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TWO AQUIFER TESTS IN WINNIPEG AND BRANDON MAP-AREAS, MANITOBA, 1962

(Report and 14 figures)

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By

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ABSTRACT

In the summer of 1962, tests were carried out to determine the hydraulic characteristics of two completely different aquifers, in conjunction with a hydrogeological study of the Red River Valley, Manitoba.

The Winkler test was made in a thick surficial deposit of sand and gravel, and the large transmissibility value obtained indicated that a large quantity of water is readily available for future use.

The St. Pierre test on the other hand was made in a bedrock aquifer where fractures control the availability of water. It showed that more than 100,000 gallons per day can be obtained from this aquifer by drilling a small-diameter well.

The results obtained from these two tests are used to solve several local groundwater problems and should also prove useful in comparing these two types of aquifers with similar types in other regions.

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TWO AQUIFER TESTS IN WINNIPEG AND BRANDON MAP-AREAS, MANITOBA, 1962

INTRODUCTION

A study of the hydrogeology of the Red River Valley, Manitoba, has been in progress since 1959. As a part of this study, aquifer tests were conducted on two entirely different types of aquifers to assess quantitatively their potential.

The first of these is a sand and gravel aquifer near the town of Winkler. This aquifer was located by the Manitoba government in the spring of 1961 when they drilled eight holes in the immediate vicinity of Winkler, in an effort to obtain a water supply for the town. A pump-test, conducted by the Manitoba government, indicated a safe yield of 100 gpm (gallons per minute). As a follow through, in the summer of the same year, a drilling crew of the Federal Department of Public Works drilled thirteen holes for the Geological Survey of Canada, to trace the northwestern extension of the aquifer. During the summer of 1962 a pumping-test was conducted in a thick sand and gravel section near the north end of this aquifer.

The second test is in a confined bedrock aquifer near St. Pierre. This aquifer has been known for some time (Johnston, 1934)[1] and many flowing wells have been drilled into it, but quantitative data were lacking. During the summer of 1962 the same drilling crew of the Federal Department of Public Works drilled two holes into this aquifer for the Geological Survey of Canada, and a pumping-test was carried out.

AN AQUIFER TEST, WINKLER, MANITOBA

In 1960, following a groundwater study carried out during the summer of 1959, the writer (Charron, 1960), reported that "The area of approximately 48 square miles surrounding Winkler has the greatest potential groundwater resources in the Plum Coulee region. The extent of these resources could be established by a systematic drill-hole program, with the holes having a minimum depth of 160 feet and a maximum depth of 290 feet."

[1] Names and/or dates in parentheses refer to publications listed in the References.

There were three reasons why the previous statement was made: (1) a gravel pit located in 11-4-5W; (2) a very good water supply from a shallow well situated in 1-4-5W; and (3) a fairly large quantity of water yielded by the individual wells in the town of Winkler. A line joining these three locations ran in a northwesterly direction. The writer suspected that a potential aquifer might be present along this line.

In the winter of 1960-61 the town of Winkler became interested in finding a water supply, and towards this end the Manitoba government drilled eight holes around the town (Fig. 1) in the spring of 1961. These holes revealed an aquifer of sand and gravel, which was pump-tested at a rate of 25 gpm. This pump-test showed that a yield of 100 gpm was feasible.

In the summer of the same year the Geological Survey of Canada undertook a drilling program to carry on the groundwater study of the region. With the information supplied by the Manitoba government the drilling was intended to find the northwest extension of this aquifer. The drilling program, which consisted of thirteen holes drilled by a crew of the Federal Department of Public Works, traced the aquifer some 7 miles to the northwest of Winkler (Fig. 1). The best hole (No. 8) penetrated about 165 feet of sand and gravel. In the summer of 1962 a pump-test was carried out near this hole to determine the quantitative and qualitative aspects of this sand and gravel aquifer.

PHYSICAL FEATURES AND GEOLOGY

The outstanding physical feature of the area is the characteristic broad, flat expanse of terrain, in which the only natural break is a beach ridge that rises 5 to 10 feet above the plain.

The entire area, except the northernmost tip of the aquifer, consists of lacustrine deposits of Lake Agassiz. These deposits can be divided vertically into a silty unit and a clayey unit. The silty unit is brown, fine-grained (0.05 to 0.005 mm), and 10 to 30 feet thick. The clay unit is grey to bluish grey, very fine grained (less than 0.005 mm) and 20 to 60 feet thick. The silt unit is considered in this area as an unconfined aquifer whereas the clay unit is considered as an aquiclude[1].

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[1] Impermeable strata which may contain water but only transmits it at a very low rate.

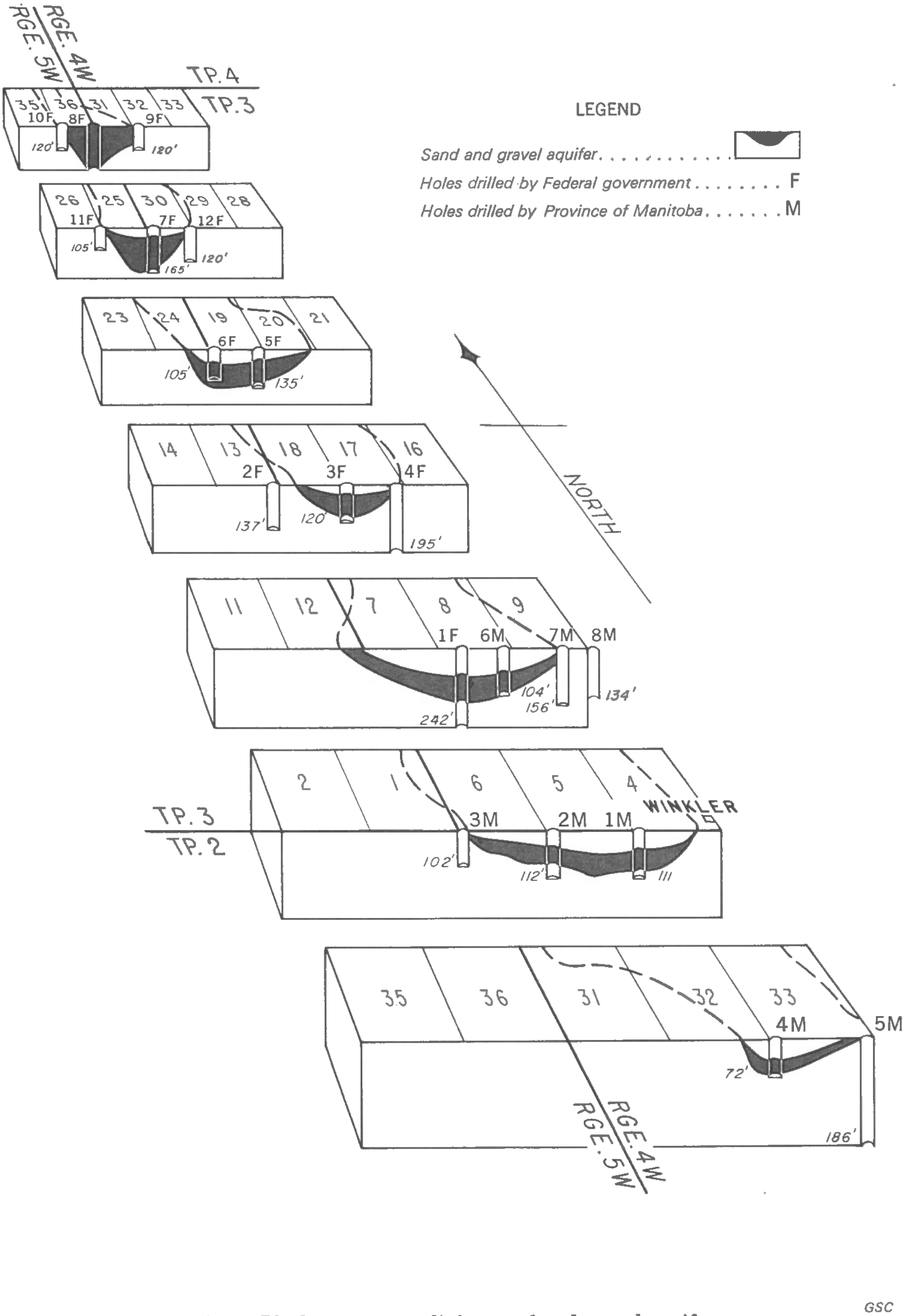


Fig. 1. Block diagram outlining sand and gravel aquifer

Till underlies these lacustrine deposits. It varies in composition from a watery quicksand to a solid dry pebbly hardpan, which is generally considered by the drillers as being harder than the bedrock underlying it. The aquifer itself may be part of this till and/or the same age as it, but is quite different in composition. It could be better described as a long narrow outwash deposit in a trough (Fig. 1). Its thickness is considerable as it is more than 200 feet thick at the north end.

The bedrock underlying the till is Cretaceous shale. Near Winkler a white unconsolidated sand about 45 feet thick was intersected below the shale during drilling operations; this sand may be a part of the Swan River Group, which is known to exist farther to the west. Very salty water (10,000 ppm) was obtained from this sand when pump-tested at 80 gpm. The Cretaceous shale is considered to be an aquiclude. No information is presently available on the geologic formations beneath this sand.

TESTING THE AQUIFER

Location

The site chosen for the pump-test was SE 36-3-5, west of the principal meridian and about 1,000 feet west of hole No. 8F (Fig. 2). It is 2 miles west and 5 miles north of the town of Winkler, along highway No. 3 (lat. 49°15', long. 98°00'). The approximate elevation of the drill site is 918 feet above sea-level.

Well Drilling

Five wells were drilled, one 6-inch and four 4-inch, inside diameter, wells. In the 6-inch (or main) well, a 5-inch by 15-foot-long iron screen with No. 93 slot openings was installed. In each of the four observation wells a 2-inch by 4-foot-long plastic screen with No. 10 slot openings was installed. The four observation wells were drilled 25 feet north, south, east, and west of the main well (Fig. 2). Apart from a foot of top soil and some big boulders (1 foot and 2 feet across) 10 to 15 feet below ground level, the five holes penetrated only sand and some lenses of gravel (Fig. 3, hole No. 8F). The wells were rotary drilled by a crew of the Department of Public Works.

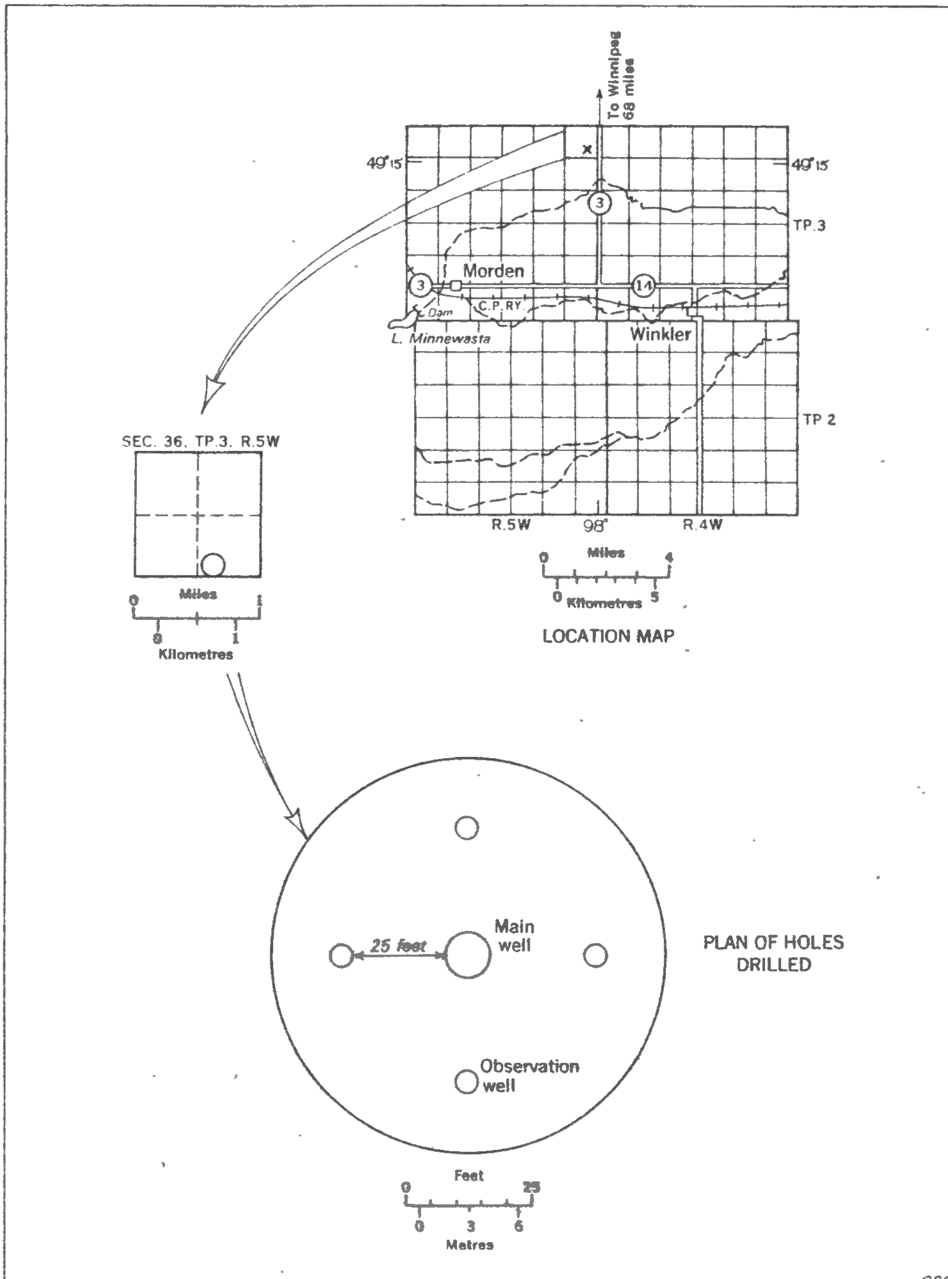


Figure 2. Location map of Winkler pump test area and plan of holes drilled

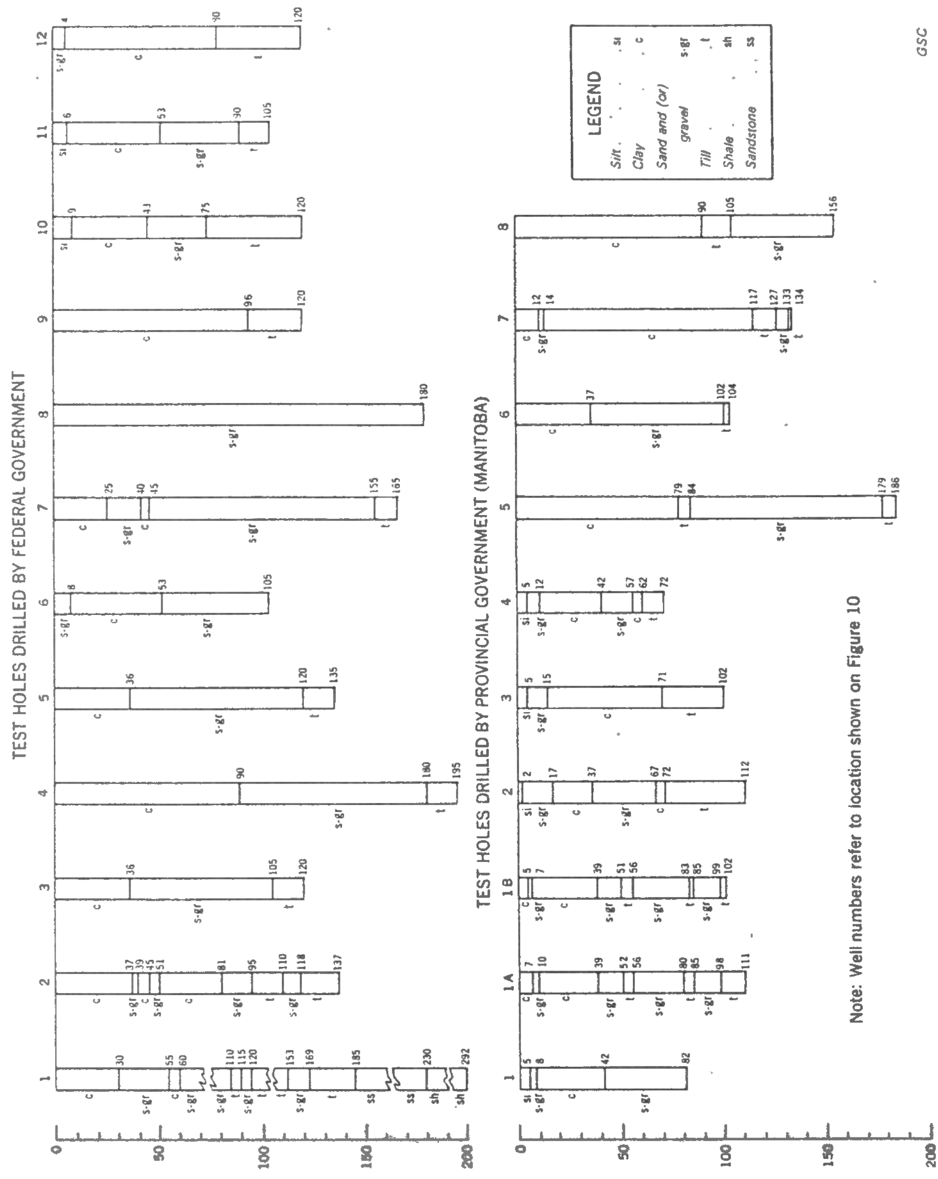


Figure 3. Logs of holes drilled in Winkler area

Data on the five wells follows. All measurements during the pump-test for drawdown as well as for the recovery were made from the top of the casing, which in each instance was 2 1/2 feet above ground level.

	Main Well	Well A	Well B	Well C	Well D
Depth	202.0'	201.5'	201.0'	201.0'	196.5'
Diameter	6"	4"	4"	4"	4"
Elevation of top of casing	919.00'	919.18'	919.77'	918.93'	918.11'
Static water level, 10.00 a.m. 25-7-62	--	897.32'	897.39'	897.36'	897.40'
Length of screen	15'	4'	4'	4'	4'
Elevation of screen setting (bottom of screen)	717.00'	717.68'	718.77'	717.93'	721.68'

<u>Pump-test</u>

Preliminary tests were carried out prior to the main pump-test to determine the final rate of pumping. At first, without a screen, pumping was attempted at various depths in the main well as the drilling progressed. A 125-cfm (cubic feet per minute) air compressor was used for these trial runs and difficulty was encountered in fine sand being sucked up the casing and plugging it. In fact, in each attempt, pumping ceased after a few minutes. Then at the 202-foot level a boulder was encountered and the casing was driven down to rest against that boulder in the hope that only a limited part of the 6-inch opening would allow fine sand to come in and that eventually natural sorting would form a gravel pack around the end of the casing, thus preventing fine sand from coming in altogether. At the beginning the well only yielded 4 gpm; with further development it yielded 12 gpm and 16 gpm, then more than 100 gpm. By this time the drawing-out of the fine sand had created a void around the casing, and the boulder had dropped 10 feet below the end of the casing. It was then decided that no more drilling was required and that the screen was to be dropped at that depth. After the 15-foot screen was installed, a maximum capacity of 500 U.S. gpm (or 416 Imperial gpm) was recorded. The pumping rate was measured through a 90-degree weir. For the 72-hour pump-test, a 315-cfm air compressor supplied the power through 127 feet of 2-inch air line using the 6-inch casing as eductor pipe. Because of the preliminary pump-testing, all activities were stopped for 2 days prior to the test in order to establish natural equilibrium in the aquifer.

For 1 hour prior to the pump-test, static water-level (S.W.L.) readings were taken every 10 minutes. The pump-test was started at 11:00 a.m. on July 25, 1962. The drawdown was measured in the four observation wells. No measurements were obtained from the main well as it was entirely required for pumping at 416 Imperial gpm.

The maximum drawdown after 3 days of pumping occurred in well A and was only 1.33 feet.

After 72 hours, pumping was stopped and recovery measurements were obtained in the same manner as for the drawdown; 51 hours after pumping had stopped, well A had completely recovered. Some 21 hours later the other three wells had almost but not quite fully recovered (Fig. 4).

Tables I and II give the readings for the drawdown and recovery in each observation well as well as the time each reading was made.

Table I

Winkler Pump-test Data (July 25-28, 1962)

Date	Time	Drawdown (feet)			
		A	B	C	D
July 25, 1962	10.00 a.m.	0.01	0.01	0.00	0.00
	10.10	0.01	0.01	0.00	0.00
	10.20	0.00	0.00	+0.01	0.00
	10.30	0.00	0.01	+0.01	0.00
	10.40	0.00	0.00	+0.01	+0.01
	10.50	0.00	0.00	0.00	0.00
	11.00	0.00	0.00	0.00	0.00
	11.01	0.99	0.69	0.76	0.75
	11.02	0.99	0.70	0.78	0.77
	11.03	1.00	0.70	0.78	0.77
	11.04	1.01	0.71	0.78	0.77
	11.05	1.01	0.71	0.78	0.77
	11.06	1.01	0.72	0.78	0.77
	11.07	1.01	0.71	0.78	0.77
	11.08	1.01	0.71	0.79	0.77
	11.09	1.01	0.72	0.79	0.78
	11.10	1.01	0.72	0.79	0.78

Table I (cont.)

Date	Time	Drawdown (feet)			
		A	B	C	D
July 25, 1962	11.11 a.m.	1.02	0.72	0.80	0.78
	11.12	1.02	0.72	0.80	0.78
	11.13	1.02	0.72	0.80	0.78
	11.14	1.02	0.72	0.80	0.78
	11.15	1.02	0.72	0.80	0.77
	11.17	1.02	0.73	0.80	0.78
	11.20	1.02	0.73	0.81	0.78
	11.22	1.02	0.74	0.81	0.78
	11.25	1.02	0.74	0.81	0.78
	11.27	1.03	0.74	0.82	0.78
	11.30	1.03	0.74	0.82	0.78
	11.33	1.04	0.74	0.82	0.78
	11.37	1.04	0.75	0.82	0.78
	11.40	1.04	0.75	0.82	0.78
	11.44	1.04	0.76	0.83	0.78
	11.48	1.05	0.76	0.84	0.78
	11.52	1.05	0.77	0.84	0.78
	11.56	1.05	0.76	0.84	0.77
	12.00 p.m.	1.05	0.77	0.84	0.76
	12.04	1.06	0.77	0.84	0.75
	12.10	1.06	0.78	0.85	0.75
	12.16	1.07	0.78	0.85	0.75
	12.20	1.06	0.78	0.86	0.75
	12.24	1.06	0.78	0.86	0.75
	12.30	1.07	0.78	0.86	0.75
	12.36	1.07	0.79	0.86	0.75
	12.40	1.07	0.79	0.86	0.75
	1.00	1.08	0.80	0.88	0.75
	1.30	1.09	0.80	0.87	0.75
	2.20	1.10	0.83	0.88	0.77
	3.00	1.11	0.84	0.90	0.61
	4.00	1.13	0.85	0.92	0.64
	5.00	1.13	0.87	0.93	0.63
	6.00	1.14	0.88	0.93	0.63
	7.00	1.16	0.89	0.96	0.65
	8.00	1.17	0.90	0.96	0.66
	9.00	1.18	0.91	0.98	0.68
	10.00	1.19	0.93	1.00	0.68
	11.00	1.20	0.93	1.00	0.70

Table I (cont.)

Date	Time	Drawdown (feet) A	B	C	D
July 26, 1962	12.00 a.m.	1.21*	0.94	1.01	0.70
	1.00	1.21	0.94	1.02	0.71
	2.00	1.22	0.95	1.03	0.72
	3.00	1.22	0.95	1.03	0.71
	4.00	1.22	0.96	1.04	0.71
	5.00	1.23	0.96	1.05	0.73
	6.00	1.24	0.97	1.06	0.73
	7.00	1.24	0.98	1.06	0.74
	8.00	1.25	0.98	1.07	0.74
	9.00	1.24	0.99	1.07	0.75
	10.00	1.24	0.99	1.07	0.75
	11.00	1.22	0.97	1.04	0.74
	12.00 p.m.	1.23	0.96	1.05	0.73
	1.00	1.23	0.97	1.05	0.73
	2.00	1.23	0.98	1.06	0.74
	3.00	1.24	0.98	1.05	0.74
	4.00	1.23	0.98	1.05	0.74
	5.00	1.23	0.97	1.05	0.74
	6.00	1.23	0.97	1.06	0.75
	7.00	1.23	0.98	1.07	0.76
	8.00	1.25	0.98	1.08	0.77
	9.00	1.25	1.00	1.08	0.78
	10.00	1.26	1.00	1.09	0.78
	11.00	1.26	1.00	1.10	0.78
July 27, 1962	12.00 a.m.	1.26	1.00	1.10	0.78
	1.00	1.26	1.00	1.10	0.78
	2.00	1.25	1.00	1.10	0.78
	3.00	1.26	1.01	1.10	0.78
	4.00	1.28	1.03	1.10	0.79
	5.00	1.28	1.02	1.10	0.79
	6.00	1.28	1.02	1.11	0.79
	7.00	1.28	1.02	1.11	0.79
	8.00	1.28	1.02	1.11	0.79
	9.00	1.27	1.02	1.11	0.79
	10.00	1.27	1.02	1.11	0.80
	11.00	1.26	1.01	1.09	0.80
	12.00 p.m.	1.28	1.01	1.09	0.80

* This drawdown figure checks exactly with the corresponding recovery figure as explained in the section "Transmissibility and Storage Coefficient", following Table II.

Table I (cont.)

Date	Time	Drawdown (feet)			
		A	B	C	D
July 27, 1962	1.00 p.m.	1.27	1.02	1.09	0.80
	2.00	1.26	1.00	1.08	0.78
	3.00	1.27	1.03	1.11	0.81
	4.00	1.28	1.03	1.11	0.81
	5.00	1.28	1.03	1.11	0.80
	6.00	1.28	1.03	1.12	0.81
	7.00	1.29	1.04	1.12	0.82
	8.00	1.30	1.04	1.12	0.83
	9.00	1.30	1.04	1.13	0.84
	10.00	1.31	1.05	1.14	0.84
	11.00	1.32	1.06	1.15	0.84
July 28, 1962	12.00 a.m.	1.32	1.06	1.15	0.83
	1.00	1.32	1.05	1.13	0.83
	2.00	1.31	1.05	1.14	0.83
	3.00	1.32	1.05	1.14	0.83
	4.00	1.32	1.05	1.14	0.83
	5.00	1.33	1.05	1.15	0.83
	6.00	1.33	1.06	1.15	0.84
	7.00	1.33	1.06	1.14	0.84
	8.00	1.32	1.06	1.14	0.83
	9.00	1.32	1.06	1.14	0.84
	10.00	1.30	1.04	1.13	0.83
	11.00	1.30	1.04	1.12	0.83

Table II

Winkler Pump-test Data (July 28-31, 1962)

Date	Time	Recovery (feet)			
		A	B	C	D
July 28, 1962	11.00 a.m.	0.00	0.00	0.00	0.00
	11.01	0.95	0.66	0.71	0.42
	11.02	0.96	0.68	0.75	0.42
	11.03	0.97	0.68	0.75	0.44
	11.04	0.97	0.68	0.76	0.44

Table II (cont.)

Date	Time	Recovery (feet)			
		A	B	C	D
July 28, 1962	11.05 a.m.	0.97	0.68	0.76	0.44
	11.06	0.97	0.69	0.76	0.45
	11.07	0.98	0.69	0.77	0.45
	11.08	0.98	0.69	0.77	0.45
	11.09	0.98	0.70	0.77	0.45
	11.10	0.98	0.70	0.78	0.45
	11.11	0.99	0.70	0.78	0.46
	11.12	0.99	0.70	0.78	0.47
	11.13	0.99	0.70	0.78	0.47
	11.14	1.00	0.70	0.78	0.47
	11.15	1.00	0.72	0.78	0.47
	11.17	1.00	0.71	0.79	0.47
	11.20	1.01	0.72	0.79	0.47
	11.22	1.01	0.72	0.80	0.48
	11.25	1.01	0.72	0.80	0.48
	11.27	1.02	0.73	0.81	0.48
	11.30	1.02	0.73	0.81	0.48
	11.33	1.02	0.74	0.81	0.49
	11.37	1.03	0.73	0.81	0.49
	11.40	1.03	0.74	0.82	0.49
	11.44	1.04	0.74	0.82	0.50
	11.48	1.04	0.75	0.82	0.50
	11.52	1.05	0.75	0.82	0.50
	11.56	1.05	0.75	0.82	0.50
	12.00 p.m.	1.05	0.76	0.82	0.50
	12.04	1.06	0.76	0.83	0.52
	12.10	1.06	0.76	0.83	0.52
	12.16	1.06	0.76	0.83	0.52
	12.20	1.07	0.76	0.84	0.53
	12.24	1.07	0.76	0.85	0.53
	12.30	1.08	0.77	0.85	0.54
	12.36	1.07	0.78	0.85	0.54
	12.40	1.08	0.78	0.86	0.54
	1.00	1.10	0.79	0.87	0.55
	1.30	1.11	0.80	0.88	0.58
	2.20	1.12	0.82	0.91	0.60
	3.00	1.13	0.83	0.92	0.60
	4.00	1.15	0.85	0.93	0.62
	5.00	1.16	0.85	0.94	0.62
	6.00	1.17	0.87	0.95	0.65

Table II (cont.)

Date	Time	Recovery (feet)			
		A	B	C	D
July 28, 1962	7.00 p.m.	1.18	0.88	0.96	0.65
	8.00	1.18	0.89	0.96	0.65
	9.00	1.19	0.90	0.97	0.66
	10.00	1.20	0.90	0.98	0.67
	11.00	1.21	0.91	0.99	0.67
July 29, 1962	12.00 a.m.	1.21*	0.91	1.00	0.68
	1.00	1.23	0.93	1.01	0.69
	2.00	1.25	0.95	1.03	0.71
	3.00	1.25	0.95	1.03	0.71
	4.00	1.25	0.96	1.04	0.72
	5.00	1.27	0.97	1.06	0.74
	6.00	1.25	0.95	1.03	0.71
	7.00	1.26	0.96	1.05	0.72
	8.00	1.26	0.95	1.03	0.72
	9.00	1.28	0.98	1.05	0.74
	10.00	1.26	0.96	1.04	0.73
	11.00	1.25	0.96	1.04	0.72
	12.00 p.m.	1.23	0.92	0.99	0.68
	1.00	1.23	0.93	1.01	0.69
	2.00	1.24	0.93	1.02	0.70
	3.00	1.25	0.94	1.03	0.72
	4.00	1.27	0.96	1.03	0.72
	5.00	1.26	0.96	1.04	0.73
	6.00	1.26	0.97	1.05	0.74
	7.00	1.26	0.97	1.04	0.73
	8.00	1.26	0.95	1.04	0.73
	9.00	1.26	0.95	1.04	0.73
	10.00	1.27	0.96	1.05	0.74
	11.00	1.27	0.97	1.05	0.74
July 30, 1962	12.00 a.m.	1.28	0.97	1.05	0.74
	1.00	1.28	0.98	1.06	0.75
	2.00	1.28	0.99	1.06	0.76
	3.00	1.29	1.00	1.06	0.76
	4.00	1.29	0.99	1.07	0.77
	5.00	1.29	0.99	1.07	0.77

* This recovery figure checks exactly with the corresponding drawdown figure as explained in the section "Transmissibility and Storage Coefficient", following this table.

Table II (cont.)

Date	Time	Recovery (feet)			
		A	B	C	D
July 30, 1962	6.00 a.m.	1.29	1.00	1.07	0.77
	7.00	1.30	1.01	1.08	0.78
	8.00	1.31	1.01	1.09	0.78
	9.00	1.33	1.03	1.10	0.80
	10.00	1.32	1.02	1.10	0.78
	11.00	1.32	1.02	1.11	0.79
	12.00 p.m.	1.32	1.03	1.10	0.78
	1.00	1.33	1.03	1.11	0.79
	2.00	1.33	1.03	1.11	0.80
	3.00	--	1.03	1.11	0.80
	4.00	--	1.03	1.11	0.80
	5.00	--	1.02	1.10	0.80
	6.00	--	1.03	1.11	0.80
	7.00	--	1.03	1.11	0.80
	8.00	--	1.03	1.10	0.79
	9.00	--	1.01	1.09	0.76
	10.00	--	1.01	1.09	0.77
	11.00	--	1.01	1.09	0.78
July 31, 1962	12.00 a.m.	--	1.01	1.09	0.78
	1.00	--	1.01	1.09	0.78
	2.00	--	1.01	1.09	0.78
	3.00	--	1.00	1.09	0.78
	4.00	--	1.01	1.09	0.77
	5.00	--	1.02	1.09	0.77
	6.00	--	1.02	1.09	0.78
	7.00	--	1.02	1.10	0.77
	8.00	--	1.02	1.09	0.78
	9.00	--	1.02	1.09	0.78
	10.00	--	1.02	1.10	0.79
	11.00	--	1.02	1.10	0.78
	12.30 p.m.	--	1.03	1.12	0.79

HYDRAULIC CHARACTERISTICS OF THE AQUIFER

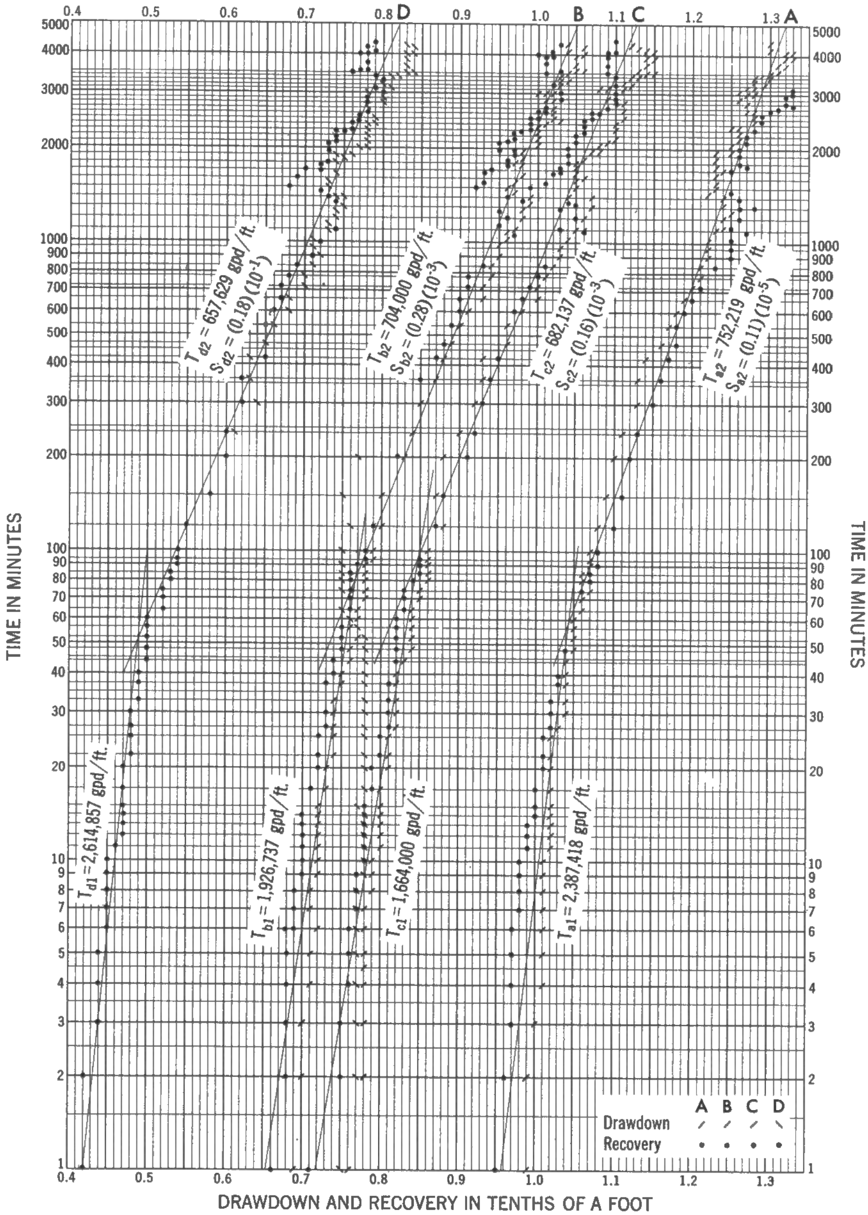
Transmissibility and Storage Coefficient

Figure 5 is a time-drawdown and a time-recovery graph for the four observation wells. From this, using the Jacob's Method (Cooper and Jacob, 1946; Jacob, 1950) of the non-equilibrium formula, the writer has calculated the transmissibility (T) and storage coefficient (S) value of the aquifer.

Apart from observation well D, the drawdown and recovery values are almost identical in each well, as well as being identical between one well and another. Table I shows that after 13 hours of pumping the drawdown in observation well A was 1.21 feet, and Table II shows that 13 hours after pumping had stopped the recovery in the same well was 1.21 feet (see asterisk). Why well D was erratic in the first 200 minutes of the pump-test is not known.

The Theis non-equilibrium time-drawdown curve was not used to analyze this pump-test because the largest percentage of the drawdown occurred within the first minute of the pump-test and the remaining drawdown was negligible in proportion to the time. In other words, equilibrium was reached too quickly. A higher rate of pumping would have probably given better results because a larger drawdown figure could have been obtained, but this would have necessitated a larger-diameter well and a deep-well turbine pump. Additional information might also have been obtained if the observation wells had not been equidistant from the main well and from one another. Other methods could then have been used (e.g. the Thiem Formula) to calculate the transmissibility and storage-coefficient figures, and a comparison could have been made of these results obtained by various mathematical formulas. By placing the observation wells equidistant from the main well and from one another it was hoped that the direction of flow of the water in the aquifer could be obtained. Unfortunately this information was not obtained. Because of the large thickness of the aquifer the direction of flow is possibly a composite of many directions; near surface the water movement may follow the configuration of the land, which slopes upwards to the southwest, whereas at a depth of 200 feet the water movement may well be in a line parallel to the strike of the aquifer, which trends southeast.

The aquifer was originally thought to be unconfined, but from the results obtained by drilling and pumping it is apparently both unconfined and confined. The top part of the aquifer, which is in sand and gravel, is considered unconfined, whereas the lower part yields water partly derived from the shale bedrock, as indicated by an analysis of the water pumped from a depth of 202 feet. The water pumped during the pump-test was a mixture of water from the unconfined sand and



Q = 416 gpm. NONEQUILIBRIUM EQUATION
JACOB METHOD

$t_{ob2} = 10^{-3}$ min.

$$T_{b2} = \frac{(264)(416)}{0.156} = 704,000 \text{ gpd/ft.}$$

$$S_{b2} = \frac{(0.36)(704,000)(10^{-3})}{(25^2)(1440)} = (0.28)(10^{-3})$$

Aquifer = sand and gravel

Permeabilty 3,868 gpd/ft^2

Hydraulic Gradient 1.14 ft/mile

Velocity 0.39 ft/day or 142 ft/year

Drawdown after one year 1.89 ft
after 100 years 2.20 ft.

Specific Capacity 260

Porosity 34 %

Figure 5. Semilog graph of drawdown and recovery versus time in observation wells, Winkler, July 25-28, 1962

gravel aquifer and water from the confined shale aquifer, which is under artesian pressure.

Figure 5 shows that two transmissibility values were obtained for each observation well. One value, the larger, is for the first $\pm$ 100 minutes of the pump-test, whereas the smaller value is for the remaining $\pm$ 70 hours of the pump-test and is the one chosen as being more realistic. The difference in values is shown on the graph (Fig. 5) as a negative boundary, which occurs somewhere between the 50- and 100-minute mark. No explanation can be given for this negative boundary except that a reduction in the artesian pressure of the confined shale aquifer may have occurred because of the pumping of the water. In general the line drawn through the points (Fig. 5) is one that averages both the drawdown and recovery data together. Beyond the 1,500-minute mark the readings are not as regular and perfect equilibrium is never reached.

The calculated transmissibility and storage coefficient values after 100 minutes of pumping are:

	Transmissibility	Storage Coefficient
Well A	752,219 gpd/ft	0.11×10^{-5}
Well B	704,000 " "	0.28×10^{-3}
Well C	682,137 " "	0.16×10^{-3}
Well D	657,629 " "	0.18×10^{-1}

The values show local variations within the aquifer, but on the whole they can be considered as fairly consistent with one another.

All calculations in the rest of this report were made using the transmissibility and storage-coefficient value of observation well B (T = 704,000 gpd/ft and S = 0.28×10^{-3}). It is also assumed that: (1) the aquifer was completely penetrated; (2) the aquifer is of infinite areal extent and homogeneous throughout; (3) no well loss occurred; and (4) total withdrawal was from storage, that is, no recharge from rainfall or other sources took place. In Imperial gallons per minute (Brandon, 1961),

if $s = \dfrac{114.6\ QW(u)}{T}$ (Theis, 1935)

where $W(u) = -0.577216 - \ln u + u - \dfrac{u^2}{2x2!} + \dfrac{u^3}{3x3!} - \dfrac{u^4}{4x4!} + - - - - - -$

$- - - - - \dfrac{(-1)^n u^n}{nxn!}$

and $u = \frac{1.56\, r^2 S}{T t}$ (Theis, 1935).

s = drawdown at any point in the aquifer in feet,
Q = discharge of pumped well 416 Imperial gpm,
T = coefficient of transmissibility of the aquifer = 704,000 gpd/ft,
t = time since pumping started in days,
r = distance from discharging well in feet,
S = coefficient of storage of the aquifer = 0.28×10^{-3}.

From the above equation the performance calculated is a continuous operation at 416 Imperial gpm. The drawdown (s) in the main well is as follows, for various values of time (t):

t = 1 day - s = 1.49 feet
t = 3 days- s = 1.56 feet
t = 10 days - - - - - - - - - - - - - - - - - - - s = 1.64 feet
t = 100 days - - - - - - - - - - - - - - - - - - s = 1.80 feet
t = 1 year (365 days) - - - - - - - - - - - - - s = 1.89 feet
t = 100 years - - - - - - - - - - - - - - - - - - s = 2.20 feet.

The drawdown 1,000 feet away would be

t = 1 day - s = 0.46 feet
t = 3 days- s = 0.53 feet
t = 10 days - - - - - - - - - - - - - - - - - - - s = 0.62 feet
t = 100 days - - - - - - - - - - - - - - - - - - s = 0.77 feet
t = 1 year (365 days) - - - - - - - - - - - - - s = 0.86 feet
t = 100 years - - - - - - - - - - - - - - - - - - s = 1.17 feet.

If the rate of pumping is doubled, theoretically the drawdown should also be doubled.

Permeability and Flow Velocity

(Theis equation in its simplest terms) $T = Km$ (Meinzer's coefficient of permeability) $K = \frac{Q}{IA}$

T = transmissibility in gpd/ft = 704,000 gpd/ft,
K = permeability in gpd/ft^2,
m = saturated thickness of the aquifer in feet = 182 feet,
Q = rate of discharge in gpd = 416 Imperial gpm,
A = X-sectional area of flow in ft^2 = 720,720 ft^2,
I = hydraulic gradient in ft/mile.

$$K = \frac{T}{m} = \frac{704,000}{182} = 3,868 \text{ gpd/ft}^2$$

$$I = \frac{Q}{KA} = \frac{599,040}{3,868 \times 720,720} = 0.000215$$

$$I = 1.14 \text{ ft/mile.}$$

If $V = \dfrac{KI}{6.25\ \theta}$ (Freeze, 1962),

V = velocity in ft/day,
θ = porosity in per cent = 34% (field test experiment)

$$V = \frac{3868 \times 0.000215}{6.25 \times 0.34} = 0.39 \text{ ft/day}$$

or V = 142 feet/year.

This is the calculated natural velocity at which the groundwater moves through the aquifer.

Velocity of Groundwater Motion (Toward a Discharging Well in an Infinite Aquifer of Uniform Thickness)

$$V = \frac{36.7\ Q}{m\ \theta\ r} \quad \text{(Freeze, 1962)}$$

V = velocity of GW at distance r in ft/day,
Q = rate of discharge in gpm = 416 Imperial gpm,
m = saturated thickness of aquifer in feet = 182 feet,
θ = porosity in per cent = 34,
r = distance from pumped well in feet = 25 feet.

$$V = \frac{36.7 \times 416}{182 \times 0.34 \times 25} = 9.9 \text{ ft/day}$$

is the velocity of the groundwater in the aquifer at 25 feet from the pumped well during the pump-test.

If the radius of the pumped well is small relative to the distance r (in this case it is 3 inches to 25 feet), then

$$tw = \frac{m\ \theta\ r^2}{73.5\ Q} \quad \text{(Freeze, 1962).}$$

tw = time of traverse to the pumped well in days.

$$tw = \frac{182 \times 0.34 \times 625}{73.5 \times 416} = 1.3 \text{ day.}$$

Therefore it took the water 1.3 days to travel from the observation wells to the main well during the pump-test. This shows that the velocity of the water increased as it approached the pumped well.

Specific Yield

The specific yield of an unconfined aquifer is the storage coefficient. It is the water that can be drained from an aquifer, and is therefore a fraction of the porosity of an aquifer.

By the method of Ramsahoye and Lang (1961),

$$\log V = \log \frac{Qr^2}{4T} + \frac{5.45\ Ts}{Q}$$

V = the volume of dewatered material in cubic feet,
Q = discharge rate of pumped well in gpd = 416 Imperial gpm,
r = distance from main well to observation well in feet = 25 feet,
T = transmissibility = 704,000 gpd/ft,
s = the drawdown at distance r in feet = 1.06 feet.

$$\log V = \log \frac{599{,}040 \times 625}{4 \times 704{,}000} + \frac{5.45 \times 704{,}000 \times 1.06}{599{,}040}$$

$$\log V = \log 132.95 + 6.79$$

$$\log V = 2.123684 + 6.79 = 8.913684$$

$$V = 819{,}817{,}000 \text{ cubic feet.}$$

If the specific yield is the volume of water pumped during the test, divided by the gross volume of dewatered material within the cone of depression, then:

$$Sp = \frac{Qt}{7.48V}$$

Sp = specific yield,
Q = discharge rate of pumped well in gpd = 416 Imperial gpm,
t = time, in days, since pumping began = 3 days,
V = volume of dewatered material in cubic feet = 819,817,000 cubic feet.

$$Sp = \frac{599{,}040 \times 3}{7.48 \times 819{,}817{,}000} = 0.29 \times 10^{-3}$$

which is almost the same as the storage coefficient value, and would indicate that this is an unconfined aquifer.

If the drawdown at the main well is taken as 1.60 feet, which is an average calculated from the values obtained at the four observation wells, the specific capacity of the main well is 260. The specific capacity of a well measures its effectiveness and is equal to the rate of discharge divided by the drawdown, or Sp C = $\frac{Q}{s}$, and is not a constant.

Spacing of Wells

If sp = permissible drawdown = 1.5 feet,
T = transmissibility = 704,000 gpd/ft,
S = storage coefficient = 0.28×10^{-3},
Q = discharge rate of pumped well = 416 Imperial gpm,
t = time since pumping began* = 0.5 day,
r_1 = effective radius of pumped well = 1 foot,
r_2 = distance in feet from new well to well already being pumped,

$$\log u_1 u_2 = -\left(\frac{sp\,T}{264\,Q} + 0.417\right) \quad \text{(Lang, 1961)}$$

$$= -\left(\frac{1.5 \times 704{,}000}{264 \times 416} + 0.417\right)$$

$$= -\quad 10.032 = 9.968 - 20$$

$$u_1 u_2 = \quad 9.29 \times 10^{-11}$$

But $K = \frac{1.56\,S}{Tt} = \frac{1.56 \times 0.28 \times 10^{-3}}{704{,}000 \times 0.5}$

$$K = 1.24 \times 10^{-9}$$

$$r_2 = \sqrt{\frac{u_1 u_2}{K r_1}}$$

---

* It is assumed that the well is only pumped in the daytime and that equilibrium is reached between each pumping session.

$$r_2 = \sqrt{\frac{9.29 \times 10^{-11}}{1.24 \times 10^{-9} \times 1}}$$

$$r_2 = 2{,}460 \text{ feet.}$$

At this minimum distance apart, two wells would not exceed the permissible drawdown if both were pumped at the conditions given. Under the same conditions but with sp = 2 feet rather than 1.5 feet, r_2 would equal 194 feet; with sp = 2.5 feet, r_2 would equal 1.55 feet, etc.

Barometric Pressure Influence and Barometric Efficiency

Changes in atmospheric pressure have no effect on water tables but do produce some fluctuations in wells penetrating confined aquifers. Figure 4 shows that the barometric pressure did have an effect on the water level (at points indicated by the arrows) in the four observation wells (A, B, C, D) during the pump-test. This again would tend to prove that the aquifer is confined. But if

$$B = \frac{\theta \gamma m}{E_w S} \quad \text{(Todd, 1959), where}$$

B = barometric efficiency in per cent,
θ = porosity = 34 per cent,
γ = specific weight of water (density) = 1,
m = aquifer thickness = 182 feet,
E_w = bulk modulus of compression of water = 3×10^5 psi,
S = coefficient of storage = 0.28×10^{-3},

$$\text{then } B = \frac{0.34 \times 1 \times 182}{3 \times 10^5 \times 0.28 \times 10^{-3}} = 73.67 \text{ per cent.}$$

The barometric efficiency is a measure of competence of the confining beds to resist pressure changes (Todd, 1959). Thick impermeable confining strata are associated with high barometric efficiencies whereas thinly confined aquifers will give low values. In this case the value 73.67 per cent is high (values usually range between 20 to 75 per cent), which illustrates that the shale aquifer is both thick and impermeable; therefore the water obtained from it must flow through fissures in it.

QUALITY OF GROUNDWATER

The temperature of the water was 44°F.

A sample of water taken on June 28, 1962, from the 202-foot horizon after some 45,000 gallons had been pumped, was analyzed by the Manitoba Health Laboratory (analysis No. 7082). Second sample, taken during the pump-test on July 28, 1962, after 71 hours of pumping, when some 1,772,160 gallons had been pumped out of the aquifer, was analyzed by the Industrial Minerals Sub-Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa (analysis No. 9172). The second sample was taken to see if there had been a considerable increase in salt (NaCl) content because of a large withdrawal of water from the aquifer. The region around Winkler contains many wells, which at first yielded potable water but in time became too salty for human consumption.

The two analyses are recorded in Table III. From these analyses the water can be considered as being extremely hard, very high in sulphates, and containing some iron. Its total solids value is high enough to qualify it chemically as fair water, although its taste seemed excellent to various persons who drank some during the pump-test.

Graph patterns (Schoeller, 1962) of these analyses (Fig. 6, Group II) show that this water is partly derived from shale and not entirely from the sand and gravel in which the pump-test was made, as would have been expected. In Figure 6, Group II, sample No. 2049 is typical of shale water in this region, whereas sample No. 7082 was taken from the sand and gravel zone at the pump-test site. The similarity of these two curves indicates that even though the sand and gravel aquifer was not totally penetrated, the bottom of the main well is close to the bedrock, which is probably Cretaceous shale of the Ashville Formation (Wickenden, 1945). The water in the shale, being under artesian pressure, is undoubtedly forced up into the sand and gravel aquifer, whereupon the two types of water mix.

Figure 6, Group I, shows plainly the increase in chloride in the second sample, No. 9172 (which was taken during the pump-test), as compared to the previous value obtained in sample No. 7082. Actually the main increase was in magnesium chloride; the sodium content remained the same but the chloride value increased by 131.2 ppm. This increase in chloride may have serious consequences for a long term supply and should receive more detailed study before a permanent water supply is established.

Table III

Chemical Analyses

	Analysis No. 7082	Analysis No. 9172
Date analyzed	21 July, 1962	14-19 December, 1962
Carbon dioxide (CO_2)	--	9.50
Colour (Hazen units)	10	10
Turbidity (ppm)	15	--
pH	7.7	7.7
Conductance (micromhos @ 25°C)	1,600	1,943
Hardness (total)	648 ppm	590 ppm
Hardness (non-carbonate)	--	341 ppm
Alkalinity ($CaCO_3$)	304 ppm	249 ppm
Calcium (Ca)	171 ppm	133 ppm
Magnesium (Mg)	53.50 ppm	62 ppm
Sodium (Na)	200 ppm	200 ppm
Potassium (K)	--	9.60 ppm
Iron (Fe)	0.80 ppm	0.15 ppm
Manganese (Mn)	--	0.26 ppm
Carbonate (CO_3)	nil	0.0 ppm
Bicarbonate (HCO_3)	371 ppm	304 ppm
Hydroxyde ($CaCO_3$)	nil	--
Sulphate (SO_4)	523 ppm	467 ppm
Chloride (Cl)	93.80 ppm	225 ppm
Fluoride (F)	0.92 ppm	0.72 ppm
Nitrate (NO_3)	nil	1.00 ppm
Silica (SiO_2)	--	26 ppm
Total solids	1,550 ppm	1,275* ppm
% Sodium	40.2%	42%
Sodium absorption ratio	3.43	3.59

* Sum of constituents.

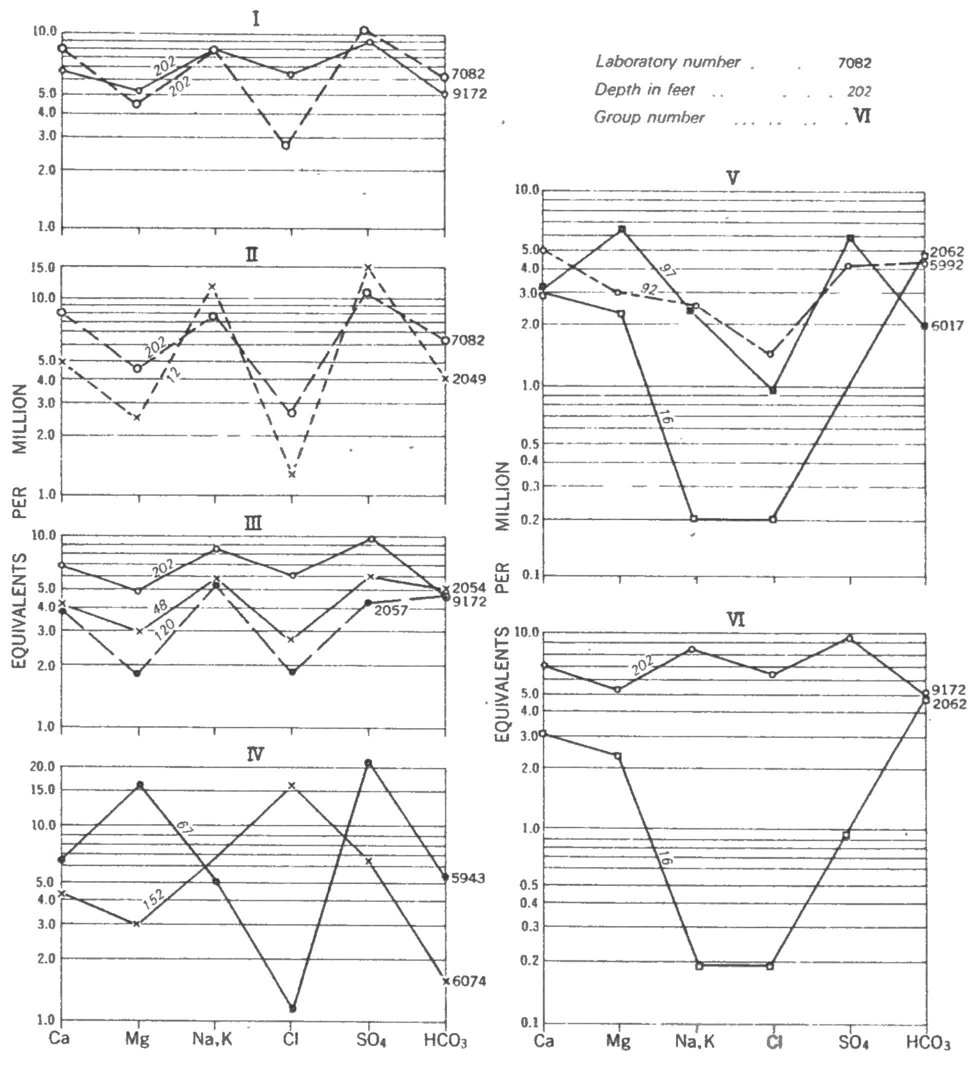


Figure 6. Chemical analyses patterns illustrating correlation of groundwater

Other patterns (Groups III to VI) are plotted on Figure 6 for purposes of comparison. Figure 6, Group III, shows two wells at distances of 2 miles (sample No. 2057) and 9 miles (sample No. 2054) from the pump-test site (sample No. 9172). The patterns are almost identical and all within the limits of one logarithmic cycle. The main difference is in the total solids value. Both sample No. 9172 and No. 2054 are within the aquifer, whereas sample No. 2057 would seem to be outside of it, if one looks at Figure 10. The aquifer, however, may extend a little farther east than is shown on Figure 10. Figure 6, Group IV, shows two wells just outside the aquifer. Sample No. 6074 is on the east side of the aquifer and high in chloride, whereas sample No. 5943 is on the west side of the aquifer and high in magnesium sulphate. These patterns are quite different from the preceding ones in Group III. The high chloride content of sample No. 6074 is probably due to its close proximity with the outcropping end of the Swan River aquifer (Dakota Sandstone). Figure 6, Group V, demonstrates three more wells within the aquifer. Samples No. 5992 and No. 6017 are quite different from previous patterns within the aquifer, which may be because the shale water did not intrude them at all or as much as it had in the previous samples (Nos. 9172, 2054, 2057); in other words, the ends of the two holes are farther away from the shale horizon than they are in the other three holes, or some impermeable zone prevents the occurrence of the mixture. Note that sample No. 6017 of this group is similar to sample No. 5943 of Group IV. Sample No. 2062 is also from a well within the aquifer, but is in a class by itself, for it is from a shallow water-table well. Group VI compares sample No. 9172 to No. 2063. Both are from the same aquifer and only 1 1/2 miles apart, but the big difference in their patterns reflects their big difference in depth, which in turn causes the big difference in total solids. The water of sample No. 9172 came from a depth of 202 feet whereas that of sample No. 2062 came from a depth of only 16 feet. The total solids in sample No. 9172 is 1,275 ppm, whereas that of sample No. 2062 is only 315 ppm. This difference clearly shows the great variability in the quality of the water with depth. The patterns of Group VI show clearly that the biggest increases with depth are mainly those of sodium, chloride, and sulphate.

In terms of irrigation this water is classified as second-class water and may not be used for all crops. The sodium content of the water is 42 per cent, whereas the sodium-adsorption ratio (SAR) is 3.59.

SIEVE ANALYSIS DATA OF AQUIFER MATERIAL

During the drilling of the main well, samples were taken every 10 feet, starting at 15 feet below ground level. In all, nineteen samples were taken. Sieve analyses of each sample were made in the sedimentology laboratory of the Geological Survey of Canada, and from these, histograms showing the grain size distribution of each sample have been prepared (Fig. 7).

Figure 8 shows that the grain size of 30 per cent of the material in the main well over a length of some 32 feet, that is from depths of 125 feet to 157 feet, is 2 millimetres or larger. Had the screen been placed at that interval the performance of the well probably would have been superior to that obtained, assuming the same conditions.

NATURAL AND ARTIFICIAL RECHARGE

Figure 9 shows that natural recharge does take place, the amount depending on the annual precipitation. It also shows the groundwater level at a minimum and at a maximum within the space of a year. When the water recorder was installed in SW-8-3-4W in August 1961, the summer had been one of the driest on record. Thus the water level in the well shown on the recorder's graph should be at an all-time low. The following hydrologic year, September 1, 1961 to September 1, 1962, was one of the wettest on record. Thus the water level in the well should be at an all-time high after the May record precipitation.

The aquifer is crossed in a west-to-east direction by Shannon Creek, 1 1/2 miles north of the pump-test site, and by Dead Horse Creek, 1 mile south of the pump-test site (Fig. 10). Both streams are intermittent, with the bottom of their beds being only a few feet above the sand and gravel aquifer. Where highway No. 3 crosses Dead Horse Creek (Fig. 10) a test hole showed only 5 feet of clayey silt above the sand and gravel. This thin cover makes an ideal situation for artificial recharge of the aquifer during spring run-off. Such recharge would help to replace water withdrawn from storage and should also help to hold the salt content down. Further study of the aquifer would be required before figures about artificial recharge could be prepared.

CONCLUSIONS

During the summer of 1962 Mr. J.E. Wyder of the Geophysics Division of the Geological Survey of Canada conducted a resistivity survey of the aquifer, which showed that this method can clearly define the aquifer and indicate zones of coarser material within it. Figure 10 shows the various zones within the aquifer, as determined by the resistivity survey, together with all groundwater data available about the aquifer.

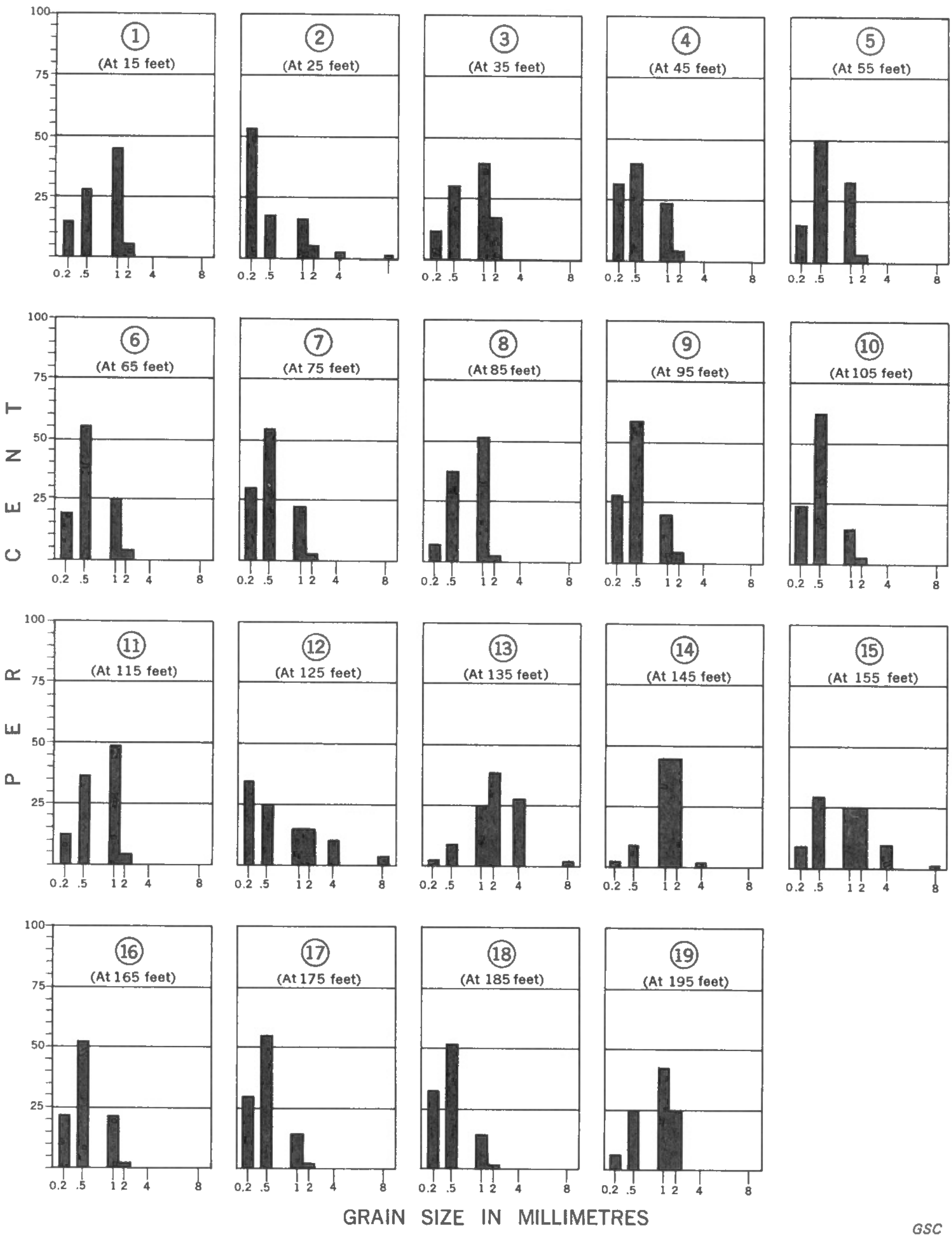


Figure 7. Histrograms of nineteen sieve analyses, Winkler aquifer

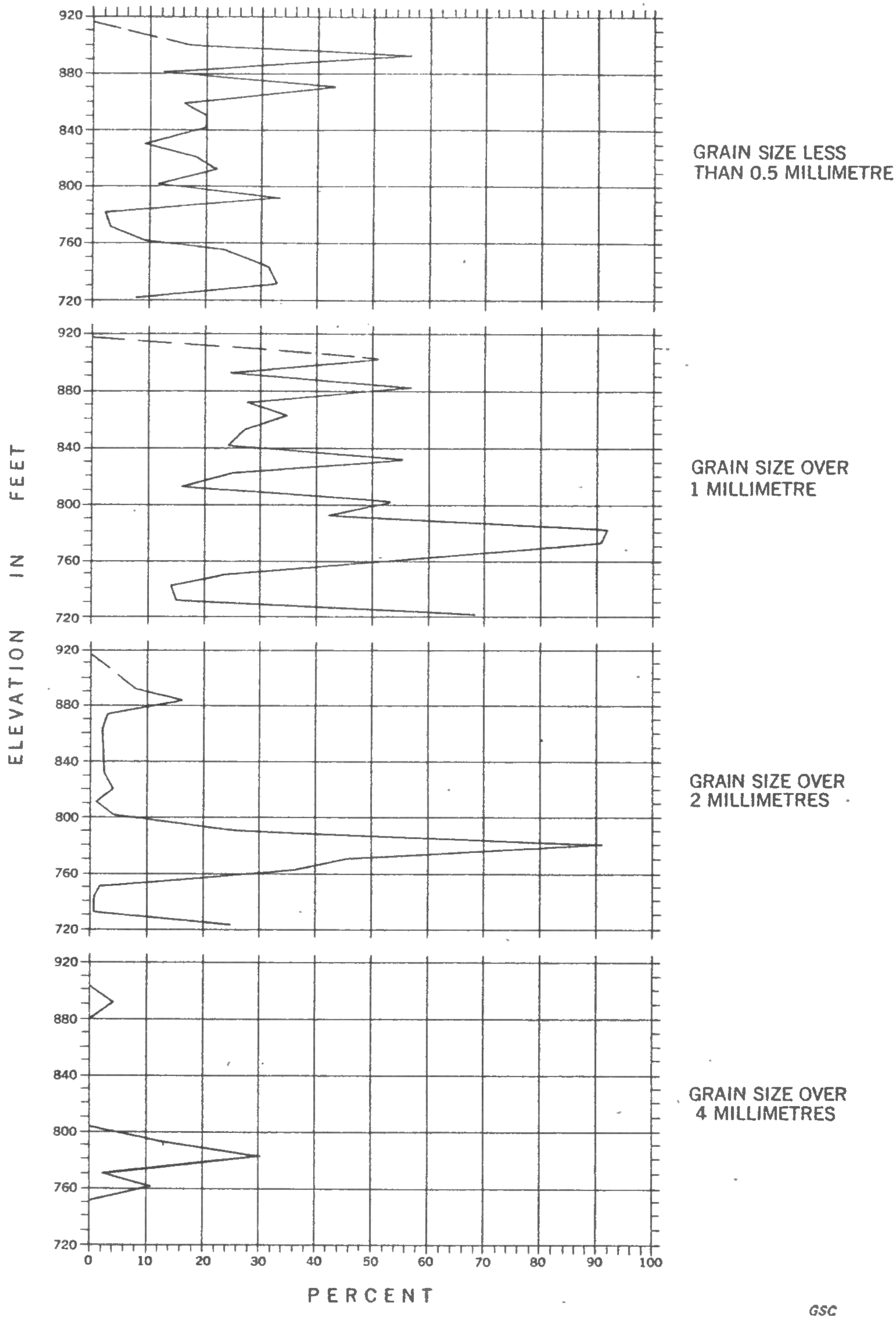
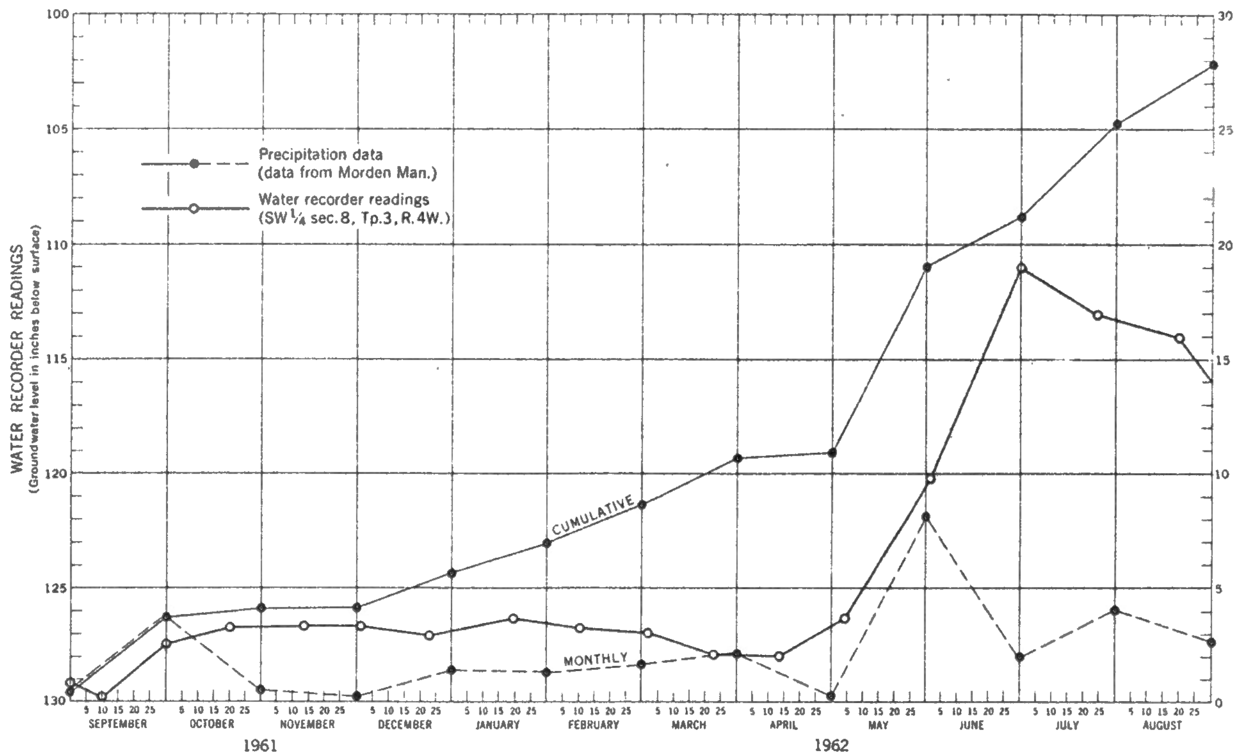


Figure 8. Histogram of grain size at various depths in main well in percent of total sample



GSC

Figure 9. Graph of water recorder and precipitation data for hydrological year 1961-62, illustrating natural recharge of the aquifer

Both the resistivity studies and the drilling, point to the northern end of the aquifer as the best source of groundwater. Groundwater could be found in sufficient quantity, closer to Winkler, but field data suggest that southeast from the pump-test site the water will be more saline, owing to the proximity of the Swan River sandstone. This sandstone underlies the shale and is under artesian pressure. A hole drilled into the Swan River sandstone in SW-8-3-4W in 1961 yielded water containing 10,000 ppm salt (NaCl).

Large-capacity wells constructed in the northern end of the aquifer should be restricted to a maximum depth of 150 feet, because the higher up in the aquifer the water is drawn from, the less chance there is of salt water, under artesian pressure, intruding from depth. Such construction is feasible at the pump-test site and possibly to the north, because the thickness of the aquifer is more than 200 feet and its saturated thickness is known to be more than 180 feet. A large supply of water is assured, whether the water is pumped from 200 feet or from a shallower depth.

AN AQUIFER TEST, ST. PIERRE, MANITOBA

The existence of a large limestone aquifer yielding soft potable water near St. Pierre, Manitoba, was reported recently (Charron, 1962; in press), but exact quantitative hydraulic data were lacking. Therefore as part of a groundwater study of the Red River Valley, Manitoba, a pump-test was carried out to give more quantitative information about the aquifer.

Although the St. Pierre region is about 50 miles away from the site of the previous pump-test, and is east of the Red River, it is similarly characteristically flat, with a general elevation of approximately 800 feet above sea-level.

The logs of the wells drilled for the test show that 60 feet of clay overlies till. Although this till is generally known as a good aquifer in the area, this was not the case at the test site, where some 54 feet of clayey till was penetrated, which was impermeable. The main surprise during the drilling was that 108 feet of red shale of the Amaranth Formation (Bannatyne, 1959) was intersected before encountering the limestone and dolomite of the Red River Formation. Before drilling, the intersection of some red shale had been expected but not nearly the thickness encountered.

Flowing wells obtaining water from the till or the limestone have been in production for more than 40 years in this area. One of the first was the Joubert well, which was drilled in 1916 and which is still flowing. In all there are more than 200 such wells. As the

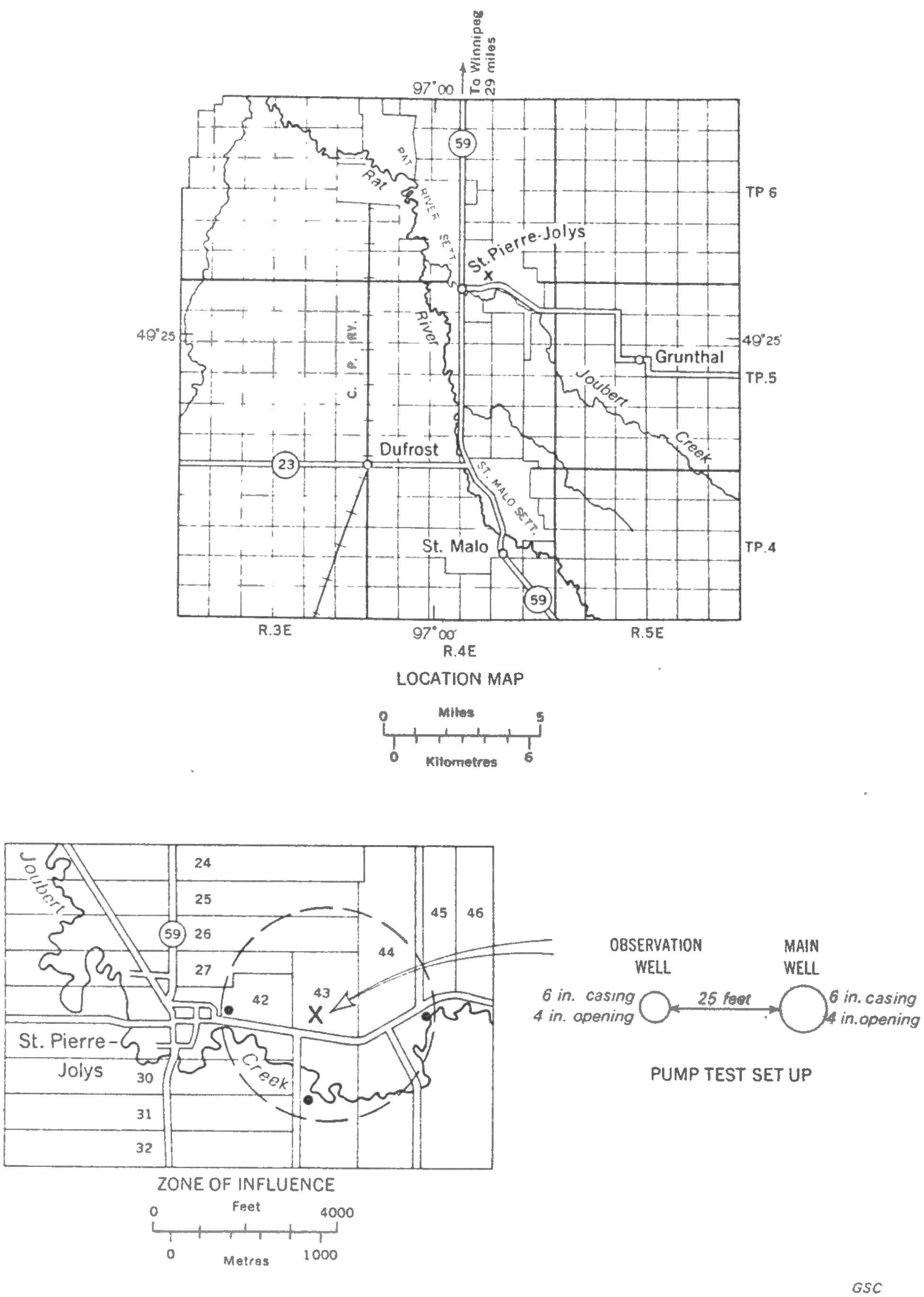


Figure 11. Location map and zone of influence of pump test, St. Pierre area, Manitoba

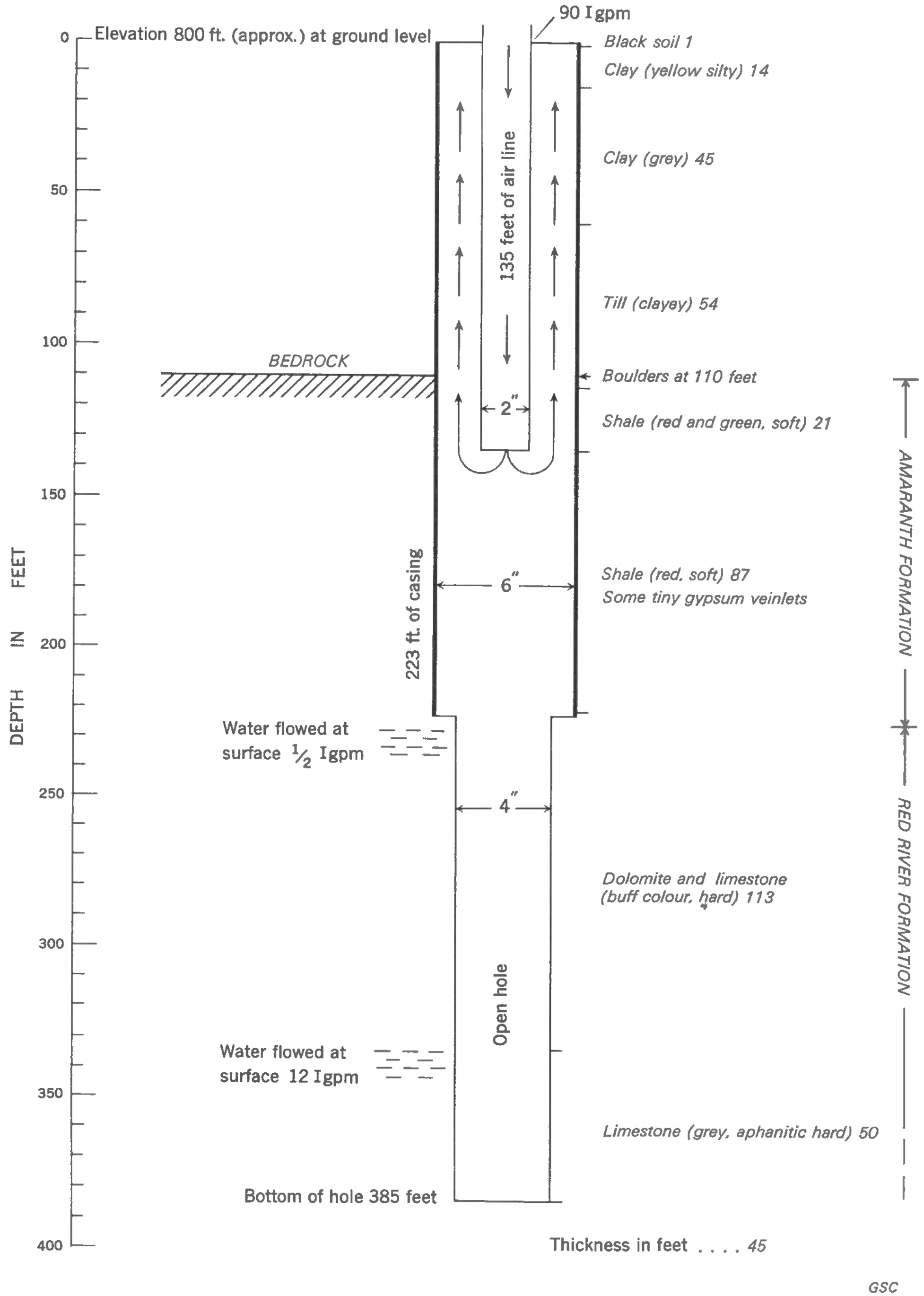


Figure 12. Diagram illustrating pumping method and log of wells

years go by a decrease in head and therefore in yield has been noticed by the older inhabitants, but no exact figures are available.

TESTING THE AQUIFER

Location

The south end of lot 43, Rat River Settlement, was chosen as the drilling site of the pump-test (Fig. 11). It is at the eastern limit of the town of St. Pierre (lat. 49°26', long. 97°02').

Well Drilling

The Department of Public Works, Ottawa, drilled two wells 25 feet apart to a depth of 385 feet. A shortage of time prevented the drilling of four observation wells, as at Winkler. Some 223 feet of 6-inch casing was driven down to the dolomite bedrock (Fig. 12). The remaining 162 feet of each hole was 4 inches in diameter and was not cased. The approximate elevation of the drill site was 800 feet above sea-level.

Pump-test

Prior to the main pump-test preliminary tests were carried out to determine the final rate of pumping. Various air line sizes (1/2-inch to 2-inch) and lengths (40 feet to 220 feet) were tried out to obtain maximum performance with the equipment available. A maximum of 90 gpm was obtained from a 315-cfm air compressor supplying power through 135 feet of 2-inch air line using the 6-inch casing as eductor pipe. The natural flow of these two wells at 5 feet above ground level was 10 gpm, whereas at 1 foot above ground level the flow was 25 gpm. All activities were stopped for one day prior to the test, in order to establish natural equilibrium in the aquifer. The wells were prevented from flowing by extending the casing about 9 feet above ground level. The pumping rate was measured through a 90-degree weir.

The pump-test of this confined bedrock aquifer was started at 11:00 a.m., August 29, 1962. The drawdown was only measured in the observation well. No measurements were obtained from the main well, for it was used as the eductor pipe.

Although planned for 72 hours the pump-test was stopped after 33 hours because the cone of influence spread over 1/2 mile, and the drawdown was large enough to stop the natural flow of four wells in town and on farms in the immediate vicinity of the pump site.

The maximum drawdown measured at the observation well after 33 hours of pumping was 22.37 feet.

Recovery measurements were obtained in the same manner as for the drawdown. Some 19 hours after pumping had stopped, the observation well had completely recovered and the water actually rose 0.19 foot higher than the static water level (S.W.L.) prior to the pump-test (Table V), perhaps because of a drop in atmospheric pressure. One private well, about 1,600 feet south of the pumped well, had stopped flowing but was back to normal 1 1/2 hours after pumping ceased. The actual drawdown and recovery values are given in Tables IV and V.

Table IV

St. Pierre Pump-test Data (August 29-30, 1962)

Date	Time	Drawdown in Observation Well (feet)	Date	Time	Drawdown in Observation Well (feet)
Aug. 29, 1962	10.00 a.m.	+0.02	Aug. 29, 1962	11.22 a.m.	18.64
	10.10	+0.02		11.25	18.76
	10.20	0.00		11.27	18.75
	10.30	0.02		11.30	18.85
	10.40	0.00		11.33	18.88
	10.50	0.00		11.37	18.93
	11.00	0.00		11.40	18.98
	11.01	--		11.44	19.10
	11.02	13.68		11.49	19.26
	11.03	--		11.52	19.42
	11.04	15.98		11.56	19.56
	11.05	16.39		12.00 p.m.	19.50
	11.06	16.58		12.04	19.52
	11.07	16.87		12.10	19.62
	11.08	17.06		12.16	19.78
	11.09	17.32		12.20	19.85

Table IV (cont.)

Date	Time	Drawdown in Observation Well (feet)	Date	Time	Drawdown in Observation Well (feet)
Aug. 29, 1962	11.10 a.m.	17.55	Aug. 29, 1962	12.24 p.m.	19.87
	11.11	17.71		12.30	19.93
	11.12	17.93		12.36	20.05
	11.13	17.97		12.40	20.16
	11.14	18.13		1.00	20.41
	11.15	18.15		1.30	20.63
	11.17	18.22		2.20	20.95
	11.20	18.42		3.00	21.18
	4.00 p.m.	21.47	Aug. 30, 1962	7.00 a.m.	21.78
	5.00	21.50		8.00	21.85
	6.00	21.46		9.00	22.03
	7.00	21.60		10.00	22.02
	8.00	21.54		11.00	21.99
	9.00	21.68		12.00 p.m.	22.04
	10.00	21.78		1.00	22.03
	11.00	21.75		2.00	22.14
Aug. 30, 1962	12.00 a.m.	21.73		3.00	22.10
	1.00	21.75		4.00	22.15
	2.00	21.73		5.00	22.12
	3.00	21.72		6.00	22.15
	4.00	21.78		7.00	22.17
	5.00	21.83		8.07	22.37
	6.00	21.82		8.30	22.35

Table V

St. Pierre Pump-test Data (August 30 - September 1, 1962)

Date	Time	Recovery in Observation Well (feet)	Date	Time	Recovery in Observation Well (feet)
Aug. 30, 1962	8.30 p.m.	0.00	Aug. 30, 1962	9.10 p.m.	18.16
	8.31	3.67		9.14	18.32
	8.32	10.42		9.19	18.50
	8.33	13.77		9.22	18.58
	8.34	14.00		9.26	18.71
	8.35	14.61		9.30	18.80
	8.36	14.97		9.34	18.92
	8.37	15.19		9.40	19.06
	8.38	15.54		9.46	19.19
	8.39	15.79		9.50	19.29
	8.40	15.97		9.54	19.38
	8.41	--		10.00	19.47
	8.42	16.28		10.06	19.56
	8.43	--		10.10	19.63
	8.44	16.54		10.30	19.78
	8.45	--		11.00	20.13
	8.47	16.86		11.50	20.69
	8.50	17.12	Aug. 31, 1962	12.30 a.m.	20.93
	8.53	17.32		1.30	21.28
	8.55	17.46		2.30	21.56
	8.57	17.55		3.30	21.78
	9.00	17.72		4.30	21.92
	9.03	17.86		5.30	22.08
	9.07	18.04		6.30	22.17
Aug. 31, 1962	7.30 a.m.	22.24		2.30 p.m.	22.33
	8.30	22.32		3.30	22.39
	9.30	22.28		4.30	22.44
	10.30	22.27		5.45	22.55
	11.30	22.27		7.45	22.54
	12.30 p.m.	22.28		10.00	22.53
	1.30	22.29		11.15	22.56
			Sept. 1, 1962	11.00 a.m.	22.56

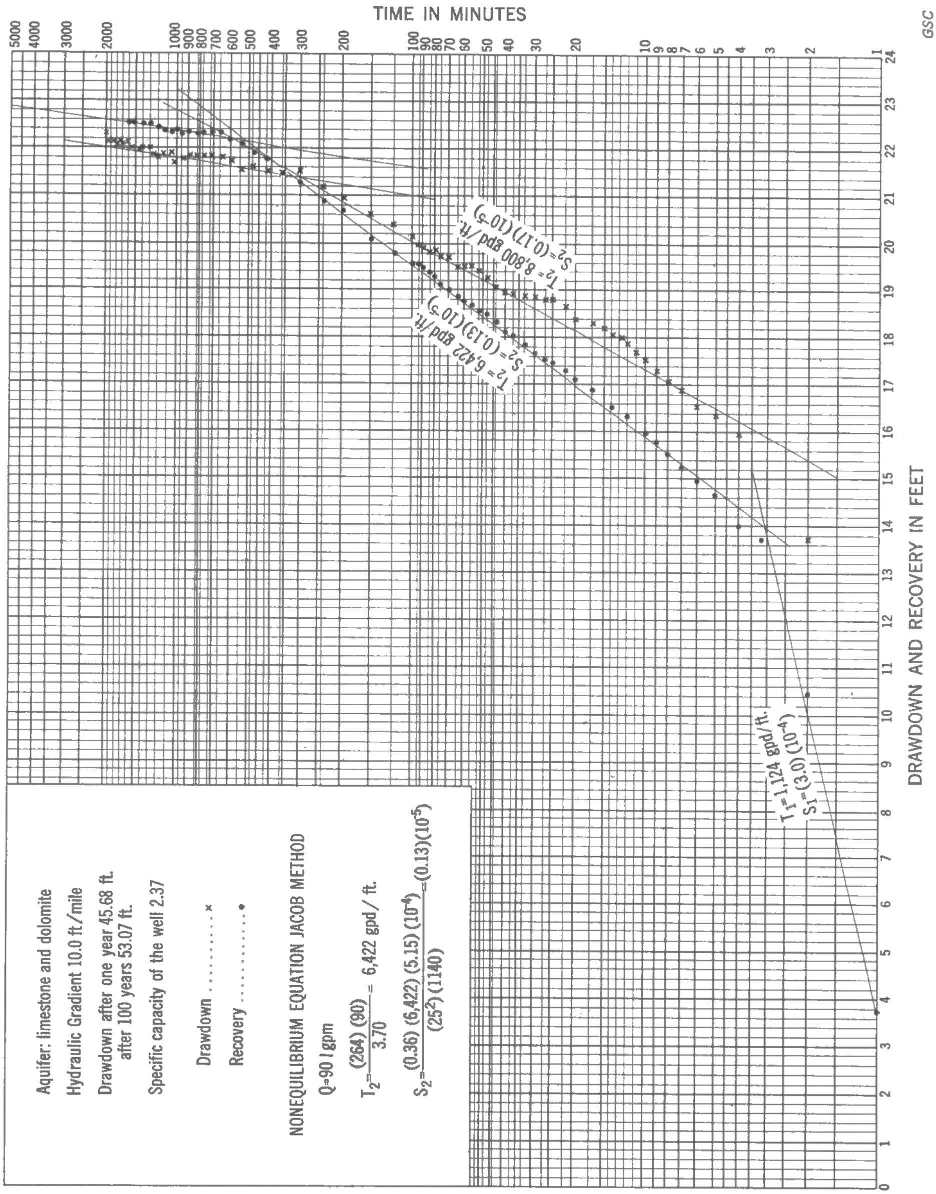


Figure 13. Semilog graph of drawdown and recovery versus time in observation well, St. Pierre, August 29-31, 1962

HYDRAULIC CHARACTERISTICS OF THE AQUIFER

Transmissibility and Storage Coefficient

The transmissibility (T) and storage coefficient (S) value of the aquifer have been calculated, using Jacob's Method of the non-equilibrium formula from the data shown on the time-drawdown and time-recovery graph for the observation well (Fig. 13). As seen on Figure 13, the drawdown and recovery values are almost identical.

The Theis non-equilibrium time-drawdown curve is again not applicable because equilibrium was reached too quickly. The largest percentage of the drawdown occurred within the first 3 minutes of the pump-test.

Figure 13 shows that two transmissibility and storage-coefficient values were obtained. Values could also have been calculated for the last part of the pump-test, but by that time the drawdown was erratic, and this only shows that equilibrium has been reached. The same figure also demonstrates that two positive boundaries exist: one about the 3-minute mark, and one after some 400 minutes of pumping. The recharge shown by the first boundary, after 3 minutes of pumping, may be due to leakage from above the aquifer; a similar assumption can also be made for the second positive boundary.

All calculations were made using the transmissibility and storage-coefficient value of the recovery in the observation well after more than 3 minutes of pumping had been reached ($T = 6,422$ gpd/ft and $S = 0.13 \times 10^{-5}$). It is also assumed that: (1) the aquifer was completely penetrated; (2) the aquifer is of infinite areal extent and homogeneous throughout; (3) no well loss occurred; and (4) total withdrawal was from storage, that is, no recharge from rainfall or other sources took place. In reality the aquifer is limestone and dolomite believed to contain fissures, and it is probable that water was obtained in various quantities at various horizons between the top of the bedrock of the Red River Formation, at a depth of 222 feet, and the bottom of the hole at 385 feet. Nevertheless the writer believes that the main water-bearing horizon is between 315 feet and 330 feet, because during the drilling more water flowed at the surface after that horizon was traversed than at any other part of the hole.

Using the same equations as were used for the Winkler test earlier in this report,

$$s = \frac{114.6\,QW(u)}{T} \text{ and } u = \frac{1.56\,r^2S}{Tt},$$

where

s = drawdown at any point in the aquifer in feet,
Q = discharge of pumped well = 90 Imperial gpm,
T = coefficient of transmissibility of the aquifer = 6,422 gpd/ft,
t = time since pumping started in days,
r = distance from discharging well in feet,
S = coefficient of storage of the aquifer = 0.13×10^{-5},

the performance calculated is a continuous operation at a steady maximum capacity of 90 Imperial gpm. The calculated drawdown in the observation well, which is 25 feet away from the discharging well, after 1 day of pumping, is 23.62 feet. The actual measured drawdown was 21.99 feet, a difference of 1.63 feet or a margin of error of 7.4 per cent.

The calculated drawdown[1] (s) in the main well for different values of time (t) is as follows:

t = 1 day - s = 36.20 feet
t = 3 days - s = 37.99 feet
t = 10 days - - - - - - - - - - - - - - - - - - - s = 39.90 feet
t = 100 days - - - - - - - - - - - - - - - - - - s = 43.60 feet
t = 1 year (365 days)- - - - - - - - - - - - - - s = 45.68 feet
t = 100 years- - - - - - - - - - - - - - - - - - s = 53.07 feet

The drawdown 1,000 feet away would be

t = 1 day - s = 15.51 feet
t = 3 days - s = 17.27 feet
t = 10 days - - - - - - - - - - - - - - - - - - - s = 19.20 feet
t = 100 days - - - - - - - - - - - - - - - - - - s = 22.90 feet
t = 1 year (365 days)- - - - - - - - - - - - - - s = 24.96 feet
t = 100 years- - - - - - - - - - - - - - - - - - s = 32.36 feet

If the rate of pumping is doubled, theoretically the drawdown should also be doubled.

Permeability and Flow Velocity

$$T = Km \qquad K = \frac{Q}{IA} \qquad V = \frac{KI}{6.25\,\theta}$$

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[1] The 7.4 per cent margin of error is not taken into consideration.

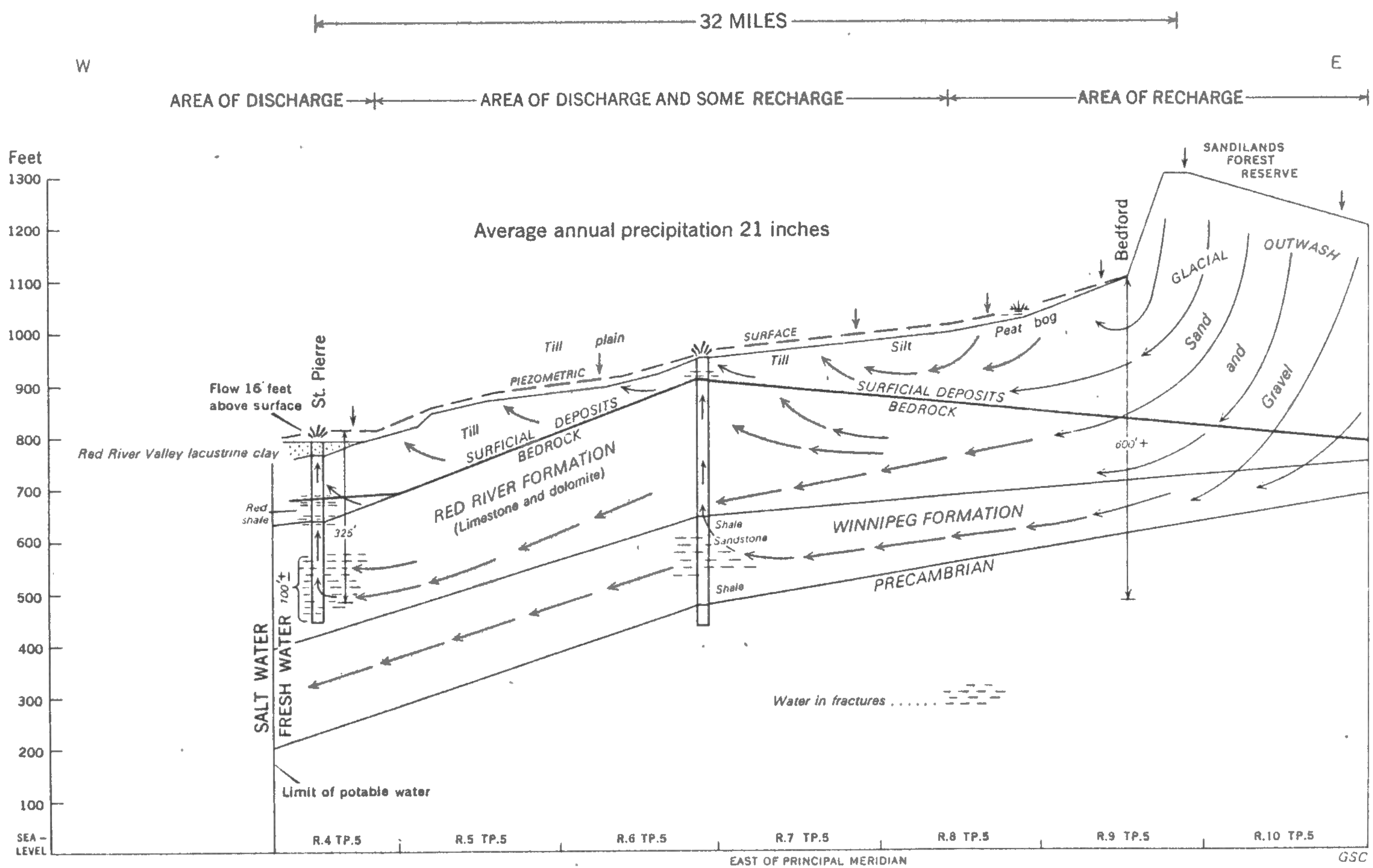

Figure 14. Diagram of flowing artesian zone in southeastern corner of 62H, Winnipeg

T = transmissibility in gpd/ft = 6,422 gpd/ft,
K = permeability in gpd/ft^2,
m = saturated thickness of the aquifer (width of fissure) in feet,
Q = rate of discharge in gpd = 90 Imperial gpm,
A = X-sectional area of flow in ft^2,
I = hydraulic gradient in ft/mile,
θ = porosity in per cent,
V = velocity in ft/day.

For this set of calculations the porosity (θ) is assumed to be 1 per cent, and the hydraulic gradient is 10 feet per mile or 0.0019. The exact width of the fissure or fracture constituting the saturated thickness of the aquifer could not be determined by drilling, but the writer thought it was between 1 foot and 3 feet wide. Schoeller's equation, however,

$$Q = 0.812\ m^2 I \quad \text{(Schoeller, 1962)}$$

where Q = discharge rate in cm^3/sec/cm^2,
m = width of the fissure in cm,
I = hydraulic gradient in cm/cm,

shows that the width (m):

$$m \text{ in feet} = \sqrt{\frac{Q}{0.812 \times 1.481 \times 10^2 \times I}}$$

or in this case m = 20.22 feet, which demonstrates that the fissure is much wider than was at first believed. The fissure is probably not entirely open for a width of 20 feet but is more likely a porous zone 20 feet wide.

Thus using m = 20.22 feet, if T = Km

$$K = \frac{6,422}{20.22} = 318 \text{ gpd/ft}^2.$$

$$\text{If } K = \frac{Q}{IA}, \text{ then } A = \frac{129,600}{318 \times 0.0019} = 216,000 \text{ ft}^2.$$

$$\text{If } V = \frac{KI}{6.25\ \theta} = \frac{318 \times 0.0019}{6.25 \times 0.05} = 9.67 \text{ ft/day,}$$

$$\text{or } V = 3529.55 \text{ feet/year.}$$

This is the calculated natural velocity at which the groundwater moves through the aquifer. If recharge takes place some 32 miles to the east as shown in Figure 14, this would mean that the water has been underground for some 47.87 years. A tritium or carbon dating of the water might prove whether this figure is valid, although the carbon dating value should be less than 48 years because of some probable groundwater infiltration along the flow strike.

Velocity of Groundwater Motion[1]

The velocity of the groundwater (V) in the aquifer at 25 feet from the pumped well during the pump-test can be obtained from the following calculation.

$$V = \frac{36.7\,Q}{m\,\theta\,r},$$

where V = velocity of groundwater at distance r in ft/day,
Q = rate of discharge in gpm = 90 Imperial gpm,
m = saturated thickness of aquifer = 20.22 feet,
θ = porosity = 1 per cent,
r = distance from pumped well in feet = 25 feet.

$$V = \frac{36.7 \times 90}{20.22 \times 0.01 \times 25} = 653.41 \text{ ft/day.}$$

The time (tw) in days for the water to travel from the observation well to the main well during the pump-test can be calculated by means of the following equation:

$$tw = \frac{m\theta r^2}{73.5\,Q},$$

$$tw = \frac{20.22 \times 0.01 \times 625}{73.5 \times 90} = 0.019 \text{ day} = 27 \text{ minutes.}$$

As the water took only 27 minutes to travel from the observation well to the main well during the pump-test, its velocity increases along the cone of influence as it approaches the well being pumped.

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[1] These calculations assume a discharging well in an infinite aquifer of uniform thickness.

Specific Yield

The water that can be drained from an aquifer is a fraction of the porosity of the aquifer.

By the same method employed in the previous test

$$\log V = \log \frac{Qr^2}{4T} + \frac{5.45\ Ts}{Q},$$

where V = volume of dewatered material in cubic feet,
Q = discharge rate of pumped well in gpd = 90 gpm,
r = distance from main well to observation well = 25 feet,
T = transmissibility = 6,422 gpd/ft,
s = the drawdown at distance r in feet = 22.37 feet.

$$\log V = \log \frac{129,600 \times 625}{4 \times 6,422} + \frac{5.45 \times 6,422 \times 22.37}{129,600}$$

$$\log V = \log 3,153.22 + 6.04$$

$$\log V = 3.4987508 + 6.04 = 9.5387508$$

$$V = 3,457,306,300 \text{ cubic feet.}$$

If the specific yield is the volume of water pumped during the test, divided by the gross volume of dewatered material within the cone of depression, then

$$Sp = \frac{Qt}{7.48\ V}.$$

Sp = specific yield,
Q = discharge rate of pumped well in gpd = 90 gpm,
t = time in days, since pumping began = 1.38 days,
V = volume of dewatered material in cubic feet = 3,457,306,300 cubic feet,

$$Sp = \frac{129,600 \times 1.38}{7.48 \times 3,457,306,300} = 0.69 \times 10^{-5}$$

which is only 0.069 per cent of the porosity, which earlier in this report has been assumed to be 1 per cent.

Therefore if the drawdown at the main well, when equilibrium is reached, is taken as 38 feet when pumping at 90 gpm, the specific capacity of the main well is 2.37. The specific capacity of a well measures its effectiveness and is equal to the rate of discharge (Q) divided by the drawdown (s), i.e., $Sp\ C = \frac{Q}{s}$.

Spacing of Wells in the Aquifer

Spacing of wells in the aquifer should be such that natural flow is still available between two wells without interference. If

- sp = permissible drawdown = 5 feet,
- T = transmissibility = 6,422 gpd/ft,
- S = storage coefficient = 0.13×10^{-5},
- Q = discharge rate (natural flow of 5 Imperial gpm),
- t = time since pumping began, one day*,
- r_1 = effective radius of flowing well = 1/2 foot,
- r_2 = distance in feet from new well to well already flowing.

$$\log u_1 u_2 = - \left(\frac{sp\,T}{264\,Q} + 0.417 \right)$$

$$= - \left(\frac{5 \times 6,422}{264 \times 5} + 0.417 \right)$$

$$= - \quad 24.743 = 5.257 - 30$$

$$u_1 u_2 = \quad 1.81 \times 10^{-25} = 0.18 \times 10^{-24}$$

But $K = \dfrac{1.56 \times 0.13 \times 10^{-5}}{6,422 \times 1}$

$K = 0.32 \times 10^{-9}$

If $\quad r_2 = \dfrac{\sqrt{u_1 u_2}}{Kr_1} = \dfrac{\sqrt{0.18 \times 10^{-24}}}{0.32 \times 10^{-9} \times 1/2}$,

$r_2 = 0.003$ feet.

The calculations shown above prove that under the conditions given the wells could be placed as close to one another as one wished.

Similarly, spacing of wells in the aquifer should also be such so that the water level does not exceed 20 feet below ground level (for use of suction lift pump).

If sp = 25 feet (to allow for the 5 feet that the water rises above ground level),
T = 6,'422 gpd/ft,
S = 0.13×10^{-5},

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* It is assumed that the well flows all day.

Q = rate of pumping 50 Imperial gpm,
t = 0.417 day (10 hours)*,
r_1 = 1 foot,
r_2 = distance from one well to another in feet.

$$\text{Again } \log u_1 u_2 = -\left(\frac{sp\,T}{264\,Q} + 0.417\right)$$

$$= -\left(\frac{25 \times 6{,}422}{264 \times 50} + 0.417\right)$$

$$\log u_1 u_2 = - \quad 12.58 = 7.42 - 20$$

$$u_1 u_2 = 2.63 \times 10^{-13}$$

$$K = \frac{1.56\,S}{T\,t} = \frac{1.56 \times 0.13 \times 10^{-5}}{6{,}422 \times 0.417} = 7.57 \times 10^{-10}$$

$$r_2 = \frac{\sqrt{u_1 u_2}}{K r_1} = \frac{\sqrt{2.63 \times 10^{-13}}}{7.57 \times 10^{-10}} = 671 \text{ feet.}$$

Therefore 671 feet is the distance required between two wells in order to satisfy the data given above. Both wells would give the same performance without affecting one another beyond the permissible drawdown.

Recharge

As shown on Figure 14 the area of recharge is about 32 miles east of St. Pierre in the sand and gravel deposits of Sandilands Forest Reserve. Slowly from that area the water migrates westward. The following factors can be used to determine the rainfall required to recharge the aquifer in the vicinity of the St. Pierre area:

1. Natural rate of flow over 100 square miles of discharge area (from 169 wells) is 1,000,000 gallons/day or 1,350 acre feet/ year. (It is assumed that all wells have been flowing at that rate for 50 years.)

2. Area of recharge is 100 square miles.

3. Storage coefficient is 0.13×10^{-5}.

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* It is assumed the well is only pumped for 10 hours at a time and that equilibrium is reached between each pumping session.

4. Thickness of aquifer with fissures is limited at 100 feet.

5. Width of the aquifer is limited at 10 miles.

6. Total aquifer volume over a length of 32 miles is 20.5×10^6 acre feet.

7. The largest drop in head in one well in 50 years is 30 feet.

8. Hydraulic gradient (between Bedford and St. Pierre) is 10 feet/mile.

9. Average annual precipitation over the recharge area is 21.0 inches.

Consequently the amount of water released from storage during the 50 year period is the maximum head loss times the storage coefficient times the aquifer volume or:

$$30 \times 0.13 \times 10^{-5} \times 20.5 \times 10^6 = 800 \text{ acre feet.}$$

The amount of water that flowed in 50 years is $1,350 \times 50 = 67,500$ acre feet; of that 800 acre feet was taken from storage, therefore the remainder of the water must come from natural recharge and amounts to 66,700 acre feet. The natural recharge per year is:

$$\frac{66,700}{50} = 1,334 \text{ acre feet/year.}$$

The natural recharge per year per acre is then 0.0208 feet or 0.25 inch per year, which amounts to only 1.2 per cent of the 21-inch average annual precipitation in the recharge area.

Therefore only 1.2 per cent of the total annual precipitation is required to supply the present withdrawal of water from the Red River Formation aquifer near St. Pierre, Manitoba.

QUALITY OF GROUNDWATER

The temperature of the water at the pump-test site was 47°F. A Hack Kit chemical analysis of a sample of water taken on August 29, 1962, after some 6,000 gallons had been pumped, gave the following results:

pH = 8.0
Iron (Fe) = less than 0.6 ppm (parts per million)

Salt (NaCl) = 350.0 ppm
Total hardness = 75.0 ppm.

Apart from a strong H_2S odour this water can be considered as excellent soft potable water. Aerating the water removes the offensive odour. It is known that all water obtained from wells in the east end of St. Pierre has a strong H_2S odour, whereas the water from wells in the west end of the town does not have that odour. It is also known from other analyses of water taken from this aquifer, that around St. Pierre the water is generally very low in sulphates (SO_4, 0 to 50 ppm) and high in fluoride (F, 1.0 to 2.5 ppm).

The H_2S odour along with the low sulphate content of the water can be explained as reduction of the sulphates caused by micro-organisms in organic matter at recharge. The softness of the water can be explained by the low value of CO_2 (2 ppm) dissolved in the water, because this gas is the most aggressive towards the more insoluble salts of Ca and Mg. The low CO_2 content also indicates that very little infiltration of water, and therefore of CO_2*, occurs between recharge and discharge. This would mean that a radiocarbon dating of the water might yield a value similar to that of 48 years, arrived at earlier, for the velocity of groundwater movement through the aquifer.

Figure 14 also demonstrates clearly that St. Pierre is close to the salt-water and fresh-water boundary. In general, west of St. Pierre the water from this same aquifer is too salty for human consumption.

The per cent sodium of the water is 75, and the sodium adsorption ratio (SAR) is 70. Consequently this water would generally be classified as unsuitable for irrigation.

SUMMARY OF THE RED RIVER FORMATION FLOWING ARTESIAN BASIN

The three flowing artesian aquifers shown on Figure 14 are probably interrelated but only the aquifer of the Red River Formation (limestone and dolomite) is summarized below.

Aquifer - Red River limestone and dolomite, Ordovician age.

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* It is known that all CO_2 dissolved in the water comes from the air and that none is available to the groundwater once it is below the zone of aeration.

Thickness -	200 feet (at St. Pierre) main fissure— 20.22 feet.
Transmissibility -	6,422 gpd/ft.
Storage coefficient -	0.13×10^{-5}.
Hydraulic gradient -	10 feet/mile.
Average annual precipitation -	21 inches.
Main recharge area -	More than 100 square miles of glacial outwash of sand and gravel in the Sandilands Forest area.
Natural discharge -	Could be considerable in proximity of the recharge area, but only very little leakage could occur where aquiclude is consolidated till or lacustrine clay.
Initial artesian head -	Variable depending on topography, but as much as 500 feet above the discharge area.
Withdrawal by natural flow -	1,345 acre feet/year.
Salvaged rejected recharge -	Large amounts collect naturally in swamps (Fig. 14).
Salvaged natural discharge -	None.

CONCLUSIONS

A continuing decline in artesian head is predicted, which will be accelerated by: (a) the continuous flowing of wells; (b) the drilling of many additional wells; and (c) the increasing usage of pumps by owners whose wells have stopped flowing or have already reduced appreciably in flow. The decline in head could be reduced by installing valves on all flowing wells so that water is used only when needed and not wasted.

The pump-test has shown that more than 100,000 gpd can be obtained from the aquifer by drilling a small-diameter well. This is more than enough to supply the present requirements of a town the size of St. Pierre.

Because the aquifer is confined, the cone of depression spreads very fast when pumping, thus affecting wells at distances of 1/2 mile or more depending on the rate of pumping. If use of this aquifer for large supplies of water is anticipated in the future, it would be necessary to bear in mind that no well owners at present have pumps nor any means of obtaining water if the wells stop flowing.

If salt (NaCl) is an objectable ingredient, it is preferable to obtain water east and northeast of St. Pierre, because the salt content increases to the west.

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