

TN
23
U44
1977-103
v.1
SECT. II

PILOT HOLE "X"

HORSE DRAW, RIO BLANCO COUNTY

COLORADO

VOLUME I

SECTION II: PERMEABILITY TESTING

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

GOLDER ASSOCIATES, INC.
Kirkland (Seattle), Washington

FINAL REPORT

on

Contract No. SC261060

James E. Hawkins, Geologist
U.S. Bureau of Mines
Denver Mining Research Center
Mine Engineering Group
Building 29, Denver Federal Center
Denver, CO 80225

March 1977

1. Report No.	2. Natural Resources Library U.S. Department of the Interior Washington, D.C. 20240 ✓	3. Recipient Accession No.	
4. Title and Subtitle U.S.B.M. PILOT HOLE "X", HORSE DRAW, RIO BLANCO COUNTY, COLORADO VOLUME I - SECTION II PERMEABILITY TESTING		5. Report Date MARCH 1977	
		6.	
7. Author(s) ADRIAN BROWN AND WILLIAM HELEY		8. Performing Organization Report No. V76357/S76029	
9. Performing Organization Name and Address GOLDER ASSOCIATES, INC. 10628 N.E. 38th Place Kirkland, Washington 98033		10. Project / Task / Work Unit No.	
		11. Contract or Grant No. S0261060	
12. Sponsoring Organization Name and Address Office of the Assistant Director - Mining Bureau of Mines Department of the Interior Washington, D.C. 20241		13. Type of Report FINAL	
		14.	
15. Supplementary Notes			
16. Abstract <p>Pilot Hole "X" was drilled to test the formations through which the ventilation shaft for the proposed U.S.B.M. demonstration oil shale mine will be drilled. Five permeability tests were performed at various stratigraphic levels within this hole. The test method used was that of pumping fluids out of the hole for three hours, using the air lift method, followed by a three-hour period where the recharge was observed.</p> <p>Transmissivity and permeability results were determined from these test data.</p> <p>The test procedure used is described and supporting data for the hydrologic tests are provided.</p>			
17. Originator's Key Words U.S.B.M. Pilot Hole "X" Piceance Creek Basin, Colorado Hydrology (Permeability) testing U.S.B.M. Demonstration oil shale mine		18. Availability Statement	
19. U.S. Security Classification of the Report	20. U.S. Security Classification of this Page	21. No. of Pages 26	22. Price

FOREWORD

This report was prepared by Golder Associates, Inc., Kirkland (Seattle), Washington under USBM Contract No. SO261060. The contract was initiated under the Advancing Oil Shale Mining Technology Program. It was administered under the technical direction of the Denver Mining Research Center with Mr. James E. Hawkins acting as Technical Project Officer. Mrs. Darlene Wilson was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as a part of this contract during the period June 1976 to March 1977. This report was submitted by the authors in March 1977.

SECTION II - PERMEABILITY TESTING

CONTENTS

1.0	INTRODUCTION	4
2.0	TECHNIQUE	4
3.0	DATA	4
4.0	ANALYSIS	4
5.0	RESULTS	5
6.0	DISCUSSION	7
	APPENDIX I - Test Data Sheets	15
	APPENDIX II - Analysis Method	23

LIST OF FIGURESFigure
Number

1	Location of Test Site in Piceance Creek Basin, Colorado
2	Detail of Site Area
3	U.S.B.M. Pilot Hole "X" - Jet Test, Depth 765 Ft.
4	U.S.B.M. Pilot Hole "X" - Jet Test, Depth 1,041 Ft.
5	U.S.B.M. Pilot Hole "X" - Jet Test, Depth 1,450 Ft.
6	U.S.B.M. Pilot Hole "X" - Jet Test, Depth 2,531 Ft.

LIST OF TABLESTable
Number

1	Transmissivity and Permeability U.S.B.M. Pilot Hole "X", Horse Draw
---	---

1.0 INTRODUCTION

Pilot Hole "X" was drilled to test the formations through which the ventilation shaft for the proposed U.S.B.M. demonstration mine will be drilled. The planning for the hole called for up to six informal pumping tests of the formation to be performed. The location of the hole is shown in Figures 1 and 2.

2.0 TECHNIQUE

The method used to perform the tests is fairly standard in the basin. An air lift system is used to pump water from the hole for three hours, and then three hours of recharge are observed. Appendix I contains details of the technique and of the test results as supplied by W.H. Engineering, who were subcontracted to perform the tests.

3.0 DATA

Of the five tests performed, only four produced any recharge data. This resulted from problems with the standard test probe, which malfunctioned as a result of the highly saline water encountered at depth, and the saline mud used.

4.0 ANALYSIS

The method of Cooper and Jacob is used, and the justification of the method is found in Appendix II. The results of plotting depth to water versus $\log t/t'$ is shown for each test in Figures 3 to 6. Analysis details are included on the figures.

5.0 RESULTS

As can be seen from the graphs, the first three tests are entirely satisfactory, producing characteristics which give a high degree of confidence in the results.

The fourth test, performed at total depth, gives largely unsatisfactory results, both because the accuracy of the readings are poor, and because the water level was felt by the testers to be highly erratic during the test. However, we feel that a not unreasonable interpretation of the transmissivity is as shown, and this also fits in with the previous three values.

Based on these values we have the transmissivity and permeability results quoted in Table 1:

TABLE 1TRANSMISSIVITY AND PERMEABILITY
USEM PILOT HOLE 'X', HORSE DRAW

<u>Depth</u> <u>(Ft)</u>	<u>Transmissivity</u> <u>(Gpd/Ft)</u>	<u>Depth</u> <u>Increment</u> <u>(Ft)</u>	<u>Transmissivity</u> <u>Increment</u> <u>(Gpd/Ft)</u>	<u>Permeability</u>	
				<u>(Gpd/Ft²)</u>	<u>(Cm/S)</u>
150		615	2,661	4.3	2×10^{-4}
765	2,661	276	9,526	34.5	2×10^{-3}
1,041	12,187	409	658	1.6	8×10^{-5}
1,450	13,845	1,081	2,539	2.4	1×10^{-4}
2,531	16,384				
	Average	2,381	16,384	6.9	3×10^{-4}

6.0 DISCUSSION

These permeabilities are relatively high for the Piceance Creek Basin, particularly in the lower zones. The area around the Mahogany Zone appears particularly prolific which is in line with the results obtained nearby, and also on C-a Tract.

The validity of the test performed at total depth can be seriously questioned. We feel that the probable likely range of transmissivities is between 16,000 gpd/ft. and 37,000 gpd/ft. which yield a range of permeabilities of 3×10^{-4} cm/sec. to 7×10^{-4} cm/sec. respectively.

We have chosen the lower figure as more likely to be correct based on our experience of analysing these tests, but it must be cautioned that any design should be based on the value which gives the more conservative final result.

The general adequacy of the test technique is not high. We describe the test approach as "informal", and hence the accuracy of the results is only second order at best. A further complicating factor is created by the method of drilling, which in this case used saline mud. We expect that this will have clogged the formation somewhat, although it can be shown that at later times in the recovery phase this effect should be negligible.

Accordingly we would recommend that the parameters developed in this test should be regarded as order of magnitude estimates, with an accuracy of ± 20 percent for the first three tests, and the above mentioned range for the test at total depth.

Respectfully submitted,

GOLDER ASSOCIATES, INC.



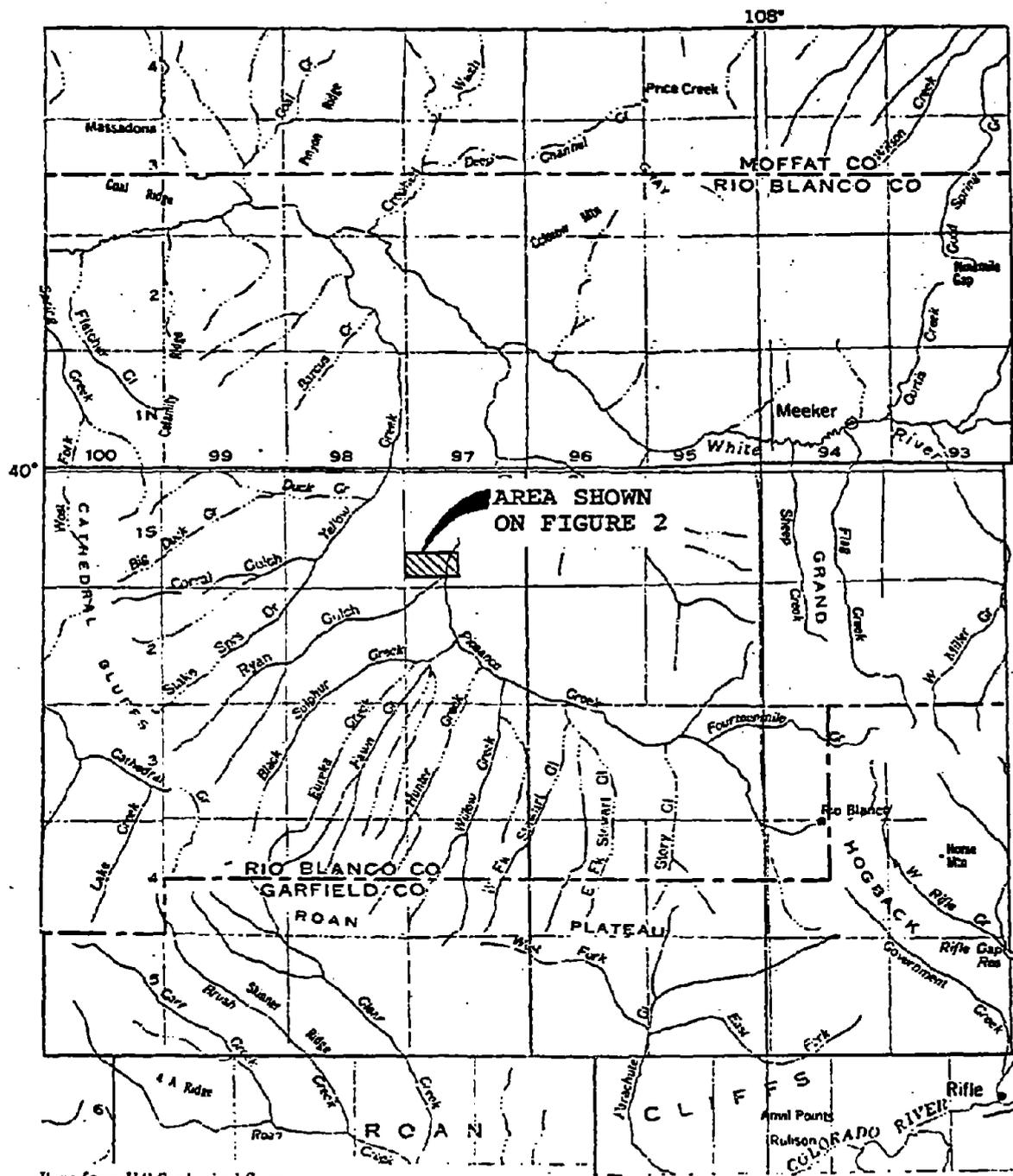
Adrian Brown

V76357

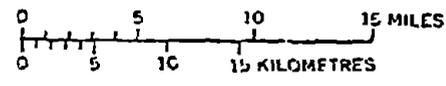
LOCATION OF TEST SITE IN
PICEANCE CREEK BASIN, COLORADO

FIGURE 1

Project No. 17-2562



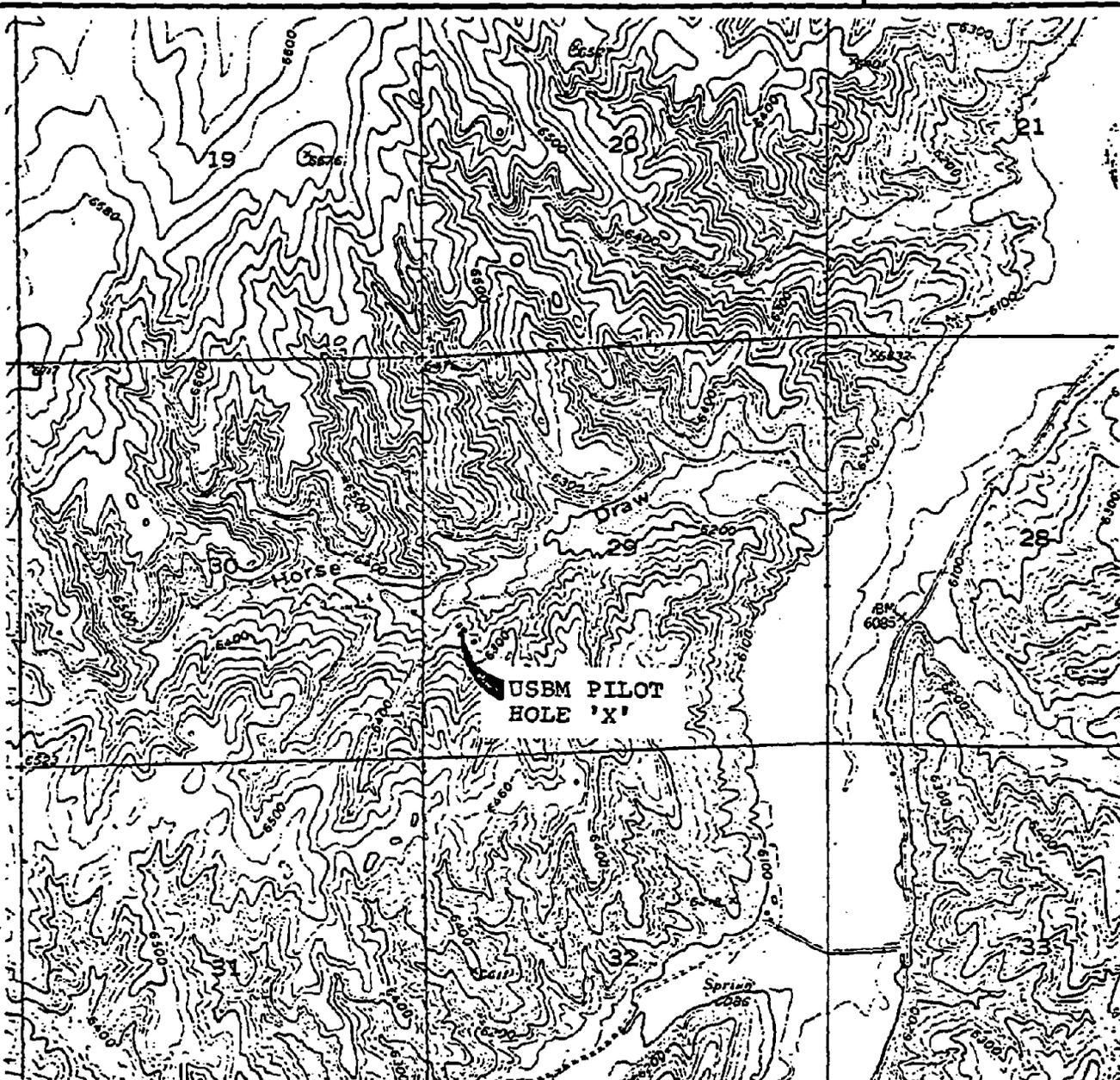
Base from US Geological Survey
State base map, 1969



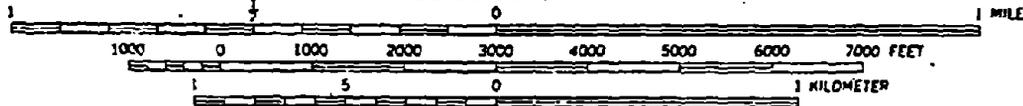
DETAIL OF SITE AREA

FIGURE 2

Project No. 17/267



SCALE 1:24000



CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

(PART OF T1S, R97W, 6th P.M.)

Reference: United States Department
of the Interior, Geological Survey.
Ranch Quadrangle, 1955.

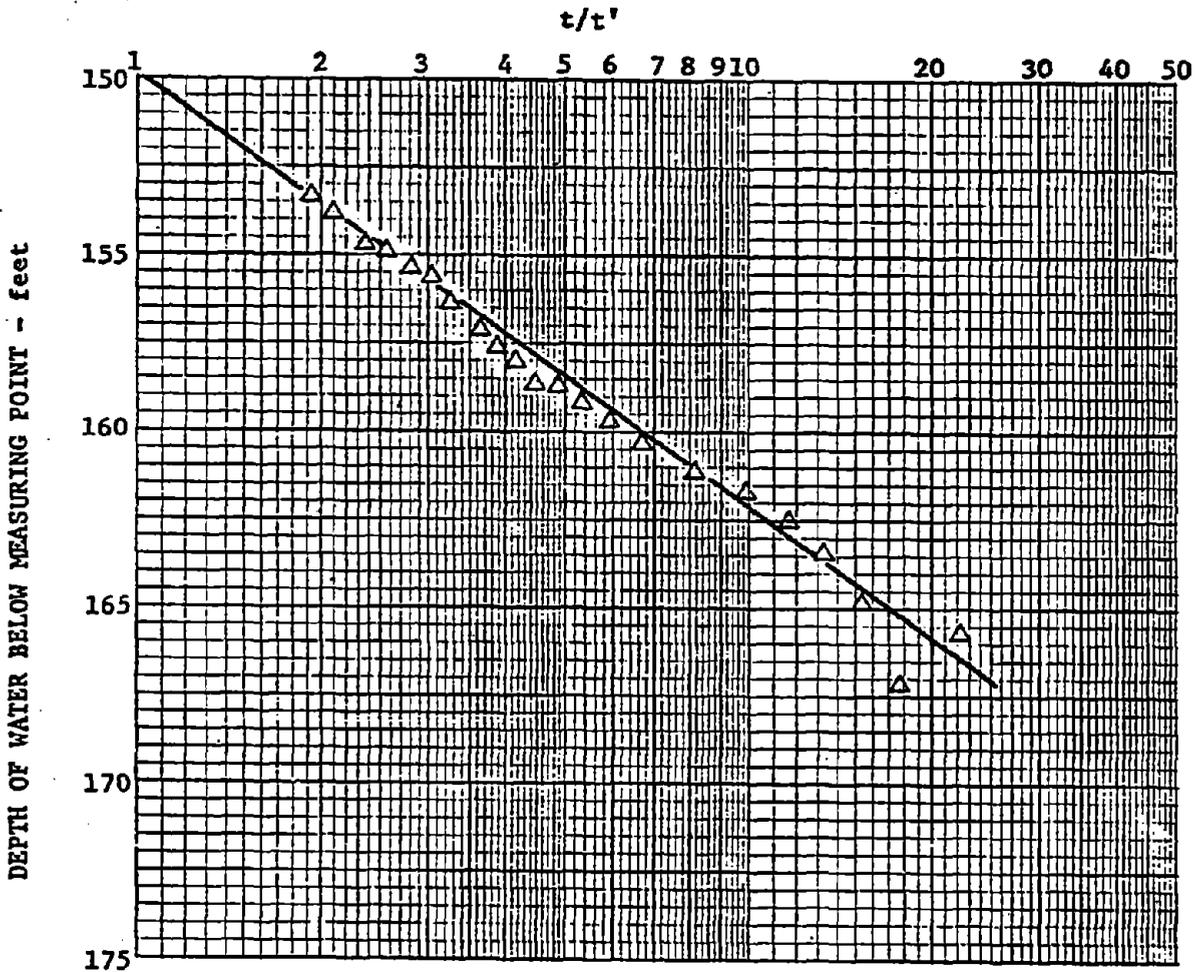
Golder Associates

1979

USBM PILOT HOLE 'X' - JET TEST
DEPTH 765 FT.

FIGURE 3

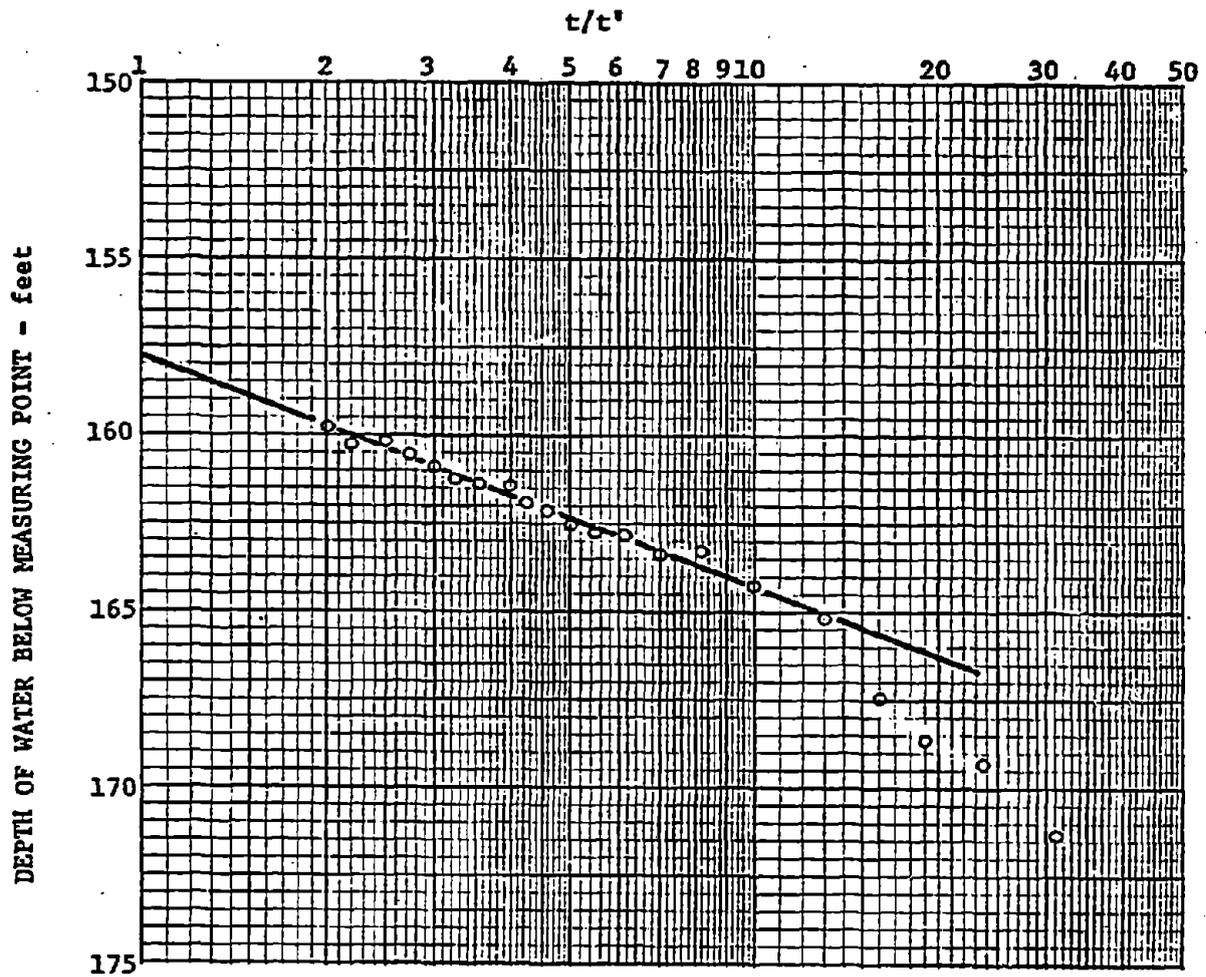
Project No. VZ-5-57



- Q = 125 gpm
- s = (149.8-162.2) = 12.4 ft.
- T = 264 Q/s = 2,661 gpd/ft.
- M = 765 - 149.8 = 615.2 ft.
- k = T/M = 4.3 gpd/ft² = 2x10⁻⁴ cm/sec.

USBM PILOT HOLE 'X' - JET TEST
DEPTH 1,041 FT.

FIGURE 4

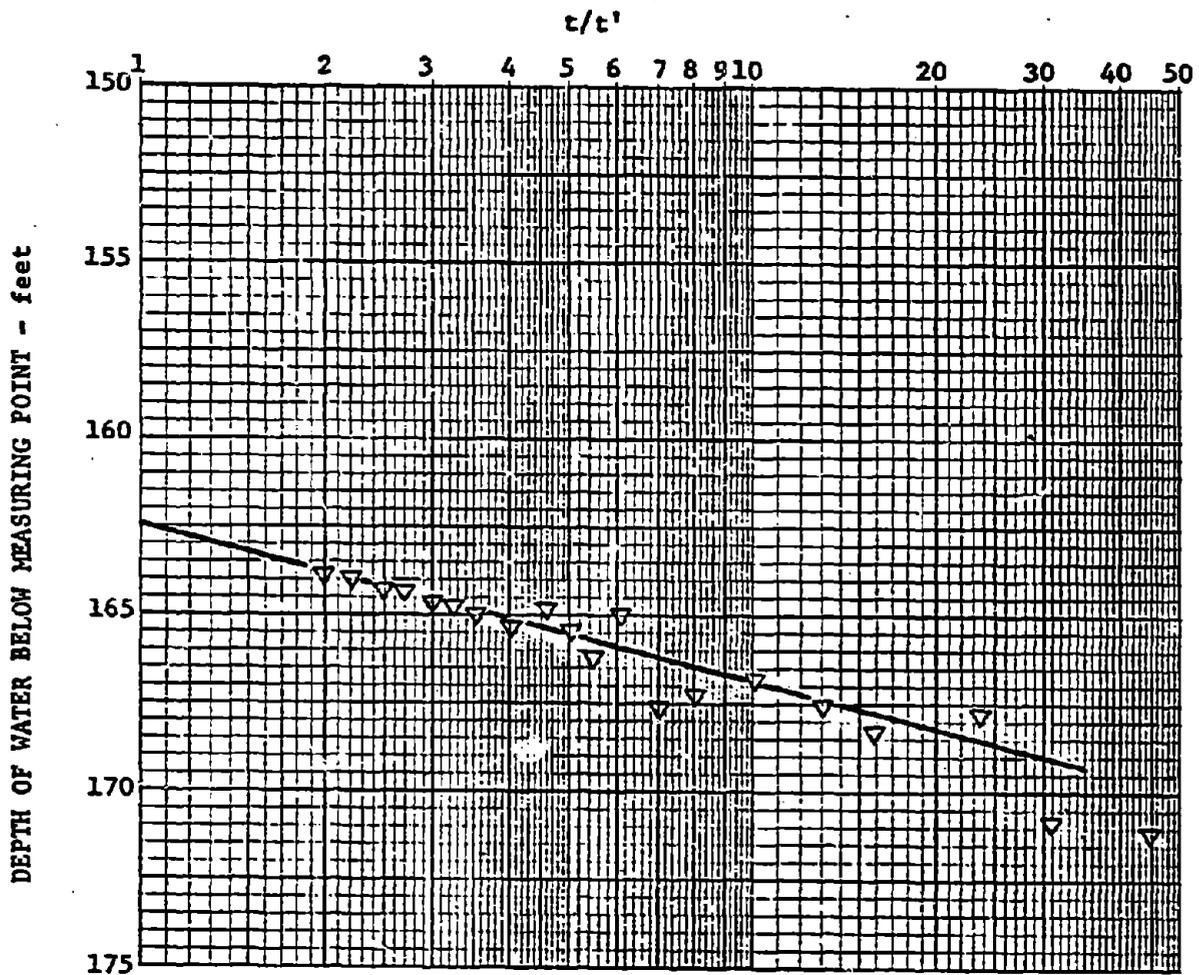


$Q = 305 \text{ gpm}$
 $\Delta s = 164.3 - 157.7 = 6.6 \text{ ft.}$
 $T = 264 Q/\Delta s = 12,187 \text{ gpd/ft.}$
 $M = 1,040.6 - (157.7 - 2.9) = 885.8 \text{ ft.}$
 $k = T/M = 13.76 \text{ gpd/ft}^2 = 6.5 \times 10^{-4} \text{ cm/sec.}$

USBM PILOT HOLE 'X' - JET TEST
DEPTH 1,450 FT.

FIGURE 5

Project No. 62-1-10-1

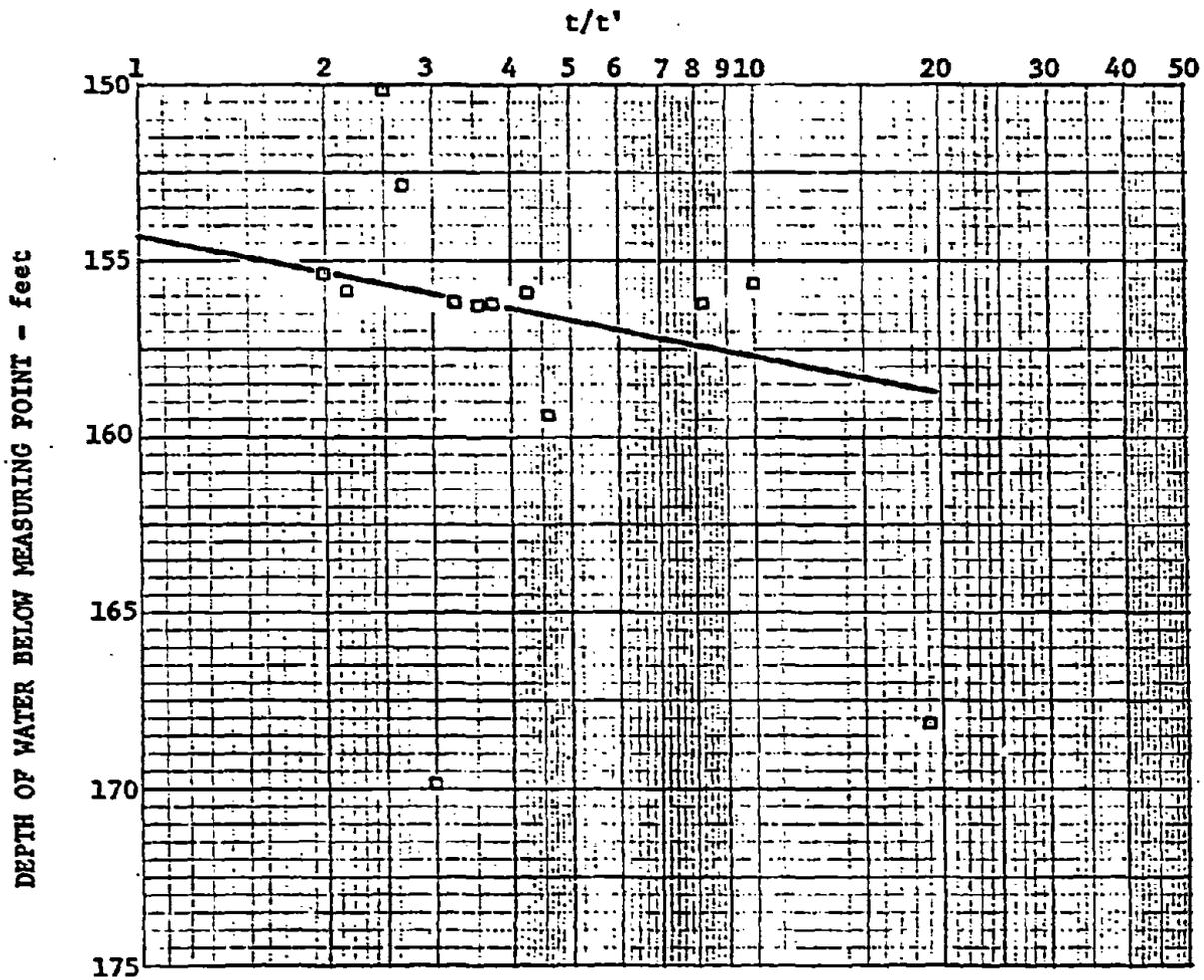


- Q = 236 gpm
- s = 167.0 - 162.5 = 4.5 ft.
- T = 26.4 Q/Δs = 13,845 gpd/ft.
- M = 1,450 - 162.5 - 2.6 = 1,284.9 ft.
- k = T/M = 10.8 gpd/ft² = 5.1 x 10⁻⁴ cm/sec.

USBM PILOT HOLE 'X' - JET TEST
DEPTH 2,531 FT.

FIGURE 6

Project No. K-1-53



- Q = 211 gpm
- s = 157.7-154.3 = 3.4' ft.
- T = 264 Q/s = 16,384 gpd/ft.
- M = 2,531-(154.3-2.4) = 2,379 ft.
- k = T/M = 6.89 gpd/ft² = 3.2x10⁻⁴ cm/sec.

VOLUME I - SECTION II

APPENDIX I

Test Data Sheets

Source: W.H. Engineering
Grand Junction, Colorado

Hydrologic Testing of Borehole Horse Draw - Pilot Hole "X":**Jet Testing Procedure**

Drilling of the test hole proceeds with a toothed tri-cone rotary bit, 6.25" in diameter to a depth designated as the bottom of a testing interval. The drilling fluid used to clean the hole is as light of a fluid as possible which will keep the hole clean and maintain circulation, or restrict circulation losses to a workable level. Where possible, clear water is the preferable fluid. After the groundwater salinity increases beyond the salinity of the creek water used for drill fluid, salt and other additives are added to the fluid to increase salinity and inhibit loss to the formation.

Once the test level is reached, circulation of either the existing fluid or a brine solution is made to wash the cuttings and/or drilling mud from the hole. The drill string is then pulled from the hole and the bit, collars, reamer, and other subs are removed. A string of open-ended drill pipe is then run into the hole to the desired depth for jetting. The contract specifies a minimum of 300 feet of pipe below the water level prior to testing. More can be used if the compressors can handle the water lift. (Actually, the ideal test would have the string on the bottom because the hole is not really unloaded below the pipe to the full drawdown head and the lower portions of the hole cannot contribute as much flow as the upper portion since the flow gradient is less.)

The kelly is then hooked to the top of the string and air pressure from a compressor is then applied to the string. (The pipe rams of the blow out preventer must be closed to prevent blowing water out of the casing!) Water forced out of the hole by the air pressure flows out of a blow line and to a measuring device. In this case, a tank has been set at the end of the pipe which is of sufficient size to allow some stilling of the water and provide a measurable rate of fill. When the water level rises to marks on the inner wall of the tank (6 inches apart) the time is noted. Some subjective interpretation is necessary due to the undulations in the water surface, but incremental measurements allow a better averaging of the fill sequence.

All of the water is not caught and measured. The initial flow, normally containing remnants of drilling mud, wall cake, etc., is dumped into the pit. After filling of the tank, the jet discharge is also dumped into the pit while the emptying gate on the tank is screwed open and then reinstalled for the next test. One fill cycle can take up to 20 minutes or more, depending on the jet discharge rate.

Jet Testing Procedure continued

After the tank has been filled to the desired level (36" normally), the thermometer is inserted into the water to determine a testing temperature. This temperature is then used to adjust the conductivity meter to a compensating scale and the specific conductance in micromhos/centimeter is read as the dip probe is inserted in the water. A Beckman SOLU Bridge is used to determine the specific conductance. The meter identification is as follows:

Beckman SOLU Bridge type RB3338
Serial Number 45072
Reference Temperature 25 degrees Centigrade
Golder Brawner Unit Number V23922

This meter is calibrated to read from 50 to 8000 micromhos/centimeter. Anything beyond this range should be sampled and taken to another testing laboratory. Dilution of samples to obtain readings should not be done, except under controlled conditions.

When the jetting has proceeded for 3 hours, the recovery test begins. The compressor is shut down and the kelly line is unpressured prior to removing the kelly from the drill pipe string. This should be done as quickly as possible consistent with good safety practices.

After the kelly is unhooked and moved away, the sounder probe is lowered into the drill pipe until the water level is found. The movement of the water level is then recorded on a time increment scale, more frequently at first and at successively less frequent intervals. Care should be taken to keep the probe as free as possible from pipe joint compound and other contaminants. The probe should be pulled and cleaned as necessary to produce reproducible results.

When the 3 hour period of recovery measurement is completed, the datum for measurements (top of drill pipe) should be established. Then the pipe may be pulled for reinstallation of the bit and drilling may resume.

The sounder to be used is a Soiltest Model DR-760A water level finder.

Jet Test No. 1

Drilled to 765 feet at 1830 hours; Tripped out of hole and removed bit, collars, & subs and tripped back into hole with drill pipe to 726 feet..

Open Hole water level after 1.5 hours undisturbed time was 147' below the rotary table or El. 6141.

Drill pipe dimensions: $2 \frac{7}{8}$ " OD, 2.151 " ID

Jetting Time: Stop 0104 (Compressor breaks down)
Start 2215

169 minutes at 150psi measured at Kelly line guage

Fill Rate: 1 foot equals 650 gallons of water

	12"	18"	24"	30"	36"	Temp °C	Conductance μ mhos
Fill I	2218:30	2221:00	2224:30	*	*	12	1600
Fill II	leak in dump gate too bad to use data					13	1740
Fill III	2339:00	2342:00	2344:30	2347:00	2349:30	12.5	1900
Fill IV	0004:00	0007:00	0009:30	0012:00	0015:15	12	1850
Fill V	0029:30	0032:00	0035:00	*	0040:00	12	1850
Fill VI	0059:00	0103:00	*	*	*		

Failure of the compressor aborted the test; unloaded the pressure at 108 AM and began recovery readings. Measurement point .75" above rotary table or EL 6288.5

Recovery:

Time hrs	Interval minutes	Depth ft.	Time hrs	Interval minutes	Depth ft
0108	0	-	0218	70	156.40
0112	4	165.75		80	156.05
0114	6	167.20		90	155.45
0116	8	164.90		105	154.95
0118	10	163.30		120	154.65
0120	12	162.50		150	153.85
0123	15	161.70	0418	180	153.30
0128	20	161.50			
	25	160.40			
	30	159.70			
	35	159.15			
	40	158.70			
	45	158.20			
	50	158.00			
	55	157.55			
0208	60	157.05			

End recovery, pull pipe string

Jet Test No. 2

Drilled to 1040.6 feet at 0115 hours; Tripped out of hole and removed bit, collars, & subs and tripped back into hole with drill pipe to 1008 feet.

Same drill pipe dimensions as test 1.

Jetting Time: Stop 0905
Start 0605

180 minutes at 200 psi (pressure rose to 300psi by the middle of the test, probably due to rocks in the air line)

Fill Rate: 1 foot equals 650 gallons of water

	12"	18"	24"	30"	36"	Temp °C	Conductance μmhos
Fill I	*	0637:00	0638:00	0639:00	0640:00	15	1800
Fill II	*	0656:40	0658:10	0659:20	0700:50	18	1600
Fill III	*	0716:00	0717:00	0718:10	0719:20	18	1600
Fill IV	*	0731:50	0732:50	0733:50	0735:10	18	1600
Fill V	*	0756:20	0757:10	0758:20	0759:20	18	1600
Fill VI	*	0834:30	0835:40	0836:40	0837:50	18	1550

The 12 inch readings were obscured by a heavy mist in the tank. Air Temp was about 5°F at the time of the test. A heavy sulfur gas odor was evident during this test.

Recovery: Measurement point was 2.9 ft above the table or El. 6290.9

Time hrs	Interval minutes	Depth ft	Time hrs	Interval minutes	Depth ft
0905	0	-	1015	70	161.35
0909	4	182.30		80	161.25
	6	171.40		90	160.95
	8	169.40		105	160.50
	10	168.65		120	160.15
	12	167.50		150	160.20
	15	165.20		180	159.80
	20	164.30			
	25	163.35			
	30	163.40			
	35	162.75			
	40	172.70			
	45	162.50			
	50	162.05			
	55	161.80			
1005	60	161.45			

End of recovery test, pull pipe string.

Jet Test No. 3

Drilled to 1450 ft. at 1135 hours; tripped out and back into hole. Compressor would not pump from TD and pulled pipe to 720'. Still would not pump. Then reentered to TD with drill pipe and flushed hole with water for 15 minutes. Then pulled string to 720 feet and began test.

Jetting Time:

Stop 0010 hrs
Start 2110

180 minutes jet time at 225 psi

Fill Rate:	1 foot equals 650 gallons of water					Temp °C	Conductance μ mhos
	12"	18"	24"	30"	36"		
Fill I	2116:10	2117:20	2118:45	2120:00	2121:25	13	1950
Fill II	2137:50	2139:00	2140:25	2141:40	2143:10	16	3500
Fill III	2157:40	2158:45	2159:25	2200:45	2202:05	18	6000
Fill IV	2210:10	2211:20	2212:50	2214:05	2215:25	18	6500
Fill V	2227:55	2229:15		2231:55	2233:20	18	6500
Fill VI	2244:45	2246:05	2247:15	2248:35	2250:00	18	6500
Fill VII	2304:25	2305:35	2306:55	2308:15	2309:40	18	6500
Fill VIII	2323:15	2324:35	2326:00	2327:25	2328:45	18	6500
Fill IX	2341:25	2342:50	2344:15	2345:35	2346:55	19	6500
Fill X	0000:45	0002:05	0003:20	0004:45	0006:05	not tested	

Recovery: Measuring Point 2.6 ft. above table or E1 6290.6

Time hrs	Interval minutes	Depth ft	Time hrs	Interval minutes	Depth ft
0010	0	-	0055	45	165.45
	4	171.10		50	164.95
	6	171.40		55	pull & clean sounder
	8	167.85		60	165.25
	10	168.10		70	165.00
	12	168.35		80	164.75
	15	176.50		90	164.65
	20	166.85		105	164.35
	25	167.20		120	164.30
	30	167.65		150	164.00
	35	165.00		180	163.90
	40	166.25			

End Recovery, pull pipe string

Jet Test No. 4:

Hole was drilled to 1950 feet at 0210 hours but following a brine flush for 15 minutes, the string was stuck in the hole and a light mud had to be circulated to free it. This mud was not washed out of the hole before testing. The string was tripped out and back in to about 720 feet by 1200 hours (notes say 735 but this is not likely since the number of pipes was the same as last test; not taped for test)

Jetting Time:

Stop 1513:00
Start 1213:00

180 minutes at 200 psi measured at Kelly Line guage

Fill Rate:	12"	18"	24"	30"	36"	Temp °C	Conductance μ mhos
Fill I	1227:50	1229:05	1230:40	1232:10	1233:40	18	>> 8000
Fill II	1249:50	1251:10	1252:40	1254:20	1256:00	18	>> 8000
Fill III	1306:15	1308:20	1310:10	1311:40	1312:15	18	"
Fill IV	1326:25	1328:00	1329:20	1330:45	1332:25	18	"
Fill V	1342:25	1344:10	1345:40	1347:00	1348:30	18	"
Fill VI	1359:40	1401:05	1402:40	1403:50	1405:40	18	"
Fill VII	1420:10	1421:45	1423:05	1424:30	1426:00	18	"
Fill VIII	1438:50	1440:00	1441:35	1442:45	1444:25	18	"
Fill IX	1456:00	1457:25	1459:05	1500:45	1502:50	(Water sample taken)	

The water was tested with the Baroid Resistivity meter: 0.8 ohm meters @ 68 °F and was tested at the Grand Junction Testing Laboratory at 15,000 μ mhos.

Recovery: Readings made from the rotary table or El. 6288

Interval	Depth	
4 min	173	A black scum covered the instrument probe and would not allow the reading to drop after the probe was pulled above the water. The readings were made as closely as possible but jerking the line upward would allow an intermediate reading wherever you wished. The water level appeared to fluctuate up and down by 3 feet which made the intermediate data points useless. There is no confidence in any of these readings and hence the numbers are not given to a precision of more than .5 feet.
20	170	
45	167	
60	166.5	
120	165	
180	165	

Jet Test No. 5

The hold was drilled to a TD of 2531 ft. on October 25, 1976 at 1125 hrs. The hole was not flushed at that time due to the necessity for mud in the hole to log it with minimal chance of hole collapse. During the logging, a tool was lost in the hole and had to be fished out. Following the completion of logging, the pipe string was reset in the hole and the hole was flushed with brine for 30 minutes. The drill pipe was then pulled to 720 feet and the jet test was begun.

Jetting Time:

Stop 1500 hrs
Start 1210 hrs

170 minutes at 225--185 psi measured at the Kelly gauge.

Fill Rate: 1 foot equals 650 gallons

	12"	18"	24"	30"	36"	Temp °C	Conductance μ mhos
Fill I	1222:05	1223:45	1225:35	1227:10	1229:05	19	8000
Fill II	1243:35	1245:05	1246:40	1247:55	1249:40	19	N/Checked
Fill III	1303:10	1304:55	1306:40	1307:55	1309:40	19	
Fill IV	-	1323:40	1325:10	1326:35	1328:25	19	
Fill V	1341:15	1343:05	1344:40	1346:05	1347:50	19	
Fill VI	1400:15	1401:40	1403:20	1404:50	1406:20	19	
Fill VII	1417:40	1418:50	1420:45	1422:10	1423:50	19	
Fill VIII	1434:40	1436:20	1437:40	1439:05	1440:50	18.5	
Fill IX	1453:00	1454:35	1456:10	compressor out of fuel, pressure off at 1500 hours, Sample of water taken.			

Grand Junction Testing Laboratory results:
 17,000 μ mhos.

Recovery: Readings made from 2.4 ft. above the rotary table or El 6290.4

Time hrs	Interval minutes	Depth ft	Time Interval hrs minutes	Depth ft
1500	0	-		
	10	168.05		
	20	155.55		
	25	156.20		
	50	158.40		
	55	155.95		
	65	156.35		
	75	156.25		
	85	156.20		
	90	169.80		
	105	152.70		
	120	150.00		
	150	155.80		
	180	155.40		

Prior to test, probe was redesigned to increase the resistivity, or to make a greater conductivity fluid necessary to make the indicator jump. Unit was tested in saline mud and worked prior to test. Again, as in last test, a scum fouled the probe. The readings also were erratic and the level appeared to move up and down. The probe was rinsed between readings to no avail.

VOLUME I - SECTION II
APPENDIX II
Analysis Method

APPENDIX II
ANALYSIS METHOD

The method used (Cooper & Jacob, 1946) relies upon the simplification of the well equation of Theis (1935) that

$$s = -\frac{Q}{4\pi T} (0.5772 + \ln u) \quad (1)$$

$$u = r^2 S / 4Tt$$

for $u < 0.01$ where

s = drawdown

Q = flow rate

T = transmissivity

r = radius

t = time

S = storage coefficient

Now for a well which has been pumped for a period t^* and then allowed to recover, the net drawdown experienced during the recovery phase can be found by superimposing the drawdown of a well pumped at rate Q from time $t = 0$, and the simultaneous recharge caused by an injection well at the same location injecting flow at a rate Q from time $t = t^*$.

$$\text{Drawdown } s = -\frac{Q}{4\pi T} [0.5772 + \ln (r^2 S / 4Tt)] \quad (2)$$

If we define t' , the time since the recovery started, by $t' = t - t^*$, then

$$\text{Recovery } s' = -\frac{Q}{4\pi T} [0.5772 + \ln (r^2 S / 4Tt')] \quad (3)$$

For time $t > t^*$, net drawdown

$$s_n = s - s' = -\frac{Q}{4\pi T} [\ln(r^2 s / 4Tt) - \ln(r^2 s / 4Tt')]]$$

Therefore,
$$s_n = -\frac{Q}{4\pi T} \ln(t/t') \quad (4)$$

Thus, to evaluate T , we simply plot the logarithm of t/t' against s_n , and equate the gradient to $Q/4\pi T$. It is usual to plot logarithms to base 10, so a conversion is required:

From the definition of the logarithm it can be shown that

$$\ln x = \ln 10 \times \log x \quad (6)$$

where "log" denotes logarithms to the base 10.

Hence

$$s_n = -\frac{Q}{4\pi T} (\ln 10) \log \frac{t}{t'} \quad (7)$$

For a single log cycle, $t/t' = 10$ and $\log t/t' = 1$.

Thus for a single log cycle,

$$\Delta s_n = -\frac{Q}{4\pi T} \ln 10$$

$$\text{and } T = \frac{Q \ln 10}{4\pi \Delta s_n} = \frac{0.183 Q}{\Delta s_n} \quad (8)$$

for homogeneous units.

For the more usual gallon/foot/day units,

$$T = \frac{263 Q}{\Delta s_n} \quad (9)$$

where T = transmissivity in gallons/day/foot

Q = flow, in gpm

Δs_n = drawdown in one log cycle of t/t' , in feet.

A final item of significance stems from this technique. Equilibrium is re-established at $t = \infty$. At this time, $t = t'$, and so $t/t' = 1$. This provides a method of evaluating the expected equilibrium depth to water in the test hole, when depth is plotted versus $\log t/t'$, and the characteristic straight line is back-extrapolated to unity.