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AQUIFER TESTING: PRACTICAL PROCEDURES
MARIOS SOPHOCLEOUS'NOTES

By

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1. Aquifer Tests - Introduction

Although much has been written describing the development of drawdown (response) curves and their use for determining the hydraulic properties of aquifers, little attention has been given to the mechanical aspects of test organization and data collection. In the following some of these aspects will be addressed.

The ideal way of making a pumping test is to select a well at a considerable distance from any other pumped well, one that can be discharged at a large rate and shut down at will; to install a large number of observation wells in all directions at varying distances from the well to be discharged; to observe the water levels in all available wells during the entire period of drawdown and recovery. There are no specific rules that can apply to all types of pumping tests. Each test is conducted under certain prevailing conditions. Because of the uncertainties and variable factors involved, experience and judgement of qualified persons conducting these tests are of great importance.

Some useful general guidelines suggested by the U.S. Geological Survey Water Resources Division (1968) are included here for consultation.

2. Field Precautions

2.1. Selection of the Pump Test Site

Perhaps the most important phase of any aquifer performance test is the selection of the site. Careful attention directed toward the choice of wells to be pumped or observed can save the analyzer many hours of struggle with correction factors and adjustments. Here is your opportunity to conform to the theoretical assumptions by rejecting any site that will give rise to complications. Some of the complications that might be expected in applying the theory to a water table aquifer (Fig. 16), for instance, are discussed later.

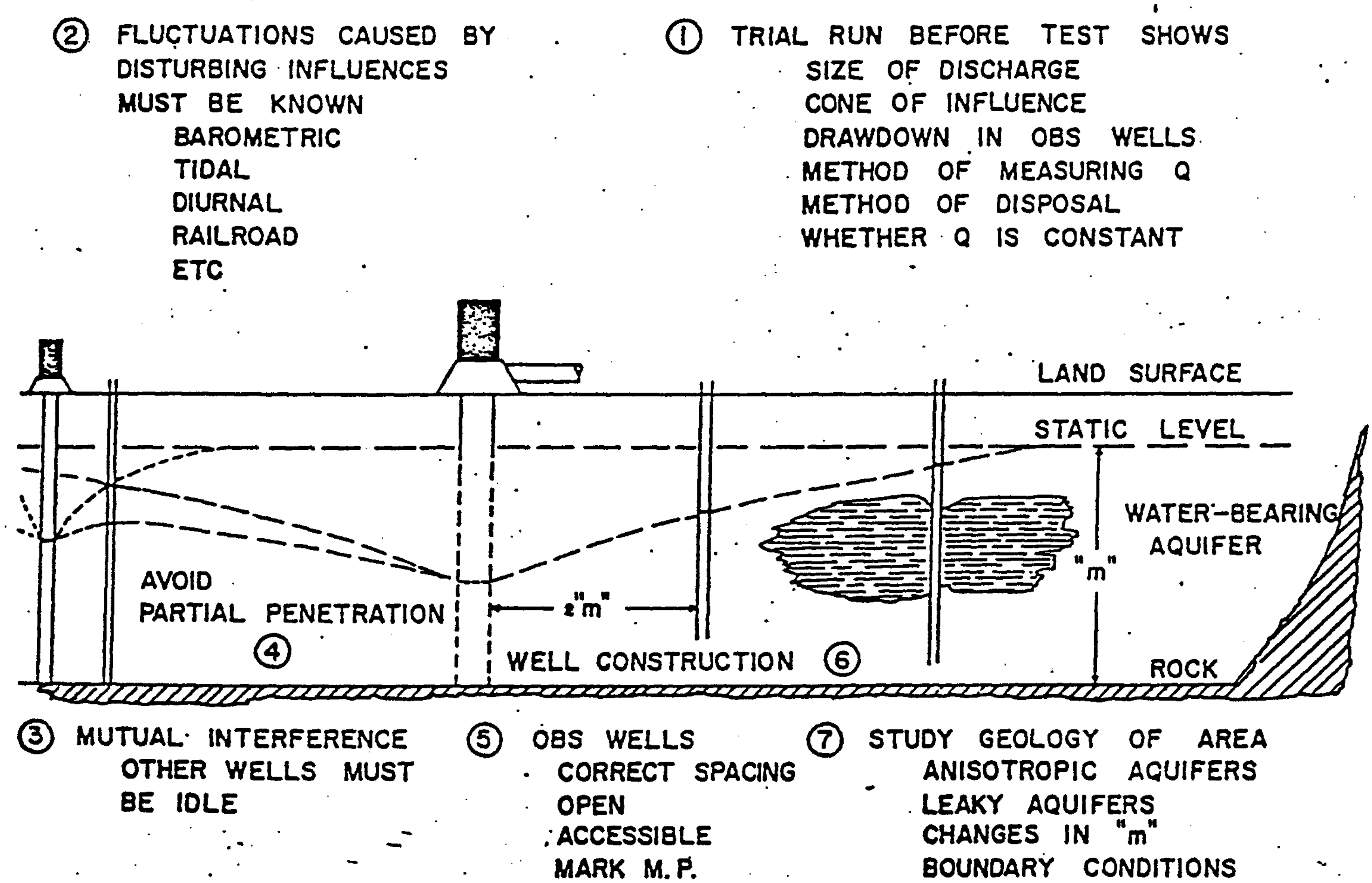

Figure 16. --Precautions in selecting a pumping test site.

2.2. Observation Wells

Item 5, Figure 16, calls your attention to the precautions that must be observed in selecting observation wells.

Observation wells must be competent wells; that is, they must be open (hydraulically) to the aquifer being tested. You can test for this by pouring water down the observation well and checking the water level a short time thereafter. As an example, for aquifers having a hydraulic conductivity of about 3,000 gallons per day, a 5-gallon slug of water should pass so rapidly that you would be able to detect, by tape measurements, only a very small change in water level in the time it would take to unreel the tape and take the measurement.

In order to avoid errors owing to partial penetration of the pumped well, an observation well must be at least two times the thickness (m) of the aquifer from the pumped well (Fig. 16). This is also a good rule to follow in order to avoid the changes in hydraulic conductivity that frequently occur in the vicinity of the pumped well. If you are forced to use a pumping well that partially penetrates the aquifer and observation wells closer than two times m, a solution may be accomplished using the appropriate correction methods (~~see page 31~~).

In selecting observation wells, try to choose a combination that will give you near, intermediate, and far observations to obtain a wider range of coverage on the type curve.

The ideal observation well would be one that fits all the above qualifications and is also adaptable to the use of a recorder. When open-casing wells are not available, manual measurements must be taken. Measuring points in this case should be readily accessible and well marked.

2.3. Discharging Well

The pumped well must have a large enough capacity to produce drawdowns in the observation wells. A trial run of the pump test (Item 1, Fig. 16) before the actual test is scheduled will reveal such information as the size of the discharge to be measured, the approximate extent of the cone of influence, the amount of drawdown to be expected in the observation wells, the method best suited to the measurement of the discharge, and the method of disposal of the water pumped. A trail run is not necessary if this information is already known. Select a pumping plant that can maintain a constant rate of discharge, or install a valve on the discharge pipe so the rate of discharge can be controlled; otherwise fluctuations will appear in the observed-data plot. Use electrically-drived pumps in preference to gasoline-driven pumps.

As stated previously, the pumped well preferably should not be a partial penetrating well. It should draw water from the full thickness of the water-bearing aquifer. A log of the well, showing where the casing is perforated or screened, would be helpful.

2.4. Fluctuations of Water Levels

The fluctuations of water levels in the area must be known, both in advance and during the test (Item 2, Fig. 16). Flucturations produced by barometric and tidal effects, railroad trains, and other pumping wells must be accounted for. Even phreatophytes may produce a marked diurnal fluctuation.

Look for and record all data pertinent to disturbing influences. It is always best to operate a recorder on at least one well in the area several days, or even weeks, before the actual test. The recorder will often reveal the number and type of fluctuations with which you will have to deal.

Many of your troubles will be due to interference caused by the operation of a nearby pump. If a complete shutdown is impracticable, a solution might still be possible, provided you record the discharge of the offending well, its distance from your test well, and the times of starting and stopping.

Item 3, Figure 16 shows what happens to the drawdown at a particular point on the cone of influence when a second cone of influence interferes. The resultant drawdown at the point of observation is the algebraic addition of the two depression cones. A similar effect takes place when the cone of depression extends outward to intercept an impervious boundary.

2.5. Geology and Water-Bearing Aquifer

Because the theory assumes an infinite isotropic and homogeneous aquifer, it will be necessary to learn as much as possible about the geology of the area before you undertake to run the test. A few of the geologic conditions which might influence the test are listed in Item 7, Figure 16. Aquifers having bedding planes, such as the shaded portion around one of the observation wells in Figure 16, are anisotropic, and hydraulic conductivity in the vertical direction may be considerably different from hydraulic conductivity in the horizontal direction. If your test is in such an area, several days of pumping might be required to obtain a representative storativity S. Large changes in aquifer thickness should be avoided, because the non-equilibrium formula assumes a constant thickness of the water-bearing materials. In thin aquifers, pumping lowers the water level sufficiently so the saturated thickness of water-bearing material is greatly altered. When this occurs, a correction factor must be applied to the observed drawdowns.

No recharge or withdrawal should occur during the operation of the test, other than that due to the well being pumped. If they do occur, the solution is more complicated. Plan to dispose of the water pumped in some manner so as to prevent its return to the aquifer.

Aquifer performance tests in confined and water table aquifers produce distinctive observed-data plots. For confined conditions, the observed-data plot will generally follow the early curvature of the type curve, while the water-table plot, showing little tendency toward following this early curvature, seems to creep up on the underside of the type curve before merging with it.

2.6. Formation and Well Losses

The drawdown in the pumped well is a combination of various effects that are customarily grouped into two classes—formation losses and well losses. Formation losses are that part of the drawdown caused by the frictional resistance of the aquifer to the flow of water and the losses due to partial penetration. The well losses are due to the frictional resistance of the screen or performations, the friction of the well casing as the water flows upward, and the change from laminar to turbulent flow conditions in the region immediately surrounding the well. The value of each loss will vary from well to well, but, in general, the major portion of the drawdown is due to formation loss. If an observation well is too close to the pumped well, the measured drawdown will be affected by formation and well losses. For this reason observation wells must be far enough distant from the pumped well to be free of these disturbances. A log of the pumped well and observation wells should be part of your basic data concerning any aquifer test.

In the following, some basic details that particularly apply to aquifer tests are discussed.

3. Measuring Pumping Rates

Control of the pumping rate during the testing requires an accurate device for measuring the discharge of the pump and a convenient means of adjusting the rate to keep it as nearly constant as possible. As the drawdown increases in the pumped well, the total pumping head increases causing the discharge to become less if it is not controlled. A valve in the discharge line of the pump provides the best control.

A simple method of determining the pumping rate is to observe the time required to fill a container of known volume. A commercial type water meter may be employed to measure the amount pumped in a given time. Also standard orifice fittings on the discharge pipe may be used.

4. Water Level Measurements (It is assumed that no prescure transducers/electronic data logging units are available)

Water levels in wells are almost constantly fluctuating and decline or rise a fraction of an inch or many feet within a relatively short time. Water levels in wells in confined aquifers under natural conditions generally fluctuate to a greater extent than water levels in water-table aquifers. Fluctuations in water levels indicate both changes in the actual quantity of water stored in aquifers and movement of groundwater. A continual decline in water level results when discharge exceeds recharge. Any pre-test trends of the water levels should be recorded as these can be extrapolated into the test period and observed drawdowns corrected accordingly.

The depth to water must be measured many times during the course of an aquifer test. Readings must be taken at close intervals during the first two hours of the test with the time between readings being gradually increased as the test continues. A detailed timing of measurements is presented further below in the section on aquifer-test procedures. Water level measurements should be recorded to the nearest ¼ inch in all observation wells. This is not always possible when measuring water level in the pumped well because of pump vibrations, etc.

Automatic recorders may be used on the observation wells to make a continuous record of water level changes. This is the best device to use, but requires observation wells of 6-inch diameter for installation. When making measurements by tape, the time at the instant of each reading must be recorded to the nearest 10 seconds. It is necessary that accurate and rapid means of making water level measurement be employed. The usual means employed are the electric sonder method, the wetted tape method and the air line method. Perhaps the handiest device to use in most cases is the electric sonder or electrical depth gauge. In order to improve the accuracy of readings, the electrode and cable of the electric gauge should be left hanging in the well for a series of readings.

5. Aquifer Test Data

In summary, the arrangements for an aquifer test must permit the following controls and measurements:

a) Constant pumping rate, even though the pumping rate may vary somewhat during the pumping period. If the pumping rate varies by more than 5% during the test, the results cannot be reliably interpreted.

b) Accurate measurements of drawdown and recovery in the pumped well and in one or more observation wells some distance away.

c) Accurate record of time for each measurement is taken as pumping proceeds.

d) Any wells within ~1,000 feet from the pumping site, which are producing a significant amount of water, will interfere with the test and may make the results obtained extremely difficult to interpret. If at all possible arrangements should be made to have such wells either shut down or produce at a constant rate for several days before the pumping test is to be started. If this cannot be done, the effects of nearby pumping wells on the water level in the well to be pumped should be observed for 2 to 3 days before the test begins, by taking periodic water-level measurements.

The aim is to get field data that permit study of the time-drawdown relationship and the distance-drawdown relationship during the period of pumping and during the period of recovery after pumping is stopped.

6. Observation Wells

The observation wells should be just large enough to allow accurate and rapid measurements of the water levels. Small diameter wells are best, since the volume of water contained in a large diameter observation well may cause a time lag in changes in drawdown. If an automatic recorder of water levels is used, the well casing must be at least 6-inch pipe. Two-inch observation wells usually serve nicely when hand methods of measuring depth to water are employed.

Observation wells should be installed to about the same depth as the middle of the well screen in the pumped well. An exception to this rule is observation wells that are terminated in strata above or below the one tapped by the pumped well to see if there is any hydraulic interconnection between the formations. This is important because it would help in determining what method of data analysis is best to use. Observation wells are commonly equipped with screens 3 to 6 feet long. Longer screens are desirable but not absolutely necessary. In unconfined aquifers, it is desirable that the observation wells completely penetrate the saturated thickness and that the casing be perforated over the entire portion that extends below the water table. This helps to insure that the water level in the observation well properly indicates the average peizometric head over the vertical section.

Mainly two factors dictate special requirements for placement of the observation wells. First, the aquifer is almost always stratified to some degree and is not uniform from top to bottom. Second, the length of the screen in the pumped well may be considerably less than the full saturated thickness of the aquifer. Both of these factors distort the distribution of hydraulic head and drawdown in the vicinity of the pumped well during the aquifer test. The distorted patterns of drawdown due to the above mentioned causes are ironed out at considerable distances from the pumped well, about 1.5 to 2 times the aquifer thickness, so that observation wells should not be located too close to the pumped well. Locating the wells too far away is not always convenient because the pumping test must be continued for a longer time in order to produce drawdown of sufficient amount at the most distant points. If several observation wells are to be used, they should be located on two radial lines making an approximate 90 degree angle with one another. This procedure will help to ascertain any deviations from symmetry that the cone of depression may exhibit.

The number of observation wells to be employed depends upon the amount of information that is desired and upon the funds available for the test program. The data obtained by measuring the drawdown at a single location outside the pumped well permit calculation of the average hydraulic conductivity and transmissivity of the aquifer and its coefficient of storage. If more observation wells are placed at different distances, the test data can be analyzed in two independent ways by studying both the time drawdown and the distance drawdown relationships. Using both these methods of analysis gives a check on the results and enhances the dependability of the conclusions. It is always better to have as many observation wells as conditions may allow.

If there is reason to suspect that water levels in observation wells are affected by factors other than pumping the well, efforts should be made to correct the drawdowns for these effects, especially if the drawdowns are relatively small. One possible source of error is a change in barometric pressure. To correct for this, the response of the water level in the observation well to barometric pressure should be observed for some period prior to pumping, so that the appropriate correction can be applied when there is a change in barometric pressure during the pumping test. Other sources of error include effects of tides or other changes in surface-water levels on groundwater tables or piezometric surfaces, pumping of other wells in the aquifer, and recharge or depletion of groundwater. If these factors are expected to significantly affect water levels in observation wells during pumping tests, groundwater levels should be observed for some time prior to pumping, so that trends can be extrapolated to the pumping period for correction of the observed drawdowns. In order to prevent these deviations as much as possible and to make them negligible, the pumping rate should be as great as feasible. A deviation of 2 cm on a drawdown of 10 cm means an error of 20%, but this value drops to only 5% when the pumping capacity is quadrupled.

7. Other Factors

The pump and power unit for an aquifer rest should be capable of continuous operation at a constant rate of pumpage for a period of at least 48 hours. In cases where the observation wells must be located at considerable distances from the pumped well, the pump must be operated continuously for several days.

The pumping rate should be measured accurately and recorded periodically. The desired pumping rate may be calculated from bail-test results which we will cover further on or estimated from previous production records and well history. Before starting the pumping tests, a complete program for depth-to-water measurements must be laid out in advance. It is not necessary to make the measurements in all the wells simultaneously. The watches used for timing the measurements, however, should be synchronized so that the time at which each reading is taken can be referred to the exact minute and hour that pumping is started.

The pumped water that is being discharged should be directed away from the test site because some of the water may leak back into the well, either through faulty well casing or through permeable ground. Thus, discharged water would then give erroneous water-level measurements and the pumping test data would not be reliable for a suitable interpretation.

8. Aquifer Test Procedure

An aquifer test procedure which is followed by the Alberta Research Council, Canada as described by J. F. Jones (1963) is presented below.

i) Measure the static water level in the well to be pumped and in all observation wells, every 2 to 3 hours for 24 hours preceding the test to determine the magnitudes of water-level fluctuations. Use the wetted-tape method or electric gauge and record the depths to water and exact times of the measurements on a log sheet, in appropriate columns.

ii) Measure the static water levels immediately before the test starts.

iii) Start the pump and record the exact time. This time is zero time (t=0) and all later times are measured from it. Measure the depths to water and record the exact time each measurement is taken, spacing the measurements, if possible, in the following manner:

a) every minute from 1 to 10 minutes.

b) every 5 minutes from 10 to 30 minutes

c) every 10 minutes from 30 minutes to 1 hour.

d) every 15 minutes from 1 to 2 hours.

e) every 30 minutes from 2 to 4 hours.

f) every 60 minutes from 4 to 12 hours.

g) every 120 minutes from 12 to 24 hours.

h) if the test is longer than 24 hours, take measurements every 6 hours until 48 hours.

For confined aquifers, the pumping test will usually end at 48 hours, but for unconfined aquifers, it may take several days or longer to establish the equilibrium conditions that are necessary when treating data from such aquifers. Water level measurements should be taken every 12 hours after 48 hours until the end of the test if the aquifer is confined. Tables 4 and 5 are examples of typical pump test data.

iv) Pumping should continue at constant rate for the duration of the test. If field conditions make it impossible to run the test at a constant rate for the recommended period of 48 hours in the case of a confined aquifer, a shorter test may provide sufficient information.

v) When the pump is shut off, start taking water-level measurements immediately to determine the rate of recovery following the same measurement schedule used for pump testing. This is particularly important if the pumping rate has varied slightly during the course of the test, as the average pumping rate can be used with these data, thus minimizing any errors that might have been introduced. Recovery measurements should be taken for a minimum period of 12 hours and preferably until the water levels approach the original non-pumping or static levels. Table 6 is an example of such recovery data. This information, perperly collected, can be used in the design of the well system.

RESEARCH COUNCIL OF ALBERTA - Groundwater Division

Water-Level Measurements (field)

Location of project Town of Cardium, Alta. Test conducted by: Big Well Drilling Ltd. Measured by: J. H. George

Well location: Lsd. or 1/4 SW Sec. 7 Tp. 58 R. 10 Mer. W. 6th

Status Pumping well #1 (pumping or observation well) R = 0' (distance from pumping well in feet and direction) Date June 1, 1962 Page 1

Lot 3, Block 7

Date	Time hrs. & mins.	Elapsed time in mins.	Tape Reading at Meas. Point	Tape Reading at Water Level	Depth to water in feet	Draw-down in feet	Q = discharge gpm		Remarks (i.e. pump adjustments, water temp., static level, etc.)
May 31	6:00 pm		17 00	1.39	15.61				Static or nonpumping level measured
	7:00 pm		17.00	1.58	15.42				with a steel tape
	10:00 pm		17.00	1.70	15.30				
	12:00 pm		17.00	1.71	15.29				
June 1	6:00 am		17.00	1.73	15 27				Pump set up previous day, discharge
	7:00 am		17.00	1.73	15.27				set at 45 Imp. gpm.
	8:00 am		17.00	1.73	15.27				
	8:30 am		17.00	1.73	15.27				
	8:55 am		17.00	1 73	15.27				
June 1	9:00 am	0	17.00	1.73	15.27		45		Start pump test
	9:01	1	17.00	0.5	15.5	1.2			Measurements on pumping well with
	9:02	2	20.0	3.1	16.9	1.6			electric tape
	9:03	3	20.0	2.8	17.2	1.9			
	9:04	4	20.0	2.7	17.3	2.0			
	9:05	5	20.0	2.3	17.7	2.4	45		1 minute to fill 45 gallon drum
	9:06	6	20.0	2.2	17.8	2.5			
	9:07	7	20.0	2.1	17.9	2.6			
	9:08	8	20.0	1.9	18.1	2.8			
	9:09	9	20.0	1.8	18.2	2.9	45		1 minute to fill 45 gallon drum
	9:10	10	20.0	1.7	18.3	3.0			Water sample at 9:10 am
	9:15	15	20.0	1.7	18.3	3.0			Temp. = 42.5° F.
	9:20	20	20.0	1.6	18.4	3.1	46		59 secs. to fill 45 gallon drum
	9:25	25	20.0	1.5	18.5	3.2			Pump adjusted slightly
	9:30	30	20.0	1.4	18.6	3.3	45		45 gallons in 60 secs.
	9:40	40	20.0	1.3	18.7	3.4			
	9:50	50	20.0	1.2	18.8	3.5			Pumping well and observation wells
	10:00 am	60	20.0	1.1	18.9	3.6			Locations shown on attached sketch

Table 4. Typical pump-test data - pumping well

RESEARCH COUNCIL OF ALBERTA – Groundwater Division

Water Level Measurements (field)

Location of project: Town of Cardium, Alta. Test conducted by: Big Well Drilling Ltd. Measured by: R. A. James

Well location: Lsd. or 1/4 SW Sec. 7 Tp. 58 R. 10 Mer. W 6th

Status: Observation Well #1 (pumping or observation well) R = 300' East of pumping well #1 (distance from pumping well in feet and direction) Date June 1/62 Page 1

Date	Time hrs. & mins.	Elapsed time in mins.	Tape reading at Meas. Point	Tape reading at Water Level	Depth to water in feet	Draw-down in feet	Q = discharge gpm		Remarks (i.e. pump adjustments, water temp., static level, etc.)
May 31	6:10 pm		18.00	1.98	16.02				Static or nonpumping level
	7:10 pm		18.00	2.14	15.86				measurements
	10:10 pm		18.00	2.23	15.77				
June 1	12:10 am		18.00	2.29	15.71				Measurement by chalked steel tape
	6:10 am		18.00	2.30	15.70		Nil. Observation Well		to nearest one-hundredth of a foot
	7:10 am		18.00	2.29	15.71				
	8:10 am		18.00	2.30	15.70				
	8:40 am		18.00	2.30	15.70				
	8:58 am		18.00	2.30	15.70				
June 1	9:00 am		18.00	2.30	15.70	0.0			Testing started at 9:00 a.m.
	9:01 am		18.00	2.29	15.71	0.01			
	9:02	2	18.00	2.28	15.72	0.02			
	9:03	3	18.00	2.27	15.73	0.03			
	9:04	4	18.00	2.25	15.75	0.05			
	9:05	5	18.00	2.23	15.77	0.07			
	9:06	6	18.00	2.17	15.83	0.13			
	9:07	7	18.00	2.09	15.91	0.21			
	9:08	8	18.00	1.97	16.03	0.33			
	9:09	9	18.00	1.83	16.17	0.47			
	9:10	10	18.00	1.69	16.31	0.61			
	9:15	15	18.00	1.49	16.51	0.81			
	9:20	20	18.00	1.39	16.61	0.91			
	9:25	25	18.00	1.29	16.71	1.01			
	9:30	30	18.00	1.20	16.80	1.10			
	9:40	40	18.00	1.11	16.89	1.19			
	9:50	50	18.00	1.03	16.97	1.27			
	10:00 am	60	18.00	0.97	17.03	1.33			

Table 5. Typical pump-test data – observation well

RESEARCH COUNCIL OF ALBERTA - Groundwater Division

Water Level Measurements (field)

Location of project: Town of Cardium, Alta.
Status: Observation Well (pumping or observation well)

Test conducted by: Big Well Drilling Ltd.
Well location: Lsd. or 1/4 SW Sec. 7 Tp. 58 R. 10 Mer. 6th
R = 300' east of pumping well #1 (distance from pumping well in feet and direction)

Measured by: R. A. James
Date: June 3/62 Page 4

Date	Time hrs. & mins.	Elapsed time in mins.	Tape Reading at Meas. Point	Tape Reading at Water Level	Depth to water in feet	Draw-down in feet	Q = discharge gpm		Remarks (i.e. pump adjustments, water temp., static level, etc.)
June 3	9:00 a.m.	2880	32.00	1.60	31.40	15.70			Pump stopped
	9:01 a.m.	2881	32.00	5.60	26.40	10.70			Recovery
	9:02 a.m.	2882	32.00	8.40	23.60	7.90			Measurements by chalked steel tape to
	9:03 a.m.	2883	32.00	10.19	21.81	6.11			nearest one-hundredth of a foot.
	9:04 a.m.	2884	20.00	0.20	19.80	4.10			
	9:05 a.m.	2885	18.00	0.35	17.65	1.95			
	9:06 a.m.	2886	18.00	0.50	17.50	1.80			
	9:07	2887	18.00	0.60	17.40	1.70			Original static
	9:08	2888	18.00	0.70	17.30	1.60			June 1, 1962, @ 9:00 a.m. 15.70
	9:09	2889	18.00	0.75	17.25	1.55			
	9:10	2890	18.00	0.80	17.20	1.50			
	9:15	2895	18.00	0.85	17.15	1.45			
	9:20	2900	18.00	0.90	17.10	1.40			
	9:25	2905	18.00	0.96	17.04	1.34			
	9:30	2910	18.00	0.99	17.01	1.33			
	9:40	2920	18.00	1.01	16.99	1.27			
	9:50	2930	18.00	1.04	16.96	1.26			
	10:00	2940	18.00	1.06	16.94	1.24			
	10:15	2955	18.00	1.15	16.85	1.15			
	10:30	2970	18.00	1.25	16.75	1.05			
	10:45	2985	18.00	1.37	16.63	0.93			
	11:00	3000	18.00	1.45	16.55	0.85			
	11:30	3030	18.00	1.50	16.50	0.80			
	12:00 noon	3060	18.00	1.54	16.46	0.76			
	12:30 p.m.	3090	18.00	1.68	16.32	0.62			
	1:00 p.m.	3120	18.00	1.70	16.30	0.60			
	1:30 p.m.	3150	18.00	1.85	16.15	0.45			

Table 6. Typical recovery-test data