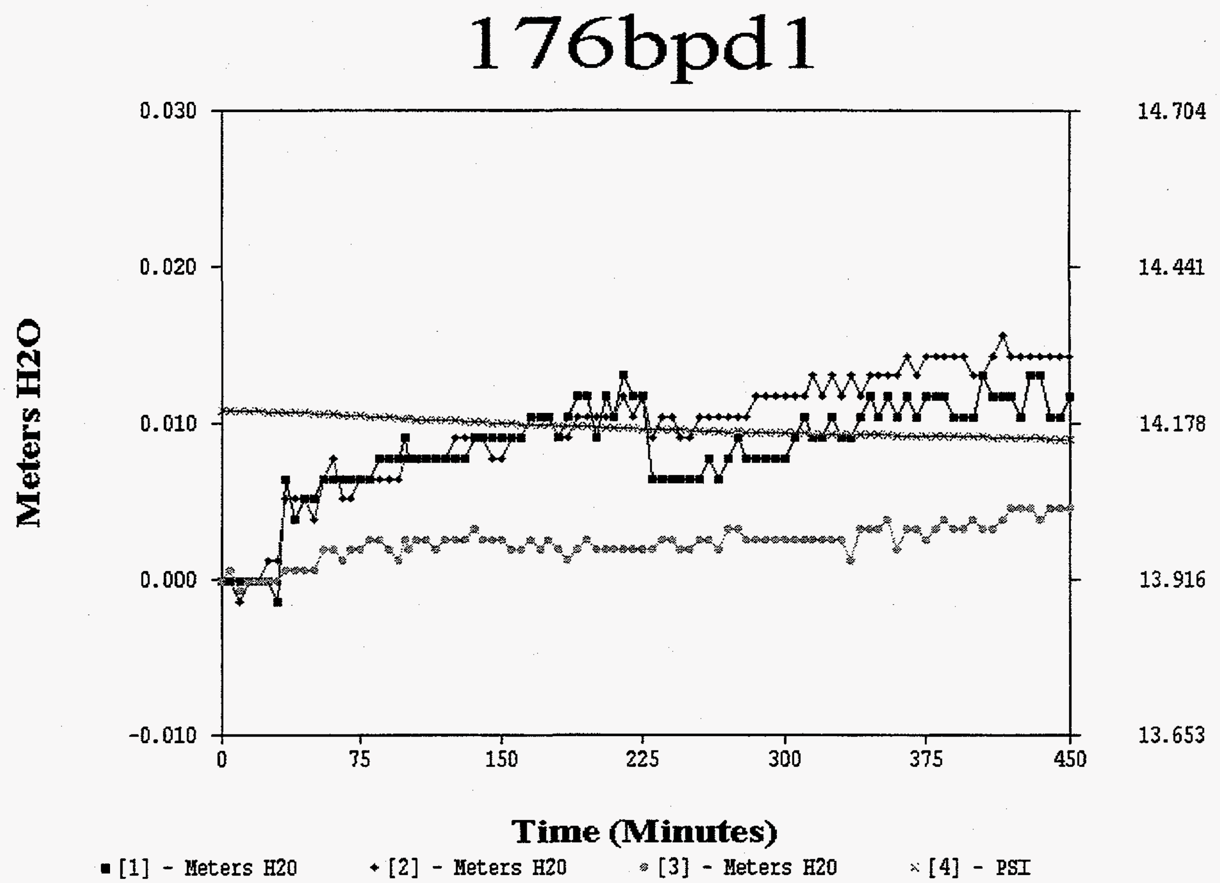


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3] and barometer [4], while pumping well 1/96 zone D at 0.63 L/min.

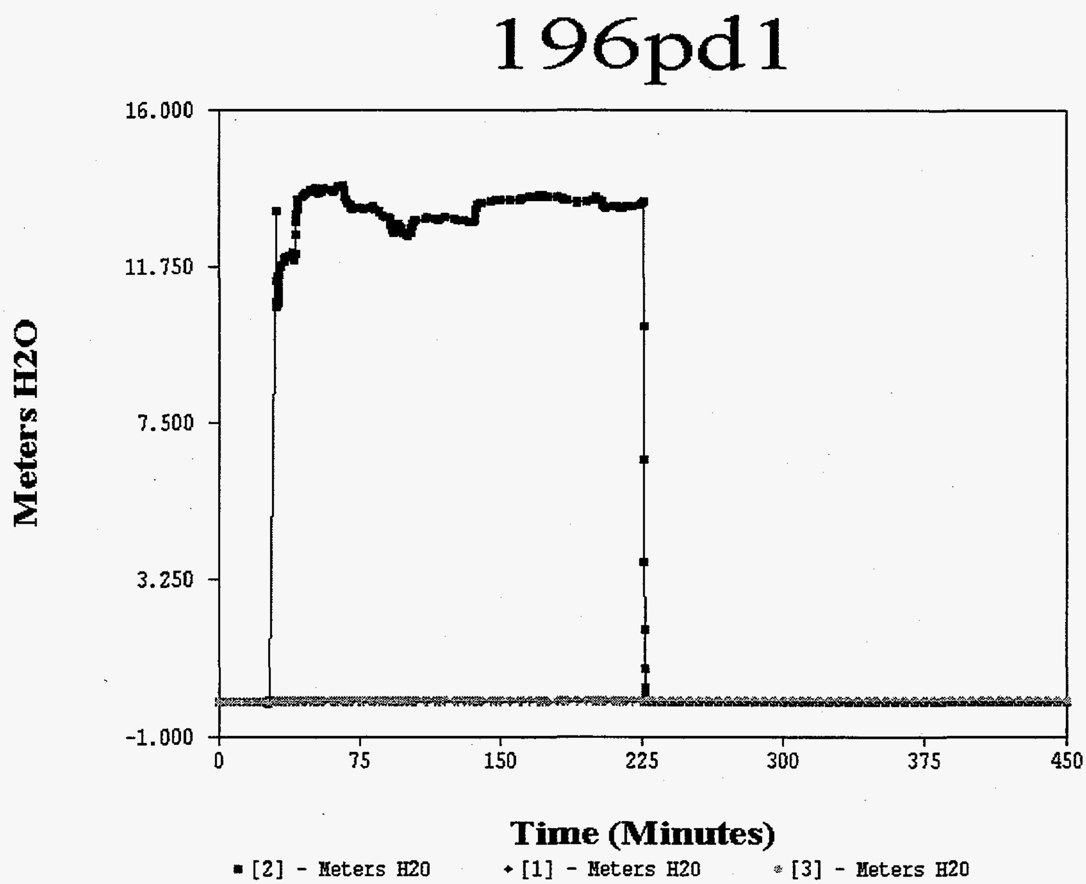


Figure Drawdown vs. time for pumping well 196, zones A-C [1], D [2], and E-G [3], while pumping at 0.63 L/min.

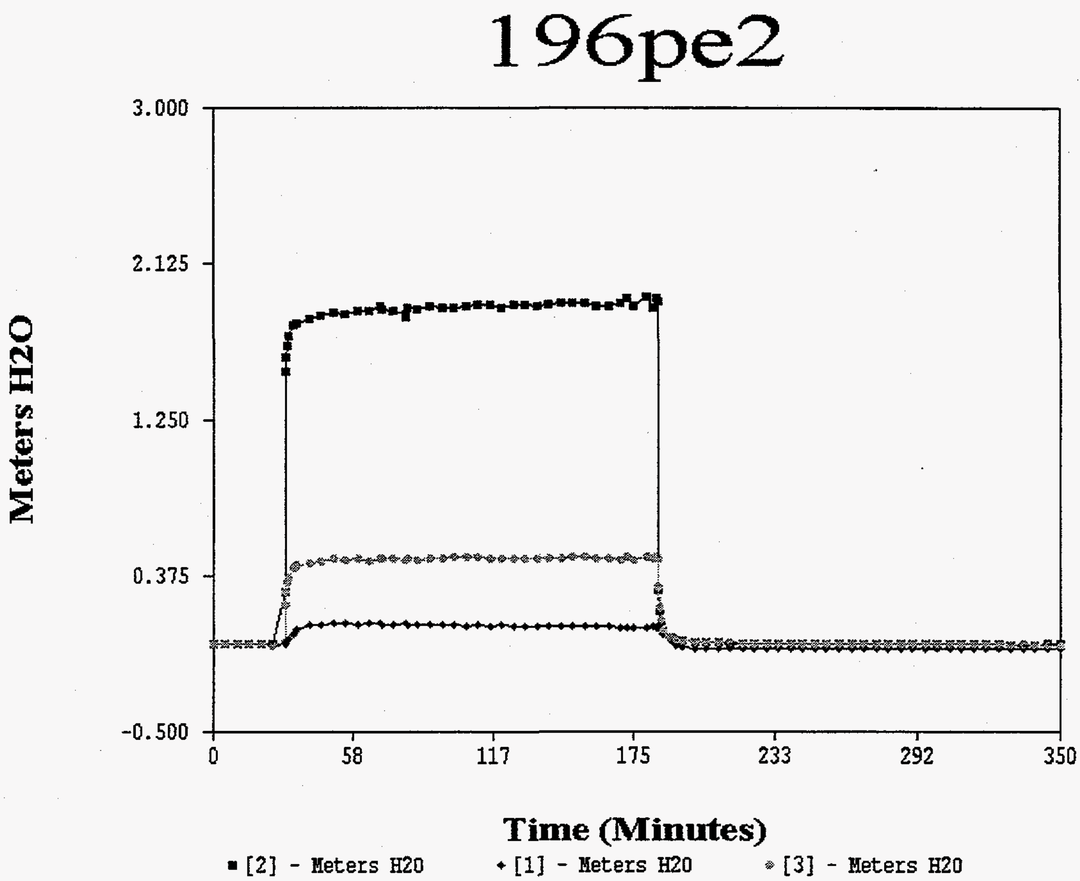


Figure Drawdown vs. time for pumping well 1/96, zones A-D[1], E [2], and F-G [3], while pumping at 75 L/min.

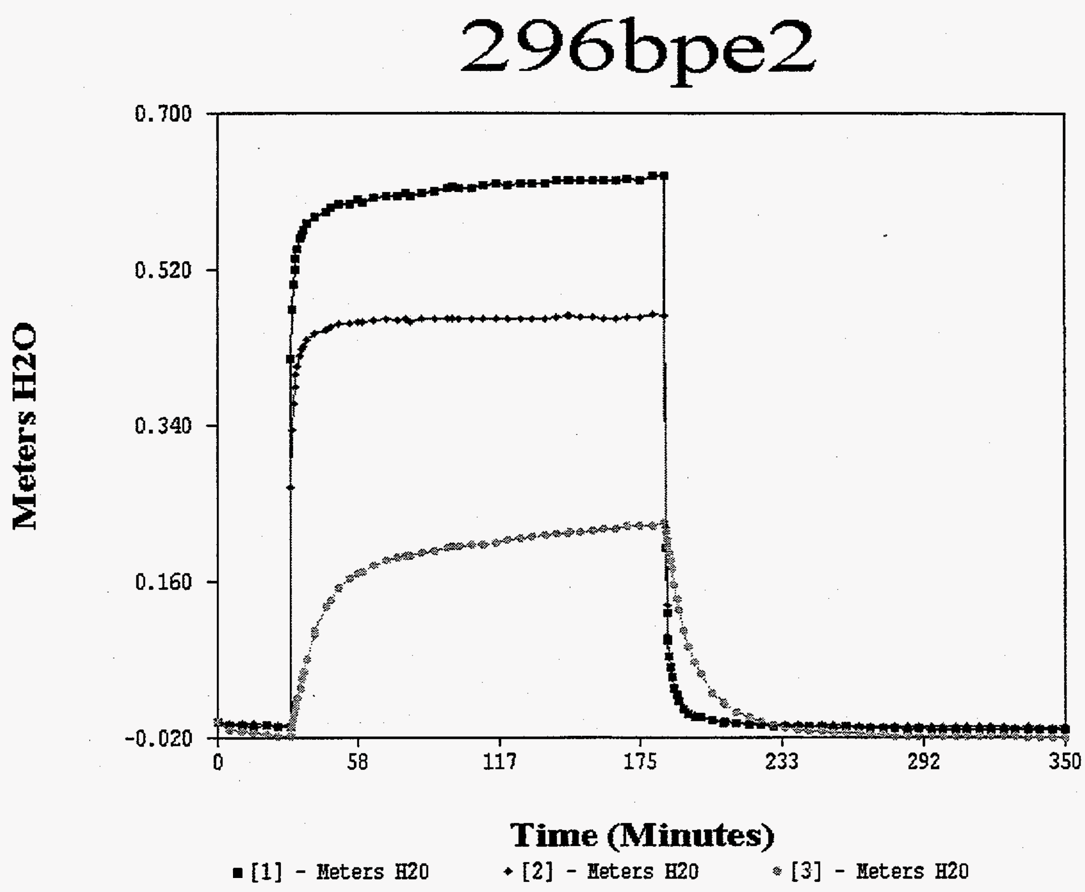


Figure Drawdown vs. time for observation well 2/96, zones D [1], E [2], and F [3], while pumping well 1/96 zone E at 75 L/min.

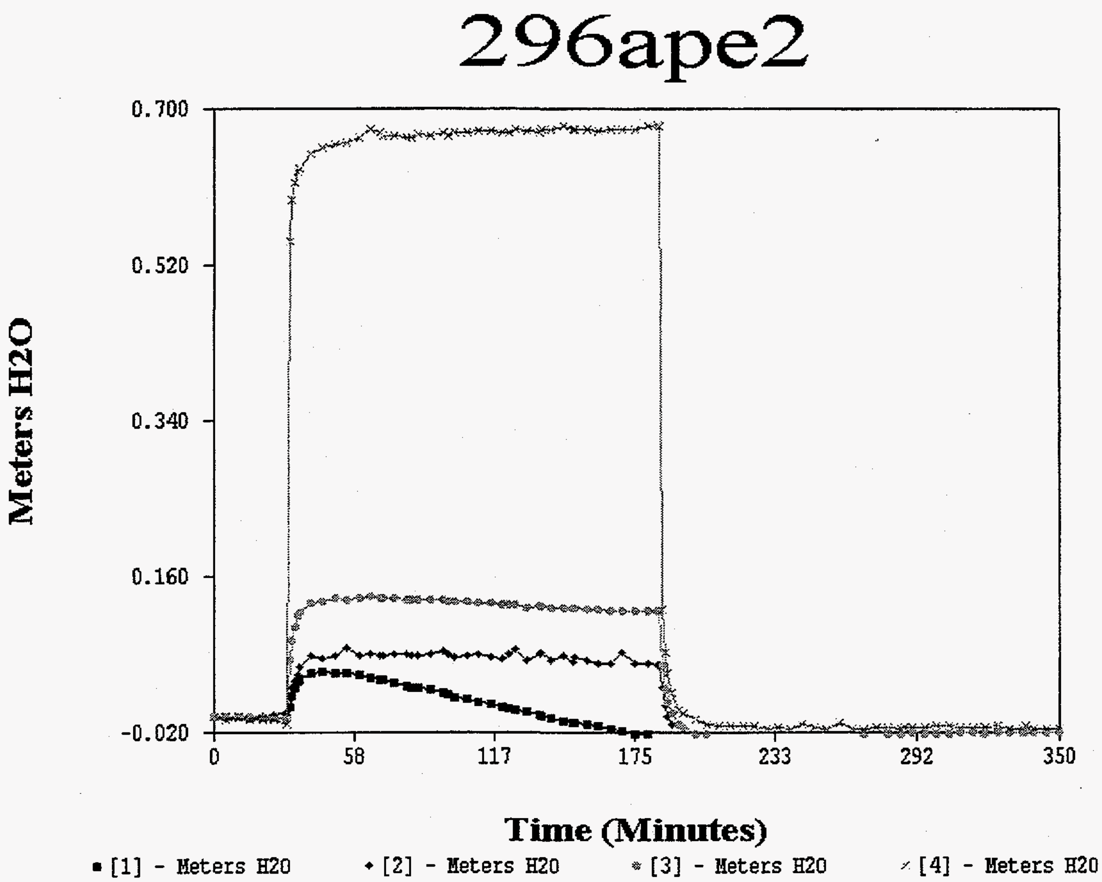


Figure Drawdown vs. time for observation well 2/96, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone E at 75 L/min.

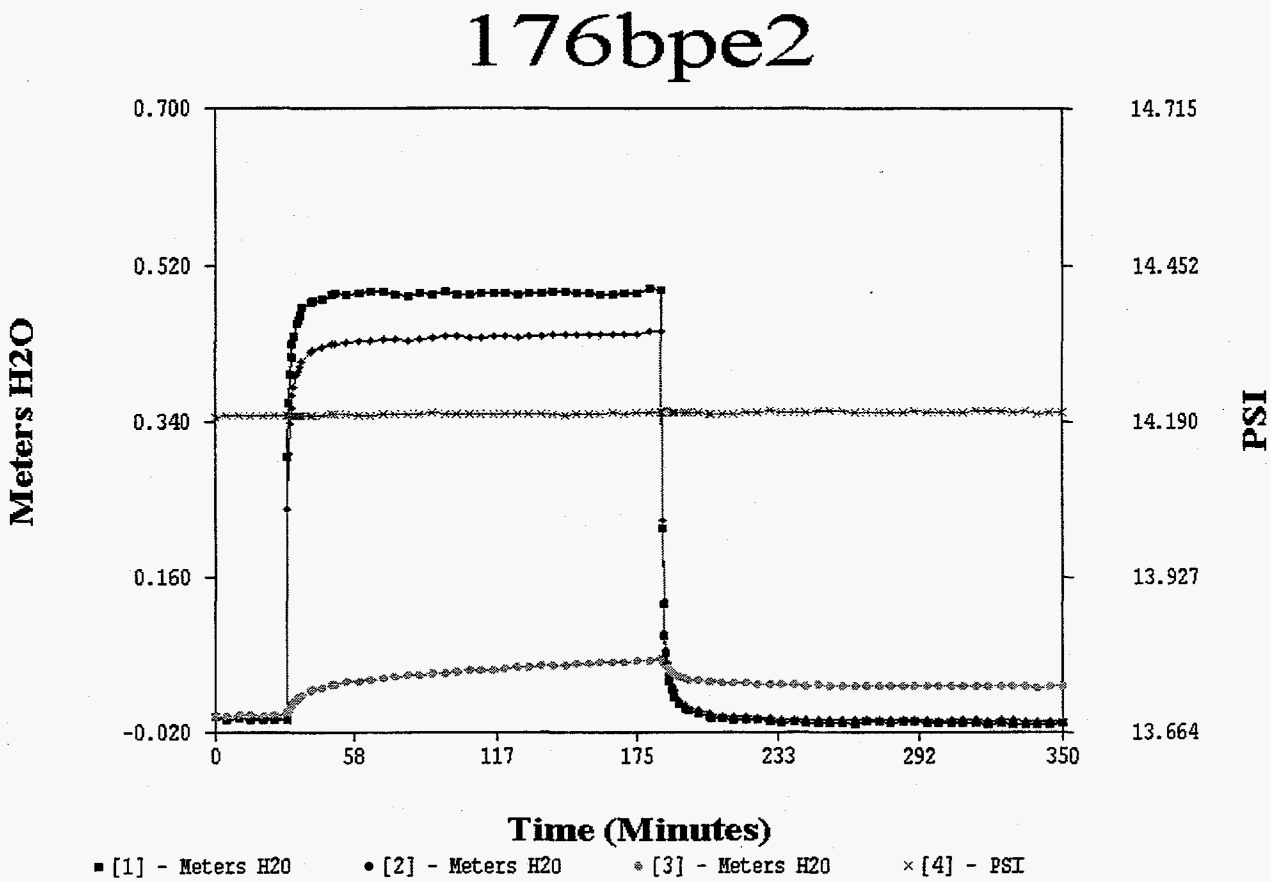


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3], and barometer [4], while pumping well 1/96 zone E at 75 L/min.

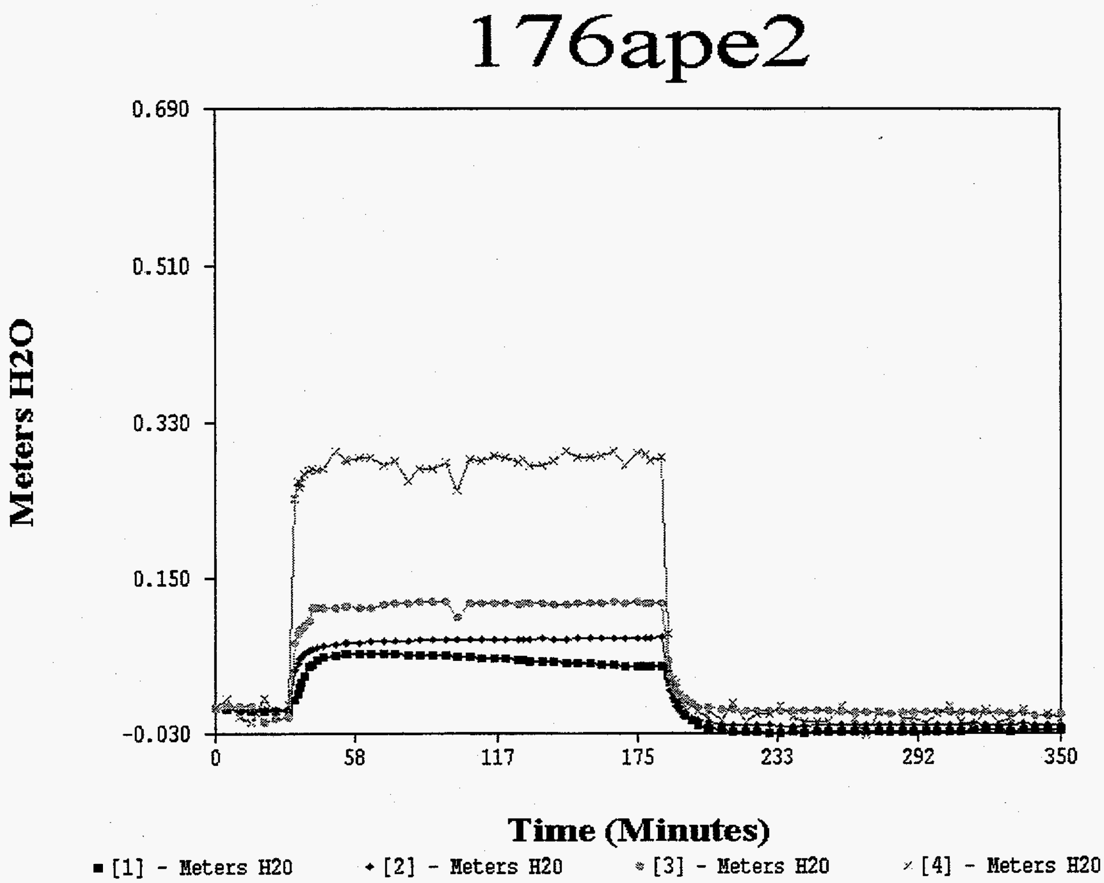


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone E at 75 L/min.

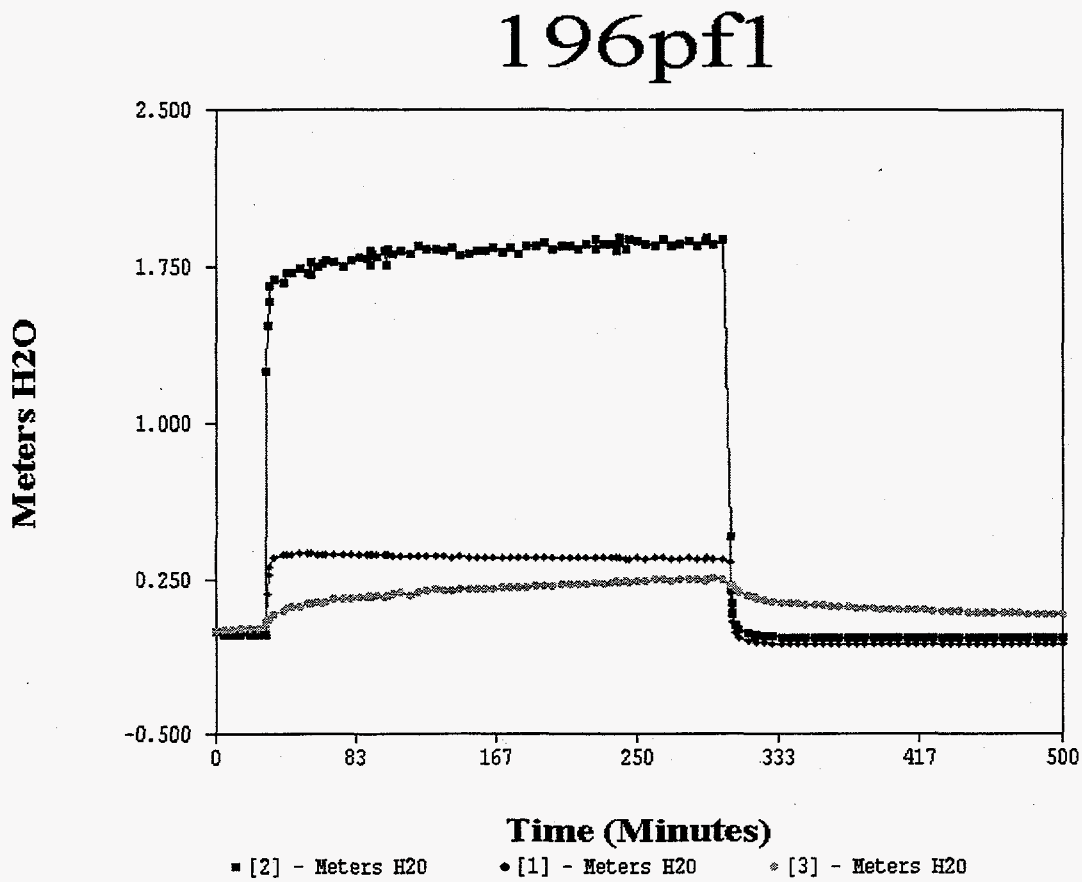


Figure Drawdown vs. time for pumping well 196, zones A-E [1], F [2], and G [3], while pumping at 75 L/min.

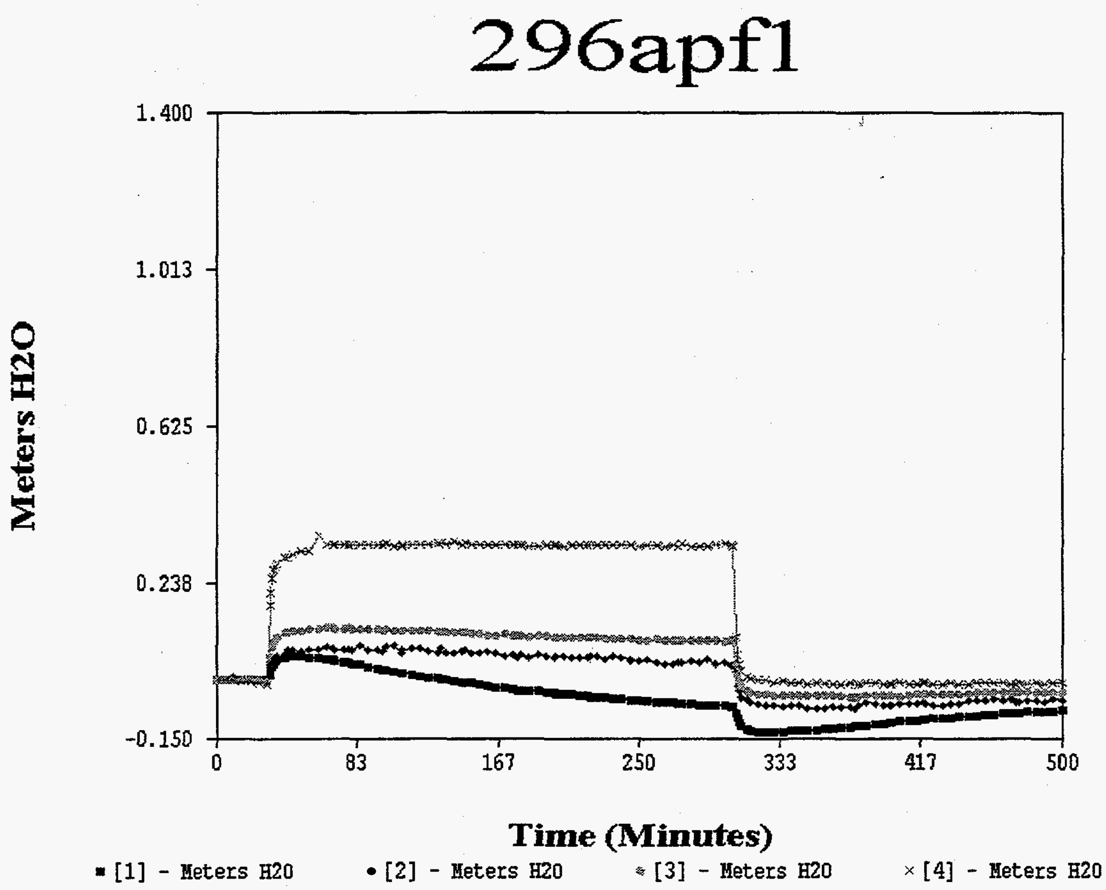


Figure Drawdown vs. time for observation well 2/96, zones A [1], B [2], C [3] and D[4], while pumping well 1/96 zone F at 75 L/min.

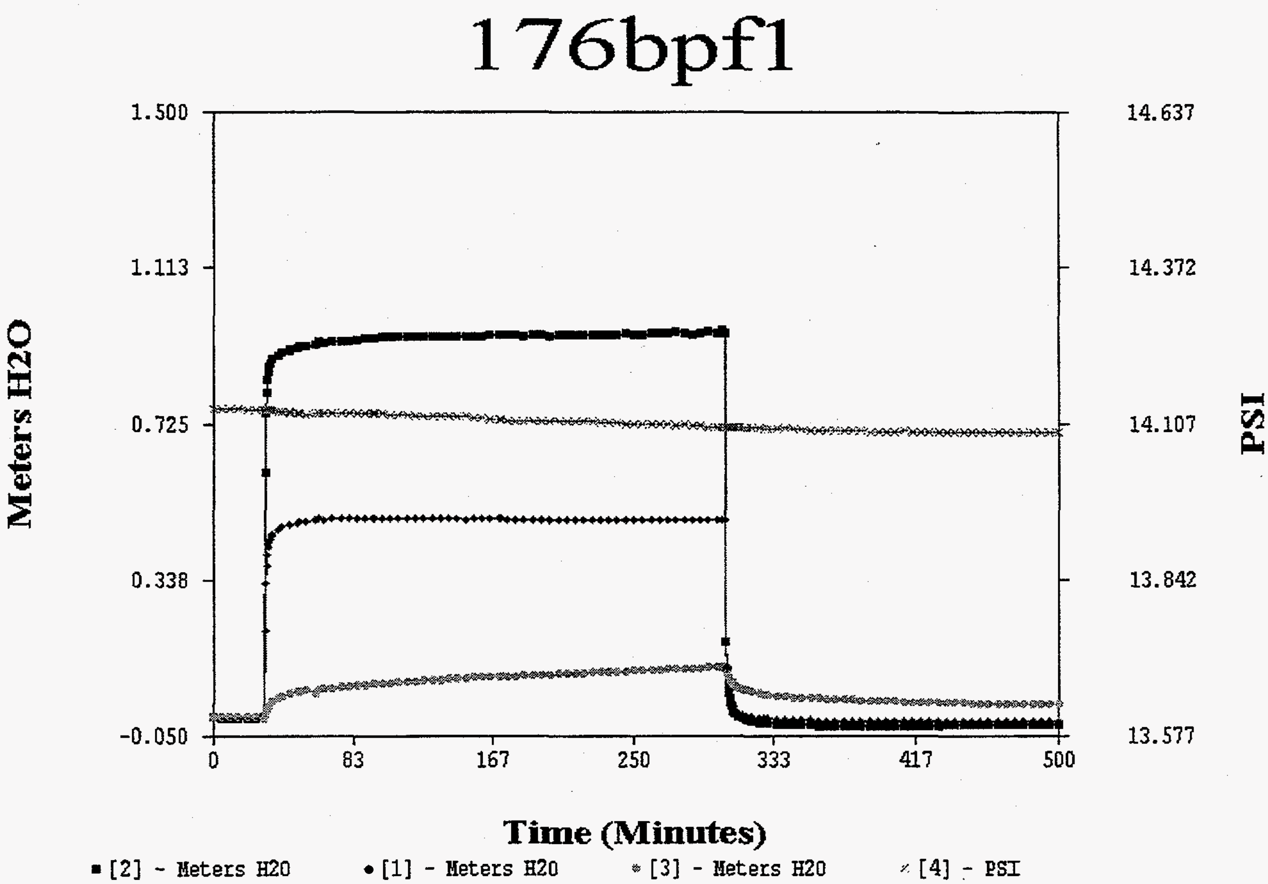


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3] and barometer [4}, while pumping well 1/96 zone F at 75 L/min.

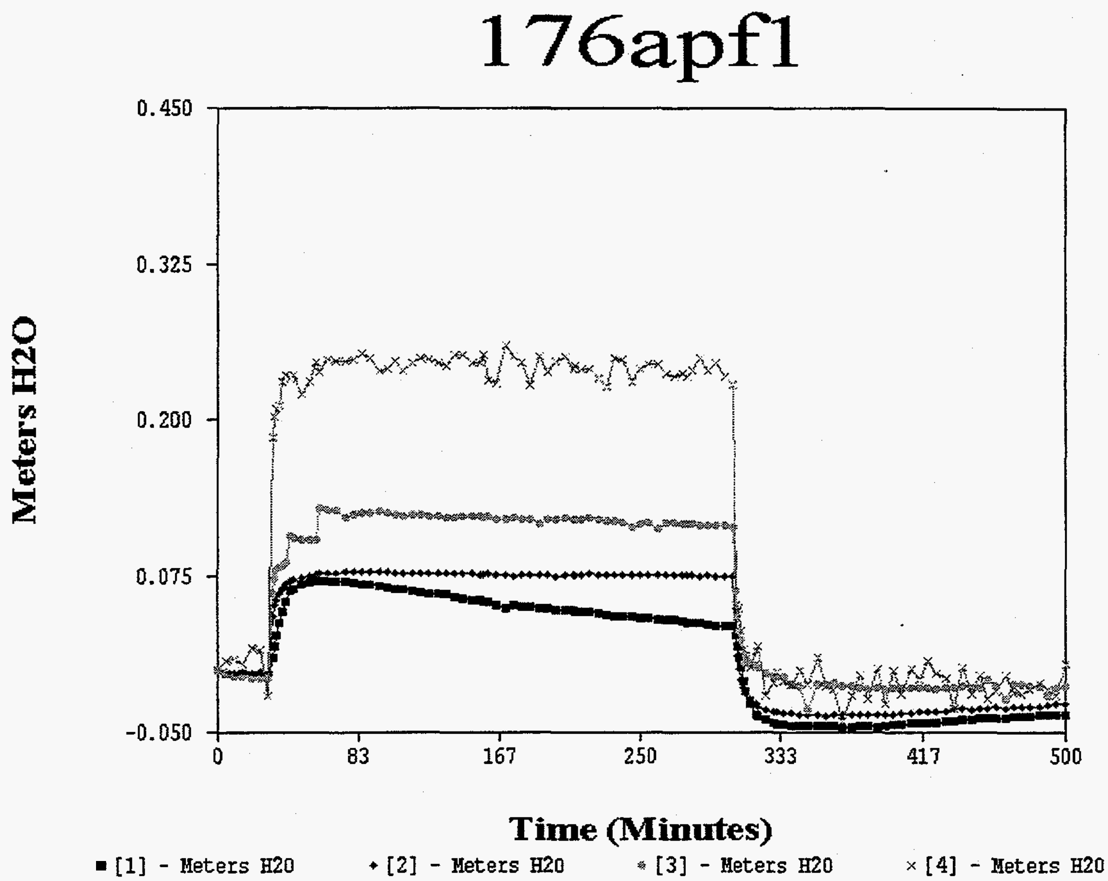


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping well 1/96 zone F at 75 L/min.

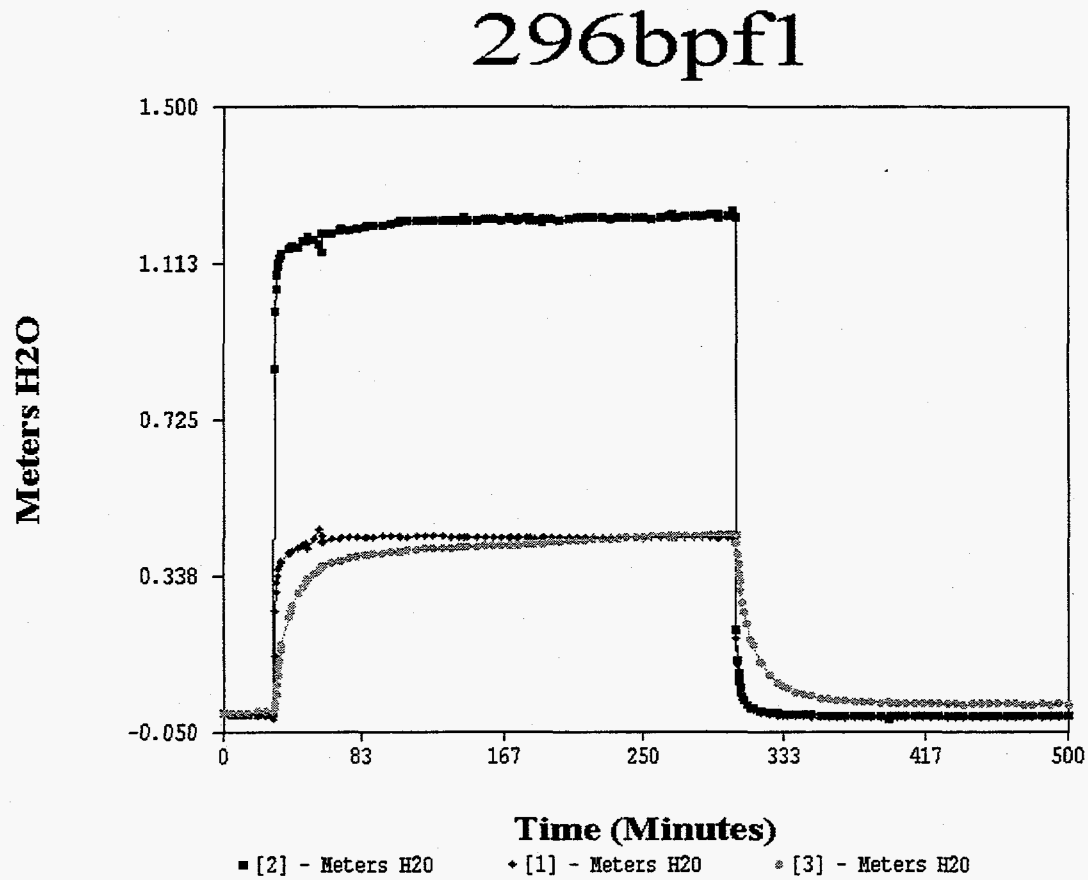


Figure Drawdown vs. time for observation well 296, zones E [1], F [2], G [3], while pumping zone F in well 1/96 at 75 L/min.

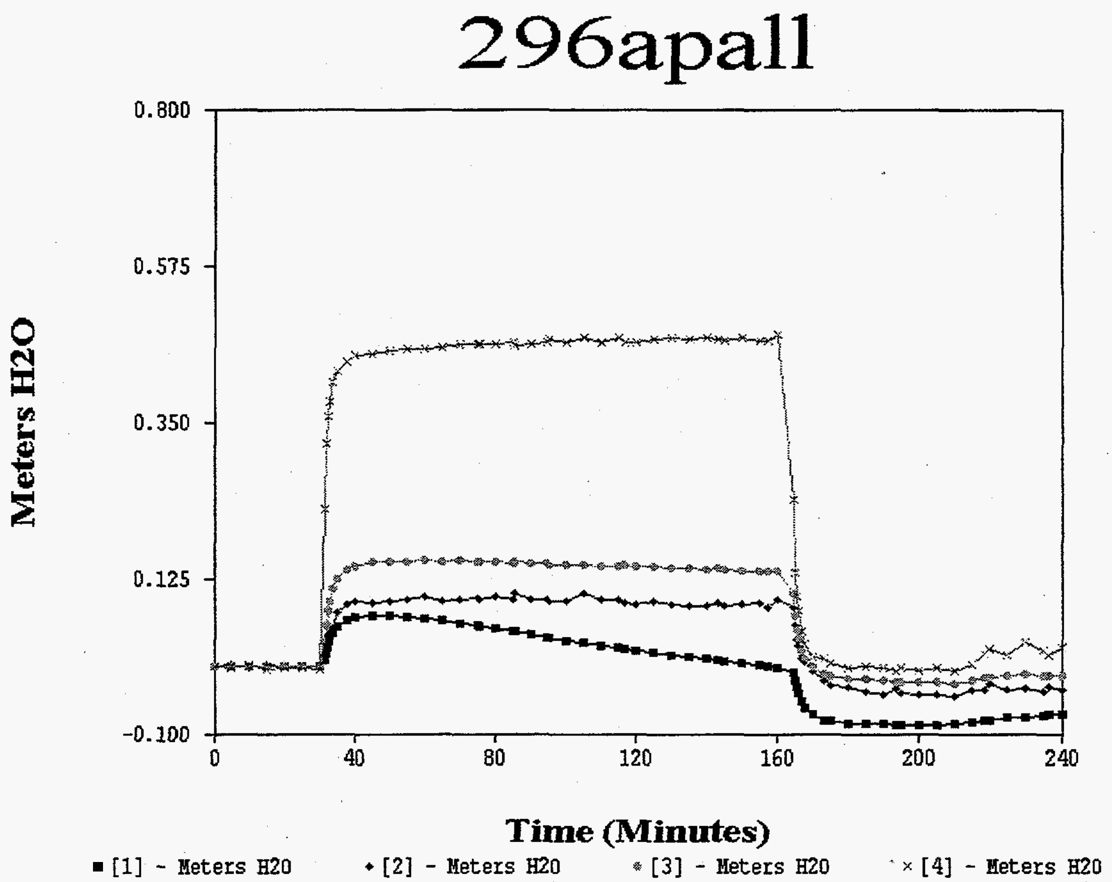


Figure Drawdown vs. time for observation well 296, zones A [1], B [2], C [3] and D [4], while pumping all zones in well 1/96 at 75 L/min.

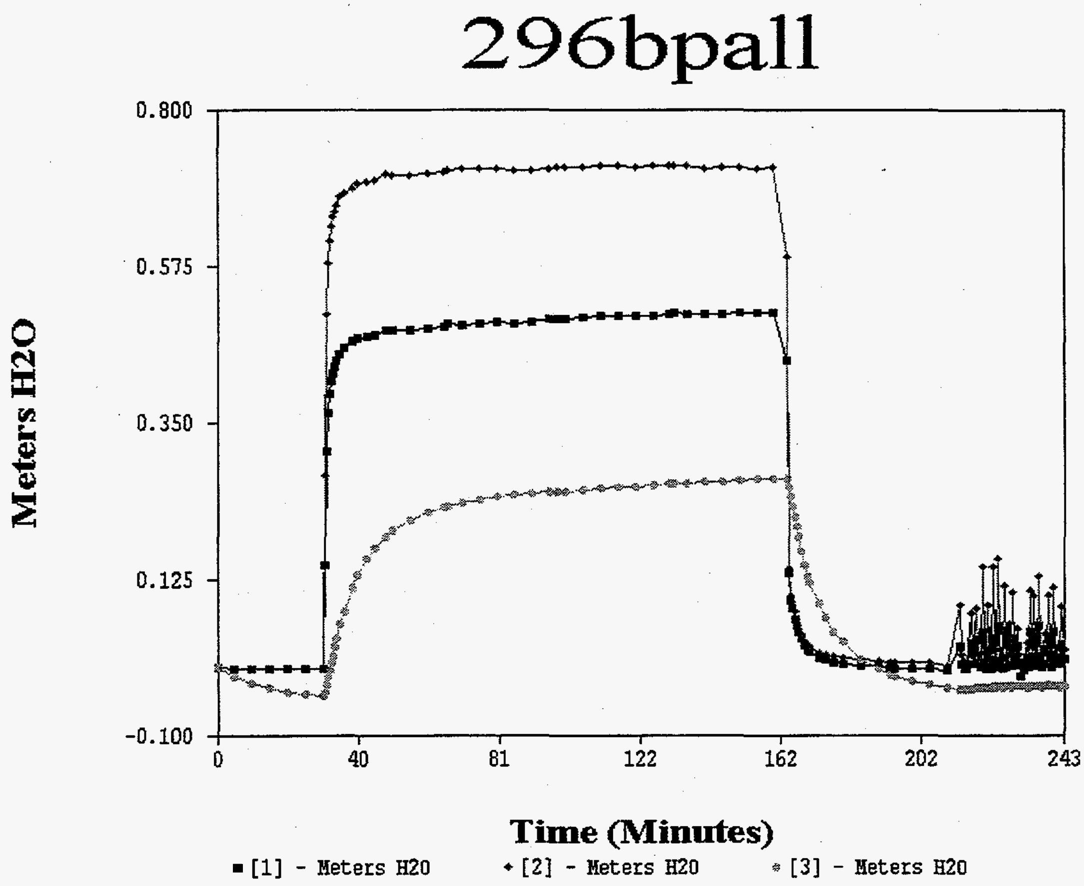


Figure Drawdown vs. time for observation well 2/96, zones D [1], E [2], and F [3], while pumping all zones in well 1/96 at 75 L/min.

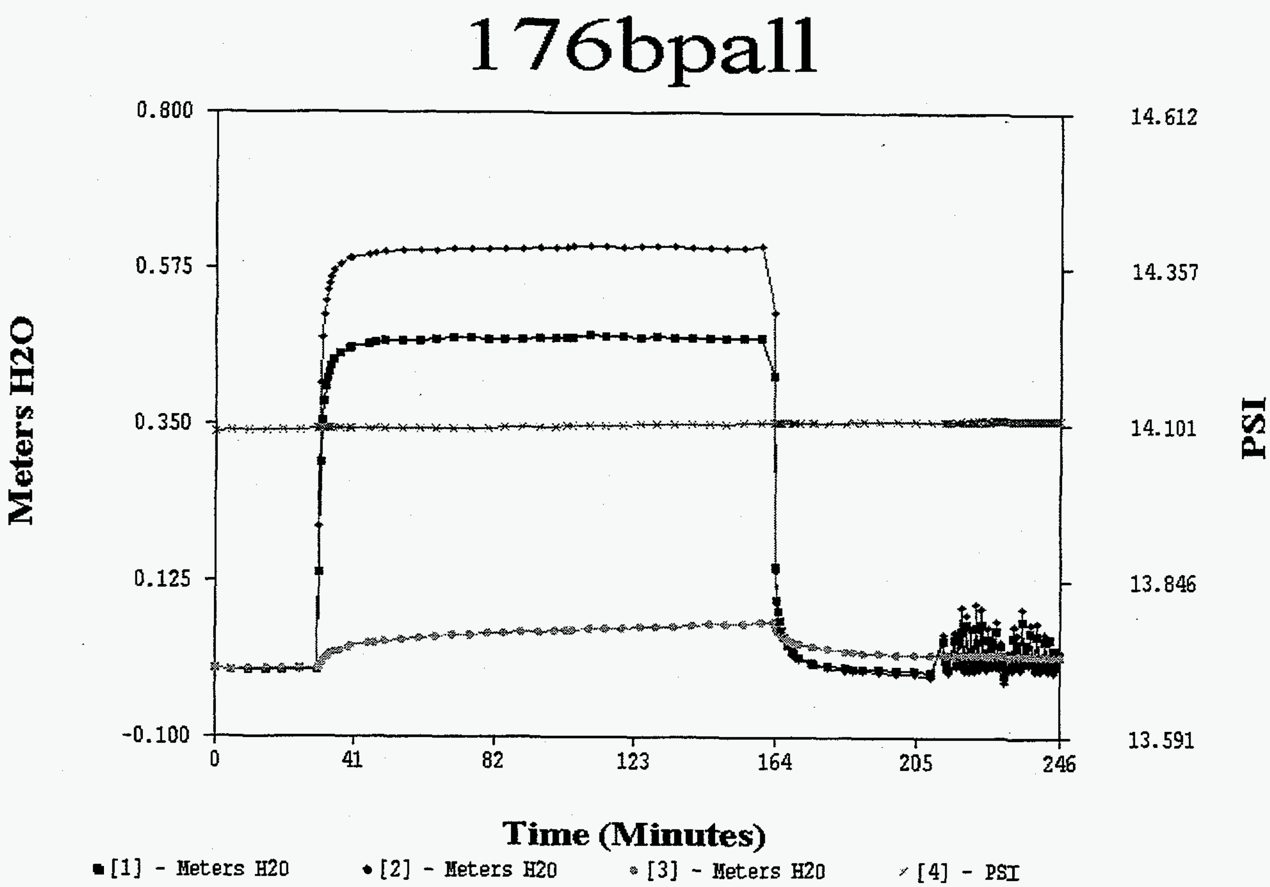


Figure Drawdown vs. time for observation well 176, zones E [1], F [2], G [3], and barometer [4], while pumping all zones in well 1/96 at 75 L/min.

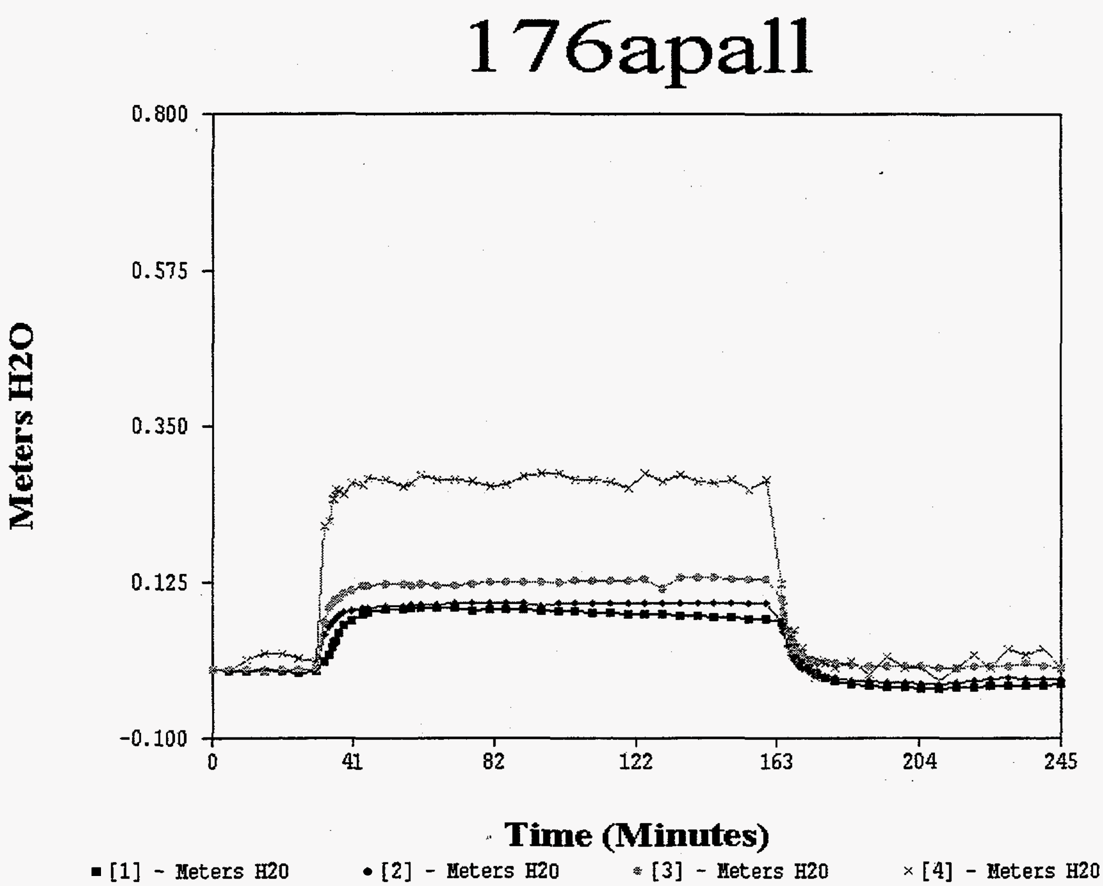


Figure Drawdown vs. time for observation well 176, zones A [1], B [2], C [3] and D [4], while pumping all zones in well 1/96 at 75 L/min.

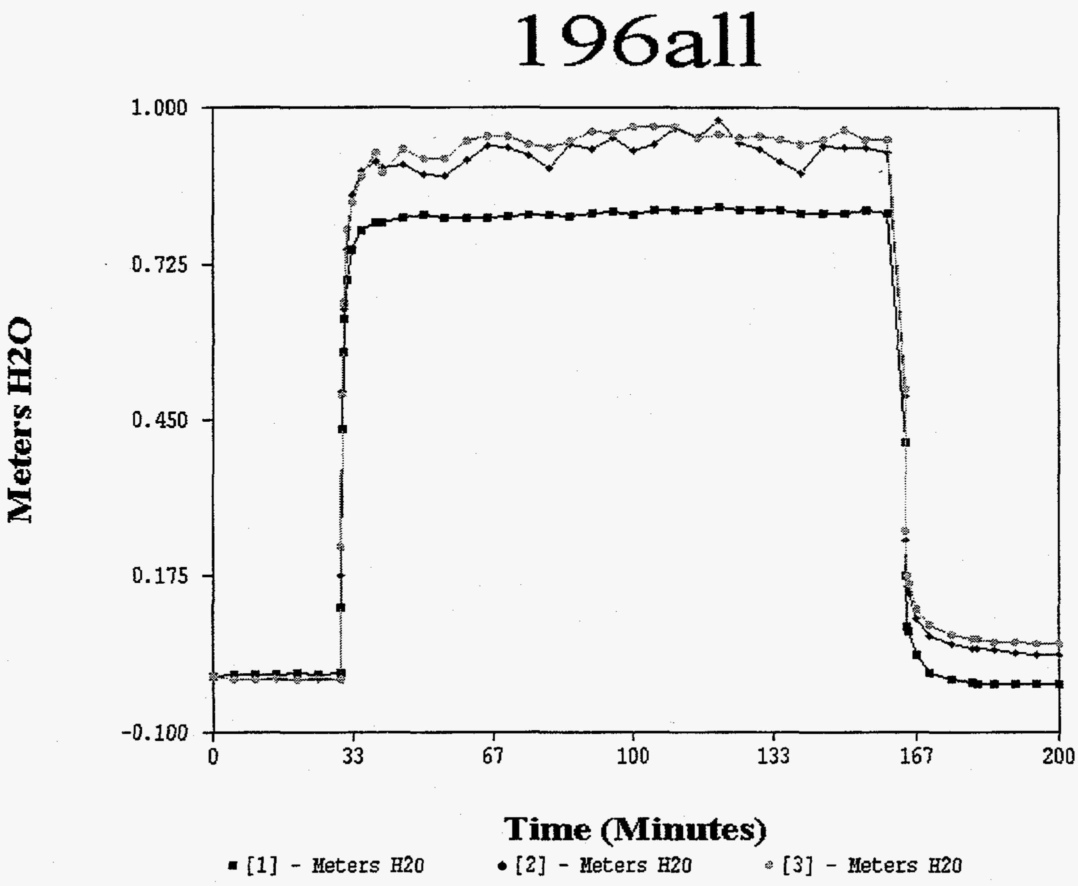


Figure Drawdown vs. time for pumping all zones in well 1/96 at 75 L/min.