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HYDROSTATIC PRESSURE AND FLUID-DENSITY DISTRIBUTION
OF THE CULEBRA DOLOMITE MEMBER OF THE RUSTLER FORMATION
NEAR THE WASTE ISOLATION PILOT PLANT, SOUTHEASTERN NEW MEXICO

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EXECUTIVE SUMMARY

BACKGROUND

The Pressure - Density Survey program was initiated in 1986. This program was designed to collect hydrogeologic data from ground-water monitoring wells installed or recompleted as part of the Waste Isolation Pilot Plant (WIPP) site characterization and performance assessment programs. The Waste Isolation Pilot Plant, located in southeastern New Mexico (Figure 1), is operated by the United States Department of Energy (DOE) for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes generated by the defense activities of the United States Government.

The Pressure - Density Survey Program (Crawley, 1987^a) was developed to provide ground-water density and pressure information needed for hydrologic analysis of the Culebra Dolomite Member of the Rustler Formation. The Culebra in the WIPP Site area, contains fluid of highly variable density. Calculation of ground-water flow directions and velocities in structurally dipping geologic units having variable density fluids, such as the Culebra, require accurately defined formation pressures and formation water densities (Jorgensen et al., 1982). Past investigations have calculated or estimated formation pressures using measured water levels from wells and single water-density values derived from past investigations or estimated for various points across the project area. The results of this project have shown that estimated formation pressures using measured water levels are often in error relative to actual measured pressures.

The primary objectives of the Pressure - Density Survey were to obtain the middle-of-formation pressures, determine well-bore fluid densities, define well-bore fluid density stratification, and to provide, where possible, formation water density values for wells where little or no information on densities exists. The survey collected ground-water pressure and density data during three field testing periods during the years 1986 and 1987. Data was collected from 33 individual wells (Figure 2) located in the vicinity of the WIPP Site.

FIELD PROCEDURES

The general field procedures consisted of measuring the static water level; lowering a pressure transducer down a cased well to the formation level while taking periodic pressure and temperature measurements in the open well casing; measuring the

open well pressures and temperatures at the top, middle, and bottom of the formation; measuring pressures below an inflated packer seated at the top of the perforations or formation; and collecting a point water sample from the middle-of-formation level for laboratory density analysis. The purpose of the open well casing pressure measurements was to obtain differential pressure values for use in defining any detectable density stratification in the well casing.

The field equipment used in this project consisted of a trailer-mounted wireline logging winch, a Selig pressure probe/field data monitor, an inflatable packer, and a downhole point sampling device (Figure 4).

PROBLEMS AND PROJECT EVOLUTION

The Pressure - Density Survey experienced some changes in scope and technique as the project was conducted. Initially, the project attempted to measure the shut-in Culebra hydrostatic pressure at the mid-formation depth. This required setting the packer within either the perforations or the open interval of the Culebra. Prior to starting the second field period, the packer set point was raised to the top-of-formation level in order to eliminate the potential for leakage around the packer through the perforated or open interval.

At the end of the first field period the electronic digital footage counter failed and was replaced with a mechanical unit made for the wireline logging industry. At some point during the third field period the accuracy of the footage counter deteriorated. This was caused by excessive wear of a mechanical component, which resulted in displayed footage values that were greater than the actual depth traveled by the probe. This problem was not discovered until most of the final field survey was completed, resulting in some of the third survey data being suspect.

PRESSURE - DENSITY FIELD DATA

The density values calculated from differential pressure measurements and from actual fluid samples collected may or may not be representative of actual formation fluid densities. In general, all of the density values determined by this project should be considered to represent only the density of the well-bore fluid at the point or depth measured. Tables 2 through 4 show the results of the laboratory analyses for samples collected during the three field survey periods. The most accurate values for water density have been produced by the Water Quality Sampling Program (WQSP). Table 5 shows a comparison of the density values reported by Mercer (1983), The WQSP, and all three rounds of the Pressure - Density Survey. In many cases the

density values from this project are in fairly close agreement with values from the WQSP.

In general, the density of Culebra fluids increases from west to east across the WIPP Site area. The density ranges from a low of 1.001 g/cm^3 at well H-07b1 to a maximum of 1.229 g/cm^3 at well P-18. Figure 7 shows the distribution of the density of ground water in the Culebra Dolomite in the study area.

Density stratification of the fluid standing in a well bore simply means that the density of that fluid is variable between the fluid level surface and the bottom of the well. The existence of fluid density stratification can produce inaccurate values for formation pressures when they are calculated using only measured water levels and assumed water densities. The calculated water-density profiles resulting from differential pressure measurements made during this project clearly indicate that density stratification does exist in many of the wells tested. There were some changes in density stratification in various wells between individual testing episodes. These changes can be attributed to other well testing and water-quality-sampling activities conducted during the interim between survey periods. This observation indicates that occasional pressure - density surveys should be performed in the future on selected wells after other types of well testing activities have occurred.

Tables 7, 8, and 9 present a comparison of calculated mid-formation pressures (using only measured water levels and density values from the literature) and mid-formation pressures actually measured during this project. The comparison indicates that there are often significant differences between actual measured pressures and those calculated from water levels. The differences in calculated and measured pressures for some wells are on the order of several feet of head.

GROUND-WATER FLOW IN THE CULEBRA DOLOMITE

The data collected during the Pressure - Density Survey were used to assess the existing ground-water flow in the Culebra Dolomite in the study area. These data were used to define an equivalent freshwater-head potentiometric surface, using actual measured formation-pressure values, and to attempt to determine density-dependent ground-water flow directions using the techniques described by Jorgensen et al. (1982). The potentiometric-surface map of the equivalent-freshwater-head distribution (Figure 8) indicates that there is considerable variability in gradient and flow direction within the area studied. The results of this analysis indicate that there is a potentiometric high in the area of wells DOE-2, H-05, and WIPP-13. The area south of the WIPP Site has a very flat gradient with the contours indicating a potentiometric low in the

area of the H-09 well pad. Ground-water flow is generally from north to south-southwest across the study area. Examination of the contours in the southern study area (between wells H-07, H-08, and H-09) indicates that there may be a local ground-water divide or a change in flow directions to a more southeasterly direction. This change may be due to local directional differences in hydraulic conductivity or perhaps some localized recharge to the Culebra near the eastern side of Nash Draw, in the vicinity of the H-07 well site.

Jorgensen et al. (1982) presents a number of analytical methods for determining density dependent ground-water flow. The method used in this study is called the test for hydrostatic conditions. In using this method, hydrostatic heads and density variations between the wells tested must be considered. A component of flow will exist between the wells tested if there is a difference in the calculated pressure values for each well, and this is called the non-equilibrium pressure differential. This method was used to test for hydrostatic conditions between a reference well and two other wells. The non-equilibrium pressure differential values were plotted and analyzed using the standard "three point problem" for strike and dip. The dip of this surface is parallel to the direction of ground-water flow among the wells being analyzed. This procedure was applied to several groups of three wells across the project area. The flow vectors determined from analyzing all of the wells included in the Pressure - Density Survey are shown on figure 10 of this report. The apparent ground-water flow direction based on this analysis is generally toward the south to southeast. To the south of the WIPP Site, in the vicinity of wells H-07, H-08, and H-09, the flow direction appears to have a more easterly component.

RESULTS AND CONCLUSIONS

The data collected as part of this program indicate that density stratification does exist in many of the wells tested, and that other well testing activities such as water-quality-sampling and permeability testing can alter density stratification. Collecting actual formation-pressure measurements is more desirable than calculating pressures using water levels and assumed fluid density values. Calculated pressures are often in error relative to measured pressures and can impact the interpretation of ground-water-flow directions in the Culebra Dolomite at the WIPP Site.

Pressure - Density Survey data have been useful to several hydrologic evaluation programs. These data will be used in the future by the Ground-Water Level and Pressure Monitoring Program to more accurately define equivalent-freshwater heads.

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1.0 INTRODUCTION

This report presents data collected during the three field periods of the Pressure - Density Survey program for the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The location of the WIPP Site is shown in Figure 1. The WIPP project is operated by the United States Department of Energy (DOE) for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes generated by the defense activities of the United States Government. This report presents data collected from 33 individual wells (Table 1A) located in the vicinity of the WIPP Site (Figure 2). Specific information concerning well completions, surveyed elevations, and other data is given in Table 1B.

The Pressure - Density Survey program (Crawley, 1987^a) was developed to provide ground-water density and pressure information needed to analyze the ground-water hydrology of the Culebra Member of the Rustler Formation. Because the Culebra is a dipping geologic unit containing highly variable density water, formation pressures and accurately defined formation water densities must be used to determine ground-water flow directions (Jorgensen et al., 1982). Past investigations have calculated or estimated formation pressures using measured water levels from wells and single water-density values derived from the literature or estimated for various points across the project area. Estimated formation pressures are often in considerable error relative to actual measured pressures. The Pressure - Density Survey program has attempted to measure directly the pressures at the formation level, and to define the density profile of the fluids in the well bores standing above the depth of the formation in each well.

FIGURE 1. LOCATION OF THE WIPP SITE AND ITS BOUNDARIES

FIGURE 2. WELL INCLUDED IN THE PRESSURE-DENSITY SURVEY

TABLE 1A.
WELLS INCLUDED IN THE PRESSURE - DENSITY SURVEY

ROUND-1		ROUND-2		ROUND-3	
<u>WELL</u>	<u>DATE</u>	<u>WELL</u>	<u>DATE</u>	<u>WELL</u>	<u>DATE</u>
H-01	10-22-86	-	-	-	-
H-02c	07-29-86	H-02c	04-13-87	H-02c	09-30-87
H-03b2	08-07-86	H-03b2	02-24-87	H-03b2	09-21-87
H-04b	08-13-86	H-04b	02-17-87	H-04b	08-05-87
H-05b	08-11-86	H-05b	04-15-87	H-05b	09-28-87
H-06b	09-03-86	H-06b	05-11-87	H-06b	09-16-87
H-07b1	10-13-86	H-07b1	03-23-87	H-07b	10-01-87
H-08b	10-15-86	H-08b	03-30-87	H-08b	10-07-87
H-09b	10-14-86	H-09b	03-24-87	H-09b	10-05-87
-	-	H-10b	04-01-87	-	-
H-11b3	09-12-86	H-11b3	03-05-87	H-11b3	09-23-87
H-12	09-30-86	H-12	03-06-87	H-12	09-24-87
-	-	-	-	H-14	09-22-87
-	-	-	-	H-15	08-31-87
-	-	-	-	H-17	12-07-87
-	-	-	-	H-18	12-10-87
P-14	08-15-86	P-14	04-23-87	P-14	08-19-87
P-15	09-16-86	P-15	02-26-87	P-15	08-28-87
P-17	09-29-86	P-17	02-25-87	P-17	08-12-87
P-18	10-17-86	P-18	03-10-87	-	-
WIPP-12	09-05-86	WIPP-12	05-08-87	WIPP-12	09-04-87
WIPP-13	09-04-86	WIPP-13	05-06-87	WIPP-13	09-10-87
WIPP-18	08-06-86	WIPP-18	05-12-87	WIPP-18	09-11-87
WIPP-19	08-05-86	WIPP-19	05-14-87	WIPP-19	09-25-87
WIPP-21	07-03-86	-	-	WIPP-21	10-13-87
WIPP-22	08-04-86	-	-	WIPP-22	09-29-87
WIPP-25	11-05-86	WIPP-25	05-05-87	WIPP-25	10-14-87
WIPP-26	10-07-86	-	-	-	-
WIPP-27	11-10-86	WIPP-27	04-27-87	WIPP-27	10-21-87
-	-	-	-	WIPP-28	10-22-87

TABLE 1A. (CONTINUED)

ROUND-1		ROUND-2		ROUND-3	
<u>WELL</u>	<u>DATE</u>	<u>WELL</u>	<u>DATE</u>	<u>WELL</u>	<u>DATE</u>
WIPP-30	11-19-86	WIPP-30	05-06-87	WIPP-30	10-20-87
DOE-1	09-10-86	DOE-1	02-19-87	DOE-1	09-02-87
DOE-2	09-09-86	DOE-2	05-13-87	DOE-2	09-08-87

TABLE 1B
FORMATION INTERVALS, ELEVATIONS, AND COMPLETION DATA
FOR WELLS INCLUDED IN THE PRESSURE - DENSITY SURVEY

<u>WELL</u> <u>NO</u>	<u>TOTAL</u> <u>DEPTH</u>	<u>CASING</u> <u>ELEV</u>	<u>GROUND</u> <u>ELEV</u>	<u>MID-FM</u> <u>DEPTH</u>	<u>MID-FM</u> <u>ELEV</u>	<u>CASING</u> <u>STIKUP</u>	<u>FORM</u> <u>INTVL</u>	<u>PERF</u> <u>INTVL</u>
H-01	856	3399.53	3398.00	688	2710.00	2.00	6676-699	675-703
H-02c	795	3378.41	3377.69	633	2743.69	0.72	624-642	624-652
H-03b2	725	3390.03	3389.33	688	2700.34	0.61	676-700	673-725
H-04b	529	3333.35	3333.35	503	2830.35	0.68	490-516	477-529
H-05b	925	3506.04	3505.38	908.5	2596.88	0.66	897-920	882-925
H-06b	640	3348.25	3347.57	615.5	2732.07	0.68	604-627	592-640
H-07b1	286	3164.17	3163.56	255.5	2908.06	0.61	237-274	230-286
H-08b	624	3434.50	3433.80	601	2832.80	0.70	588-614	575-624
H-09b	708	3406.30	3405.58	662	2743.58	0.67	647-677	640-708
H-10b	1398	3687.80	3687.01	1375.5	2311.51	0.78	1360-1391	1346-1398
H-11b3	787	3412.39	3411.97	740.5	2671.57	0.32	734-759	733-787
H-12	890	3427.19	3425.98	836.5	2589.48	1.21	823-850	820-890
H-14	589	3347.11	3345.60	561.0	2788.00	1.60	545-572	532-589
H-15	900	3481.63	3480.20	872.0	2609.60	1.40	861-883	853-900
H-17	870	3385.31		718.0			706-731	693-773
H-18	830.5	3414.21		702.0		1.00	689-713	673-766
P-14	759(P)	3361.06	3359.76	584	2775.76	1.31	573-595	573-601
P-15	620(P)	3311.38	3309.77	424	2885.77	1.61	413-435	410-438
P-17	731(P)	3337.24	3335.77	570.5	2765.27	1.47	558-583	550-586
P-18	1125(P)	3478.42	3477.30	926	2551.30	1.12	912-940	912-940
WIPP-12	2784(P)	3472.06	3471.30	822.5	2648.80	0.76	810-835	815-840
WIPP-13	3850	3405.71	3405.36	712.5	2692.86	0.35	701-724	702-727
WIPP-18	1046(P)	3458.76	3456.42	797.5	2658.92	2.35	787-808	784-806
WIPP-19	1033(P)	3435.14	3433.13	767.5	2665.63	2.01	756-779	754-780

TABLE 1B. (CONTINUED)

<u>WELL</u> <u>NO</u>	<u>TOTAL</u> <u>DEPTH</u>	<u>CASING</u> <u>ELEV</u>	<u>GROUND</u> <u>ELEV</u>	<u>MID-FM</u> <u>DEPTH</u>	<u>MID-FM</u> <u>ELEV</u>	<u>CASING</u> <u>STIKUP</u>	<u>FORM</u> <u>INTVL</u>	<u>PERF</u> <u>INTVL</u>
WIPP-21	1014	3418.96	3417.00	743.0	2676.00	1.78	729-753	727-751
WIPP-22	1452	3428.12	3426.00	753.0	2673.00	2.21	742-764	748-770
WIPP-25	650	3214.39	3212.46	459.5	2752.96	1.93	447-472	445-475
WIPP-26	503	3153.20	3152.00	199.5	2954.00	1.50	185-210	185-210
WIPP-27	592	3178.98	3177.16	305	2872.16	1.82	292-318	290-320
WIPP-28	801	3349.21	3347.00	433.0	2916.00	2.32	420-446	420-446
WIPP-30	913	3429.04	3427.48	642	2785.48	1.56	631-653	631-654
DOE-1	4057	3465.22	3465.09	831.5	2633.59	0.13	820-843	821-843
DOE-2	4325	3419.09	3418.35	834	2584.35	0.81	822-846	822-848

2.0 PROJECT SCOPE AND OBJECTIVES

2.1 OBJECTIVES

The primary objectives of the Pressure - Density Survey were to obtain the middle-of-formation pressures, determine well-bore fluid densities, define well-bore density stratification, and to define, where possible, ground-water densities at wells completed in the Culebra in areas where little or no information on densities exists. The primary reason for collecting these data is to provide hydrologists with the information needed to perform hydrologic analysis and ground-water modeling of the Culebra Dolomite Member of the Rustler Formation. Because the Culebra Dolomite Member of the Rustler Formation is a structurally dipping water-bearing unit containing variable-density water, formation pressures and fluid densities are required to determine ground-water flow directions. Ground-water flow directions in an aquifer having variable-density water may not be orthogonal to contours of the commonly defined potentiometric surfaces. It has been common practice for hydrologists to simplify the effects of a variable-density flow system by converting ground-water head or water-level data to equivalent freshwater head and then constructing an equivalent freshwater head potentiometric surface. Such a correction technique may lead to inaccurate interpretations of the directions and velocity of local and regional ground-water flow (Jorgensen et al., 1982; Hubbert, 1940; Luszczynski, 1961). The equivalent freshwater-head gradient represents only the component of flow that is driven by horizontal pressure differentials within the formation. The density-related component represents the vertical component of flow that is driven by gravity. Actual flow directions are a combination of the pressure-driven and gravity-driven flow components.

Inaccurate definition of the direction and magnitude of ground-water flow may result if the gravity (density) driven component is not considered in the analysis.

2.2 PROJECT SCOPE

The scope of the Pressure - Density Survey program included the collection of hydrologic data during three separate field periods. During each of these field survey periods, well-specific formation hydrostatic pressures were measured and a point ground-water sample was collected.

The general field procedure consisted of measuring the static water level; lowering a pressure transducer down a cased well to the formation level while taking periodic pressure and temperature measurements in the open well casing; measuring open well pressures and temperatures at the top, middle, and bottom of the formation; measuring pressures below an inflated packer seated at the top of the perforations or formation; and collecting a point water sample from the middle of the formation for density analysis. A flow chart illustrating the components of the field-data-collection program is shown in Figure 3.

2.2.1 Barometric-Pressure Measurements

During the course of the measurements in each well, the barometric pressure was measured and recorded using the pressure transducer. These measurements were taken as a zero check before and after each well test. This was necessary because the transducer measures absolute pressure as opposed to gage pressure.

FIGURE 3. OPERATIONAL PLAN FLOW DIAGRAM

2.2.2 Water-Level Measurements

The water level in each test well was measured with a calibrated Solinst electric tape. All measurements were made from the top of the well casing. Due to the slug effect induced by lowering the equipment into the well, thus causing continuous water-level changes during each test, it was necessary to measure water levels each time that open-well-casing pressure measurements were made.

2.2.3 Well-Casing Pressure Measurements

After the transducer enters the water, and before the top of the perforations or open interval is reached, open-well-casing pressure measurements were made at selected intervals in each well tested. The purpose of these measurements was to obtain differential pressure values for use in defining any detectable density stratification of the fluid in the well casing above the formation level. Because of equipment limitations (Section 2.3), it was not possible to accurately define density differences of less than 0.01 g/cm^3 within a 100-foot interval. Therefore, well-casing pressure measurements were made at approximately 100-foot intervals beginning 20 feet below the static water level until the depth of the perforations or open interval was reached. In order for the probe to equilibrate with the temperature of the water, approximately 20 minutes were required to elapse between the time that a given depth was reached and the time that the temperature and pressure for that depth were measured.

2.2.4 Formation Measurements

Pressure and temperature measurements were made at the top, middle, and bottom of the Culebra Dolomite. The purpose of these measurements was to define any gross water-density

stratification within each well across the formation interval and to determine the actual hydrostatic pressure at the top, middle, and bottom of the unit. The top-of-formation pressure was again measured below an inflated packer. These packed-off measurements were taken in order to isolate the unit from the column of water standing in the well above the formation.

2.2.5 Middle-of-Formation Fluid Samples

Upon completion of the pressure and temperature measurements and with the packer inflated, the downhole point sampler was allowed to fill with fluid from the middle-of-formation level. The sample was transported to the WIPP field water-quality lab for analysis of specific gravity, chloride concentration, and specific conductance.

2.2.6 Modified Procedure for PIP Wells

Many wells included in the survey were equipped with production injection packers (PIP). The general operating procedures outlined above remained the same with the exception that the probe was lowered inside the 2-3/8 inch tubing string above the PIP instead of inside the well casing. The transducer probe was not allowed to pass through or below the PIP.

The major difference for operating in the PIP wells was that a single packed-off pressure measurement was made within the 2-3/8 inch tubing. This measurement was made at a depth slightly above the PIP. The equivalent formation fluid pressure was then calculated using the elevation difference between the measurement point and the mid-point of the formation, and the density of the fluid sample collected at the measurement point.

2.3 EQUIPMENT

The major downhole equipment used in the Pressure - Density Survey program consisted of a trailer-mounted Phoenix Dataline wireline logging winch, a Seling pressure probe/field data monitor, an inflatable packer, and a downhole point sampling device (Figure 4). Each component is discussed below.

2.3.1 Wireline Winch

The logging winch consists of a drum, which is chain-driven by a 12-volt electric motor, and a digital display for footage measurements. The drum contains 2,000 feet of 3/16-inch single-conductor armored cable. The motor is powered by two solar-charged 12-volt deep-draw batteries connected in parallel. The digital display can show the depth to the nearest 0.1 foot, which is the manufacturer's reported accuracy.

2.3.2 Seling Probe and Monitor

The Seling probe consists of a quartz-crystal pressure transducer, a temperature sensor, and a field data monitor. The transducer and sensor are mounted in a stainless steel case. The transducer range is 0 - 3,000 pounds per square inch absolute (psia) with an accuracy of ± 0.60 psia, a precision of ± 0.15 psia, and a resolution of 0.01 psia. The transducer is temperature compensated over a range of -40°C to 135°C . The temperature sensor has an accuracy and precision of $\pm 0.6^{\circ}\text{C}$ and a resolution of $\pm 0.1^{\circ}\text{C}$.

The field data monitor (FDM) consists of a power supply and an Epson HX-20 microcomputer. The computer performs the multiplexing function for operation of the probe as well as

FIGURE 4. SCHEMATIC DIAGRAM OF PRESSURE-DENSITY SURVEY EQUIPMENT

functioning as the data-acquisition system. The computer can output to the LCD screen, an onboard printer, an onboard cassette tape drive, or to a modem for output to another computer.

The accuracy of the entire system, consisting of computer, pressure transducer, and temperature sensor, is ± 1.5 psia. The precision of the Seling system is ± 0.30 psia.

2.3.3 Point Sampler

The sampler is a pneumatic downhole sampling pump. The sampler is opened by releasing the internal gas pressure and closed by the pressure differential between the pressure inside and the pressure outside of the sampler. The sampler has a capacity of 500 milliliters (ml) and the sample container is constructed of stainless steel. The sampler is pressurized to a predetermined amount, using nitrogen gas, prior to lowering the probe and sampler into the well. The sampler internal pressure is released through a valve at the land surface at the appropriate time for sample collection. During each well test approximately 20 minutes was allowed to elapse in order to assure proper filling of the sampler.

3.0 TECHNICAL CONSTRAINTS

There are certain technical constraints which affect both the logistics and the variability of the results of the Pressure - Density Survey. These constraints can be categorized into the following areas: well accessibility, hydrologic characteristics of the Culebra, and operational constraints of the equipment. These technical constraints were recognized prior to conducting the field program. Each of these constraints and their impact on the execution of the field program are discussed below.

3.1 WELL ACCESS

The operational plan involved lowering a pressure transducer, sampler, and packer to the depth of the Culebra. This required that the well casing be open with no tubing strings or obstructions to at least a depth equal to or greater than the base of the Culebra. As previously discussed, several of the wells included in the Pressure - Density Survey were equipped with production-injection packers (PIP). These wells required a slightly modified operating procedure. The modified procedure precluded the measurement of pressures and fluid densities at the formation level. The risk of equipment loss associated with allowing the downhole equipment to go through the PIP and out of the bottom was not warranted by the data which could be obtained. Figure 5 presents a diagram of the operation within the PIP wells.

The experience gained by performing the field survey on the PIP wells indicates that the most desirable hydrologic data cannot be collected using the present testing procedure. Data from non-PIP wells have shown that fluid density stratification

**FIGURE 5. SCHEMATIC DIAGRAM OF PRESSURE MEASUREMENT
IN WELLS WITH PIPS INSTALLED**

usually occurs in the deeper portion of the wells or near the formation interval. Measuring pressures and collecting fluid samples from depths above the PIP do not provide representative density values for the deeper sections of the wells near the formation level, resulting in calculated formation pressures which may not be accurate for these specific well locations.

At various hydropad locations, several wells completed in the Culebra have been found to not be open through the entire formation interval. The primary reason for this is believed to be the collapse of the formation into the well bore.

Several wells have been constructed with relatively large-diameter casing (9-5/8 or 10-3/4 inch O.D.). Because of the limitations of the wireline equipment used in the survey, it was not possible to run a sufficiently large packer to allow the measurement of formation pressures below a packer in these wells. Only open well-bore densities and pressures can be obtained. The wells with large-diameter casing include WIPP-12, WIPP-13, DOE-1, and DOE-2.

3.2 HYDROLOGIC CHARACTERISTICS OF THE CULEBRA

If a downhole probe of significant volume is submerged below the water level in a well, the water level will rise and then decline. The rate of decline is controlled by the casing or hole diameter and the transmissivity and storativity of the hydrologic unit. A mathematical formulation which describes the water-level decline was first presented by Cooper et al. (1967) for analysis of slug tests. The basic equation is:

$$H/H_0 = F(\beta, \alpha) \quad (1)$$

where:

- H_0 = instantaneous maximum head change in well at $t=0$
(t_0)
- H = head change in well at time t ,
- $F(\beta, \alpha)$ = the slug test well function whose values are
calculated for several orders of β and α ,
- $\beta = Tt/r_c^2$,
- $\alpha = r_s^2 S/r_c^2$,
- r_c = radius of the well casing in the interval over
which the head change takes place,
- r_s = effective radius of the well (usually taken to
equal the radius of the well screen),
- t = time since the instantaneous head change ($t=t_0$)
- S = storativity, and
- T = transmissivity

For formations of low transmissivity (less than approximately $0.10 \text{ ft}^2/\text{d}$), the time required for the instrument-induced slug effect to dissipate is very substantial if the well casing remains open. The only feasible way to mitigate this problem is to set a packer above the interval being tested. A mathematical formulation of this was described by Bredehoeft and Papadopoulos (1980) and Neuzil (1982). The results of these analyses indicate that a packed-off test section will respond approximately 400 times faster than an open well.

3.3 EQUIPMENT OPERATIONAL CONSTRAINTS

There are several equipment-related constraints which affected the operation of the field program. One constraint is the required time of 20 to 30 minutes specified by the manufacturer for temperature stabilization of the transducer probe. Other constraints are related to the accuracy of the equipment being

used in the Pressure - Density Survey. The precision of the Seling transducer system is ± 0.30 psia and the footage meter on the wireline winch has an accuracy of ± 0.1 foot. Because of these limitations, it is unlikely that density variations of less than ± 0.01 g/cm³ over a 100-foot thickness could be detected by using differential pressure measurements.

4.0 PROBLEMS AND PROJECT EVOLUTION

The Pressure - Density Survey program experienced some changes in scope and in technique as the project was conducted. These changes in scope and technique, as well as specific problems encountered during execution of the field program, are discussed below.

4.1 TEST WELLS AND THEIR CONSTRUCTION

Ground water testing and monitoring wells at the WIPP Site are completed, basically, in two styles. One type of installation includes drilling the well to some depth greater than the depth of the Culebra Dolomite, and then casing the well to the bottom of the drilled hole. The interval of the Culebra is then perforated to allow access to the formation for testing and sampling purposes. The second type of well completion consists of drilling the hole to a depth just above the Culebra, installing well casing to the bottom of the drilled hole, and then coring or drilling through the Culebra interval, leaving the interval open to the well. The two types of well completions are shown in Figure 6.

Initially, the Pressure - Density Survey attempted to measure the shut-in Culebra hydrostatic pressure at the mid-formation depth. This required setting the inflatable packer within either the perforations or the open Culebra interval. All of the wells included in the first field survey period were tested in this manner. Prior to starting the second field period, the decision was made to eliminate setting the packer in the perforated or open interval, and to raise the shut-in test point to the top-of-formation depth. This decision was made because of the potential for leakage around the packer through the

FIGURE 6. SCHEMATIC OF WELL CONSTRUCTION TYPES

annulus surrounding the well casing or through fractures in the formation. Beginning with the second field survey period, the formation pressure measured below the inflated packer was changed from the mid-formation depth to the top-of-formation depth. This change in procedure resulted in a somewhat inconsistent formation pressure database.

4.2 EQUIPMENT PERFORMANCE AND CHANGES

The basic test equipment used in the Pressure - Density Survey did not change during the course of the program. However, there were some equipment malfunctions and failures. The individual incidents of equipment failure and their respective remedies are discussed below.

Near the end of the first field survey period, the level-wind system of the wireline logging winch failed. This mechanical component was repaired and strengthened. At the time of this repair, the length of armored single-conductor cable was increased to 2,000 feet. This addition provided the project with the capability to measure formation depth pressures and to collect a fluid sample in well H-10b. Prior to this, it was not possible to measure formation pressures due to the depth of the Culebra in this well (1,375.5 ft).

Shortly after repairing the level-wind device on the winch, the digital footage counter began to fail routinely. This original footage counter was an electronic digital readout device. After assessment of the future reliability of this device, the decision was made to replace it with a mechanical footage counter made for the wireline logging industry. This mechanical footage counter had a digital readout of the depth to the nearest 0.10 foot. The footage counter performed well throughout most of the program. During the third and final

field survey period, the accuracy of the footage counter deteriorated. This was caused by excessive wear of a mechanical component, which resulted in displayed footage values that were greater than the actual depth traveled by the probe. Unfortunately, this problem was not discovered until most of the final field survey was completed.

5.0 PRESSURE - DENSITY FIELD DATA

The basic information collected by the Pressure - Density Survey included open-well pressure measurements at various intervals above the formation level, pressure measurements at the top, middle, and bottom of the formation, and laboratory analyses of fluid densities taken at the mid-formation level in each test well. These data are used to assess the existence of fluid density stratification within the test well bores, to determine the average density of the fluid in each well, and to define actual formation hydrostatic pressures.

5.1 CULEBRA GROUND-WATER DENSITIES

Ground-water density data from the WIPP Site area have been collected by a number of different investigations in the past (Mercer and Orr, 1979; Mercer, 1983; Uhland and Randall, 1986; Uhland, Randall and Carrasco, 1987; and Randall, Crawley, and Lyon, 1988). Ground-water density data have also been collected as part of the Pressure - Density Survey. Water densities at the middle-of-formation level were determined both by measuring the differential pressures and by collecting point water samples for laboratory analysis. The results of the laboratory analyses for samples collected during all three field survey periods of the Pressure - Density Survey are given in Tables 2 through 4. The density values calculated from differential pressure measurements and from actual fluid samples collected may or may not be representative of actual formation fluid density. For wells with sufficient flow through the Culebra interval, the densities measured at the formation level may be representative of true formation fluid density. In general, all of the densities determined by the Pressure - Density Survey should be considered to represent only the density of the well-bore fluid at the point or depth measured.

TABLE 2.
SUMMARY OF ANALYSES OF MID-FORMATION WATER SAMPLES
COLLECTED DURING THE FIRST FIELD PERIOD
OF THE PRESSURE-DENSITY SURVEY

WELL NO.	SPECIFIC GRAVITY (g/cm)	SPECIFIC CONDUCTIVITY (umhos/cm)	CHLORIDE CONCENTRATION (mg/l)
H-01	-	-	-
H-02c	1.0430	87,900	35,200
H-02b2	1.0162	35,600	11,400
H-03b2	1.0420	78,000	30,900
H-04b	1.0146	28,100	7,500
H-05b	1.0980	164,400	82,300
H-06b	1.0420	77,900	31,700
H-07b1	1.0018	7,000	1,400
H-08b	1.0008	5,100	716
H-09b	1.0038	29,100	950
H-11b3	1.0804	95,500	59,200
H-12	1.1806	313,300	79,400
P-14	1.0172	32,300	11,900
P-15	1.0062	10,300	2,100
P-17	1.0920	142,900	39,300
P-18	1.2294	338,100	203,800
WIPP-12	-	-	-
WIPP-13	1.0482	88,300	36,000
WIPP-18	1.0850	158,400	80,500
WIPP-19	1.0142	33,700	12,100
WIPP-21	1.0360	70,000	27,200
WIPP-22	1.1396	275,600	122,100
WIPP-25	1.0022	760	163
WIPP-26	-	-	-
WIPP-27	1.0416	75,900	31,100
WIPP-30	1.1746	131,000	60,300
DOE-1	1.0824	134,500	71,200
DOE-2	1.0422	77,200	32,400

TABLE 3.

SUMMARY OF ANALYSES OF MID-FORMATION WATER SAMPLES
COLLECTED DURING THE SECOND FIELD PERIOD OF THE
PRESSURE - DENSITY SURVEY

WELL NO.	SPECIFIC GRAVITY (g/cm)	SPECIFIC CONDUCTIVITY (umhos/cm)	CHLORIDE CONCENTRATION (mg/l)
H-02c	1.0436	85,000	69,100
H-03b2	1.0396	71,900	27,800
H-04b	1.0166	30,300	8,700
H-05b	1.0688	121,700	56,900
H-06b	1.0406	76,000	28,500
H-07b1	1.0012	3,800	178
H-08b	1.0008	3,300	40
H-09b	1.0018	3,500	292
H-10b	1.0818	137,600	66,700
H-11b3	1.0780	135,000	65,200
H-12	1.1324	190,000	112,300
P-14	1.0240	46,000	19,000
P-15	1.0052	11,400	2,600
P-17	1.0668	116,000	53,100
P-18	-	-	-
WIPP-12	1.0340	63,000	28,000
WIPP-13	1.0482	86,000	37,100
WIPP-18	1.1058	163,000	90,700
WIPP-19	1.1024	166,000	90,200
WIPP-25	1.0104	20,400	6,400
WIPP-27	1.0416	86,000	35,100
WIPP-30	1.0682	120,000	56,900
DOE-1	1.0944	155,000	78,200
DOE-2	1.0488	89,000	39,400

TABLE 4.
SUMMARY OF ANALYSES OF MID-FORMATION WATER SAMPLES
COLLECTED DURING THE THIRD FIELD PERIOD OF THE
PRESSURE - DENSITY SURVEY

WELL NO.	SPECIFIC GRAVITY (g/cm)	SPECIFIC CONDUCTIVITY (umhos/cm)	CHLORIDE CONCENTRATION (mg/l)
H-02c	1.0402	77,000	31,100
H-03b2	1.0382	72,700	28,900
H-04b	1.0160	27,600	7,500
H-05b	1.1024	161,000	82,300
H-06b	1.0400	77,400	32,200
H-07b1	1.0020	5,380	801
H-08b	1.0026	3,120	70
H-09b	1.0020	3,410	183
H-11b3	1.0764	130,200	66,300
H-12	1.0952	154,400	80,500
H-14	1.0238	46,600	18,300
H-15	1.1482	205,200	130,400
H-17	1.1804	212,000	168,700
H-18	1.1788	227,000	162,800
P-14	1.0168	35,600	13,500
P-15	1.0046	10,000	2,000
P-17	1.0622	109,300	49,300
WIPP-12	1.1066	151,200	93,600
WIPP-13	1.0464	86,900	35,400
WIPP-18	1.1062	164,900	92,800
WIPP-19	1.1064	170,200	94,500
WIPP-21	1.0644	118,000	55,000
WIPP-22	1.0982	152,500	
WIPP-25	1.0082	16,600	5,000
WIPP-27	1.0352	74,100	31,300
WIPP-28	1.0086	25,500	9,100
WIPP-30	1.0628	119,000	56,600
DOE-1	1.0822	139,800	68,000
DOE-2	1.0426	82,000	33,600

The most accurate values for Culebra water density have been produced by the Water Quality Sampling Program (WQSP). Ground-water samples from this program are collected after extensive pumping and monitoring of selected chemical parameters, and are the most accurate and representative water-density values available for selected wells at the WIPP Site. A comparison of Culebra water-density values from Mercer (1983), the WIPP Water Quality Sampling Program for 1987 and 1988, and from the first, second, and third field periods of the Pressure - Density Survey is offered in Table 5. A review of the information in Table 5 reveals, that in many cases the density values from the Pressure - Density Survey are in fairly close agreement with values from the WQSP. For wells not included in the WQSP, users of water density data may find that the Pressure - Density Survey samples represent good estimates of formation fluid densities in those wells which have not had foreign fluid introduced into them.

5.1.1 Culebra Fluid Density Distribution

The density of ground water in the Culebra Member of the Rustler Formation in the vicinity of the WIPP Site is highly variable. In general, the density of water in the Culebra increases from west to east across the WIPP Site area. Density values from both the Pressure - Density Survey and the WQSP indicate that the density ranges from a low of 1.001 g/cm^3 at well H-07b1 to a maximum of 1.229 g/cm^3 at well P-18 (there is some question as to the reliability of water-quality and hydrologic data collected from well P-18). Ground-water densities in the Culebra to the east, northeast, and southeast of the site generally have densities greater than 1.09 g/cm^3 . The area south and southwest of the site, which includes Culebra wells on hydropads H-07, H-08, and H-09, has Culebra ground-water densities between 1.001 and 1.003 g/cm^3 , which is extremely

TABLE 5.

GROUND-WATER DENSITY SUMMARY FROM MERCER(1983),
THE THREE FIELD PERIODS OF THE PRESSURE - DENSITY
SURVEY, AND THE WATER QUALITY SAMPLING PROGRAM

WELL NO	MERCER (1983) (g/cm ³)	WQ SAMPLING PROGRAM (g/cm ³)	P-D SURVEY 1st PERIOD (g/cm ³)	P-D SURVEY 2nd PERIOD (g/cm ³)	P-D SURVEY 3rd PERIOD (g/cm ³)
H-01	1.016	-	-	-	-
H-02b2	1.012	1.008(H-02a)	1.016	-	-
H-02c	-	-	1.043	1.044	1.040
H-03b2	1.024	1.038(H-03b3)	1.042	1.040	1.038
H-04b	1.024	1.015	1.015	1.017	1.016
H-05b	1.106	1.102	1.098	1.069	1.102
H-06b	1.040	1.040	1.042	1.041	1.040
H-07b1	1.001	1.001	1.002	1.001	1.002
H-08b	1.000	1.002	1.001	1.001	1.003
H-09b	-	1.002	1.004	1.002	1.002
H-10b	1.045	-	-	1.082	-
H-11b3	-	1.080	1.080	1.078	1.076
H-12	-	1.100	1.181	1.132	1.095
H-14	-	1.012	-	-	1.024
H-15	-	1.156	-	-	1.148
H-17*	-	1.103	-	-	1.180
H-18*	-	1.018	-	-	1.179
P-14	1.018	1.019	1.017	1.024	1.017
P-15	1.080	-	1.006	1.005	1.005
P-17	1.082	1.062	1.092	1.067	1.062
P-18	-	-	1.229	-	-
WIPP-12	-	-	-	1.034	1.107
WIPP-13	-	1.048	1.048	1.048	1.046
WIPP-18	-	-	1.085	1.106	1.106
WIPP-19	-	1.072	1.014**	1.102	1.106
WIPP-21	-	-	1.036	-	1.064
WIPP-22	-	-	1.140	-	1.098
WIPP-25	1.014	1.011	1.002	1.010	1.008

TABLE 5. (CONTINUED)

WELL NO	MERCER (1983) <u>(g/cm³)</u>	WQ SAMPLING PROGRAM <u>(g/cm³)</u>	P-D SURVEY 1st period <u>(g/cm³)</u>	P-D SURVEY 2ND PERIOD <u>(g/cm³)</u>	P-D SURVEY 3rd PERIOD <u>(g/cm³)</u>
WIPP-26	1.013	1.010	-	-	-
WIPP-27	1.094	-	1.042	1.042	1.035
WIPP-28	1.044	-	-	-	1.009
WIPP-30	1.072	1.020	1.175	1.068	1.063
DOE-1	-	1.091	1.082	1.094	1.082
DOE-2	-	1.043	1.042	1.049	1.043

* These wells had brine left in the well casing after drilling and completion and the reported Pressure - Density Survey density values do not reflect real Culebra fluid densities.

** Sample was collected at shallow depth and this well was density stratified at the time the sample was collected.

low compared to most of the Culebra in the WIPP Site area. The area within Nash Draw, which includes wells WIPP-25, WIPP-26, WIPP-27, WIPP-28, and WIPP-29, does not follow the same general ground-water density trend seen in most of the area included in this study. The Culebra and the rest of the Rustler Formation in Nash Draw have been extensively altered due to dissolution of the evaporites and removal of halite from the Rustler and the underlying Salado Formation. This alteration may create some interconnection with ground water from other water-bearing zones and provide for infiltration of effluent from potash mining activities in the northern parts of Nash Draw. Figure 7 shows the distribution of the density of ground water in the Culebra Dolomite in the study area. The data used to create this contour map are from the most recent sampling of wells included in the WQSP and from the Pressure - Density Survey for wells not included in the WQSP.

5.2 WELL-BORE DENSITY STRATIFICATION

Density stratification of the fluid standing in a well bore simply means that the density of that fluid is variable between the fluid level surface and the bottom of the well. There are several ways for the fluid in a well to become density stratified. For the wells used in the hydrologic investigations at the WIPP Site, there are four possible causes of well-bore fluid-density variability, and these are discussed below.

- * Foreign fluids or water may be introduced into the well during completion of the well, servicing or cleaning of the well, or during inflation of the production-injection packers or other packers-plugs. These fluids are usually either fresh water with a density near 1.000 g/cm^3 , or brine having a very high density of approximately 1.200 g/cm^3 . When these foreign fluids are left in a well, they generally result in density

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stratification within the well bore and an average well-bore density which is considerably different from that of the formation fluid.

- * Extensive pumping of Culebra ground water during aquifer testing and the Water Quality Sampling Program may promote stratification of well-bore fluids. This is often the result of pumping formation water from beneath an inflated packer set just above the perforations or open interval. Pumping draws fresh formation water into the well bore beneath the packer. This water may be of higher or lower density than the stagnant water standing above the packer.
- * Many of the hydrologic test wells at the WIPP Site were completed "open hole" with the formation interval, and in some cases, many additional feet of drill hole left open and uncased. This type of well completion may result in halite, which occurs in the Rustler Formation beneath the Culebra Dolomite at some locations, being exposed to the open interval in the well. The exposed halite, which is highly soluble, increases the sodium and chloride concentrations considerably and thus increases the fluid density in the well bore. Such an increase in density in the lower sections of these wells will create significant density stratification, and produce fluid standing in the well bore having an average density greater than the actual density of the formation fluid.
- * The Culebra Dolomite may contain fluid which is density stratified. At the present time it has not been determined if indeed the Culebra does contain fluid of variable density, however, it is possible and such a condition would produce fluid-density stratification.

5.2.1 Measurement of Density Stratification

The existence of fluid-density stratification within the well bores can produce inaccurate values for formation hydrostatic pressures when these pressures are calculated using only measured water levels and assumed water densities. In the past most of the analyses of ground-water flow in the Culebra have been performed by simply converting measured water levels to an equivalent freshwater head. Flow directions and gradients would then be determined from the equivalent freshwater head distribution.

The Pressure - Density Survey has attempted to define the density profile of the fluids in the well bores above and at the formation levels. The field analysis for determining density stratification in the well casing was made using the differential pressure equation:

$$\rho = \frac{\Delta P_d}{g \Delta z} \quad (2)$$

where:

ρ	= density,	$[M/L^3]$
ΔP_d	= change in pressure (corrected)	$[(ML/T^2)/L^2]$
g	= acceleration of gravity, and	$[L/T^2]$
Δz	= change in depth.	$[L]$

For the equipment used in the Pressure - Density Survey, where the pressure is measured in pounds per square inch and depth is measured in feet:

$$\rho = \frac{\Delta P_d}{g\Delta z} \left[\frac{6894.8 \text{ Pa}}{\text{psi}} \right] \times \frac{\text{ft}}{.3048 \text{ m}} \times \frac{\text{g/cm}^3}{1000 \text{ kg/m}^3} \quad \text{or}$$

$$\rho = 22.620 \frac{\Delta P_d}{g\Delta z}$$

If $g = 9.807 \text{ m/sec}^2$, then:

$$\text{Then} \quad \rho = 2.3066 \frac{\Delta P_d}{\Delta z} \quad (3)$$

A sample calculation would be:

$$\begin{aligned} \Delta P_d &= 70 - 25.5 = 44.5 \text{ psi} \\ \Delta z &= 601.0 - 499.9 = 101.1 \text{ ft} \\ \rho &= 2.3066 \left(\frac{44.5}{101.1} \right) = 1.01 \text{ g/cm}^3 \end{aligned}$$

This equation was applied between each two depths where pressures were measured as the test was being conducted.

As a result of the slug effect of the equipment being lowered into the well, it was generally necessary to adjust all open-well pressure measurements in order to correct out the fluctuation in water level between readings. The correction equation that was applied is:

$$P_c = \frac{\rho \Delta h}{2.3066} \quad (4)$$

where:

ρ = water density (g/cm^3),

Δh = water level reading - water level initial (ft), and

P_c = pressure correction (psi).

The pressure correction equation used is:

$$P_d = P_m + P_c \quad (5)$$

where:

P_d = corrected pressure at given depth (psia), and

P_m = measured pressure at given depth (psia).

In the field, during the first field survey period, the density used in Equation (4) for the first or shallowest sampling depth was either from the Water Quality Sampling Program or from Mercer (1983). For the second and third field survey periods, the density value for the first sampling point was from the Water Quality Sampling Program or from the previous field period of the Pressure - Density Survey. For each subsequent sampling depth, the density used in Equation (4) was the value calculated for the test interval just above it. After the completion of a well test, the densities calculated from the differential pressure measurements were used to recalculate the pressure correction as necessary.

Each depth-interval density was compared to the density of the

interval above. If the calculated density difference was greater than 0.01 g/cm^3 , then all calculations, pressure measurements, and surface equipment operation were checked prior to proceeding deeper into the well. If all checks were positive, then the density variation was considered to be real and reported as such.

Density stratification at the formation level was also measured in the same manner as described above using the differential, open-hole pressure measurements made before packer inflation.

The calculated water-density profiles clearly indicate that density stratification does exist in many of the wells tested during all three field surveys. The basic field data collected during the field surveys have been presented in previous data release reports (Crawley, 1987a, Crawley, 1987b, and Crawley, 1988). The basic field data for all three field surveys are also presented in this report in Appendix A. Review of the basic data from each of the field periods indicates that there were some changes with regard to density stratification in various wells between individual testing episodes. These observed changes can generally be attributed to well testing and water-quality-sampling activities conducted during the interim between field-survey periods.

Density stratification becomes significant when the overall average density of the column of fluid standing in a well bore is different than the density of the fluid in the formation at that point. Such differences in the average relative to the formation fluid density will lead to inaccurate calculations of formation pressure or hydrostatic head. A comparison of the average densities of the fluid standing in wells included in the Pressure - Density Survey relative to the formation fluid density as reported by Mercer (1983) or the Water Quality Sampling Program is presented in Table 6. The data presented in

TABLE 6.
AVERAGE DENSITY OF WELL-BORE FLUIDS IN WELLS INCLUDED
IN THE PRESSURE - DENSITY SURVEY

AVERAGE WELL BORE FLUID DENSITY VALUE

WELL NO.	PUBLISHED DENSITY (g/cm ³)	FIRST FIELD PERIOD (g/cm ³)	SECOND FIELD PERIOD (g/cm ³)	THIRD FIELD PERIOD (g/cm ³)
H-02c	1.008	1.054	1.040	1.033
H-03b2	1.038	1.036	1.037	1.020
H-04b	1.015	1.019	1.018	1.012
H-05b	1.102	1.106	1.097	1.090
H-06b	1.040	1.038	1.030	1.027
H-07b1	1.001	1.003	1.015	0.990
H-08b	1.002	1.000	1.000	0.977
H-09b	1.002	1.000	0.998	0.986
H-10b	1.045	-	1.085	-
H-11b3	1.080	1.081	1.075	1.061
H-12	1.100	1.097	1.098	1.082
H-14	1.012	-	-	1.002
H-15	1.156	-	-	1.134
H-17	1.103	-	-	1.177
H-18	1.018	-	-	1.179
P-14	1.019	1.014	1.007	1.002
P-15	1.080	1.000	1.034	0.985
P-17	1.062	1.074	1.063	1.050
P-18	-	1.112	1.116	-
WIPP-12	-	1.002	0.993	1.050
WIPP-13	1.048	1.025	1.031	1.017
WIPP-18	-	1.030	1.098	1.091
WIPP-19	1.072	1.099	1.124	1.100
WIPP-21	-	1.013	-	1.047
WIPP-22	-	1.116	-	1.085
WIPP-25	1.011	0.966	1.000	0.994

TABLE 6. (CONTINUED)

WELL NO.	PUBLISHED DENSITY (g/cm ³)	FIRST FIELD PERIOD (g/cm ³)	SECOND FIELD PERIOD (g/cm ³)	THIRD FIELD PERIOD (g/cm ³)
WIPP-26	1.010	1.000	-	-
WIPP-27	1.094	1.008	1.032	1.023
WIPP-28	1.044	-	-	1.000
WIPP-30	1.020	1.064	1.058	1.042
DOE-1	1.091	1.075	1.106	1.064
DOE-2	1.043	1.030	1.024	1.020

Table 6 indicate that there are often considerable differences in the average density of the fluid standing in the well bores with respect to formation water densities reported in the literature.

5.3 MEASUREMENT OF FORMATION PRESSURES

One of the goals of this program was to measure and compare formation pressures both between wells and within a well. The intra-well data were analyzed to define vertical density stratification and the inter-well data were collected to provide needed information for use in analyzing lateral flow directions and gradients. There has been considerable hydraulic stress placed on the Culebra Dolomite water-bearing unit in the past several years. Ground water has been produced from this unit both by long-term pumping and discharge from aquifer testing and water-quality sampling as well as through leakage into unlined shafts. This stress has resulted in some measurable decline in the water levels and presumably formation pressures in a number of wells at the WIPP Site. However, for a given hydrologic analysis of the ground-water flow system, the static, undisturbed formation pressures may be needed. Because of the previous and ongoing activity, it was not possible to measure static formation hydrostatic pressures. Hydrogeologists conducting hydrologic analyses which require the static undisturbed pressures should be fully aware that the pressures measured in this program reflect a disturbed system and should not be used to represent unstressed flow conditions. Estimation of undisturbed pressures for the Culebra was beyond the scope of this project.

The pressures in the wells at mid-formation depth were measured in all wells included in the Pressure - Density Survey where possible. The techniques used to obtain these pressures were designed so that the measured pressures were good approximations

of the actual pressures that existed within the formation at the time of measurement. Tables 7, 8, and 9 present the middle-of-formation open-well bore pressures as calculated using a single water density and the pre-test measured water level in comparison with the pressures actually measured during the three individual field testing periods of the Pressure - Density Survey. The water densities used for the calculated pressures were from either Mercer (1983) or the WIPP Water Quality Sampling Program. The individual basic data collected during the field testing program, including open-well-casing pressure measurements, water levels, formation-pressure measurements made below the inflated packer, and all other test related information, are provided in Appendix A.

Review of the data shown in Tables 7, 8, and 9 indicates that there are often significant differences in formation-pressure values between those obtained by using only measured water levels and assumed water-density values with respect to those obtained by direct measurement. The differences in calculated and measured pressures in some wells are on the order of several feet of head. The measured formation-pressure data can be utilized by the on-going water-level monitoring and aquifer testing programs in the future.

TABLE 7.
COMPARISON OF THE CALCULATED AND MEASURED
MID-FORMATION PRESSURES FOR THE FIRST
FIELD PERIOD OF THE PRESSURE - DENSITY SURVEY

WELL NO.	CALCULATED MID-FORMATION PRESSURE (psig)	MEASURED MID-FORMATION PRESSURE (psia)	MEASURED MINUS ATMOSPHERIC PRESSURE (psig)	DIFFERENCE (psi)
DOE-1	157.57	167.04	155.17	-2.40
DOE-2	213.32	222.59	210.67	-2.65
H-02b2	113.05	-	-	-
H-02c	111.83	131.57	117.19	+5.36
H-03b2	120.54	134.65	120.26	-0.28
H-05b	202.47	217.03	202.84	+0.27
H-06b	142.89	153.72	141.92	-0.97
H-07b1	39.16	54.06	39.23	-0.07
H-08b	70.03	85.04	69.64	-0.39
H-09b	100.45	115.52	100.16	-0.29
H-11b3	142.52	153.14	141.17	-1.35
H-12	176.92	188.88	176.85	-0.07
P-14	115.57	126.79	114.95	-0.62
P-15	52.25	64.43	52.43	+0.18
P-17	97.62	109.54	97.58	-0.04
P-18	163.37	158.04	142.68	-20.69
WIPP-12	179.72	188.14	176.34	-3.38
WIPP-13	164.04	171.82	159.98	-4.06
WIPP-18	178.41	184.18	169.86	-8.55
WIPP-19	168.10	174.65	160.28	-7.82
WIPP-21	139.70	152.03	137.67	-2.03
WIPP-22	148.25	159.48	145.07	-3.18
WIPP-25	129.76	140.16	125.81	-3.95
WIPP-27	94.08	101.61	87.58	-6.50
WIPP-30	121.67	135.33	121.72	+0.05

TABLE 8.
COMPARISON OF CALCULATED AND MEASURED
MID-FORMATION PRESSURES FOR THE SECOND
FIELD PERIOD OF THE PRESSURE - DENSITY SURVEY

WELL NO.	CALCULATED MID-FORMATION PRESSURE (psig)	MEASURED MID-FORMATION PRESSURE (psia)	MEASURED MINUS ATMOSPHERIC PRESSURE (psig)	DIFFERENCE (psi)
H-02C	113.73	131.16	117.10	+3.37
H-03b2	125.07	142.66	128.54	+3.47
H-04b	71.45	85.63	71.68	+0.23
H-05b	203.20	215.71	201.70	-1.50
H-06b	143.50	155.61	141.33	-2.17
H-07b1	39.52	53.90	40.10	+0.58
H-08b	70.01	84.26	69.71	-0.30
H-09b	100.60	114.37	100.02	-0.58
H-10b	303.65	318.71	304.27	+0.62
H-11b3	143.48	155.89	141.32	-2.16
H-12	176.55	190.86	176.38	-0.17
P-14	115.45	128.18	114.03	-1.42
P-15	52.54	67.80	54.27	+1.73
P-17	97.61	111.35	97.46	-0.15
P-18	160.72	160.49	145.91	-14.81
WIPP-12	180.76	190.19	175.66	-5.10
WIPP-13	164.81	175.88	161.74	-3.07
WIPP-18	165.67	182.76	168.35	+2.68
WIPP-19	162.79	173.52	159.10	-3.69
WIPP-25	128.68	141.70	127.67	-1.01
WIPP-27	89.48	102.84	88.86	-0.62
WIPP-30	121.62	134.44	120.27	-1.35
DOE-1	158.90	175.28	161.05	+2.15
DOE-2	214.33	224.50	210.50	-3.83

TABLE 9.
COMPARISON OF THE CALCULATED AND MEASURED
MID-FORMATION PRESSURES FOR THE THIRD
FIELD PERIOD OF THE PRESSURE - DENSITY SURVEY

WELL NO.	CALCULATED MID-FORMATION PRESSURE (psig)	MEASURED MID-FORMATION PRESSURE (psia)	MEASURED MINUS ATMOSPHERIC PRESSURE (psig)	DIFFERENCE (psi)
H-02c	111.57	127.83	114.14	+2.57
H-03b2	119.04	130.89	116.96	-2.08
H-04b	72.69	85.33	71.28	-1.41
H-05b	203.28	213.77	200.19	-3.09
H-06b	143.46	154.93	141.43	-2.03
H-07b1	39.45	52.41	38.78	-0.67
H-08b	70.07	81.87	68.01	-2.06
H-09b	100.65	112.77	98.93	-1.72
H-11b3	141.38	151.46	137.49	-3.89
H-12	176.64	188.14	174.23	-2.41
H-14	93.22	105.79	92.10	-1.12
H-15	168.97	179.88	165.83	-3.14
H-17 *	125.29	147.58	133.77	+8.48
H-18 *	129.85	164.01	150.39	+20.54
P-14	115.56	127.49	113.57	-1.99
P-15	52.44	65.10	51.59	-0.85
P-17	98.49	110.22	96.55	-1.94
WIPP-12	134.42	151.94	138.01	+3.59
WIPP-13	165.76	173.90	160.35	-5.41
WIPP-18	167.07	182.62	168.75	+1.68
WIPP-19	167.67	174.19	160.35	-7.32
WIPP-21	136.42	152.09	138.54	+2.12
WIPP-22	158.88	164.59	150.91	-7.97
WIPP-25	128.79	140.20	127.18	-1.61
WIPP-27	89.30	101.01	87.83	-1.47
WIPP-28	63.54	74.47	61.14	-2.40
WIPP-30	122.67	132.97	119.49	-2.96
DOE-1	156.47	166.53	152.53	-3.94
DOE-2	215.09	224.01	210.45	-4.64

* These wells had brine left in the casing after drilling and completion.

6.0 GROUND-WATER FLOW IN THE CULEBRA DOLOMITE

Formation-pressure and ground-water-density data collected during the Pressure - Density Survey and the Water Quality Sampling Program were used to assess the existing ground-water flow characteristics of the Culebra Dolomite in the vicinity of the WIPP Site. These data were used to define an equivalent freshwater-head potentiometric surface, using actual measured formation-pressure values, and to attempt to determine density-dependent ground-water flow directions using the techniques described by Jorgensen et al. (1982). The following discussion presents the results of these hydrologic analyses.

6.1 EQUIVALENT-FRESHWATER-HEAD DISTRIBUTION

Actual measured middle-of-formation pressures from the majority of Culebra wells were used to estimate an equivalent-freshwater-head distribution of the Culebra Dolomite within the area included in this investigation. The pressure measurements used to define an equivalent-freshwater-head potentiometric surface were from the second field period of the Pressure - Density Survey. The second field survey period occurred during the time period between February and May, 1987.

The middle-of-formation depth was selected as the reference level for both the pressure measurement and the formation elevation used in calculating the equivalent freshwater head at each well location. The equivalent-freshwater-head values were calculated using the following equation:

$$h_f = z + \frac{P}{\rho f g} \quad (6)$$

where:

h_f	= equivalent freshwater head	(meters)
P	= pressure	(pascals)
g	= acceleration of gravity	(m/sec ²)
ρ_f	= freshwater density.	(kg/m ³)
z	= elevation above a datum	(meters)

For the equipment used in this study, where pressure is measured in pounds per square inch, depths are measured in feet, and the freshwater density is set equal to 1.000 g/cm³:

$$h_f = z + (P \times 2.3066) \quad (7)$$

where:

h_f	= equivalent freshwater head	(feet)
P	= measured pressure	(psia)
z	= elevation above a datum	(feet)

Equivalent freshwater head is defined as the elevation of the water level in a well that is filled with freshwater to a level which will balance the fluid pressure in the aquifer (Luszczynski, 1961; DeWiest, 1965). As stated previously, freshwater heads have been calculated for observation wells at the WIPP Site using measured water levels and estimated well-bore fluid densities. The freshwater heads presented in this report are the product of actual measured formation fluid pressures and are given in Table 10. The potentiometric-surface map of the equivalent-freshwater-head distribution constructed from measured formation pressures is shown in Figure 8.

The contours on this map indicate that there is considerable variability in gradient and flow direction within the area studied. These variabilities may be the result of lateral

TABLE 10.

EQUIVALENT FRESHWATER HEADS FOR WELLS INCLUDED IN THE
SECOND FIELD PERIOD OF THE PRESSURE - DENSITY SURVEY

<u>WELL NO.</u>	<u>MID-FORMATION ELEVATION</u>	<u>MEASURED PRESSURE</u>	<u>ELEVATION OF FRESHWATER HEAD</u>
H-02c	2743.69	117.10	3013.79
H-03b2	2700.34	128.54	2996.83
H-04b	2830.35	71.68	2995.68
H-05b	2596.88	201.70	3062.12
H-06b	2732.07	141.33	3058.04
H-07b1	2908.06	40.10	3000.55
H-08b	2832.80	69.71	2993.59
H-09b	2743.58	100.02	2974.28
H-10b	2311.51	304.27	3013.33
H-11b3	2671.57	141.32	2997.54
H-12	2589.48	176.38	2996.32
P-14	2775.76	114.03	3038.78
P-15	2885.77	54.27	3010.95
P-17	2765.27	97.46	2990.07
P-18	2551.30	145.91	2887.85
WIPP-12	2648.80	175.66	3053.98
WIPP-13	2692.86	161.74	3065.93
WIPP-18	2658.92	168.35	3047.24
WIPP-19	2665.63	159.10	3032.61
WIPP-25	2752.96	127.67	3047.44
WIPP-26	2954.00	27.12	3016.55
WIPP-27	2872.16	88.86	3077.12
WIPP-28	2916.00	61.14	3057.02
WIPP-30	2785.48	120.27	3062.89
DOE-1	2633.59	161.05	3005.07
DOE-2	2584.35	210.50	3069.89

FIGURE 8. CULEBRA FRESHWATER HEAD POTENTIOMETRIC SURFACE

variations in Culebra permeability and differences in fracture orientation as discussed in Mercer (1983). A comparison of the potentiometric-surface map presented in Figure 8 with the adjusted potentiometric surface of the Culebra shown in Mercer (1983, p. 57) indicates that overall, there are some minor differences between the two contour maps. Generally, these differences can be attributed to changes in water levels in the wells tested, the use of more accurate density values from the Water Quality Sampling Program, and the availability of additional wells (wells that had not been drilled at the time of Mercer's investigation). The hydraulic gradient in the immediate WIPP Site vicinity is approximately 20 feet/mile while the gradient south and southwest of the site is much flatter. The gradient between wells H-07b and H-09b is less than 5 feet/mile, while the gradient from H-07b to H-08b is less than 1 foot/mile.

Mercer (1983) reports that the contours shown in that report indicated a potentiometric high associated with the area near test hole H-05b, which he attributed to the effects of the conversion of brine density to freshwater head. The results of the equivalent freshwater head analysis in this investigation also indicate that the area of the H-05 well site is a potentiometric high for the Culebra, and it extends to and includes the areas associated with wells DOE-2 and WIPP-13. The potentiometric surface south of the WIPP Site has a very flat gradient with the contours indicating an apparent potentiometric low in the region surrounding the H-09 well site. Examination of the contours in the southern study area (between wells H-07, H-08, and H-09) indicates that there may be a local divide or a change in the general ground-water flow direction. This represents a change from the basic south-southwest flow direction to a somewhat more southeasterly direction. This change in flow direction may be the result of local directional differences in hydraulic conductivity or perhaps some localized recharge to the Culebra near the eastern side of Nash Draw, in the vicinity of the H-07 well site.

6.2 EFFECTS OF VARIABLE DENSITY ON GROUND WATER FLOW

Ground water flow in a dipping geologic unit such as the Culebra Dolomite may be influenced by density-related gravity forces. Lusczynski (1961) and DeWiest (1965) have shown that strictly horizontal ground-water flow is driven by head gradients. If there is some vertical component of flow, then head gradients alone do not account for all of the forces contributing to fluid flow. Although, it is beyond the scope of the Pressure - Density Survey to conduct an in-depth numerical evaluation of density-related forces acting on fluid flow in the Culebra, it was possible to assess the influence of spatial variation in fluid density on ground-water flow in the Culebra.

Jorgensen et al. (1982) present a number of analytical methods for determining the occurrence of ground-water flow and its probable direction. If density values for formation water are known, a simple method can be used for determining if flow exists between two wells. This method is to determine if hydrostatic conditions exist between wells. If hydrostatic conditions do not exist, then flow exists. In using this method there are certain assumptions required. The formation must maintain a constant direction of dip and there cannot be a reversal in flow gradient or a ground-water divide between the wells being evaluated. In using this method, hydrostatic heads and density variations between the two wells being tested need to be considered.

For a constant-density system hydrostatic conditions require that the pressure (P_L) to the left or at well (1) must be equal to the pressure (P_R) of a well to the right, well (2) in order for flow not to occur between the wells. When there is a difference in pressure then flow does exist. Using the following equation for a constant-density system, the pressure to the left (P_L), or at the first well (1) is defined as:

$$P_1 = \rho g (h_1 - z_1) \quad (8)$$

where:

P_1	= pressure	(pascals)
ρ	= density of formation fluid	(kg/m ³)
h_1	= head elevation above a datum	(meters)
z_1	= measuring point within the aquifer above a datum	(meters)

The calculated hydrostatic pressure to the right (P_r) or for well (2) is:

$$P_r = P_2 + \Delta P_{2-1} \quad (9)$$

where:

P_2 = pressure measured at well (2)

and

$$\Delta P_{2-1} = \rho g (z_2 - z_1)$$

A variable density system can also be analyzed for flow by testing for these same conditions. In the variable-density system, the density variation between the two wells being tested must be taken into consideration. Generally, the actual variability of the density distribution between the wells usually is not known. In this case, a linear vertical density variation between wells (1) and (2) may be assumed for the analysis, and the average density between (1) and (2) can be used as an approximation. Using Equation 8 and the definitions described above, the pressure to the left (P_1) at well (1) can be calculated, or as in this investigation, measured directly

with the formation-level pressure measurements. The pressure to the right (P_r) or at well (2) is:

$$P_r = P_2 + \Delta P_{2-1}$$

$$= \rho g(h_2 - z_2) + \int_2^1 g dz$$

So,

$$P_r = \rho g(h_2 - z_2) + \left(\frac{\rho_2 + \rho_1}{2} \right) g(z_2 - z_1) \quad (10)$$

Taking Equation 10 and adjusting for pressures measured in pounds per square inch, depths and elevations measured in feet, and simplifying terms it becomes:

$$P_r = P_2 + \left(\frac{\rho_2 + \rho_1}{2} \right) \left(\frac{z_2 - z_1}{2.3066} \right) \quad (11)$$

where:

P_2 = measured pressure (psi)
 ρ_1 and ρ_2 = fluid density at each well (g/cm³)
 z_1 and z_2 = measuring points within the aquifer above a datum (feet)

A component of flow will exist between the wells if there is a difference in the calculated pressure values for each well. The pressure difference between P_1 and P_r is termed the non-equilibrium pressure differential, π . This method can be

applied to any two points in the same aquifer, assuming there are no external sources or sinks and that the aquifer is continuous.

This analytical technique can be used to test for hydrostatic conditions between a reference well and two other wells. The non-equilibrium pressure differential values can be plotted and analyzed by using the standard "three-point problem" for strike and dip. This analysis results in a planar surface being fitted through the three points and the strike and dip are defined. The dip of this surface is parallel to the direction of ground-water flow among the wells being analyzed.

An example of this "three-point analysis" for wells H-07, P-15, and P-17 is shown in Figure 9. The test for hydrostatic conditions between wells P-15 and P-17 gives a non-equilibrium pressure differential of +11.10 psi. The test between wells P-15 and H-07 yields a differential of +4.60 psi, and between wells P-17 and H-07 the differential is -6.68 psi. These pressure differentials represent components of flow between each pair of wells tested. In this example there is a component of flow from well P-15 to well P-17, and from well P-15 to H-07. The analysis for wells P-17 to H-07 yielded a negative pressure differential, thus the component of flow would be from well H-07 toward P-17.

Certain conventions can be used to fit the planar surface to the pressure differential values. The well whose calculated π value is intermediate between the highest and lowest values is denoted as π_b . Thus, $\pi_a < \pi_b < \pi_c$. In the example shown in Figure 9 well H-07 was selected as π_b , well P-17 as π_a , and well P-15 as π_c . A line connecting a and c is drawn and the strike of the planar surface is represented by a line drawn from b to b'. The point b' is located somewhere along the line connecting

FIGURE 9. EXAMPLE OF THE THREE WELL ANALYSIS

a to c. The location of point b' is found by the proportionality relationship:

$$\frac{b'c}{ac} = \frac{(\pi_c - \pi_b)}{(\pi_c - \pi_a)} \quad (12)$$

where the distances b'c and ac are determined by measurement on a base map. For the example given here:

$$\frac{b'c}{2.25} = \frac{(4.60 - 0.0)}{4.60 - (-6.68)} = 0.92 \text{ miles.}$$

If b' is scaled off at a distance of 0.92 miles from c, the line bb' represents the strike of the planar surface. The dip, or the direction of the maximum gradient, is at a right angle to the strike and in a direction toward π_a , and is represented by ray d as shown in Figure 9.

This analytical procedure was applied to several groups of three wells across the project area. In many cases individual wells were included in different three-well sets in order to check for continuity of the analytical results. The product of each "three-well analysis" is a vector which represents the main component or direction of flow between the wells included in that set. The flow vectors determined from analyzing all of the wells included in the Pressure - Density Survey are shown on Figure 10.

The apparent ground-water flow direction based on this analysis is generally toward the south to southeast. To the south of the WIPP Site, in the vicinity of wells H-07, H-08, and H-09, the flow direction appears to have a more easterly component.

FIGURE 10. RESULTS OF THE VARIABLE DENSITY FLOW ANALYSIS

7.0 RESULTS AND CONCLUSIONS

The data collected as part of the Pressure - Density Survey indicate that fluid-density stratification does exist in many of the wells tested. The data gathered during each of the three field periods showed that hydrologic testing and water-quality-sampling activities can alter density stratification. The introduction of foreign fluids into wells during PIP installation, moving sampling and pumping equipment up and down the well bores, pumping, and other well testing all have an effect on the density profile of the fluid standing in any of the wells included in this program.

Collecting actual formation-pressure measurements is more desirable than calculating formation pressures using water levels and single estimates of water density. The results of this program indicate that there can be considerable error in calculating formation pressures using estimated density values when compared to those measured at the formation level. The differences in calculated and measured pressure in some wells are on the order of several feet of head. These differences can be significant to the interpretation of ground-water flow directions in the Culebra Dolomite in the WIPP Site area.

The results of the field data collection program indicate that the most desirable hydrologic data cannot be collected from those wells equipped with production-injection packers. It is recommended that in the future these wells be eliminated from the field data collection program.

Pressure - Density Survey data have been useful to several hydrologic evaluation programs. These data will be used in the future by the ground-water-level and pressure monitoring

program. Now that the density profiles of WIPP wells have been defined and the average densities of the fluids standing in these wells are known, more accurate equivalent freshwater heads can be calculated from measured water levels.

REFERENCES

Bredehoeft, J. D. and S. S. Papadopoulos, 1980, " A method for determining the hydraulic properties of tight formations ", Water Resources Research, Vol. 16, No. 1, pp. 233-238.

Cooper, H.H., Jr., J.D. Bredehoeft, and I.S. Papadopoulos, 1967, "Response of a Finite-Diameter Well to an Instantaneous Charge of Water", Water Resources Research, Vol. 3, No. 1, pp. 263-269.

Crawley, M.E., 1987^a, " Pressure - Density Survey program plan, Waste Isolation Pilot Plant Carlsbad, New Mexico ", IT Corporation, 41 pp.

Crawley, M.E., 1987^b, " Initial data release report for the Pressure - Density Survey Program ", WID, WS:87:00002.

Crawley, M.E., 1987^c, " Second data release report for the Pressure - Density Survey Program ", WID, WS:87:00015.

Crawley, M.E., 1988, " Third data release report for the Pressure - Density Survey Program ", WID, WS:88:00005.

DeWeist, R.J.M., 1965, " Geohydrology ", John Wiley and Son, New York, 366 pp.

Gonzales, M.M., 1988, Compilation and Comparison of Test-Hole Location Surveys in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site. SAND-1065, Sandia National Laboratories, Albuquerque, New Mexico

Hubbert, M.K., 1940, " Theory of Ground-Water Motion", Journal of Geology, Vol.48, No. 8, Pt. 1, pp. 785-944

Jorgensen, D. G., T. Gogel, and D. C. Signor, 1982, " Determination of flow in aquifers containing variable-density water ", Ground Water Monitoring Review, Spring 1982, pp. 40-45.

REFERENCES

(Continued)

Luszczynski, N.J., 1961, "Head and Flow of Ground Water of Variable Density", Journal of Geophysical Research, Vol. 66, No. 12, pp. 4247-4256.

Mercer, J.W., and B.R. Orr, 1979, " Interim data report on the geohydrology of the proposed Waste Isolation Pilot Plant site, southeast New Mexico ", U.S. Geological Survey Water-Resources Investigations 79-98, 178 pp.

Mercer, J. W., 1983, " Geohydrology of the proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico ", U. S. Geological Survey, Water Resources Investigations 83-4016, 113 pp.

Neuzil, C. E., 1982, " On conducting the modified 'slug' test in tight formations ", Water Resources Research, Vol. 18, No. 2, pp. 439-441.

Randall, W.S., M.E. Crawley, and M.L. Lyon, 1988, " Annual Water Quality Data Report for the Waste Isolation Pilot Plant ", U.S. Department of Energy Report, DOE-WIPP-88-006

Uhland, D.W., and W.S. Randall, 1986, " Annual Water Quality Data Report for the Waste Isolation Pilot Plant ", U.S. Department of Energy Report, DOE-WIPP-86-006

Uhland, D.W., W.S. Randall, and R.C. Carrasco, 1987, " Annual Water Quality Data Report for the Waste Isolation Pilot Plant ", U.S. Department of Energy Report, DOE-WIPP-87-006

Winstanley, D.J., and R.C. Carrasco, 1986, " Annual Hydrogeologic Data Report 1985/1986 ", U.S. Department of Energy Report, DOE-WIPP-86-004

APPENDIX A

FIRST FIELD SURVEY PERIOD

DATE 09-10-86

TOTAL DEPTH	4057
CASING ELEVATION	3463.96
GROUND ELEVATION	
MID-FORM. ELEVATION	2632
PRE-TEST WATER LEVEL	498.97
MID-FORM. DEPTH	832
PUBLISHED DENSITY	1.091

CASING STICKUP	<u>0.31</u>
FORMATION INTERVAL	<u>821 - 843</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>10</u>
ATMO. PRESSURE	<u>11.87</u>
PERF. INTERVAL	<u>820 - 843</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
475	10:46	22.4	11.87	498.87	--	1.071	
600	11:08	22.9	58.85	498.81	58.82	1.074	
700	11:30	22.7	105.42	498.81	105.39	1.073	
800	11:55	23.2	151.95	498.81	151.92	1.084	
821	12:15	23.2	161.82	498.81	161.79	1.095	
832	12:35	23.2	167.04	498.81	167.01	1.086	
843	12:54	23.3	172.22	498.80	172.19	1.090	before
832	13:00	23.4	167.02	498.80	166.99	--	sampling
832	13:10	23.4	167.01	--	--	--	after sampling

Well diameter too large to seat packer - No inflated packer measurements

WELL NO. DOE-2

DATE 09-09-86

WELL DATA

TOTAL DEPTH 4325
 CASING ELEVATION 3419.16
 GROUND ELEVATION 3418.4
 MID-FORM. ELEVATION 2579
 PRE-TEST WATER LEVEL 367.78
 MID-FORM. DEPTH 840
 PUBLISHED DENSITY 1.042

CASING STICKUP 1.33
 FORMATION INTERVAL 829 - 850
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 10
 ATMO. PRESSURE 11.92
 PERF. INTERVAL 822 - 848

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
360	11:01	22.4	11.92	367.78	--		
						1.027	
400	11:22	21.8	26.32	367.68	26.27		
						1.024	
500	11:43	21.9	70.72	367.70	70.68		
						1.026	
600	12:04	22.4	115.21	367.69	115.17		
						1.027	
700	12:28	22.8	159.75	367.68	159.70		
						1.033	
800	12:49	23.2	204.54	367.68	204.49		
						1.040	
829	13:08	23.4	217.61	367.67	217.56		
						1.044	
840	13:28	23.4	222.59	367.67	222.54		
						1.082	
850	13:48	23.5	227.28	367.67	227.23		

Well diameter too large to seat packer. No inflated packer measurements

WELL NO. H-01

DATE 10-22-86

WELL DATA

TOTAL DEPTH	856
CASING ELEVATION	3398.6
GROUND ELEVATION	3398
MID-FORM. ELEVATION	2710
PRE-TEST WATER LEVEL	416.53
MID-FORM. DEPTH	688
PUBLISHED DENSITY	1.016

CASING STICKUP	2.0
FORMATION INTERVAL	676 - 699
PRODUCING UNIT	Culebra
CASING I.D. (in.)	2.45
ATMO. PRESSURE	14.09
PERF. INTERVAL	675 - 703

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
400	11:38	20.1	14.09	416.53	14.09		
430	12:20	21.3	22.58	411.39	20.32	1.0661	
480	12:51	Hole Blocked Off at 480 Fr.					

PIP set at 651 ft. - Could not get probe past 480 ft.

no inflated packer measurement made

WELL NO. H-02cDATE 07-29-86WELL DATA

TOTAL DEPTH 795
 CASING ELEVATION 3377.5
 GROUND ELEVATION 3376.3
 MID-FORM. ELEVATION 2743
 PRE-TEST WATER LEVEL 378.60
 MID-FORM. DEPTH 634
 PUBLISHED DENSITY 1.010

CASING STICKUP 1.25
 FORMATION INTERVAL 624 - 642
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 6.0
 ATMO. PRESSURE 14.38
 PERF. INTERVAL 624 - 652

PROBE DEPTH (ft.)	CLOCK TIME	TEMP. (°C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM ³)	REMARKS
400	11:59	22.5	25.56	377.35	25.01		
375	12:10	22.4	14.38	--	--	--	out of water
500	12:33	22.1	70.73	377.22	70.13	1.041	
600	12:55	22.4	116.24	377.12	115.59	1.049	
625	13:24	22.6	127.56	377.17	126.93	1.046	
643	13:40	22.7	135.76	377.20	135.15	1.053	
641	14:01	22.7	135.28	376.25	--	--	open
641	14:30	22.7	135.25	376.31	--	--	packer
634	14:41	22.6	131.57	377.40	131.05	--	packer
634	15:25	22.6	131.36	376.42	--	--	open
625	15:36	22.6	127.83	377.55	127.37	--	packer
625	16:08	22.6	127.55	376.50	--	--	open

WELL NO. H-03b2DATE 08-07-86WELL DATA

TOTAL DEPTH 725
 CASING ELEVATION 3388.93
 GROUND ELEVATION 3388.63
 MID-FORM. ELEVATION 2699.9
 PRE-TEST WATER LEVEL 421.14
 MID-FORM. DEPTH 689
 PUBLISHED DENSITY 1.038

CASING STICKUP 0.60
 FORMATION INTERVAL 676 - 700
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 14.39
 PERF. INTERVAL 673 - 725

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
450	09:51	23.3	--	421.12	--	--	
415	10:06	22.4	14.39	--	--	--	
550	10:23	22.2	71.99	421.14	71.99	1.040	
650	10:39	22.6	117.07	421.16	117.08	1.041	
677	10:57	22.8	129.24	421.18	129.26	1.040	
689	11:12	22.8	134.65	421.19	134.67	--	
677	12:26	22.8	129.27	--	--	--	
689	13:00	23.0	134.74	420.93	--	--	<u>packer</u>
689	13:30	23.0	134.73	420.93	--	--	<u>packer</u>
450	13:45	22.5	27.12	--	--	1.035	
550	10:23	22.2	71.99	421.14	--	--	

DATE 08-13-86

TOTAL DEPTH	529
CASING ELEVATION	3331.4
GROUND ELEVATION	-
MID-FORM. ELEVATION	2826
PRE-TEST WATER LEVEL	341.07
MID-FORM. DEPTH	505
PUBLISHED DENSITY	1.015

CASING STICKUP	<u>1.29</u>
FORMATION INTERVAL	<u>493 - 515</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>13.98</u>
PERF. INTERVAL	<u>477 - 529</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
350	08:52	22.4	19.41	339.09	18.54		
335	9:11	21.5	13.98	--	--	1.006	
450	9:37	21.5	63.04	339.03	62.14	1.018	
494	9:58	21.8	82.46	339.03	81.56	1.015	
499	10:20	21.8	84.61	339.13	83.76		
494	11:11	21.8	81.85	338.20	--		packer
494	11:49	21.8	81.81	338.23	--		packer
494	12:26	21.8	81.80	338.27	--		packer
330	No Readings - Computer Down						

WELL NO. H-05b

DATE 08-11-86

WELL DATA

TOTAL DEPTH	<u>916</u>	CASING STICKUP	<u>1.10</u>
CASING ELEVATION	<u>3506.35</u>	FORMATION INTERVAL	<u>897 - 920</u>
GROUND ELEVATION	<u>3525.38</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2596</u>	CASING I.D. (in.)	<u>5.0</u>
PRE-TEST WATER LEVEL	<u>487.35</u>	ATMO. PRESSURE	<u>14.19</u>
MID-FORM. DEPTH	<u>1.105</u>	PERF. INTERVAL	<u>882 - 925</u>
PUBLISHED DENSITY			

<u>PROBE DEPTH (ft.)</u>	<u>CLOCK TIME</u>	<u>TEMP (C)</u>	<u>MEASURED PRESSURE (PSIA)</u>	<u>WATER LEVEL (FT.)</u>	<u>CORRECTED PRESSURE (PSIA)</u>	<u>CALCULATED DENSITY (G/CM)</u>	<u>REMARKS</u>
500	08:51	21.8	21.58	485.30	20.60	--	
484	09:06	21.7	14.19	--	--	1.103	
600	09:24	21.9	69.45	485.15	68.40	1.106	
700	09:40	22.4	117.47	484.96	116.33	1.104	
800	09:57	22.7	165.44	484.75	164.19	1.106	
898	10:18	23.2	212.53	484.57	211.20	1.101	<u>Upper</u>
910	10:34	23.3	218.26	484.58	216.93	--	<u>Mid</u>
918	No Reading - Total Depth Well = 916 ft.					--	<u>Bottom</u>
898	10:42	23.2	212.53	483.65	--	--	<u>Packer</u>
898	12:00	23.2	212.14	483.80	--	--	<u>Packer</u>
910	12:10	23.2	220.03	483.80	--	--	<u>Packer</u>
910	13:54	23.4	217.03	484.10	--	--	<u>Packer</u>
450	14:17	22.4	14.41	--	--	--	

WELL NO. H-06bDATE 09-03-86WELL DATA

TOTAL DEPTH 640
 CASING ELEVATION 3346.76
 GROUND ELEVATION --
 MID-FORM. ELEVATION 2725
 PRE-TEST WATER LEVEL 305.70
 MID-FORM. DEPTH 622
 PUBLISHED DENSITY 1.042

CASING STICKUP 1.22
 FORMATION INTERVAL 611 - 632
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 11.81
 PERF. INTERVAL 592 - 640

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (°C)	MEASURED PRESSURE (FSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (FSIA)	CALCULATED DENSITY (G/CM ³)	REMARKS
300	9:20	22.4	11.81	--	--	--	
350	9:49	21.5	31.76	305.73	31.77	1.036	
450	10:14	21.7	76.67	305.74	76.69	1.039	
550	10:35	22.3	212.71	305.74	121.73	1.040	
612	10:55	22.5	149.67	305.75	149.69	1.040	open
621	11:18	22.6	153.72	305.76	153.75	--	
626	Well Plugged at 626						
612	12:16	22.6	149.69	305.56	--	--	packer
300	13:54	22.3	11.91	--	--	--	

DATE 10-13-86

TOTAL DEPTH	286
CASING ELEVATION	3164
GROUND ELEVATION	3163
MID-FORM. ELEVATION	2904
PRE-TEST WATER LEVEL	169.77
MID-FORM. DEPTH	260
PUBLISHED DENSITY	1.001

CASING STICKUP	<u>1.0</u>
FORMATION INTERVAL	<u>230 - 286</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.125</u>
ATMO. PRESSURE	<u>14.83</u>
PERF. INTERVAL	<u>230 - 286</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
160	10:44	21.0	14.83	169.77	14.83	0.999	out of water
200	10:52	21.1	27.93	169.75	27.92	1.007	
230	11:07	21.5	41.03	169.75	41.02	1.003	
260	11:21	21.6	54.07	169.75	54.06	1.003	open
280	11:43	21.7	62.77	169.75	62.76	1.003	open
260	12:18	21.7	54.14	--	--	--	packer

DATE 10-15-86

WELL DATA

TOTAL DEPTH	624
CASING ELEVATION	3432
GROUND ELEVATION	3434
MID-FORM. ELEVATION	2833
PRE-TEST WATER LEVEL	440.12
MID-FORM. DEPTH	601
PUBLISHED DENSITY	1.004

CASING STICKUP	<u>1.23</u>
FORMATION INTERVAL	<u>575 - 624</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.5</u>
ATMO. PRESSURE	<u>15.40</u>
PERF. INTERVAL	<u>575 - 624</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (°C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
420	10:42	22.4	15.40	440.12	15.40		out of water
						0.04	
450	11:04	22.4	19.44	440.08	19.42		
						0.999	
500	11:16	22.7	41.09	440.10	41.08		
						1.004	
575	11:28	23.0	73.74	440.10	73.73		
						1.003	
601	11:42	23.2	85.04	440.10	85.04		open
						1.009	
619	11:58	23.3	92.92	440.10	92.91		open
601	12:32	23.2	85.06	--	85.06		packer

Bottom well at 620 ft. Could not get probe to 624 ft. or bottom of formation.

WELL NO. H-09b

DATE 10-14-86

WELL DATA

TOTAL DEPTH	<u>708</u>	CASING STICKUP	<u>1.0</u>
CASING ELEVATION	<u>3405</u>	FORMATION INTERVAL	<u>640 - 708</u>
GROUND ELEVATION	<u>3406</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2744</u>	CASING I.D. (in.)	<u>6.125</u>
PRE-TEST WATER LEVEL	<u>431.00</u>	ATMO. PRESSURE	<u>15.36</u>
MID-FORM. DEPTH	<u>662</u>	PERF. INTERVAL	<u>638 - 708</u>
PUBLISHED DENSITY	<u>1.003</u>		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
420	10:39	22.4	15.36	431.00	15.36		out of water
						0.95	
450	10:50	22.4	23.21	430.97	23.20		
						1.003	
500	11:08	22.7	44.95	430.97	44.94		
						1.005	
600	11:36	23.2	88.53	430.98	88.52		
						1.004	
640	11:54	23.4	105.95	430.98	105.94		
						1.004	
662	12:06	23.5	115.53	430.98	115.52		open
						1.009	
670	12:35	23.5	119.03	430.98	119.02		bottom
						--	
662	13:09	23.5	115.56	--	--		packer

Bottom of hole at 671 ft. Could not get probe to 708 ft. or bottom of formation

DATE 09-12-86

TOTAL DEPTH	787
CASING ELEVATION	3409.62
GROUND ELEVATION	--
MID-FORM. ELEVATION	2662
PRE-TEST WATER LEVEL	445.68
MID-FORM. DEPTH	747
PUBLISHED DENSITY	1.091

CASING STICKUP	<u>0.58</u>
FORMATION INTERVAL	<u>736 - 758</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>11.97</u>
PERF. INTERVAL	<u>733 - 787</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP. (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM ³)	REMARKS
440	9:17	22.4	11.97	--	--	--	
500	9:40	22.7	37.77	445.63	37.75	1.077	
600	10:04	22.5	84.46	445.64	84.44	1.077	
700	10:26	22.8	131.16	445.64	131.14	1.077	
736	10:46	23.0	147.7	445.64	147.95	1.078	
747	11:08	23.1	153.11	445.64	153.09	1.097	
756	11:28	23.0	157.39	445.64	157.37	--	
756	11:53	23.1	157.42	445.62	--	--	packer
747	12:19	23.1	153.14	445.59	--	--	packer
736	12:54	23.0	148.05	--	--	--	packer
440	13:10	22.4	11.96	--	--	--	packer

WELL NO. H-12DATE 09-30-86WELL DATA

TOTAL DEPTH 890
 CASING ELEVATION 3424.5
 GROUND ELEVATION 3423.0
 MID-FORM. ELEVATION 2586
 PRE-TEST WATER LEVEL 465.66
 MID-FORM. DEPTH 838
 PUBLISHED DENSITY 1.096

CASING STICKUP 1.45
 FORMATION INTERVAL 824 - 849
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 12.03
 PERF. INTERVAL 820 - 890

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
450	10:03	22.4	12.03	465.66	--		out of water
500	10:18	22.6	29.45	463.25	28.30	1.093	
600	10:33	22.4	77.11	462.91	75.80	1.096	
700	10:48	22.6	124.73	462.55	123.25	1.095	
800	11:03	23.1	172.43	462.18	170.78	1.096	
825	11:17	23.3	184.36	462.14	182.69	1.099	open
838	11:33	23.3	190.63	462.13	188.95	1.111	open
850	11:49	23.4	196.44	462.15	194.77	1.119	open
838	13:02	23.3	189.13	461.23	--	--	packer after sample
838	14:10	23.3	188.88	461.30	--	--	out of water
450	14:32	22.4	12.14	--	--		

WELL NO. P-14DATE 08-15-86WELL DATA

TOTAL DEPTH 1545
 CASING ELEVATION 3361.72
 GROUND ELEVATION 3354.76
 MID-FORM. ELEVATION 2776
 PRE-TEST WATER LEVEL 324.40
 MID-FORM. DEPTH 586
 PUBLISHED DENSITY 1.019

CASING STICKUP 1.72
 FORMATION INTERVAL 573 - 595
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 4.0
 ATMO. PRESSURE 11.84
 PERF. INTERVAL 573 - 601

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
350	8:49	22.5	23.03	324.40	23.03		
315	9:10	21.7	11.84	--	--	--	air
450	9:35	21.9	66.93	324.42	66.94	1.013	
550	9:58	22.3	110.91	324.43	110.92	1.014	
575	10:19	22.5	121.91	324.43	121.92	1.015	open
586	10:39	22.6	126.75	324.43	126.76	1.015	open
597	11:00	22.6	131.62	324.43	131.63	1.021	open
595	11:26	22.6	130.75	324.43	--	--	packer
586	12:15	22.6	126.79	324.33	--	--	packer
575	12:45	22.5	121.95	324.25	--	--	
315	12:56	22.3	11.87	--	--	--	

DATE 09-16-86

TOTAL DEPTH	<u>437</u>
CASING ELEVATION	<u>3311.56</u>
GROUND ELEVATION	<u>3309.77</u>
MID-FORM. ELEVATION	<u>2886</u>
PRE-TEST WATER LEVEL	<u>305.47</u>
MID-FORM. DEPTH	<u>426</u>
PUBLISHED DENSITY	<u>1.00</u>

CASING STICKUP	<u>1.75</u>
FORMATION INTERVAL	<u>413 - 435</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>4.0</u>
ATMO. PRESSURE	<u>12.00</u>
PERF. INTERVAL	<u>410 - 438</u>

[illegible]

DATE 09-29-86

WELL DATA

TOTAL DEPTH	1660
CASING ELEVATION	3335.65
GROUND ELEVATION	--
MID-FORM. ELEVATION	2764
PRE-TEST WATER LEVEL	360.58
MID-FORM. DEPTH	572
PUBLISHED DENSITY	1.065

CASING STICKUP	<u>1.50</u>
FORMATION INTERVAL	<u>558 - 583</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>4.0</u>
ATMO. PRESSURE	<u>11.96</u>
PERF. INTERVAL	<u>550 - 586</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
370	12:18	22.4	17.75	357.90	16.51	--	out of water
350	12:39	22.3	11.96	--	--	1.057	
470	13:02	21.9	63.56	357.93	62.34	1.064	
559	13:23	22.0	104.55	358.08	103.40	1.066	
572	13:41	22.1	110.39	358.45	109.41	1.257	open
584	14:00	22.2	116.79	358.76	115.95	--	open
572	14:31	22.2	109.66	358.04	--	--	packer after
572	14:51	22.3	109.54	358.14	--	1.244	sample density
584	14:58	22.2	116.52	359.20	115.88	--	check out of
350	15:10	22.4	12.06	--	--		water

WELL NO. P-18

DATE 10-17-86

WELL DATA

TOTAL DEPTH	<u>1998</u>	CASING STICKUP	<u>1.33</u>
CASING ELEVATION	<u>3477</u>	FORMATION INTERVAL	<u>909 - 938</u>
GROUND ELEVATION	<u>3477</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2553</u>	CASING I.D. (in.)	<u>4.0</u>
PRE-TEST WATER LEVEL	<u>626.34</u>	ATMO. PRESSURE	<u>15.36</u>
MID-FORM. DEPTH	<u>924</u>	PERF. INTERVAL	<u>912 - 940</u>
PUBLISHED DENSITY	<u>1.266</u>		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
620	11:12	22.4	15.36	626.34	15.36		out of water
						1.0761	
700	11:30	22.8	51.08	623.80	49.73		
						1.0656	
800	11:57	23.3	97.81	622.30	95.92		
						1.1657	
900	12:22	23.1	148.57	621.78	146.46		
						1.1806	
912	12:40	23.2	154.94	621.72	152.60		open
						1.2225	
922	13:05	23.2	160.29	621.68	157.90		open
						--	
940	--	--	--	--	--		
						1.2225	before
922	13:17	23.3	160.28	621.66	157.90		packer
						--	after
922	12:22	23.3	160.55	--	--		packer

Well blocked off at 923 ft. Could not get probe to 940 ft. or bottom of formation.

WELL NO. WIPP-1209-05-86WELL DATA

TOTAL DEPTH 3928
 CASING ELEVATION 3473
 GROUND ELEVATION 3472
 MID-FORM. ELEVATION 2649
 PRE-TEST WATER LEVEL 417.58
 MID-FORM. DEPTH 824
 PUBLISHED DENSITY 1.020

CASING STICKUP
 FORMATION INTERVAL 812 - 835
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 9.0
 ATMO. PRESSURE 11.80
 PERF. INTERVAL 815 - 840

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (°C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM ³)	REMARKS
400	9:14	20.5	11.80	417.58	--		air press
						1.0025	
450	9:38	21.4	26.18	416.93	25.89	.998	
550	9:59	21.9	69.46	416.90	69.17	.999	
650	10:19	22.4	112.77	416.88	112.47	.997	
750	10:39	22.8	156.03	416.83	155.70	.999	
813	10:59	23.2	183.33	416.82	183.00	1.009	
824	11:39	23.3		416.82	187.81	1.024	
836	11:19	23.4	193.83	416.83	193.50		
400	12:26	22.4	11.97	--	--		

Well diameter too large to seat packer; No inflated packer measurement.

WELL NO. WIPP-13

DATE 09-04-86

WELL DATA

TOTAL DEPTH 3856
 CASING ELEVATION --
 GROUND ELEVATION 3405.4
 MID-FORM. ELEVATION 2690.9
 PRE-TEST WATER LEVEL 355.65
 MID-FORM. DEPTH 716
 PUBLISHED DENSITY 1.050

CASING STICKUP 1.02
 FORMATION INTERVAL 704 - 725
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 9.0
 ATMO. PRESSURE 11.84
 PERF. INTERVAL 702 - 727

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
350	8:34	21.3	11.84	--	--	1.021	
400	8:56	21.5	31.47	355.67	31.48	1.017	
500	9:20	22.0	75.55	355.67	75.56	1.017	
600	9:40	22.4	119.65	355.69	119.67	1.036	
705	10:02	23.1	166.81	355.73	166.85	1.0568	
716	10:24	23.1	171.84	355.75	171.89	1.050	
726	10:44	23.1	176.39	355.75	176.44	1.054	
716	11:00	23.1	171.82	355.75	171.87		

Well diameter too large to seat packer. No inflated packer measurements.

WELL NO. WIPP-18DATE 08-06-86WELL DATA

TOTAL DEPTH	<u>1050</u>
CASING ELEVATION	<u>--</u>
GROUND ELEVATION	<u>--</u>
MID-FORM. ELEVATION	<u>2659</u>
PRE-TEST WATER LEVEL	<u>419.97</u>
MID-FORM. DEPTH	<u>801</u>
PUBLISHED DENSITY	<u>1.080</u>

CASING STICKUP	<u>2.25</u>
FORMATION INTERVAL	<u>787 - 808</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.50</u>
ATMO. PRESSURE	<u>14.32</u>
PERF. INTERVAL	<u>784 - 806</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
450	8:50	22.5	28.34	417.90	27.44	--	
415	9:05	22.4	14.32	--	--	--	
550	9:19	21.9	71.68	417.78	70.73	.999	
650	9:35	22.4	115.52	417.58	114.47	1.009	
750	9:55	23.0	161.15	417.40	159.98	1.050	
791	10:11	23.2	180.63	417.37	179.45	1.095	
801	10:30	23.2	185.37	417.38	184.19	1.093	
810	10:43	23.3	189.62	417.41	188.45	1.092	
805	10:44	23.2	187.24	--	--	--	open
805	11:54	23.2	186.25	416.42	--	--	packer
791	13:00	23.2	179.61	416.56	--	--	packer
801	13:24	23.2	184.45	--	--	--	packer
801	14:31	23.2	184.18	416.65	--	--	packer

WELL NO. WIPP-1908-05-86WELL DATA

TOTAL DEPTH	<u>1037</u>
CASING ELEVATION	<u>--</u>
GROUND ELEVATION	<u>--</u>
MID-FORM. ELEVATION	<u>2666</u>
PRE-TEST WATER LEVEL	<u>432.83</u>
MID-FORM. DEPTH	<u>770</u>
PUBLISHED DENSITY	<u>1.150</u>

CASING STICKUP	<u>2.38</u>
FORMATION INTERVAL	<u>756 - 779</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>14.37</u>
PERF. INTERVAL	<u>754 - 780</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
400	9:15	22.4	14.37	--	--	--	
450	9:37	22.5	22.78	430.88	21.81	.996	
550	9:55	22.2	66.0	430.78	64.98	1.119	
660	10:10	22.5	119.46	430.58	118.34	1.178	
758	10:15	22.8	169.58	430.41	168.37	1.188	
770	10:45	23.1	175.74	430.45	174.55	1.187	
781	10:57	23.2	181.37	430.50	180.21	1.176	
778	11:03	23.2	179.82	430.54	178.68	--	open
778	11:58	23.1	178.72	429.60	--	--	packer
770	13:00	23.1	174.65	429.73	--	--	packer
770	--	--	--	--	--	--	
758	14:30	23.0	168.52	429.83	--	--	packer

WELL NO. WIPP-21DATE 07-30-86WELL DATA

TOTAL DEPTH 1014
 CASING ELEVATION --
 GROUND ELEVATION --
 MID-FORM. ELEVATION 2676
 PRE-TEST WATER LEVEL 430.15
 MID-FORM. DEPTH 743
 PUBLISHED DENSITY 1.030

CASING STICKUP 1.78
 FORMATION INTERVAL 729 - 753
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 14.36
 PERF. INTERVAL 727 - 751

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
450	11:00	22.5	23.72	428.64	23.04		
425	11:15	22.4	14.36	430.47	--	--	out of water
550	11:42	23.0	67.21	428.62	66.53	1.003	
650	12:09	22.8	110.89	428.45	110.13	1.006	
731	12:37	23.1	147.04	428.32	146.20	1.027	
743	13:00	23.2	152.44	428.32	151.62	1.042	
753	13:28	23.2	156.92	428.35	156.12	1.038	
750	13:31	23.2	155.58	428.35	154.78	1.030	open
750	14:46	23.1	155.28	427.33	--	--	packer
743	15:02	--	--	427.38	--	--	packer
743	16:00	23.0	152.03	427.46	--	--	
731	16:07	--	--	427.50	--	--	packer
731	16:30	23.1	146.77	427.55	--	--	

WELL NO. WIPP-22DATE 08-04-86WELL DATA

TOTAL DEPTH 1014
 CASING ELEVATION --
 GROUND ELEVATION 3425.83
 MID-FORM. ELEVATION 2685
 PRE-TEST WATER LEVEL 443.05
 MID-FORM. DEPTH 743
 PUBLISHED DENSITY 1.140

CASING STICKUP 2.20
 FORMATION INTERVAL 729 - 753
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 14.41
 PERF. INTERVAL 727 - 751

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
460	10:45	22.5	22.80	441.07	21.82		
435	11:00	22.4	14.41	--	--	--	Out of Water
560	11:25	22.3	69.81	440.97	68.78	1.083	
660	11:54	22.8	119.35	440.87	118.27	1.142	
731	12:10	22.9	154.49	440.82	153.39	1.141	
743	12:35	22.9	160.41	440.87	159.33	1.142	
755	12:55	23.0	166.33	440.94	165.29	1.150	
750	13:04	23.1	163.32	440.94	162.28	1.390	before packer seat
750	13:55	23.0	163.02	440.10	--	--	packer
743	15:20	23.1	159.55	440.27	--	--	packer after sample
743	15:53	23.1	159.48	440.27	--	--	
731	16:30	23.1	153.67	440.40	--	--	

WELL NO. WIPP-25

DATE 11-05-86

WELL DATA

TOTAL DEPTH 651
 CASING ELEVATION 3214
 GROUND ELEVATION 3212
 MID-FORM. ELEVATION 2752
 PRE-TEST WATER LEVEL 163.65
 MID-FORM. DEPTH 460.0
 PUBLISHED DENSITY 1.010

CASING STICKUP 1.84
 FORMATION INTERVAL 447 - 472
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 2.0
 ATMO. PRESSURE 14.35
 PERF. INTERVAL 445 - 475

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (°C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
150	12:28	20.5	14.34	163.65	14.34		out of water
						.849	
205	12:52	20.7	29.64	163.48	29.56		
						.9975	
250	13:09	20.9	49.09	163.48	49.02		
						1.0001	
300	13:28	21.1	70.78	163.47	70.70		
						.9983	
325	13:45	21.3	81.60	163.46	81.52		
						1.0020	
350	14:02	21.4	92.46	163.46	92.38		open
						--	
350	14:21	21.4	92.47	--	--		packer
							out of
150	15:00	21.0	14.30	--	--		water

PIP set at 359 ft. - packer inflated at 350 ft. - mid-fm. depth = 460 ft.

Calculated mid-formation pressure using ΔZ - 110 ft., Density = 1.0020

$\Delta Pd = 47.78$ PSIA

Calculated mid-formation pressure = 140.16 PSIA

WELL NO. WIPP-26

DATE 10-07-86

WELL DATA

TOTAL DEPTH 503
 CASING ELEVATION 3153
 GROUND ELEVATION 3152
 MID-FORM. ELEVATION 2954
 PRE-TEST WATER LEVEL 137.65
 MID-FORM. DEPTH 199.5
 PUBLISHED DENSITY 1.012

CASING STICKUP 1.5
 FORMATION INTERVAL 185 - 210
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 14.88
 PERF. INTERVAL 185 - 210

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
125	12:08	21.0	14.88	137.65	14.88		out of water
150	12:18	21.0	20.24	137.64	20.24	1.003	open
180	13:22	21.2	33.25	137.63	33.24	1.000	open
185	--	--	--	--	--	--	blocked
180	13:35	21.2	33.25	137.63	33.24	1.000	open

Well blocked off at 184.53 ft. Could not get probe past 184.5 ft.

or to top of formation level. Packer was not inflated in this well.

WELL NO. WIPP-27

DATE 11-10-86

WELL DATA

TOTAL DEPTH 592
 CASING ELEVATION 3179
 GROUND ELEVATION 3177
 MID-FORM. ELEVATION 2872
 PRE-TEST WATER LEVEL 106.64
 MID-FORM. DEPTH 305
 PUBLISHED DENSITY 1.0416

CASING STICKUP 1.74
 FORMATION INTERVAL 292 - 318
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 2.0
 ATMO. PRESSURE 14.03
 PERF. INTERVAL 290 - 320

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
100	12:47	19.5	14.03	106.64	14.03		out of
						.9203	water
150	13:20	20.7	31.24	106.85	31.33		
200	13:39	20.9	53.92	106.84	54.01	1.0463	
225	14:05	21.1	65.22	106.86	65.32	1.0435	
250	14:25	20.8	76.50	107.05	76.69	1.0486	
250	15:21	21.2	76.61	--	76.61	--	open
100	15:40	20.5	15.02	--	15.02	--	packer
							out of
							water

PIP set at 267 ft. - Packer inflated at 250 ft. - mid-fm. depth = 305 ft.

Calculated mid-formation pressure using $\Delta Z = 55$ ft., Density = 1.0486

$\Delta P_d = 25.00$ PSIA

Calculated mid-formation pressure = 101.61 PSIA

WELL NO. WIPP-30

DATE 11-19-86

WELL DATA

TOTAL DEPTH 913
 CASING ELEVATION 3426.8
 GROUND ELEVATION 3424.5
 MID-FORM. ELEVATION 2782
 PRE-TEST WATER LEVEL 380.70
 MID-FORM. DEPTH 642.5
 PUBLISHED DENSITY 1.201

CASING STICKUP 2.34
 FORMATION INTERVAL 631 - 654
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 2.0
 ATMO. PRESSURE 13.61
 PERF. INTERVAL 631 - 654

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
370	11:02	21.3	13.61	380.70	13.61		out of water
400	11:20	21.6	23.94	376.53	22.10	1.0153	
450	11:42	21.8	47.30	376.03	45.24	1.0675	
500	12:05	21.9	70.75	375.56	68.37	1.0669	
550	12:25	22.2	94.18	375.08	91.58	1.0707	
570	12:48	22.3	103.48	375.15	100.90	1.0753	open
570	15:01	22.4	101.53	--	101.53	--	packer

PIP set at 585 ft. - packer inflated at 570 ft. - mid-fm. depth = 642.5 ft.

Calculated mid-formation pressure using $\Delta Z = 72.5$ ft., density = 1.0753

$\Delta P_d = 33.80$ PSIA

Calculated mid-formation pressure = 135.33 PSIA

SECOND FIELD SURVEY PERIOD

DATE 04/13/87

TOTAL DEPTH	795
CASING ELEVATION	3377.5
GROUND ELEVATION	3376.3
MID-FORM. ELEVATION	2743
PRE-TEST WATER LEVEL	374.26
MID-FORM. DEPTH	634
PUBLISHED DENSITY	1.010

CASING STICKUP	1.25
FORMATION INTERVAL	624 - 642
PRODUCING UNIT	Culebra
CASING I.D. (in.)	6.0
ATMO. PRESSURE	14.06
PERF. INTERVAL	624 - 652

[illegible]

DATE : 02/24/87

TOTAL DEPTH	725
CASING ELEVATION	3388.93
GROUND ELEVATION	3388.63
MID-FORM. ELEVATION	2699.9
PRE-TEST WATER LEVEL	411.07
MID-FORM. DEPTH	689
PUBLISHED DENSITY	1.038

CASING STICKUP	0.60
FORMATION INTERVAL	<u>676 - 700</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>14.12</u>
PERF. INTERVAL	<u>673 - 725</u>

[illegible]

DATE 02/17/87

TOTAL DEPTH	529
CASING ELEVATION	3331.44
GROUND ELEVATION	
MID-FORM. ELEVATION	28.26
PRE-TEST WATER LEVEL	340.62
MID-FORM. DEPTH	503
PUBLISHED DENSITY	1.015

CASING STICKUP	1.29
FORMATION INTERVAL	490 - 516
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.75
ATMO. PRESSURE	13.95
PERF. INTERVAL	477 - 529

[illegible]

WELL NO. H-05h
DATE 04/15/87

WELL DATA

TOTAL DEPTH	916
CASING ELEVATION	3506.35
GROUND ELEVATION	3505.38
MID-FORM. ELEVATION	2596
PRE-TEST WATER LEVEL	485.85
MID-FORM. DEPTH	910
PUBLISHED DENSITY	1.105

CASING STICKUP	1.10
FORMATION INTERVAL	897 - 920
PRODUCING UNIT	Culebra
CASING I.D. (in.)	5.0
ATMO. PRESSURE	14.01
PERF. INTERVAL	882 - 925

[illegible]

DATE 05/11/87

WELL DATA

TOTAL DEPTH	640
CASING ELEVATION	3346.76
GROUND ELEVATION	
MID-FORM. ELEVATION	2725
PRE-TEST WATER LEVEL	304.35
MID-FORM. DEPTH	622
PUBLISHED DENSITY	1.042

CASING STICKUP	1.22
FORMATION INTERVAL	611 - 632
PRODUCING UNIT	Culebra
CASING I.D. (in.)	5.0
ATMO. PRESSURE	14.28
PERF. INTERVAL	592 - 640

[illegible]

DATE 03/23/87

TOTAL DEPTH	286
CASING ELEVATION	3164
GROUND ELEVATION	3163
MID-FORM. ELEVATION	2904
PRE-TEST WATER LEVEL	168.93
MID-FORM. DEPTH	260.0
PUBLISHED DENSITY	1.001

CASING STICKUP	<u>1.0</u>
FORMATION INTERVAL	<u>230 - 286</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.125</u>
ATMO. PRESSURE	<u>13.80</u>
PERF. INTERVAL	<u>230 - 286</u>

[illegible]

DATE 03/30/87

TOTAL DEPTH	624
CASING ELEVATION	3432
GROUND ELEVATION	3434
MID-FORM. ELEVATION	2833
PRE-TEST WATER LEVEL	440.15
MID-FORM. DEPTH	601
PUBLISHED DENSITY	1.004

CASING STICKUP	1.23
FORMATION INTERVAL	575 - 624
PRODUCING UNIT	Culebra
CASING I.D. (in.)	6.5
ATMO. PRESSURE	14.55
PERF. INTERVAL	575 - 624

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
420	14:05	22.4	14.55	440.15	14.55		ATMO PSI
						.943	
450	14:21	22.4	18.64	440.01	18.58		
						1.003	
500	14:37	22.7	40.37	440.03	40.32		
						1.003	TOP FM
575	14:55	23.0	72.99	440.03	72.94		OPEN
						1.004	MID FM
601	15:12	23.2	84.31	440.03	84.26		OPEN
						1.006	BOTTOM FM
617	15:25	23.2	91.29	440.02	91.23		OPEN
							TOP FM
575	15:51	23.0	73.02	-----	73.02		PACKER SET
601	Sample Collected Here						

DATE 03/24/87

WELL DATA

TOTAL DEPTH	708
CASING ELEVATION	3405
GROUND ELEVATION	3406
MID-FORM. ELEVATION	2744
PRE-TEST WATER LEVEL	430.66
MID-FORM. DEPTH	662
PUBLISHED DENSITY	1.003

CASING STICKUP	<u>1.0</u>
FORMATION INTERVAL	<u>640 - 708</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.125</u>
ATMO. PRESSURE	<u>14.35</u>
PERF. INTERVAL	<u>638 - 708</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
420	11:02	22.3	14.35	430.66	14.35		ATMO PSI
						.960	
450	11:18	22.4	22.40	430.61	22.38		
						1.000	
500	11:40	22.7	44.08	430.61	44.06		
						1.002	
600	12:04	23.2	87.51	430.61	87.49		
						.990	TOP FM
640	12:24	23.4	104.86	430.61	104.83		OPEN
						1.000	MID FM
662	12:44	23.5	114.40	430.69	114.37		OPEN
						1.009	BOTTOM FM
670	12:55	23.5	117.90	430.58	117.87		OPEN
							TOP FM
640	13:22	23.4	104.82	-----	104.82		PACKER SE
662	Sample Collected Here						

DATE 04/01/87

TOTAL DEPTH	1398	CASING STICKUP	1.10
CASING ELEVATION	<u>3687.92</u>	FORMATION INTERVAL	<u>1376 - 1398</u>
GROUND ELEVATION	<u>3687.01</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2301</u>	CASING I.D. (in.)	<u>6.125</u>
PRE-TEST WATER LEVEL	<u>699.12</u>	ATMO. PRESSURE	<u>14.44</u>
MID-FORM. DEPTH	<u>1386</u>	PERF. INTERVAL	<u>1346 - 1398</u>
PUBLISHED DENSITY	1.044		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (FSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (FSIA)	CALCULATED DENSITY (G/CM)	REMARKS
680	11:45	22.3	14.44	699.12	14.44	1.012	ATMO PSI
800	12:00	22.9	59.56	697.20	58.69	1.030	
900	12:49	23.4	104.22	697.09	103.33	1.033	
1000	12:32	23.9	149.12	696.90	148.13	1.038	
1100	12:44	24.4	194.22	696.69	193.13	1.053	
1200	13:03	24.9	239.94	696.50	238.77	1.085	
1300	13:21	25.5	287.10	696.30	285.81	1.084	TOP OF
1346	14:25	25.7	308.75	696.32	307.43	1.083	OPEN HOLE
1370	14:36	25.9	320.03	696.30	318.71		MIDDLE OF OPEN HOLE
Hole Bottomed Out at Just Over 1374 Ft.							
No Inflated Packer Measurement Made							
1370 Sample Collected Here							

DATE 03/05/87

TOTAL DEPTH	787
CASING ELEVATION	3409.62
GROUND ELEVATION	
MID-FORM. ELEVATION	2662
PRE-TEST WATER LEVEL	443.65
MID-FORM. DEPTH	747
PUBLISHED DENSITY	1.091

CASING STICKUP	0.58
FORMATION INTERVAL	734 - 759
PRODUCING UNIT	Culebra
CASING I.D. (in.)	5.0
ATMO. PRESSURE	14.57
PERF. INTERVAL	733 - 787

[illegible]

DATE 03/06/87

WELL DATA

TOTAL DEPTH	890
CASING ELEVATION	3424.5
GROUND ELEVATION	3423
MID-FORM. ELEVATION	2586
PRE-TEST WATER LEVEL	466.45
MID-FORM. DEPTH	838
PUBLISHED DENSITY	1.096

CASING STICKUP	1.45
FORMATION INTERVAL	824 - 849
PRODUCING UNIT	Culehra
CASING I.D. (in.)	5.0
ATMO. PRESSURE	14.48
PERF. INTERVAL	820 - 890

[illegible]

WELL NO. P-14
DATE 04/23/87

WELL DATA

TOTAL DEPTH	1545
CASING ELEVATION	3361.72
GROUND ELEVATION	<u>3359.76</u>
MID-FORM. ELEVATION	2776
PRE-TEST WATER LEVEL	324.67
MID-FORM. DEPTH	586
PUBLISHED DENSITY	1.019

CASING STICKUP	1.72
FORMATION INTERVAL	573 - 595
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.0
ATMO. PRESSURE	14.15
PERF. INTERVAL	573 - 601

[illegible]

DATE 02/26/87

TOTAL DEPTH	1465
CASING ELEVATION	3311.56
GROUND ELEVATION	3309.77
MID-FORM. ELEVATION	2886
PRE-TEST WATER LEVEL	304.80
MID-FORM. DEPTH	426
PUBLISHED DENSITY	1.000

CASING STICKUP	1.75
FORMATION INTERVAL	413 - 435
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.0
ATMO. PRESSURE	13.53
PERF. INTERVAL	410 - 438

[illegible]

DATE 02/25/87

TOTAL DEPTH	1660
CASING ELEVATION	3335.65
GROUND ELEVATION	
MID-FORM. ELEVATION	2764
PRE-TEST WATER LEVEL	360.60
MID-FORM. DEPTH	572
PUBLISHED DENSITY	1.065

CASING STICKUP	<u>1.50</u>
FORMATION INTERVAL	<u>558 - 583</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>4.0</u>
ATMO. PRESSURE	<u>13.89</u>
PERF. INTERVAL	<u>550 - 586</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
350	12:19	21.0	13.89	360.60	13.89	1.0637	ATMO PSI
470	12:45	21.6	65.81	357.42	64.34	1.0602	TOP FM.
559	13:08	22.0	106.68	357.50	105.25	1.0815	OPEN
572	13:28	22.1	112.60	357.87	111.35	1.0488	MID FM.
584	13:50	22.2	117.95	358.15	116.80	-----	OPEN
559	14:13	22.0	105.99	-----	105.99	-----	TOP FM.
572	SAMPLE COLLECTED HERE						PACKER SET

WELL NO. P-18
DATE 03/10/87

WELL DATA

TOTAL DEPTH	1998
CASING ELEVATION	3477
GROUND ELEVATION	3477
MID-FORM. ELEVATION	2553
PRE-TEST WATER LEVEL	620.46
MID-FORM. DEPTH	924
PUBLISHED DENSITY	1.2294

CASING STICKUP	<u>1.33</u>
FORMATION INTERVAL	<u>909 - 938</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>4.0</u>
ATMO. PRESSURE	<u>14.58</u>
PERF. INTERVAL	<u>912 - 940</u>

[illegible]

WELL NO. DOE-1
 DATE 02/19/87

WELL DATA

TOTAL DEPTH	<u>4057</u>	CASING STICKUP	<u>0.31</u>
CASING ELEVATION	<u>3463.96</u>	FORMATION INTERVAL	<u>821 - 843</u>
GROUND ELEVATION	<u> </u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2632</u>	CASING I.D. (in.)	<u>10</u>
PRE-TEST WATER LEVEL	<u>496.05</u>	ATMO. PRESSURE	<u>14.23</u>
MID-FORM. DEPTH	<u>832</u>	PERF. INTERVAL	<u>820 - 843</u>
PUBLISHED DENSITY	<u>1.091</u>		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
475	12:37	21.7	14.23	496.05	14.23		ATMO PSI
						1.154	
600	13:04	22.2	66.23	496.05	66.23		
						1.080	
700	13:29	22.7	113.04	496.05	113.04		
						1.084	
800	13:51	23.1	160.05	496.05	160.05		
						1.097	
821	14:10	23.2	170.04	496.05	170.04		TOP FM. OPEN
						1.099	
832	14:25	23.3	175.28	496.05	175.28		MID FM. OPEN
						1.123	
842	14:43	23.3	180.15	496.05	180.15		BOTTOM FM. OPEN
832	SAMPLE COLLECTED HERE						

NO INFLATED PACKER MEASUREMENT - HOLE DIAMETER TOO LARGE

WELL NO. DOE-2

DATE 05/13/87

WELL DATA

TOTAL DEPTH	<u>4325</u>	CASING STICKUP	<u>1.33</u>
CASING ELEVATION	<u> </u>	FORMATION INTERVAL	<u>829 - 850</u>
GROUND ELEVATION	<u>3418.4</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2579</u>	CASING I.D. (in.)	<u>10</u>
PRE-TEST WATER LEVEL	<u>365.55</u>	ATMO. PRESSURE	<u>14.00</u>
MID-FORM. DEPTH	<u>840</u>	PERF. INTERVAL	<u>822 - 848</u>
PUBLISHED DENSITY	<u>1.042</u>		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
360	7:49	21.3	14.00	365.55	14.00		ATMO PSI
						.974	
400	8:06	21.3	28.54	365.57	28.55		
						1.022	
500	8:27	21.6	72.85	365.58	72.86		
						1.023	
600	8:48	22.2	117.21	365.60	117.23		
						1.028	
700	9:32	22.7	161.77	365.63	161.81		
						1.033	
800	10:05	23.2	206.55	365.65	206.60		
						1.037	
829	11:04	23.3	219.59	365.66	219.64		TOP FM.
							OPEN
840	11:21	23.4	224.45	365.66	224.50		MID FM.
						1.020	OPEN
						1.077	
850	11:41	23.4	229.12	365.66	229.17		BOTTOM FM.
							OPEN

840 SAMPLE COLLECTED HERE

NO INFLATED PACKER MEASUREMENT MADE - WELL DIAMETER TOO LARGE

WELL NO: WIPP-12

DATE 05/08/87

WELL DATA

TOTAL DEPTH 3928
 CASING ELEVATION 3473
 GROUND ELEVATION 3472
 MID-FORM. ELEVATION 2649
 PRE-TEST WATER LEVEL 415.20
 MID-FORM. DEPTH 824
 PUBLISHED DENSITY 1.020

CASING STICKUP
 FORMATION INTERVAL 812 - 835
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 9.0
 ATMO. PRESSURE 14.53
 PERF. INTERVAL 815 - 840

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
400	11:12	22.3	14.53	415.20	14.53		ATMO PSI
						.920	
450	11:22	21.7	28.50	415.00	28.41		
						.995	
550	11:40	21.9	71.68	414.88	71.54		
						.997	
650	11:58	22.4	114.95	414.75	114.76		
						1.006	TOP FM.
750	12:14	22.6	158.13	414.63	157.88		OPEN
						1.015	MID FM.
813	12:56	23.2	185.63	414.56	185.35		OPEN
						1.051	BOTTOM FM.
824	13:08	23.3	190.48	414.54	190.19		OPEN
836	13:24	23.3	195.95	414.54	195.66		
824	SAMPLE COLLECTED HERE						

NO INFLATED PACKER MEASUREMENTS - WELL DIAMETER TOO LARGE

WELL NO. WIPP-13

DATE 05/06/87

WELL DATA

TOTAL DEPTH 3856
 CASING ELEVATION 3405.4
 GROUND ELEVATION 3405.4
 MID-FORM. ELEVATION 2690.9
 PRE-TEST WATER LEVEL 353.95
 MID-FORM. DEPTH 716
 PUBLISHED DENSITY 1.050

CASING STICKUP 1.02
 FORMATION INTERVAL 704 - 725
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 9.0
 ATMO. PRESSURE 14.14
 PERF. INTERVAL 702 - 727

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM.)	REMARKS
350	9:16	21.3	14.14	353.95	14.14		ATMO PSI
						1.002	
400	9:45	21.5	34.15	353.95	34.15		
						1.024	
500	10:09	22.0	78.56	353.95	78.56		
						1.026	
600	11:07	22.5	123.03	353.95	123.03		
						1.050	TOP FM.
705	11:33	23.1	170.85	353.95	170.84		OPEN
						1.057	MID FM.
716	11:46	23.1	175.89	353.95	175.88		OPEN
						1.056	BOTTOM FM.
726	12:01	23.2	180.47	353.95	180.46		OPEN
716	SAMPLE COLLECTED HERE						

NO INFLATED PACKER MEASUREMENT MADE - WELL DIAMETER TOO LARGE

DATE 05/12/87

WELL DATA.

TOTAL DEPTH	1050
CASING ELEVATION	3458
GROUND ELEVATION	3456
MID-FORM. ELEVATION	2659
PRE-TEST WATER LEVEL	447.17
MID-FORM. DEPTH	801
PUBLISHED DENSITY	1.080

CASING STICKUP	2.25
FORMATION INTERVAL	787 - 808
PRODUCING UNIT	Culebra
CASING I.D. (in.)	5.50
ATMO. PRESSURE	14.41
PERF. INTERVAL	784 - 806

<u>PROBE DEPTH</u> <u>(ft.)</u>	<u>CLOCK TIME</u>	<u>TEMP</u> <u>(C)</u>	<u>MEASURED PRESSURE</u> <u>(PSIA)</u>	<u>WATER LEVEL</u> <u>(FT.)</u>	<u>CORRECTED PRESSURE</u> <u>(FSIA)</u>	<u>CALCULATED DENSITY</u> <u>(G/CM)</u>	<u>REMARKS</u>
430	8:12	22.3	14.41	447.17	14.41	1.054	ATMO PSI
500	8:28	21.9	39.41	445.35	38.56	1.107	
550	8:55	22.1	63.38	445.35	62.55	1.106	
650	9:31	22.6	111.45	445.14	110.48	1.104	
750	9:51	22.9	159.44	444.83	158.32	1.106	TOP FM.
791	10:15	23.2	179.14	444.76	177.99	1.101	OPEN
801	10:30	23.2	183.91	444.77	182.76	1.102	MID FM. OPEN
810	10:50	23.3	188.18	444.82	187.06		BOTTOM FM. OPEN
791	13:00	23.1	177.91	-----	177.91		TOP FM. PACKER SET
801	SAMPLE COLLECTED HERE						

DATE 05/14/87

WELL DATA

TOTAL DEPTH	1040
CASING ELEVATION	3435
GROUND ELEVATION	3433
MID-FORM. ELEVATION	2666
PRE-TEST WATER LEVEL	443.48
MID-FORM. DEPTH	770
PUBLISHED DENSITY	1.150

CASING STICKUP	2.38
FORMATION INTERVAL	<u>756 - 779</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>14.42</u>
PERF. INTERVAL	<u>754 - 780</u>

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
430	9:24	22.3	14.42	443.48	14.42		ATMO PSI
						1.083	
500	9:42	21.9	41.73	441.91	40.95		
						1.135	
600	10:11	22.5	90.97	441.76	90.16		
						1.131	
700	10:30	22.7	140.18	441.48	139.20		
						1.125	TOP FM. OPEN
758	10:40	22.8	168.55	441.30	167.48		
						1.160	MID FM. OPEN
770	10:54	23.1	174.57	441.32	173.52		
						1.129	BOTTOM FM. OPEN
781	11:09	23.1	179.97	441.35	178.90		
						-----	TOP FM. PACKER SET
758	12:18	23.0	167.63	-----	167.63		
770	SAMPLE COLLECTED HERE						

WELL NO. WIPP-25

DATE 05/05/87

WELL DATA

TOTAL DEPTH 651
 CASING ELEVATION 3214
 GROUND ELEVATION 3212
 MID-FORM. ELEVATION 2752
 PRE-TEST WATER LEVEL 166.13
 MID-FORM. DEPTH 460
 PUBLISHED DENSITY 1.010

CASING STICKUP 1.84
 FORMATION INTERVAL 447 - 472
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 2.0
 ATMO. PRESSURE 14.03
 PERF. INTERVAL 445 - 475

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
150	10:03	21.0	14.03	166.13	14.03		ATMO PSI
						.970	
200	10:18	20.6	28.25	166.13	28.25		
						1.004	
250	10:38	20.9	50.02	166.13	50.02		
						1.008	
300	10:53	21.2	71.87	166.13	71.87		
						1.005	
325	11:12	21.3	82.76	166.13	82.76		
						1.007	
350	11:34	21.4	93.68	166.13	93.68		

PIP WELL - PIP SET AT 359 FT. - MID.FM. DEPTH = 460 FT.

CALCULATED MID.FM. PRESSURE USING = 110 FT., DENSITY = 1.007

Pd = 48.02

CALCULATED MID FORMATION PRESSURE = 93.68 + 48.02 = 141.70

WELL NO. WIPP-27

DATE 04/27/87

WELL DATA

TOTAL DEPTH	<u>592</u>	CASING STICKUP	<u>1.74</u>
CASING ELEVATION	<u>3179</u>	FORMATION INTERVAL	<u>292 - 318</u>
GROUND ELEVATION	<u>3177</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2872</u>	CASING I.D. (in.)	<u>2.0</u>
PRE-TEST WATER LEVEL	<u>106.84</u>	ATMO. PRESSURE	<u>13 - 98</u>
MID-FORM. DEPTH	<u>305</u>	PERF. INTERVAL	<u>290 - 320</u>
PUBLISHED DENSITY	<u>1.0416</u>		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
100	11:55	21.0	13.98	106.84	13.98		ATMO PSI
						1.022	
150	12:04	20.7	33.13	106.77	33.10		
						1.037	
200	12:15	21.0	55.60	106.77	55.57		
						1.033	
225	12:27	20.7	66.80	106.77	66.77		
						1.040	
250	12:39	20.8	78.06	106.79	78.04		
250	SAMPLE COLLECTED HERE						

PIP WELL - PIP SET AT 267 FT. - MID-FM. DEPTH = 305 FT.

CALCULATED MID-FM. PRESSURE USING $Z = 55$ FT., DENSITY = 1.040

$P_d = 24.80$ PSIA

CALCULATED MID-FM. PRESSURE = $24.80 + 78.04 = 102.84$ PSIA

DATE 05/06/87

TOTAL DEPTH	913	CASING STICKUP	2.34
CASING ELEVATION	3426.8	FORMATION INTERVAL	631 - 654
GROUND ELEVATION	3424.5	PRODUCING UNIT	Culebra
MID-FORM. ELEVATION	2782	CASING I.D. (in.)	2.0
PRE-TEST WATER LEVEL	380.81	ATMO. PRESSURE	14.17
MID-FORM. DEPTH	642.5	PERF. INTERVAL	631 - 654
PUBLISHED DENSITY	1.072		

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
370	9:45	21.3	14.17	380.81	14.17		ATMO PSI
400	10:21	21.7	23.55	378.44	22.45	.995	
450	10:39	21.8	46.73	378.20	45.60	1.068	
500	11:00	21.9	69.89	377.95	68.57	1.060	
550	11:21	22.2	93.10	377.75	91.69	1.067	
570	11:37	22.3	102.36	377.74	100.94	1.066	
570	SAMPLE COLLECTED HERE						
PIP WELL - PIP SET AT 858 FT., MID FM. DEPTH = 642.5							
CALCULATED MID.FM. PRESSURE USING $Z = 72.5$ FT., DENSITY = 1.066							
$P_d = 33.51$							
CALCULATED MID.FM. PRESSURE = $33.51 + 100.94 = 134.44$							

THIRD FIELD SURVEY PERIOD

DATE 9-30-87

TOTAL DEPTH	795
CASING ELEVATION	3378.41
GROUND ELEVATION	3377.69
MID-FORM. ELEVATION	2743.69
PRE-TEST WATER LEVEL	379.20
MID-FORM. DEPTH	634
PUBLISHED DENSITY	1.010

CASING STICKUP	0.72
FORMATION INTERVAL	624 - 642
PRODUCING UNIT	Culebra
CASING I.D. (in.)	6.0
ATMO. PRESSURE	13.69
PERF. INTERVAL	624 - 652

[illegible]

WELL NO. H-03b2

DATE 9-21-87

WELL DATA

TOTAL DEPTH 725
 CASING ELEVATION 3388.95
 GROUND ELEVATION 3388.34
 MID-FORM. ELEVATION 2700.34
 PRE-TEST WATER LEVEL 424.48
 MID-FORM. DEPTH 688
 PUBLISHED DENSITY 1.038

CASING STICKUP 0.61
 FORMATION INTERVAL 676 - 700
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 13.93
 PERF. INTERVAL 673 - 725

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
410	9:49	22.3	13.93	424.48	13.93		ATMO PSI
						.9234	
450	10:32	22.5	24.16	424.45	24.15		
						1.0258	
550	10:58	22.2	68.63	424.46	68.62		
						1.0339	
650	11:20	22.7	113.46	424.45	113.45		
						1.0376	TOP FM
677	11:41	22.9	125.61	424.44	125.59		OPEN
						1.0179	MID FM
689	11:58	22.9	130.91	424.43	130.89		OPEN
							TOP FM
677	12:29	22.9	125.58	-----	125.58		PACKER SET
689	12:35	SAMPLE COLLECTED HERE					SAMPLED
							POST TEST
410	12:50	22.3	14.01	-----	14.01		ATMO PSI

WELL OBSTRUCTED AT APPROXIMATELY 699 FEET.

DID NOT PERFORM BOTTOM FM. MEAS. MENT

DATE 8-5-87

TOTAL DEPTH	529
CASING ELEVATION	3334.03
GROUND ELEVATION	3333.35
MID-FORM. ELEVATION	2830.35
PRE-TEST WATER LEVEL	339.80
MID-FORM. DEPTH	503
PUBLISHED DENSITY	1.015

CASING STICKUP	0.68
FORMATION INTERVAL	490 - 516
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.75
ATMO. PRESSURE	14.05
PERF. INTERVAL	477 - 529

[illegible]

WELL NO. H-05b
DATE 9-28-87

WELL DATA

TOTAL DEPTH 925
CASING ELEVATION 3506.04
GROUND ELEVATION 3505.38
MID-FORM. ELEVATION 2596.88
PRE-TEST WATER LEVEL 485.67
MID-FORM. DEPTH 908.50
PUBLISHED DENSITY 1.105

CASING STICKUP 0.66
FORMATION INTERVAL 897 - 920
PRODUCING UNIT Culebra
CASING I.D. (in.) 5.0
ATMO. PRESSURE 13.58
PERF. INTERVAL 882 - 920

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
475	9:22	21.6	13.58	485.67	13.58		ATMO PSI
						1.0644	
600	9:46	21.9	67.23	483.81	66.34		
						1.0999	
700	10:06	22.4	115.02	483.51	114.02		
						1.0942	
800	10:28	23.0	162.65	483.18	161.46		
						1.0968	TOP FM
898	10:54	23.2	209.38	482.89	208.06		OPEN
						1.0978	MID FM
910	11:15	23.3	215.08	482.92	213.77		OPEN
						1.0921	BOTTOM FM
915	11:40	23.3	217.42	482.98	216.14		OPEN
							TOP FM
898	6:47	23.2	208.50	-----	208.50		PACKER SET
910	7:00	SAMPLE COLLECTED HERE					SAMPLED

DATE 9-16-87

TOTAL DEPTH	640
CASING ELEVATION	3348.25
GROUND ELEVATION	3347.57
MID-FORM. ELEVATION	2732.07
PRE-TEST WATER LEVEL	303.44
MID-FORM. DEPTH	615.50
PUBLISHED DENSITY	1.042

CASING STICKUP	0.68
FORMATION INTERVAL	604 - 627
PRODUCING UNIT	Culebra
CASING I.D. (in.)	5.0
ATMO. PRESSURE	13.50
PERF. INTERVAL	592 - 640

[illegible]

DATE 10-1-87

WELL DATA

TOTAL DEPTH	286
CASING ELEVATION	3164.17
GROUND ELEVATION	3163.56
MID-FORM. ELEVATION	2908.06
PRE-TEST WATER LEVEL	169.10
MID-FORM. DEPTH	255.5
PUBLISHED DENSITY	1.001

CASING STICKUP	<u>0.61</u>
FORMATION INTERVAL	<u>237 - 274</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.125</u>
ATMO. PRESSURE	<u>13.63</u>
PERF. INTERVAL	<u>230 - 286</u>

[illegible]

DATE 10-7-87

TOTAL DEPTH	624
CASING ELEVATION	3434.50
GROUND ELEVATION	3433.80
MID-FORM. ELEVATION	2832.80
PRE-TEST WATER LEVEL	440.03
MID-FORM. DEPTH	601
PUBLISHED DENSITY	1.004

CASING STICKUP	0.70
FORMATION INTERVAL	588 - 614
PRODUCING UNIT	Culebra
CASING I.D. (in.)	6.5
ATMO. PRESSURE	13.86
PERF. INTERVAL	575 - 624

[illegible]

WELL NO. H-09b
DATE 10-5-87

WELL DATA

TOTAL DEPTH	708
CASING ELEVATION	3406.25
GROUND ELEVATION	3405.58
MID-FORM. ELEVATION	2743.58
PRE-TEST WATER LEVEL	430.53
MID-FORM. DEPTH	662
PUBLISHED DENSITY	1.003

CASING STICKUP	<u>0.67</u>
FORMATION INTERVAL	<u>647 - 677</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>6.125</u>
ATMO. PRESSURE	<u>13.84</u>
PERF. INTERVAL	<u>640 - 708</u>

[illegible]

WELL NO. H-11b3

DATE 9-23-87

WELL DATA

TOTAL DEPTH 787
 CASING ELEVATION 3412.39
 GROUND ELEVATION 3412.07
 MID-FORM. ELEVATION 2671.57
 PRE-TEST WATER LEVEL 448.09
 MID-FORM. DEPTH 740.50
 PUBLISHED DENSITY 1.091

CASING STICKUP 0.32
 FORMATION INTERVAL 734 - 759
 PRODUCING UNIT Culebra
 CASING I.D. (in.) 5.0
 ATMO. PRESSURE 13.97
 PERF. INTERVAL 733 - 787

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
435	10:36	22.3	13.97	448.09	13.97		ATMO PSI
						1.0151	
500	10:58	22.6	36.82	448.08	36.82		
						1.0738	
600	11:28	23.1	83.37	448.09	83.37		
						1.0676	
700	11:49	22.9	129.66	448.08	129.66		
						1.0729	
736	12:07	23.1	146.40	448.09	146.40		TOP FM
						1.0610	OPEN
747	12:25	23.2	151.46	448.09	151.46		MID FM
						1.0766	OPEN
756	12:47	23.1	155.67	448.07	155.66		BOTTOM FM
							OPEN
747	12:55	SAMPLE COLLECTED HERE					SAMPLED
							POST TEST
200	13:06	22.3	13.89	-----	13.89		ATMO PSI

NO INFLATED PACKER MEASUREMENT MADE

SLUG EFFECT DISSIPATED INSTANTANEOUSLY

DATE 9-24-87

TOTAL DEPTH	890
CASING ELEVATION	3427.19
GROUND ELEVATION	3425.98
MID-FORM. ELEVATION	2589.48
PRE-TEST WATER LEVEL	466.25
MID-FORM. DEPTH	836.5
PUBLISHED DENSITY	1.096

CASING STICKUP	<u>1.21</u>
FORMATION INTERVAL	<u>823 - 850</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>13.91</u>
PERF. INTERVAL	<u>820 - 890</u>

<u>PROBE DEPTH</u>	<u>CLOCK TIME</u>	<u>TEMP (C)</u>	<u>MEASURED PRESSURE (PSIA)</u>	<u>WATER LEVEL (FT.)</u>	<u>CORRECTED PRESSURE (PSIA)</u>	<u>CALCULATED DENSITY (G/CM³)</u>	<u>REMARKS</u>
450	9:38	22.3	13.91	466.25	13.91	1.0073	ATMO PSI
500	9:59	22.5	29.50	464.46	28.65	1.0905	
600	10:21	23.1	76.77	464.32	75.93	1.0857	
700	10:43	22.9	124.06	464.00	123.00	1.0894	
800	11:07	23.2	171.44	463.67	170.23	1.0871	TOP FM OPEN
825	11:30	23.2	183.25	463.62	182.01	1.0881	MIDDLE FM OPEN
838	11:50	23.3	189.38	463.62	188.14	1.1214	BOTTOM FM OPEN
850	12:09	23.3	195.22	463.61	193.97		TOP FM PACKER SET
825	13:29	23.3	182.19	-----	182.19		SAMPLED POST TEST ATMO PSI
838	13:40	SAMPLE COLLECTED HERE					
300	14:02	22.3	13.89	-----	13.89		

DATE 9-22-87

TOTAL DEPTH	589
CASING ELEVATION	3347.20
GROUND ELEVATION	3345.60
MID-FORM. ELEVATION	2788
PRE-TEST WATER LEVEL	348.58
MID-FORM. DEPTH	561
PUBLISHED DENSITY	1.0122

CASING STICKUP	1.6
FORMATION INTERVAL	545 - 572
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.75
ATMO. PRESSURE	13.69
PERF. INTERVAL	532 - 589

[illegible]

DATE 8-31-87

TOTAL DEPTH	900
CASING ELEVATION	3481.60
GROUND ELEVATION	3480.20
MID-FORM. ELEVATION	2609.60
PRE-TEST WATER LEVEL	534.85
MID-FORM. DEPTH	872
PUBLISHED DENSITY	1.156

CASING STICKUP	<u>1.4</u>
FORMATION INTERVAL	<u>861 - 883</u>
PRODUCING UNIT	<u>Culebra</u>
CASING I.D. (in.)	<u>5.0</u>
ATMO. PRESSURE	<u>14.05</u>
PERF. INTERVAL	<u>853 - 900</u>

[illegible]

DATE 12-7-87

WELL DATA

TOTAL DEPTH	870
CASING ELEVATION	
GROUND ELEVATION	
MID-FORM. ELEVATION	
PRE-TEST WATER LEVEL	455.90
MID-FORM. DEPTH	718
PUBLISHED DENSITY	1.1026

CASING STICKUP	<u>706 - 731</u>
FORMATION INTERVAL	<u>Culebra</u>
PRODUCING UNIT	<u>6.5</u>
CASING I.D. (in.)	<u>13.81</u>
ATMO. PRESSURE	<u>693 - 773</u>
PERF. INTERVAL	

[illegible]

DATE 12-10-87

WELL DATA

TOTAL DEPTH	830.5
CASING ELEVATION	
GROUND ELEVATION	
MID-FORM. ELEVATION	
PRE-TEST WATER LEVEL	407.85
MID-FORM. DEPTH	702
PUBLISHED DENSITY	1.0182

CASING STICKUP	+1.00
FORMATION INTERVAL	689 - 713
PRODUCING UNIT	Culebra
CASING I.D. (in.)	6.5"
ATMO. PRESSURE	13.62
PERF. INTERVAL	673 - 766

[illegible]

DATE 8-19-87

TOTAL DEPTH	<u>1545 (759 to plug)</u>
CASING ELEVATION	<u>3361.07</u>
GROUND ELEVATION	<u>3359.76</u>
MID-FORM. ELEVATION	<u>2775.76</u>
PRE-TEST WATER LEVEL	<u>324.41</u>
MID-FORM. DEPTH	<u>584</u>
PUBLISHED DENSITY	1.019

CASING STICKUP	1.31
FORMATION INTERVAL	573 - 595
PRODUCING UNIT	Culebra
CASING I.D. (in.)	4.0
ATMO. PRESSURE	14.15
PERF. INTERVAL	573 - 601

[illegible]

DATE 8-28-87

TOTAL DEPTH	1465 (620 to plug)	CASING STICKUP	1.61
CASING ELEVATION	<u>3311.38</u>	FORMATION INTERVAL	<u>413 - 435</u>
GROUND ELEVATION	<u>3309.77</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2885.77</u>	CASING I.D. (in.)	<u>4.0</u>
PRE-TEST WATER LEVEL	<u>305.05</u>	ATMO. PRESSURE	<u>13.51</u>
MID-FORM. DEPTH	<u>424</u>	PERF. INTERVAL	<u>410 - 438</u>
PUBLISHED DENSITY	<u>1.00</u>		

[illegible]

DATE 8-12-87

TOTAL DEPTH	<u>1660 (731 to plug)</u>	CASING STICKUP	<u>1.47</u>
CASING ELEVATION	<u>3337.24</u>	FORMATION INTERVAL	<u>558 - 583</u>
GROUND ELEVATION	<u>3335.77</u>	PRODUCING UNIT	<u>Culebra</u>
MID-FORM. ELEVATION	<u>2765.27</u>	CASING I.D. (in.)	<u>4.0</u>
PRE-TEST WATER LEVEL	<u>358.68</u>	ATMO. PRESSURE	<u>13.67</u>
MID-FORM. DEPTH	<u>570.5</u>	PERF. INTERVAL	<u>550 - 586</u>
PUBLISHED DENSITY	<u>1.065</u>		

[illegible]

DATE 9-4-87

TOTAL DEPTH	2784
CASING ELEVATION	3472
GROUND ELEVATION	3471
MID-FORM. ELEVATION	2649
PRE-TEST WATER LEVEL	520.02
MID-FORM. DEPTH	823
PUBLISHED DENSITY	1.020

CASING STICKUP	0.76
FORMATION INTERVAL	810 - 835
PRODUCING UNIT	Culebra
CASING I.D. (in.)	9.0
ATMO. PRESSURE	13.93
PERF. INTERVAL	815 - 840

PROBE DEPTH (ft.)	CLOCK TIME	TEMP (C)	MEASURED PRESSURE (PSIA)	WATER LEVEL (FT.)	CORRECTED PRESSURE (PSIA)	CALCULATED DENSITY (G/CM)	REMARKS
510	10:22	22.3	13.93	520.02	13.93	1.0369	ATMO PSI
550	10:41	22.5	27.73	519.29	27.41	1.0377	
650	11:03	23.0	72.84	519.03	72.40	1.0402	
750	11:22	22.8	118.07	518.73	117.49	1.0647	TOP FM
813	11:40	23.1	147.27	518.47	146.57	1.1268	OPEN
824	11:59	23.4	152.75	518.27	151.94	1.1172	MIDDLE FM
836	12:18	23.5	158.59	518.10	157.76		OPEN
824	12:20	SAMPLE COLLECTED HERE					SAMPLED
500	12:36	22.8	14.00	518.87			POST TEST
							ATMO PSI
NO INFLATED PACKER MEASUREMENT MADE							
WELL DIAMETER TOO LARGE							