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Groundwater Exploration Program - Hanna

5 - 13 - 31 - (14 - 15) - W4

by

G.R. Kunkle

1961

Alberta
RESEARCH COUNCIL

CONTENTS

	Page
Present Water Supply	1
The Test Program	
Figure 1: Bedrock Topography of the Hanna Channel	
Figure 2	
Average Coefficients Determined	3
Water Analysis Reports	
Table 1	4
Appendix A: Hanna Test Program (well logs)	6
Appendix B: Pump Tests	
Appendix C: Groundwater Sieves	
Appendix D: Hanna Water Plant, 1951 - 1961	
Appendix E: Hanna Project (draft), September 19, 1960	
Appendix F: Field Notes	

GROUNDWATER EXPLORATION PROGRAM-HANNA

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Commencing August 8, the Town of Hanna drilled 14 test holes mostly along an east-west line due west of the town site. The purpose of the exploration program was to ascertain whether or not a buried bedrock channel, the Hanna Channel, contains any sand and gravel suitable of producing about 100 gallons per minute for a duration of about 20 years. The Hanna Channel (see figure 1) provides the only possibility for obtaining the yield necessary for the town from groundwater sources. Elsewhere, a low permeability silty till overlies a sandy shale. Local sandstone lenses may be expected to produce up to 30 gallons per minute, but for unknown durations.

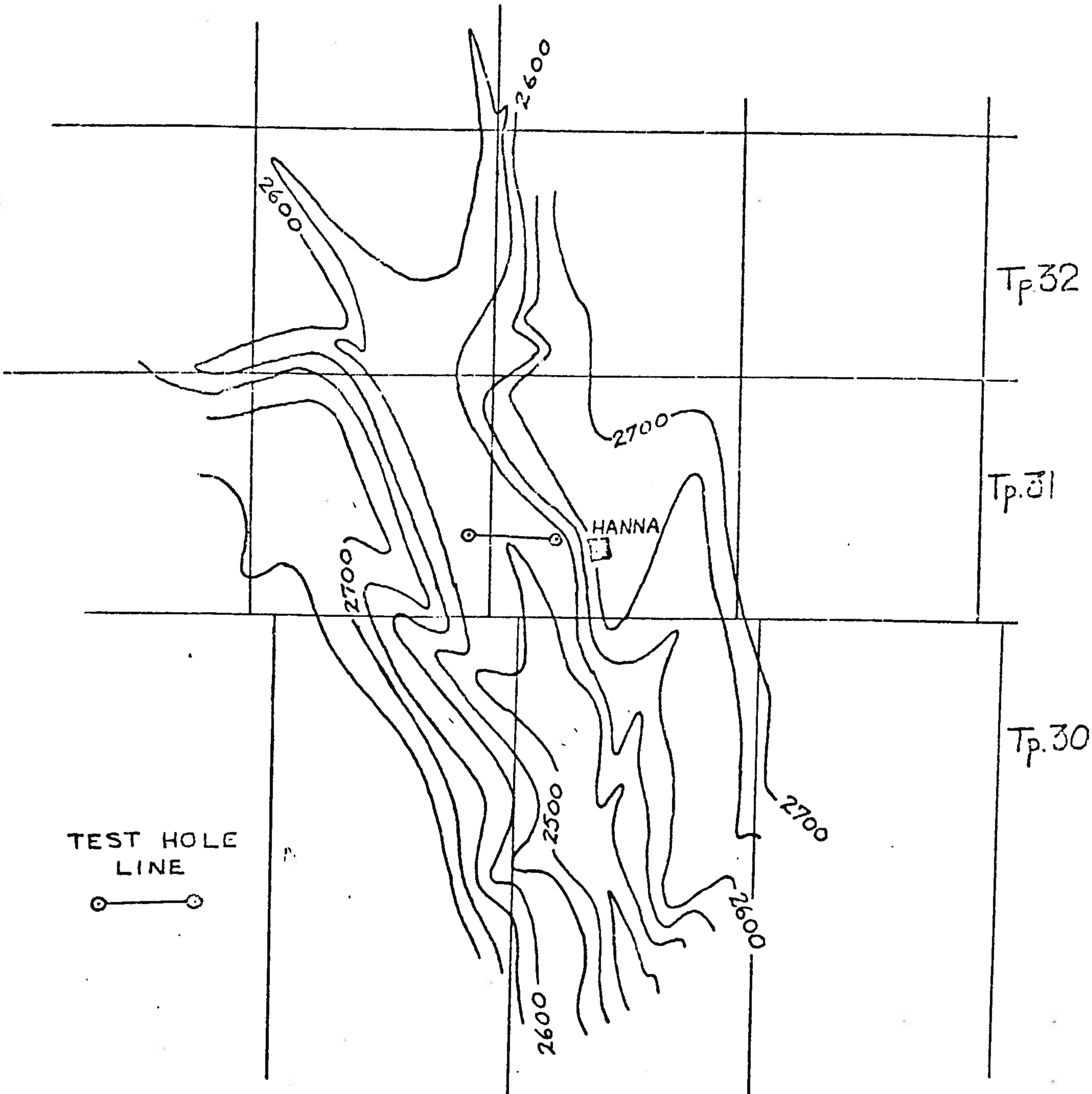
Present Water Supply

The town at present obtains its water from reservoirs fed by Bullpond Creek. Because of negligible runoff within the last several years, the storage, in the reservoir to date, is estimated to contain only one more year's supply.

In addition, the town has one operable well which produces about 15 gallons per minute. This well is sometimes used during the summer to help meet peak demands. The well originally produced about 30 gallons per minute in the early 1940's, but due to a drop in the pumping level, production was curtailed to the present yield.

The Test Program

The test holes span the central part of the Hanna Channel (fig. 1). Three occurrences of sand and gravel were noted (fig. 2). The closest occurrence to the town was penetrated by test holes 8, 9, and 10. These holes indicate a maximum thickness



BEDROCK TOPOGRAPHY OF THE HANNA CHANNEL

contour interval = 50 feet

FIGURE 1

of 10 feet and a cross-sectional width of about 1500 feet. The deposit is composed mostly of medium grained sand, a few lenses of gravel, and an appreciable amount of fine sand. It is estimated that a well completed in this aquifer would produce between 10 to 25 gallons per minute, but for an undetermined period of time.

The next occurrence of sand and gravel was penetrated by test holes 11 and 5. This aquifer is not sufficient thick to warrent further consideration. It could, at some future time, be developed into a farm supply.

The farthest occurrence of sand and gravel was penetrated by the first test hole. Two holes were drilled at distances of about 500 feet to the east and west of the No. 1 test hole to determine the width of the aquifer. The holes penetrated considerable clay intermixed with the sand and gravel indicating ~~aquifer becomes quite clayey at these distances;~~ the sand and gravel body is little more than 1000 feet in width.

Although it was thought that this aquifer would be only marginal in supply, considering its distance from Hanna, the critical shortage of water in the town required that every possibility be fully investigated. Therefore, a pump test of 50 hours duration was conducted on a screened (#20 slot), 4-inch well completed 12.2 feet from test hole 1. Two observation wells, one 774 feet north, and the other 919 feet south, were also drilled. The north well penetrated 32 feet of sand and gravel, and the south well 14 feet of sand at the same depth range as in test hole 1.

Beginning on August 29, the aquifer was pumped at an average rate of 58 gallons per minute while drawdown measurements were taken at selected times. On August 31, the pump was shut off and recovery measurements taken for an additional 50 hours. Results of this test are as follows.

A plot of drawdown against time shows the aquifer to be limited hydrologically. This fact was known from the test drilling program which indicated the width of the water-bearing gravels at 1000 feet. However, the pump test shows that these geologic boundaries are not as serious hydrologically as was at first thought. The presence of the boundary imposes a problem on interpretation and necessitates the determination of a first and second limb coefficient of transmissibility.

> The coefficient of transmissibility, T, is the amount of water in gallons per day that is transmitted through one foot of aquifer width under a hydraulic gradient of one.

In addition, the coefficient of storage, S, was determined which may be defined as the percent of water released from one square foot of aquifer when the hydraulic head (water level) is lowered one foot.

AVERAGE COEFFICIENTS DETERMINED

First limb T = 6000 gallons per day per foot.
Second limb T = 2500 gallons per day per foot.
$S = 2.0 \times 10^{-4}$

Using these coefficients, the amount of drawdown can be calculated within the pumping well and at any distance from it using any discharge and period of time desired. In this case, the amount of head is 70 feet. Allowing for a well with only 70% efficiency, the amount of available drawdown is 50 feet. This is a limiting factor and was used to compute the safe discharge for the periods of time given in Table I.

As can be seen from this table, little advantage is gained either from decreasing the time period or pumping intermittently. This is chiefly because most of the drawdown will take place within the first year with only small increments from then on.

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UNIVERSITY OF ALBERTA
QUAECUMQUE VERA

EDMONTON, ALBERTA
CANADA

Sept. 7, 1961

WATER ANALYSIS REPORT
CHEMICAL

Submitted by Secretary, Town of Hanna

Date received Sept. 5, 1961

Address

Date reported

Source of Sample Hanna.

Container No.

Serial No.

BEGINNING OF PUMP TEST

Lab. No. 61 - 8111

PARTS PER MILLION

Total Solids	1626
Ignition Loss	104
Hardness	275
Sulphates	477
Chlorides	63
Alkalinity	670
Nature of Alkalinity	Bicarbonate of lime, magnesium and soda
Nitrites	nil
Nitrates	nil
Iron	0.4
Fluorine	

REMARKS:

Soda content - 29.3 grains/gallon. will corrode aluminum and harm plants. Water is chemically suitabl.e

C. Emerson Nobl e
Provincial Analyst

CEN:as

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EDMONTON, ALBERTA
CANADA

Sept. 7, 1961

WATER ANALYSIS REPORT
CHEMICAL

Submitted by: Secretary Town of Hanna
Address:
Container No.: 4

Date received: Sept. 5, 1961
Date reported:
Source of Sample: Hanna, test well 220'
Serial No.:
Lab. No.: 61 - 8110

AFTER 48 hours of Pumping

PARTS PER MILLION

Total Solids	1886
Ignition Loss	258
Hardness	260
Sulphates	546
Chlorides	58
Alkalinity	655
Nature of Alkalinity	Bicarbonate of lime, magnesium and soda
Nitrites	nil
Nitrates	nil
Iron	0.4
Fluorine	

REMARKS:

Soda content - 29.3 grains/gallon. Will corrode aluminum and harm plants. Water is chemically suitablee

C. Emerson Noble
Provincial Analyst

CEN:as

TABLE I

Safe Discharge For Period Indicated
One Well

Time Period	Continuous Productions Gallons/Minute	Pumping 10 hrs of each day Gallons/Minute	Gallons/Day Continuous Production	Gallons/Day Pumping 10 hours Each Day
20 years	63	74	90,600	44,400
10 years	65.4	75.5	94,200	45,300
5 years	68.8	77.2	99,000	46,400
3 years	71.0	78.5	102,100	47,100
1 year	76.3	81.0	109,800	48,600

The next consideration is two wells. When two wells are installed, each will produce a smaller amount than one well by itself. This results from each well having not only its own self-caused drawdown, but drawdown due to interference from the other well. Two wells spaced 1000 feet away could each produce 40 gallons/minute for 20 years, or a total of 115,200 gallons/day. The addition of a third well would not be too advantageous because of the long, narrow shape of the aquifer. In a three-well field, the two outside wells could produce 40 gallons/minute, but the middle well would be reduced to approximately 20 gallons/minute, because of interference from the other wells.

It is, therefore, recommended that if the Town of Hanna decides to use this aquifer that a two-well field be used, each well tentatively pumping 40 gallons/minute.

Since this analysis is based on two days of pump testing but extrapolated to 20 years, the well field must include observation wells to allow a continuing re-evaluation of the aquifer as pumping progresses. A re-evaluation does not necessarily imply that the situation will become worse as it could, to the contrary, become better and allow greater quantities to be extracted. For instance, the pumping rates now determined were computed on the basis of no recharge to the aquifer. From past experience, we know this to be erroneous, and that a certain amount of recharge will occur. However, there is also the other possibility of additional adverse hydrologic boundaries appearing. The present analysis is based on the fact that both will probably occur but have a cancelling effect. In either case, though, it is extremely important to know what is occurring.

The pump test also showed that an anomalous situation exists between the pumping well and observation well #3 (south well) by the fact that #3 well was very late in showing any effect due to pumping. This situation could be caused by an increase in storage towards the south or the lack of a direct connection between the aquifer at #3 well. The latter is the more probable case indicating that future testing in that direction should be more offset to the east.

For future production wells, it is recommended that 6" wells be used with screens and gravel packs adjacent to the aquifer. The location of the present pumping well is suitable for one well and the other should be 1000 feet to the north or to the south east. It is recommended that the present three observation wells be kept for that purpose. If the town elects not to use this site, the Research Council would like to purchase, for the price of the casing, test hole #1 = observation well #1.

Appendix A

HANNA TEST PROGRAM

Appendix A

Well Logs

T.H. #1 (on line LSD 5/4, Sec. 13, Tp. 31, R. 15, W. 4M.) = observation well #1

0 - 47	silty black clay
47 - 60	sandy clay till
60 - 80	sandy clay till lost some circulation
80 - 114	sandy clay till
114 - 115	fine gravel
115 - 119	clay
119 - 136	fine gravel and coarse sand
136 - 140	sandy shale

T.H. #2 (on line LSD 5/4, Sec. 13, Tp. 31, R. 15, W. 4M.) 500' east of T.H. #1

0 - 40	silty clay
40 - 114	clay till
114 - 115	gravel
115 - 119	clay
119 - 140	gravel, sand, and clay
140 - 144	shale

T.H. #3 (on line LSD 5/4, Sec. 13, Tp. 31, R. 15, W. 4M.) 400' west of T.H. #1

0 - 117	till
117 - 120	sand and a little gravel
120 - 137	clay with sand and gravel
137 - 140	shale

T.H. #4 (N 1/2 LSD 1, Sec. 13, Tp. 31, R. 15, W. 4M.)

0 - 20	sandy brown till
20 - 40	brown till
40 - 60	till with gravel lenses
60 - 80	sandy till
80 - 120	sandy till
120 - 140	sandy clay
140 - 160	clay
160 - 165	shale

T.H. #5 (NW 1/4 LSD 3, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 153	till @ 153 thin layer of gravel
153 - 155	shale

T.H. #6 (W 1/2 LSD 8, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 152	till
152 - 160	shale

T.H. #7 (N.W. Cor. LSD 15, Sec. 8, Tp. 31, R. 14, W. 4M.)

0 - 142	till
142 - 148	black shale

T.H. #8 (SW 1/4 LSD 7, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 157	sandy clay till, coal pebbles
157 - 158	gravel
158 - 160	sand, med. to fine
160 - 168	sand, med. to fine, some gravel
168 - 175	sand, med. to fine
175 - 200	shale

T.H. #9 (S 1/2 LSD 6, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 25	silty brown boulder clay
25 - 143	silty grey till, few boulders
143 - 153	fine to med. sand, little gravel
153 - 160	shale, sandy

T.H. #10 (E 1/2 LSD 7, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 35	brown silty boulder clay
35 - 60	grey silty clay
60 - 80	sandy clay
80 - 150	grey silty till
150 - 156	sand, med.
156 - 160	shale

T.H. #11 (N.W. 1/4 LSD 4, Sec. 18, Tp. 31, R. 14, W. 4M.)

0 - 45	brown silty boulder clay
45 - 80	grey silty till
80 - 81.5	sand (lost all circulation)
81.5 - 152	grey silty till
152 - 158	sand and fine gravel
158 - 160	shale

T.H. #12 = Pumping well, 12.2' East of #1 T.H.

0 - 114	clay
114 - 136	gravel and sand
136 - 140	shale

T.H. #13 = Observation Well #2 774' North of T.H. #12

0 - 108	clay
108 - 112	sand
112 - 121	gravel
121 - 136	sand and gravel
136 - 140	shale

T.H. #14 = Observation Well #3, 919' South of T.H. #12

0 - 117	clay
117 - 121	coal and wood
121 - 135	sand
135 - 140	shale

Appendix B

AQUIFER COEFFICIENTS

Method	Transmissibility #1	Transmissibility #2	Storage #1	Storage #2	#3
THEIS	5×10^3	2.75×10^3	2.2×10^{-4}	2.64×10^{-4}	
THEIS	3.9×10^3	3.3×10^3	1.48×10^{-4}	1.56×10^{-4}	
THEIM FIRST LIMB	7.5×10^3	6.6×10^3	1.33×10^{-5}	5.7×10^{-5}	8.3×10^{-4}
Second LIMB	3.4×10^3	3.7×10^3			

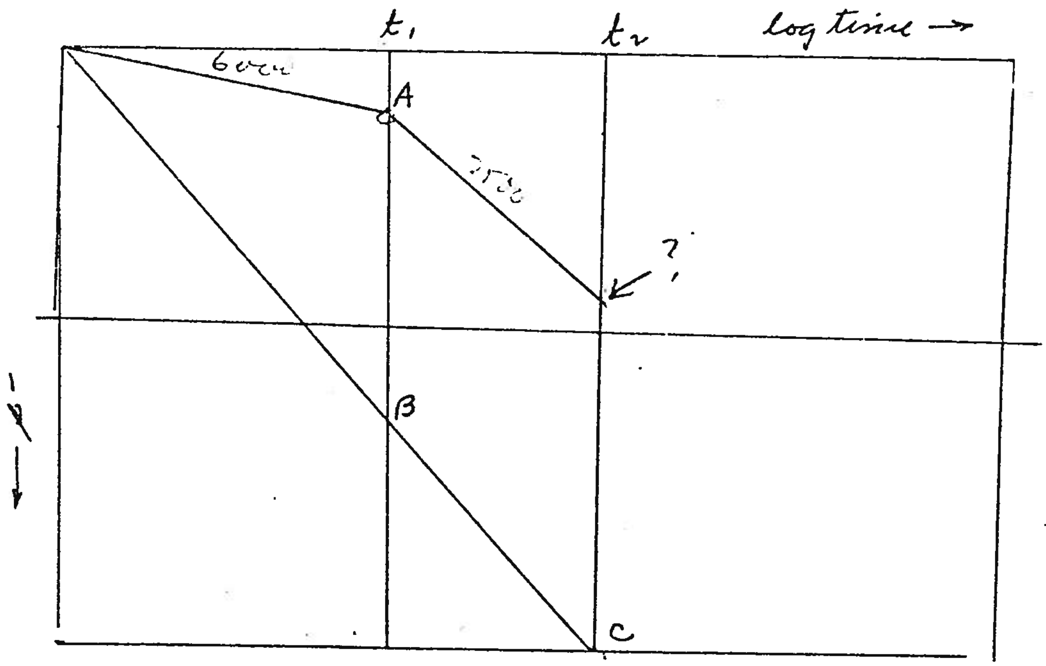
COEFFICIENTS SELECTED.

T — 6.0×10^3 for first limb

2.5×10^3 for second limb

S — 2.0×10^{-4}

SOLUTION OF TWO LIMB PROBLEM



at any time t_2 the total drawdown will be equal to $C-(B-A)$.

t_1 in all cases will ~~be 100 minutes~~ ~~in every~~ ~~be when s = 10 feet at a distance 12.2 feet from pumping well~~.

be 100 minutes since the pressure cone expands at the ~~same~~ essentially the same rate despite the pumping rate.

determined in actual time vs dd plot pump test.

Find equation relating Q and s for twenty years.

$r = 3'' = .25'$ $r^2 = .06$

$365 \times 20 = 7300$ days.

20 years

(A) $u = \frac{1.87 \times r^2 \times S}{T t} = \frac{1.87 \times 6\times10^{-2} \times 2\times10^{-4}}{6\times10^{3} \times \frac{100}{1440}}$

$= \frac{22.4\times10^{-6}}{4.16\times10^{2}} = 5.4\times10^{-8}$

$W(u) = 13.85$

$s = \frac{1.146\times10^{2}\, Q\, W(u)}{6.0\times10^{3}} = 2.64\times10^{-1} Q$

(B) $u = \frac{22.4\times10^{-6}}{2.5\times10^{3}\times\frac{100}{1440}} = \frac{22.4\times10^{-6}}{1.73\times10^{2}} = 12.9\times10^{-8} = 1.29\times10^{-7}$

$W(u) = 15.28$

$s = \frac{1.146\times10^{2} Q \times 15.28}{2.5\times10^{3}} = 7.00\times10^{-1} Q$

(C) $u = \frac{22.4\times10^{-6}}{2.5\times10^{3}\times7.3\times10^{3}} = \frac{22.4\times10^{-6}}{18.3\times10^{6}} = 1.22\times10^{-12}$

$W(u) = 26.86$

$s = \frac{1.146\times10^{2} Q \times 26.86}{2.5\times10^{3}} = 12.3\times10^{-1} Q$

total dd after 20 years $= 1.230\, Q - (0.700 Q - 0.264 Q)$

$= 0.794 Q$

700
264
.436
1.230
436
.794

63 gpm uses 50' of available dd.

10 years

For ten years.

3650 days.

(C) $u = \frac{22.4\times10^{-6}}{2.5\times10^{3}\times3.65\times10^{3}} = \frac{22.4\times10^{-6}}{9.12\times10^{6}} = 2.46\times10^{-12}$

$W(u) = 26.17$

$s = \frac{1.146\times10^{2} Q \times 26.17}{2.5\times10^{3}} = 12.0\times10^{-1} Q$

total dd after 10 years $= 1.200 Q - (0.436 Q)$

$= 0.764 Q$

$Q = 65.4$ gpm for 50' available dd.

For five years.
365
5
1825

(c) $u = \frac{22.4\times10^{-6}}{2.5\times10^3\times1.825\times10^3} = \frac{22.4\times10^{-6}}{4.25\times10^6} = 5.27\times10^{-12}$

$W(u) = 25.39$

$s = \frac{1.146\times10^2\times Q\times25.39}{2.5\times10^3} = 11.64\times10^{-1}Q$

total dd $= 1.164Q - (0.436Q)$
$= 0.728Q$

$Q = 68.8$ gpm for 50' available dd

For three years
365
3
1095

(c) $u = \frac{22.4\times10^{-6}}{2.5\times10^3\times1.095\times10^3} = \frac{22.4\times10^{-6}}{2.74\times10^6} = 8.17\times10^{-12}$

$W(u) = 24.95$

$s = \frac{1.146\times Q\times10^2\times24.95}{2.5\times10^3} = 11.40\times10^{-1}Q$

total dd $= 1.140 - (0.436Q)$
$= 0.704Q$

$Q = 71$ gpm for 50' available dd.

For One year

(c) $u = \frac{22.4\times10^{-6}}{2.5\times10^3\times3.65\times10^2} = \frac{22.4\times10^{-6}}{9.12\times10^5} = 2.45\times10^{-11}$

$W(u) = 23.85$

$s = \frac{1.146\times Q\times10^2\times23.85}{2.5\times10^3} = 10.91\times10^{-1}Q$

total dd $= 1.091 - (0.436Q)$
$= 0.655Q$

$Q = 76.3$ gpm for 50' available dd.

For 10 hours

(c) $u = \frac{22.4\times10^{-6}}{25\times10^2\times\frac{10}{24}} = \frac{22.4\times10^{-6}}{1.04\times10^3}$
$= 21.5\times10^{-9} = 2.15\times10^{-8}$
$W(u) = 17.03$
$s = 7.80\times10^{-1}Q$
total dd $= 0.780Q - (0.436Q)$
$= .344$

$Q = 145$ gpm

~~(c) $u = \frac{22.4\times10^{-6}}{2.5\times10^3\times\frac{10}{24}} = \frac{22.4\times10^{-6}}{.104\times10^5} = 21.5\times10^{-9} = 2.15\times10^{-7}$~~

~~$W(u) = 17.03$~~

~~$s = \frac{1.146\times Q\times10^2\times17.03}{2.5\times10^3} = 7.80\times10^{-1}Q$~~

~~total dd $= 0.994Q - (0.436Q)$~~
~~$= 0.558Q$~~

~~$Q = 89.8$ gpm for 50' available dd.~~

10 hours / day

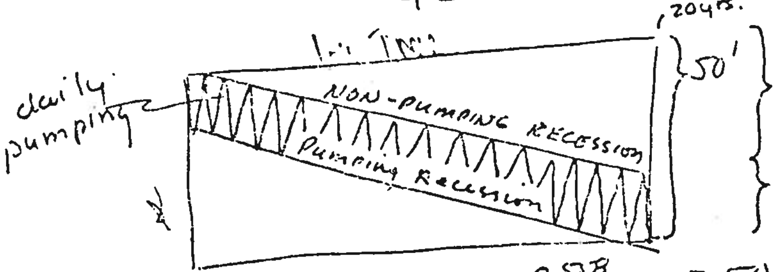
50 feet available dd

Q_1 = average pump rate (as if pumping continuously)

Q_2 = actual " "

Equations: $10\ Q_2 = 24\ Q_1$

$Q_2 = 2.4\ Q_1$ (1)



$0.794\ Q_1$ (for 20 years)

~~0.558~~ ~~0.157~~ 0.344 Q_2 (for 10 hours)

(2)

$0.794\ Q_1 + $ ~~0.157~~ 0.558 $Q_2 = 50'$

$0.794\ Q_1 + 2.4($~~0.157~~ 0.558 $Q_2) = 50$

$0.794\ Q_1 + $ ~~0.377~~ 1.339 $Q_1 = 50$

$0.794\ Q_1 + $

~~1.17~~ 2.133 $Q_1 = 50$

$Q_1 = $ ~~42.6~~ 23.4 gpm

$Q_2 = $ ~~102~~ 56.3 gpm

for 20 years

For 10 years

$0.764\ Q_1 + 0.157\ Q_2 = 50$

$0.764\ Q_1 + 0.377\ Q_1 = 50$

$1.141\ Q_1 = 50$

$Q_1 = 43.7$

$Q_2 = 105$ gpm

0.558 × 2.4 = 2232 + 1116 = 1.3392; + .794 = 2.133

For 20 years.

$0.794\ Q_1 + 0.344\ Q_2 = 50$

$0.794\ Q_1 + 0.826\ Q_1 = 50$

$1.620\ Q_1 = 50$

$Q_1 = 30.9$ gpm

$Q_2 = 74$ gpm

344 × 2.4 = 1376 + 688 = .8256

For 10 years.

$0.764\ Q_1 + 0.826\ Q_1 = 50$

$1.590\ Q_1 = 50$

$Q_1 = 31.4$ gpm

$Q_2 = 75.5$ gpm

For 5 years.

$$0.728\,q_1 + 0.826\,q_1 = 50$$
$$1.554\,q_1 = 50$$
$$q_1 = 32.1 \text{ gpm}$$
$$q_2 = 77.2 \text{ gpm}$$

For 3 years.

$$0.704\,q_1 + 0.826\,q_1 = 50$$
$$1.530\,q_1 = 50$$
$$q_1 = 32.7 \text{ gpm}$$
$$q_2 = 78.5 \text{ gpm}$$

For One year

$$0.655\,q_1 + 0.826\,q_1 = 50$$
$$1.484\,q_1 = 50$$
$$q_1 = 33.7 \text{ gpm}$$
$$q_2 = 81 \text{ gpm}$$

ONE WELL

TIME PERIOD	continuous Production GPM	Pumping 10 hours of each Day GPM	gpd @continuous production	gpd @ 10hours per day
20 years	63	74	90,600	44,400
10 years	65.4	75.5	94,200	45,300
5 years	68.8	77.2	99,000	46,400
3 years	71.0	78.5	102,100	47,100
1 year	76.3	81.0	109,800	48,600

Two wells - 1000 feet apart.

40 gpm each
for 20 years or 115,200 gal per day.

1960 daily consumption
138,000 gallons.

Two wells supply 80% of present need.

TWO WELL PROBLEM

1000' $r = 1000'$

(A) $u = \dfrac{1.87\times(10^3)^2 \times 2\times10^{-4}}{6\times10^3 \times 100/1440} = \dfrac{3.74\times10^2}{4.16\times10^2} = 9.05\times10^{-1}$ $W(u) = 0.2558$

$s = \dfrac{1.146 \times Q \times 0.2558\times10^0}{6\times10^3} = \underline{4.9Q\times10^{-5}}$

(B) $u = \dfrac{3.74\times10^2}{1.73\times10^2} = 2.16$ $W(u) = 0.38$

$s = \dfrac{1.146\times Q\times 38}{2.5\times10^3} = \underline{15.2\times10^{-3}} Q$

(C) $u = \dfrac{3.74\times10^2}{1.83\times10^7} = 2.04\times10^{-5}$ $W(u) = 10.24$

$s = \dfrac{1.146\times Q\times 10.24\times10^2}{2.5\times10^3} = \underline{4.7\times10^{-1}}\, Q$

total dd @ 1000 $= 0.47Q - (0.015Q - 0.005Q)$
$= 0.47Q - 0.01$
$= 0.46Q$

Test wells 1000' apart.
self-caused $= 0.794\,Q$
interference $= 0.460\,Q$
$0.794Q + 0.460Q = 50$
$1.254\,Q = 50$
$Q = 40$ gpm

Two wells 2000' apart

$u = 4.16 \times 10^{-5}$ $W(u) = 9.52$

$s = \frac{1.146 \times 10^{2} Q \times 9.52}{2.5 \times 10^{3}} = 4.37 \times 10^{-1} Q$

total dd @ 2000 $= 0.437 Q - (0.01)$ ← approx.

$= 0.43 Q$

.438 ← actually

$$63 \overline{)27.6}$$
252
240
189
510
504

$0.794 Q + 0.435 Q = 50$

$1.232 Q = 50$

$Q = 40^{+}$ gpm

$\frac{1.87 \times (2 \times 10^{3})^{2} \times 2 \times 10^{-4}}{1.83 \times 10^{7}}$

$\frac{15 \times 10^{2}}{1.83 \times 10^{7}} = 8.2 \times 10^{-7}$

For ten years.

~~[illegible]~~
self caused dd $= 0.764 Q$

interference $= \frac{3.74 \times 10^{2}}{2.5 \times 10^{3} \times 3.65 \times 10^{3}} = \frac{3.74 \times 10^{2}}{9.12 \times 10^{6}} = .411 \times 10^{-4}$

365
10
―
50

$= 4.11 \times 10^{-5}$

$W(u) = 9.52$

$s = \frac{1.146 \times 10^{2} Q \times 9.52}{2.5 \times 10^{3}} = .437 Q$

total dd $= 0.437 Q - (.015 - .005)$

$= 0.427 Q$

$0.764 Q + 0.427 Q = 50$

$1.191 Q = 50$

$Q = 42$ gpm

500

Q_2 = [illegible] well

$0.824 Q_1 + .490 Q_2 + + .460 Q_1 = 50$

$0.824 Q_2 + 0.980 Q_1 = 50$

$$Q_2 = \frac{50 - 0.980 Q_1}{0.824}$$

$$0.824 Q_1 + 0.490 \left(\frac{50 - 0.980 Q_1}{0.824} \right) + 0.460 Q_1 = 50$$

$0.824 Q_1 + 29.80 - 0.582 Q_1 + 0.460 Q_1 = 50$

$1.284 Q_1 - .582 Q_1 = 20.20$

$.702 Q_1 = 20.20$

$Q_1 = 28$ gpm

$0.824 Q_2 + 27.4 = 50$

$0.824 Q_2 = 22.6$

$Q_2 = 27$ gpm

Two wells 1000' apart.

self caused $= 0.824 Q_1$

interference $= 0.460 Q_1$

$1.284 Q_1 = 50$

$Q_1 = 39$ gpm

for 10 yrs.

(c) $u = \frac{32.4 \times 10^{-3}}{5.5 \times 10^3 \times 3.65 \times 10^3 \times 1.440 \times 10^3} = \frac{32.4 \times 10^{-3}}{13.15 \times 10^9} = 2.16 \times 10^{-1?}$

$W(u) = 26.17$

$s = \frac{1.146 \times 10^2 \, Q \, 26.17}{5.5 \times 10^3} = 12 \times 10^{-1} Q$

total dd after 10 yrs. = .794 Q

Max Q_1 = 63 gpm

Well spacing 500'

Q_1 = outside rate
Q_2 = inside

outside wells.

$Q_1 = 60.5 - 0.592 Q_2$

$0.824 Q_1 + .490 Q_2 = 50$ ÷ / $1 Q_1 + 0.592 Q_2 = 60.5$

Inside $0.824 Q_2 + .490 Q_1 + .490 Q_1 = 50$

$0.824 Q_2 + .980 Q_1 = 50$

$0.824 Q_2 + 0.980 (60.5 - 0.592 Q_2) = 50$

$0.824 Q_2 + 59.4 - 0.580 Q_2 = 50$

$.254 Q_2 = -9.4$

$Q_2 = -37$ gpm.

$0.824 Q_1 + .490 Q_2 = 50$

$0.824 Q_1 + 18.2 = 50$

$0.824 Q_1 = 31.8$

$Q_1 = 38.5$

$r^2 = 6\times10^{-2}$

$$\mu = \frac{2.693\times10^{3}\times6\times10^{-2}\times2\times10^{-4}}{6\times10^{3}\times1.80\times10^{2}} = \frac{32.4\times10^{-3}}{10.8\times10^{5}} = 3\times10^{-8}$$

(A) $W(u) = 16.74$

$$s = \frac{1.146\times10^{2}\,Q\,16.74}{6\times10^{3}} = 3.2\times10^{-1}Q$$

(B)

$$\mu = \frac{32.4\times10^{-3}}{2.5\times10^{3}\times1.80\times10^{2}} = \frac{32.4\times10^{-3}}{4.5\times10^{5}} = 7.2\times10^{-8}$$

$W(u) = 15.86$

$$s = \frac{1.146\times10^{2}\,Q\times15.86}{2.5\times10^{3}} = 7.26\times10^{-1}Q$$

(C)

$$\mu = \frac{32.4\times10^{-3}}{2.5\times10^{3}\times7.3\times10^{3}\times1.440\times10^{3}} = \frac{32.4\times10^{-3}}{26.3\times10^{9}} = 1.23\times10^{-12}$$

$W(u) = 26.87$

$$s = \frac{1.146\times10^{2}\,Q\;26.87}{2.5\times10^{3}} = 12.3\times10^{-1}Q$$

Total dd after 20yrs. = C − B + A

$1.23Q - .726Q + .32Q = 0.824Q =$

(50') available dd. gives $Q = 60.7$ gpm.

$50 = 0.520Q_1 + 0.490Q_2$

1800' Spacing
Three wells

outside well. $0.824 Q_1 + 0.460 Q_2 + 0.430 Q_1 = 50$

Inside well $0.824 Q_2 + 0.920 Q_1 = 50$

$$Q_2 = \frac{50 - 0.920 Q_1}{0.824}$$

$$0.824 Q_1 + 0.460 \left(\frac{50 - 0.920 Q_1}{0.824} \right) + 0.430 Q_1 = 50$$

$$0.824 Q_1 + 27.9 - 0.514 Q_1 + 0.43 Q_1 = 50$$

824
430
1.254
.514
.740

50.0
27.9
22.1

$0.740 Q_1 = 22.1$
$Q_1 = 30$ gpm

$0.824 Q_2 + 27.6 = 50$
$.824 Q_2 = 22.4$
$Q_2 = 27$ gpm

50.0
27.6
22.4

30
30
27
87

2000' spacing ~~three~~ two wells.

$0.824 Q_1 + 0.430 Q_1 = 50$
$1.254 Q_1 = 50$
$Q_1 = 40$ gpm

Well Location: No 1. TEST HOLE Pumping Test: Drawdown Date: Aug 29, 19[illegible]

Status: Obs. well

r: 12.2' from pumping well Conducted by: G. [illegible] Page: 1

Date	Time	t minutes	r^2/t / $r^2/1/t$	Static water level	Depth to water	Draw-down	30 gals. Volume in sec.	Q GPM	Remarks
Aug 29	7 AM			52.59					Measurements from [illegible]
	8:25			52.65	52.55				3.9' above ground surface
	8:55			52.64	52.64				
	9:30			52.75	52.47				
	10:00	0		52.52					
		1	2.14 × 10^5		58.01	5.49			
		2			58.50	[illegible]			
		3	7.07 × 10^4		59.06	6.54			
		5			59.60	7.08			
		7			59.88	7.36			
		10	2.14 × 10^4		60.19	7.67	30		
		12			60.37	7.85			
		15			60.60	8.12	31;32		
		20	1.06 × 10^4		60.78	8.26	32		
		25			60.94	[illegible]			
		30	7.07 × 10^3		61.11	[illegible]			
		35			61.22	[illegible]			
		40	5.3 × 10^3		61.33	[illegible]			
		45			61.44	[illegible]			
		50	4.24 × 10^3		61.58	[illegible]			
		60			61.69	9.17			
		70	3.03 × 10^3		61.84	9.32			
		80			61.97	9.45			
		90	2.35 × 10^3		62.13	[illegible]			
		100		52.50	62.24	9.74			
		120			62.38	9.88			
		140			62.59	10.09			
		160			62.71	10.21			
		180			62.85	10.35			
		210	1.01 × 10^3	52.48	63.22	[illegible]			

Well Location: No. 1 Test hole　　Pumping Test: drawdown　　Date: Aug 79

Status: Obs. well　　Conducted by: J. [illegible]　　Page: 2

r: 12.2' from pumping well

Date	Time	t minutes	r^2/t / $r^2/1k$	Static water level	Depth to water	Draw-down	Volume	Q GPM	Remarks
		240	[illegible]	52.48	63.44	10.96	34		Pump off 2:07-2:11 pm
		270			63.66	11.18	34		
		300	[illegible]	52.46	63.88	11.42	34		
		340			64.10	11.64	31		
		380	[illegible] x10²		64.40	[illegible]	↓		
		420		[illegible]	64.[illegible]	12.[illegible]			
		480	[illegible] x10²	[illegible]	64.71	12.[illegible]			
		520		[illegible]	65.13	12.71			
		600	[illegible] x10²	[illegible]	65.36	12.95			
		660			65.46	13.0[illegible]			
		720	[illegible] x10²	[illegible]	65.6[illegible]	13.[illegible]			
		780	[illegible] x10²	[illegible]	65.74	13.3[illegible]			
		900	[illegible]	[illegible]	65.89	13.[illegible]	↓		
		1080	[illegible]		–	-			Pump on 7:10 – 7:3[illegible] pm
		1260	1.[illegible]		–	-			
		1320	[illegible]		–	-	31		
		1380	1.55	52.31	66.40	14.09	32		
		1440	[illegible]	[illegible]	66.57	14.27	31		Pump off 11:45 - 12:[illegible]
		1500	[illegible]	[illegible]	66.66	14.31	32		" " 2:15 - 2:30 pm
		1620	1.32	[illegible]	66.78	14.51	31		
		1800	[illegible]	[illegible]	66.97	14.71	↓		
		1980	1.07	[illegible]	67.19	14.94			
		2280	9.3[illegible]	[illegible]	67.49	15.2[illegible]	↓		
		2640	[illegible]	[illegible]	67.6[illegible]	15.50	32		
		3000	7.07	[illegible]	67.[illegible]3	[illegible].67	[illegible]		

3000 min

50 hrs

Well Location #1 TEST HOLE Pumping Test: RECOVERY Date: [illegible]

Status:

r: Conducted by: Page:

Date	Time	t minutes	$\frac{r^2}{t}$ / $\frac{r^2}{1/t}$	Static water level	Depth to water	RECOVERY Draw-down	Volume	Q GPM	Remarks
1:31	12:00			67.83					
		1			[illegible]	2.73			
		[illegible]			[illegible]	4.93			
		[illegible]			[illegible]	5.78			
		[illegible]			[illegible]	6.59			
		7			[illegible]	7.00			
		[illegible]			60.50	7.33			
		[illegible]			60.25	7.58			
		[illegible]			60.00	7.83			
		20			59.[illegible]	8.11			
		25			59.51	8.32			
		30			59.31	8.52			
		35			59.14				
		40			58.99				
		45			58.88				
		50			58.75				
		60			58.54				
		70			58.36				
		80			58.19				
		90			58.04				
		100			57.90				
	2PM	120			57.73				
	2:20	140			57.50				
	2:40	16[illegible]			57.29				
	3PM	[illegible]			57.15				
	3:30	21[illegible]			56.[illegible]				
	4:00	240			56.68				
	4:30	270			56.50				
	5:00	300			56.40				
	5:40	340			55.95				

Well Location ______

Status: Observation well #1

r: 12.2'

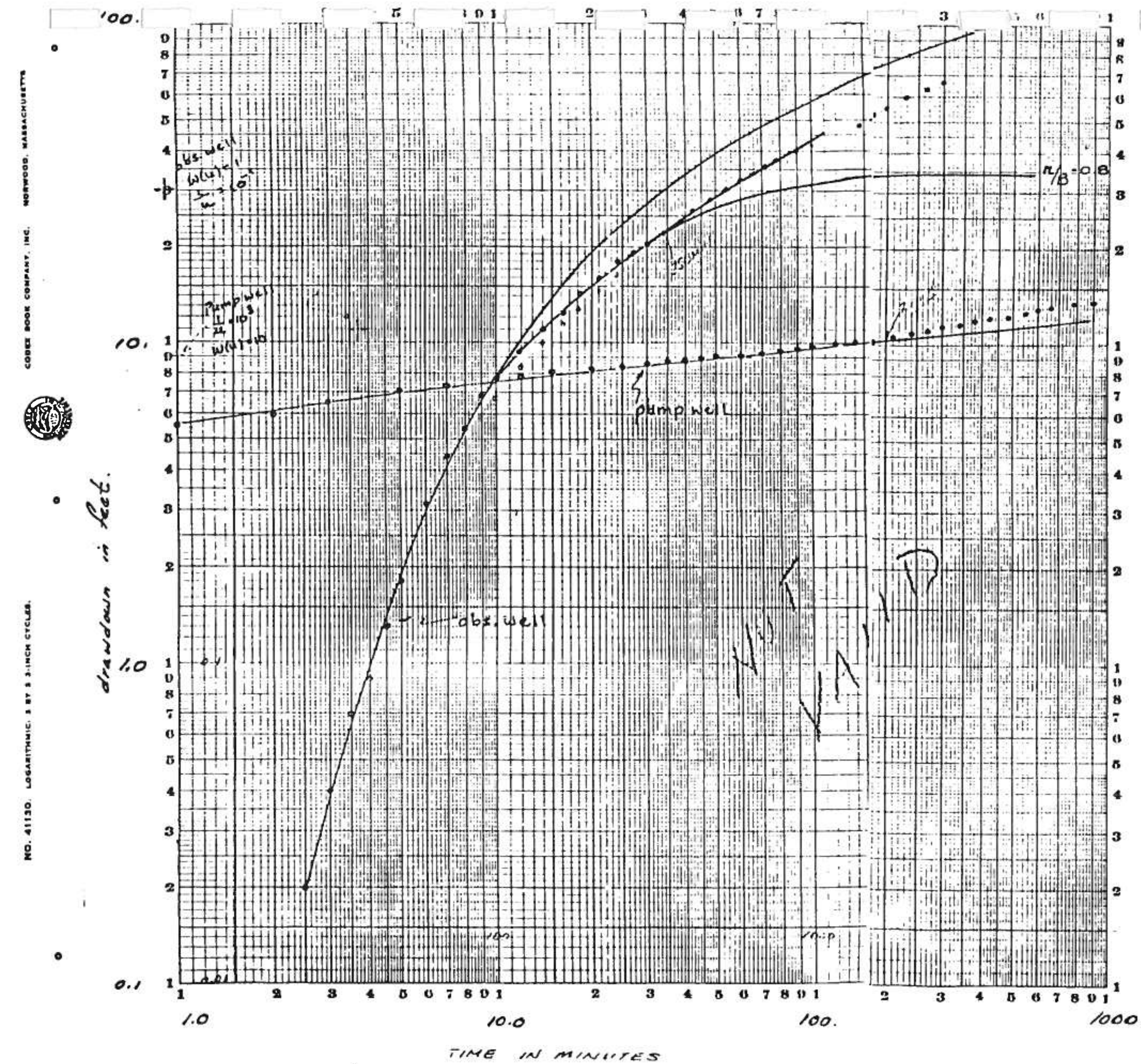
Pumping Test: Recovery

Conducted by: [illegible signature]

Date: ______

Page: ______

Date	Time	t minutes	r^2/t / $r^2/1/t$	Static water level	Depth to water	Draw-down	Volume	Q GPM	Remarks
		0		67.83					
		1			65.10				
		2			62.90				
		3			62.05				
		5			61.24				
		7			60.83				
		10			60.50				
		12			60.25				
		15		67.84	60.00				
		20			59.72				
		25			59.51				
		30		67.86	.31				
		35			.14				
		40			58.99				
		45		67.88	.88				
		50			.75				
		60		67.90	.54				
		70			.36				
		80			.19				
		90		67.93	.04				
		100		67.95	57.90				
		120		67.97	.73				
		140		67.99	.50				
		160		68.02	.29				
		180		68.04	.15				
		210		68.07	56.90				
		240		68.11	.68				
		270		68.14	.50				
		300		68.18	.40				
		360		68.22	55.95				



pump well for late curve fit

$s = \frac{114.6 \times Q}{T} W(u)$

$T = \frac{1.146 \times 10^2 \times 58 \times 10}{11}$

$= 60 \times 10^2$

$= 6000$ gpd/ft

$u = \frac{2693 r^2 S}{Tt}$

$10^{-3} \times 74 \times 10^3 \times 1 = 2693 \times 144 S$

$\frac{60}{144 \times 2693} = S$

$S = \frac{60}{3.87 \times 10} = 15.5 \times 10^{-5}$

$= 1.55 \times 10^{-4}$

obs. well

early curve

$T = \frac{1.146 \times 10^2 \times 58 \times 1}{3}$

$= 2.2 \times 10^3$

$= 2200$ gpd/ft.

$P = \frac{2200}{15} = 146$

$10^1 \times 2.2 \times 10^3 \times 0.9 = 2693 \times (7.74 \times 10^2)^2 S$

$1.98 \times 10^5 = 2693 \times 60 \times 10^4 S$

$\frac{1.98 \times 10^5}{16.1 \times 10^8} = S$

$S = 0.123 \times 10^{-3}$

$= 1.23 \times 10^{-4}$

barrier boundary - obs well data

$t_1 = 120$, $t_2 = 920$

$r_1 = 775$, $r_2 = ?$

$120 r_2^2 = 5.5 \times 10^8$

$r_2^2 = 0.046 \times 10^8$

$\frac{t_1}{r_1^2} = \frac{t_2}{r_2^2}$

$r_2^2 = 4.6 \times 10^6$

$r_2 = 2.14 \times 10^3$

$= 2140$ ft

$a = 1070$ ft

$P' = \frac{Tm' (\frac{r}{B})^2}{r^2}$

$m = 100$, $T = 2.2 \times 10^3$

$= \frac{2.2 \times 10^3 \times 1 \ldots (\ldots)^2}{60 \times 10^4}$

$= \frac{140.8 \times 10^3}{60 \times 10^4} = \ldots$

6.6×10^2

$6. \times 10^5$

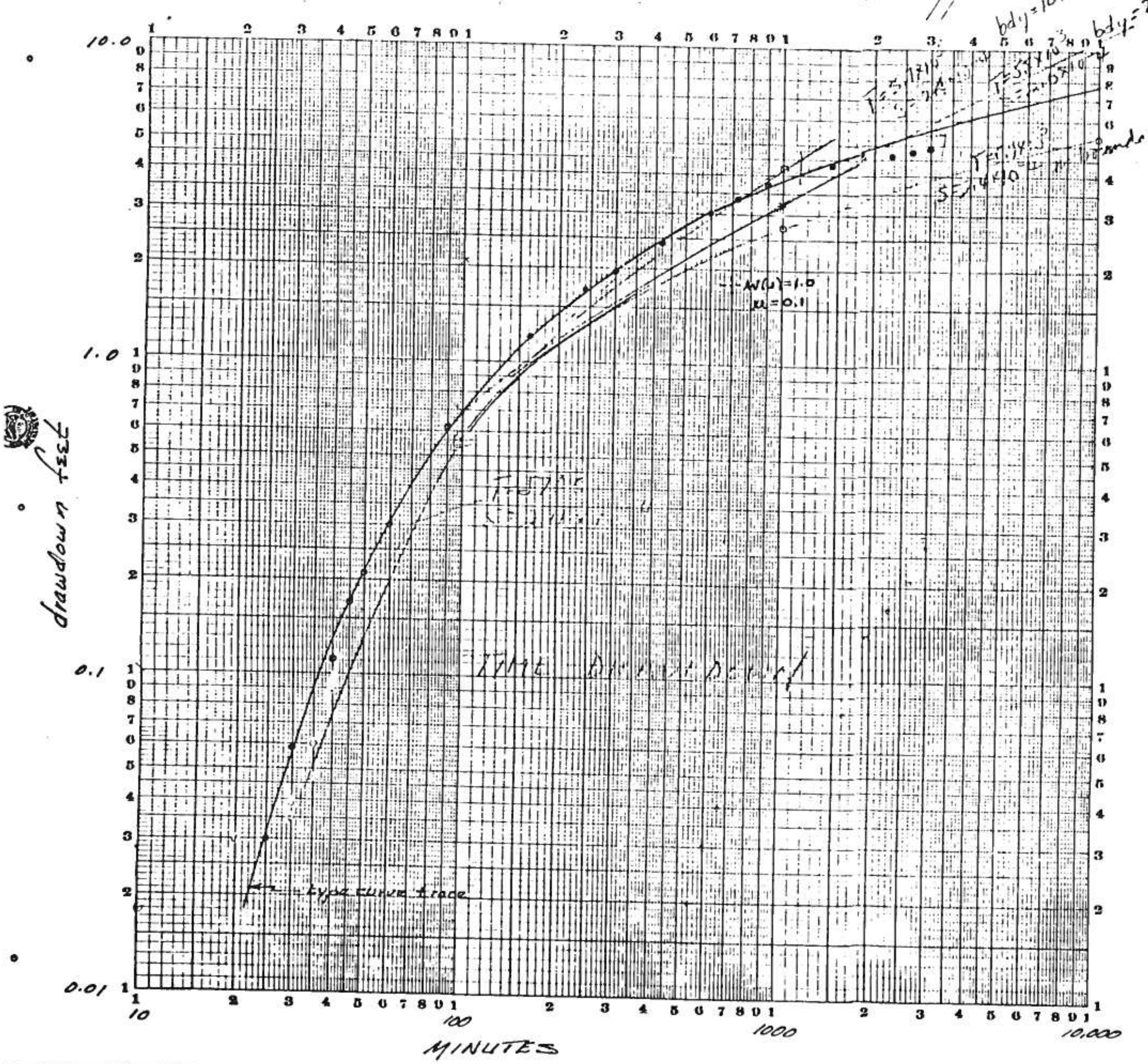
39.6×10^7

66×10^1

60×10^4

3960

$\frac{39.6 \times 10^7}{40}$

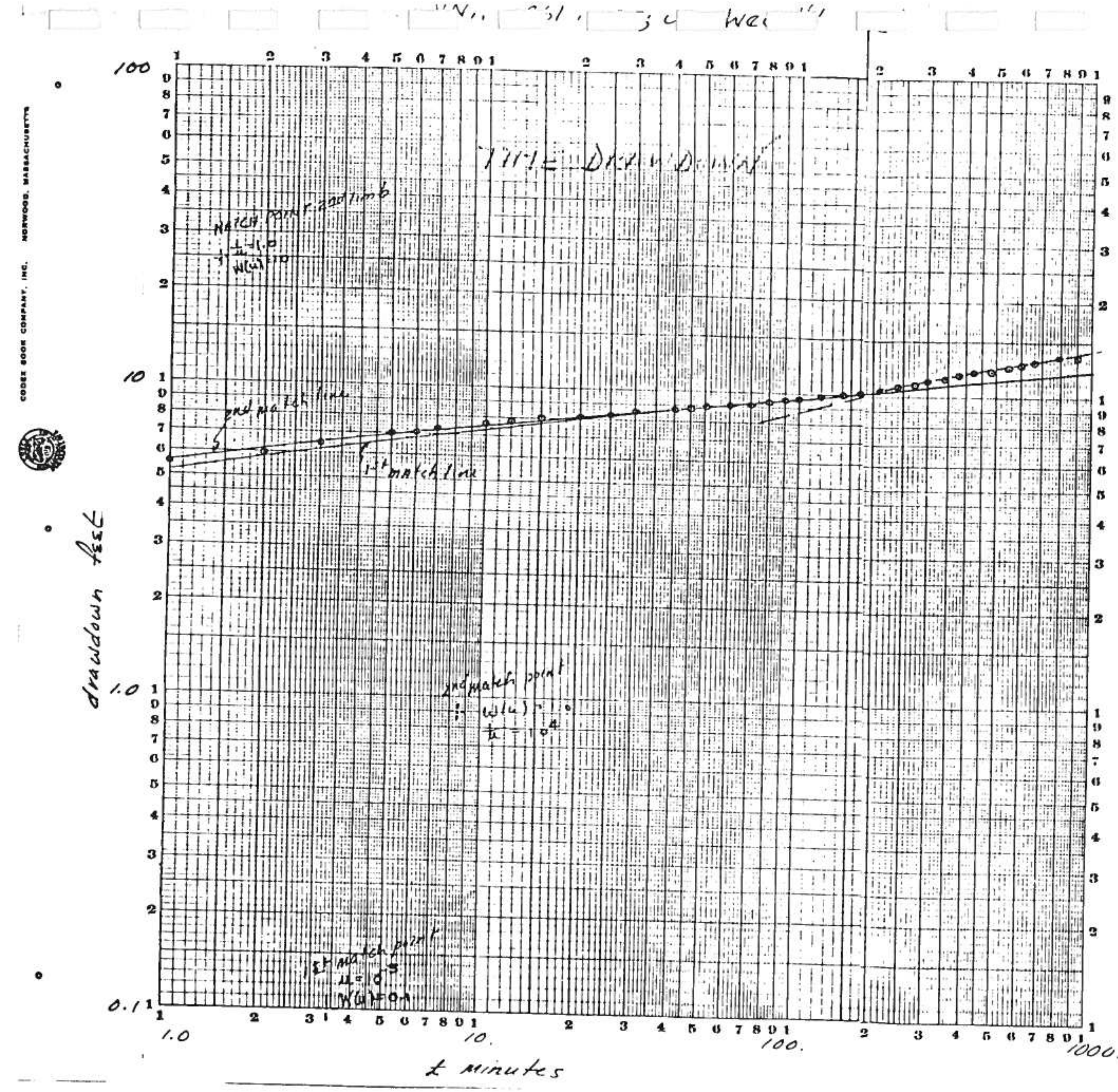


$$T = \frac{1.146\times10^{2}\times5.8\times10^{1}\times4.0}{1.8} = \frac{6.65\times10^{3}}{1.8} = 3.7\times10^{3} = 5700\,\text{gpd/ft.}$$

$$u = \frac{2693\,r^{2}S}{Tt} = \frac{2.693\times10^{3}\times6\times10^{5}\times S}{3.7\times10^{3}\times7.0\times10^{2}} = 0.1$$

$$16.15\times10^{8}\,S = 25.9\times10^{4}$$

$$S = 1.6\times10^{-4}$$



$$T = \frac{1.146\times10\times5.8\times10\times0.1}{0.1} = \underline{6650}$$

$$S = \frac{uTt}{2693r^2} = \frac{10^{-3}\times6.6\times10^{3}\times3.4}{2.693\times10^{3}\ 1.44\times10^{2}}$$

$$= \frac{224}{3.87\times10^{5}} = \underline{5.8\times10^{-5}}$$

2nd Match

$T = 7000$

$S = 1.5\times10^{-5}$

2nd limb

$$T = \frac{1.146\times10^{2}\times5.8\times10^{1}\times10}{24.5} = 2.76\times10^{3} = \underline{2760}$$

$s=1$ when $W(u)=1$ $\frac{1}{u}=3.8$ $u = 0.263$

$$1 = \frac{1.146\times10^{2}\times5.8\times10^{1}\times1}{6.6\times10^{3}}$$

$$5.8\times10^{-5} = \frac{0.263\times6.6\times10^{3}\times t}{.269\times10^{4}\times1.44\times10^{2}}$$

$8.35\times10^{-3} = 6.6\times10^{3}t$

$1.26\times10^{-6} = t$ when $s=1$

$$\frac{r_1^2}{t_1} = \frac{r_2^2}{t_2} \qquad \frac{1.44\times10^{2}}{1.26\times10^{-6}} = \frac{r_2^2}{450}$$

$6.5\times10^{4} = 1.26\times10^{-6}r_2^2$

$5.15\times10^{10} = r_2^2$ ← too high.

try $S = 1.2\times10^{-4}$

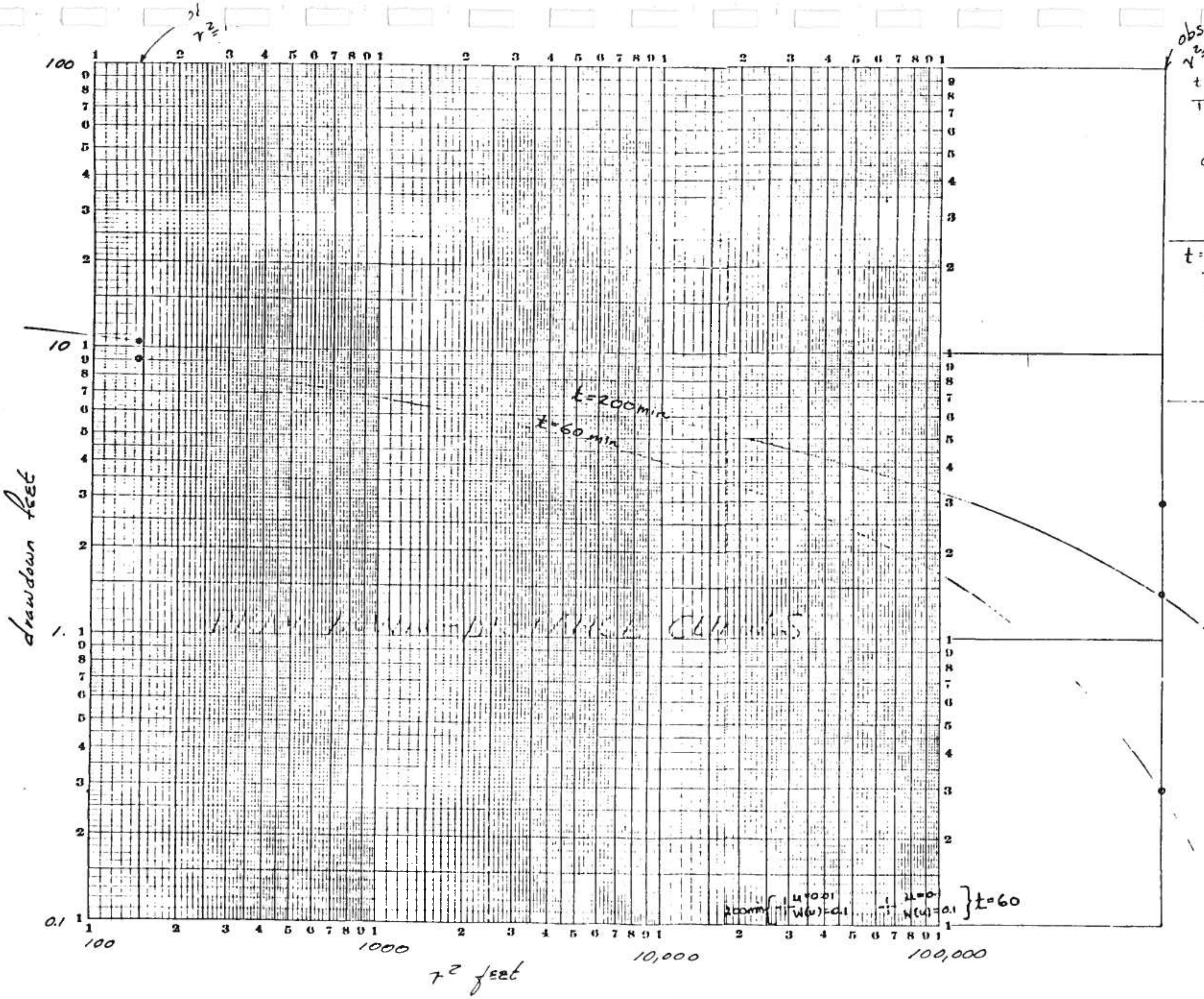
$1.73\times10^{-2} = 6.6\times10^{3}t$

$0.262\times10^{-5} = t = 2.6\times10^{-6}$

$6.5\times10^{4} = 2.6\times10^{-6}r_2^2$

$2.5\times10^{+10} = r_2^2$

$r_2 = 1.58\times10^{5}$



$t = 60$ min

$T = \frac{1.146\times10^{?}\cdot 5.?\times10^{?}\times 0.1}{0.117} = \underline{5670}$

$0.1 = \frac{2.693\times10^{3}\times 6.6\times10^{4} S}{5.67\times10^{3}\times 6\times10^{?}}$

$34\times10^{3} = 17.75\times10^{7} S$

$\underline{S = 5.2\times10^{-4}}$

$t = 200$ min.

$T = \underline{5670}$

$.01 = \frac{2.693\times10^{3}\times 2.9\times10^{4} S}{5.67\times10^{3}\times 2\times10^{2}}$

$11.35\times10^{3} = 7.8\times10^{7} S$

$\underline{S = 1.45\times10^{-4}}$

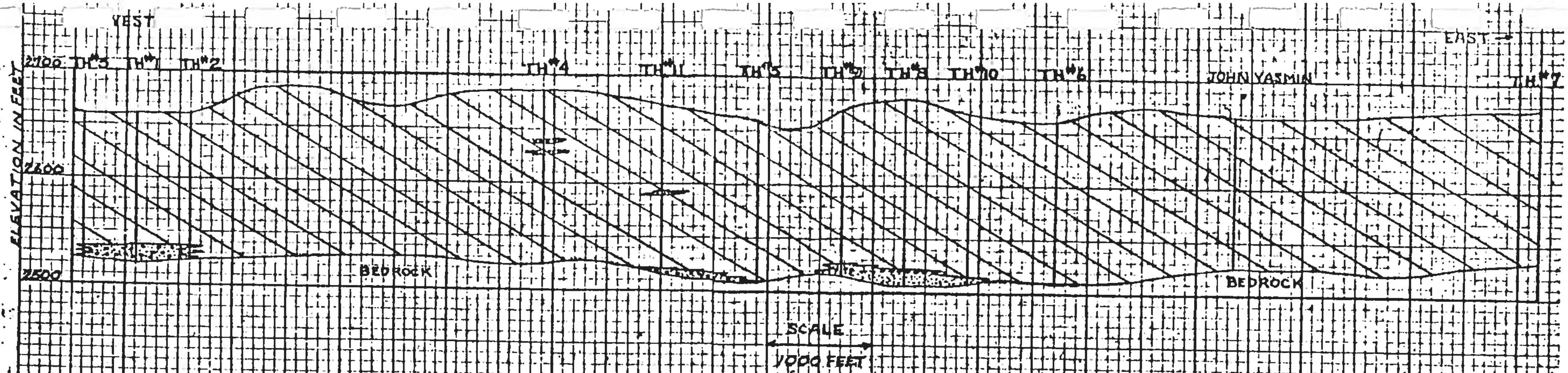

WEST
EAST
ELEVATION IN FEET
2700
2600
2500
TH#3
TH#1
TH#2
TH#4
TH#11
TH#5
TH#9
TH#8
TH#10
TH#6
JOHN YASMIN
T.H.#7
BEDROCK
BEDROCK
SCALE
1000 FEET

FIGURE 2

D T
R F
A

Hanna Project

The Town of Hanna depends upon a small surface reservoir, replenished by ephemeral surface run-off from Bullpound Creek, through a series of structures constructed by P. F. R. A. and Ducks Unlimited, to the reservoir, any excess going to Fox Lake. The run-off for the past three years has been inadequate to maintain sufficient water in the town reservoir. It is possible to divert water from Fox Lake, adjacent to the town reservoir; however, the water in Fox Lake is highly turbid. Small quantities of water from Fox Lake have been diverted to the reservoir over the past two years; this has resulted in a marked and persistent increase in the alum pre-treatment and settling time required at the filtration plant. The present peak consumption at Hanna is reported to be 260,000 gpd. This figure is excessive for the population (2,500) and indicated both wasteful consumption and excessive transmission losses. In early August, treated reservoir storage was insufficient to supply the peak suppertime demand, and the water had to be shut off periodically to maintain fire-fighting reserves.

There are several conflicting solutions which involve surface water; all of these depend ultimately upon construction of the Red Deer river diversion. The immediate demand, however, could be accommodated if it is possible to economically treat water from Fox Lake. This demand could also be met by utilizing the abandoned C.N.R. reservoir just south of Hanna, provided that sufficient inflow is obtained from the rather limited drainage basin of this reservoir.

All available sources of surface water can obtain at considerable expense a product which at best can be described as "slough water".

Until eight years ago the town obtained water from wells completed in the basal strata of the Edmonton formation. Poor well construction and absolutely no well maintenance program resulted in a gradual deterioration of the wells. There is no evidence that there has been any decrease in the amount of groundwater available. The wells have been utilized (after chemical and bacteriological analyses, but without general public knowledge) this summer to augment the supply.

A buried channel has been located about two miles west of Hanna. This channel is known to extend south from Byemoor, through the Hanna reservoir, and southward along Bullpound Creek. A five-mile seismic profile run this summer proved the location of the channel at Hanna. Examination of confidential oil company information (I.O.L. slim hole logs, not released) confirms the location and shows that up to 20 feet of coarse granular material may occur in this channel. A water analysis of water obtained from a well completed in this channel at Byemoor indicates that the water quality is above the accepted limits in total solids and alkalinity. One analysis cannot, however, be considered conclusive. It is significant that the existing pipeline from the reservoir to the town extends to the estimated position of the channel centre-line. Any wells located on or near the existing line, even if water quality was not too good, could be produced directly to the pipeline. The resultant mixture would have a lower total solids and lower turbidity (and lower treatment time), thus permitting the existing treatment facilities to carry a higher load. If production from the gravel induces infiltration from the overlying reservoir, then the water quality would improve with time, and if sufficient water can be obtained then the only treatment required at the filtration plant would be chlorination. This would substantially reduce operating costs without any large capital investment.

The aspects of this problem of interest to us are:

i) what is the hydrologic behavior of narrow sharply incised bedrock channels, can they be expected to yield large quantities of water, or will the boundary conditions prove too restrictive,

ii) can induced infiltration be anticipated from overlying lakes, if so to what extent, and what net effect will there be on water quality.

The area immediately around the Hanna reservoir offers a favorable situation for investigating the above problems. The geologic situation, so far as is known, is present, right of entry can be readily obtained since the town owns or rents the land we would be operating on, power is available, and waste water can be disposed of to the reservoir or to Hanalta Lake.

Since Hanna would benefit directly if such a program were successful, I feel that they should be required to accept financial responsibility for certain aspects of the research program. I would propose that the research program be subdivided into three phases:

i) test drilling to determine the location, extent, and approximate hydrologic properties of the channel deposits,

ii) completion of a production well and three observation wells,

iii) completion of additional observation wells if required, and a deep stratigraphic core hole to provide detailed control for necessary stratigraphic studies in eastern Alberta.

The groundwater division could carry out phase 1 this year. If it is successful then the town should be committed to carry out phase 2, during 1960. Phase 3 would then be carried out by us.

This program would have the advantage that a production well would be owned by the town. The initial risk involved would be taken by us, and the additional observation wells, necessary for our research objectives, would also be financed by us. This program would be in keeping with our general policy whereby those who will benefit must assume a reasonable risk that the project may not be an economic success.

I feel that some such financial commitment is necessary as a deterrent to avoid a deluge of requests for similar programs throughout Alberta.

September 19, 1960.

Appendix F

Hanna Area.

Well drilled by Ole Sagodal
approximately 3 mls East & 4 miles
North of Hanna.

Depth 70 feet
To Water 60 feet

Log 0 – 68 Clay & pebbles
68 – 70 gravel.

Reported to be a "high producing
well.

The above may be of interest
to you. Info. from the driller
working for the Chemical Plant
at Innisfail.

The Hanna area is underlain by sandstone and shale strata of the Edmonton and Bearpaw formations. The bedrock is ~~two~~ overlain by 40 to 150 feet of glacial drift. The maximum thickness of drift occurs along a southeasterly trending channel incised into the Edmonton formation ~~and later infilled with glacial glacial drift. Sand~~ Sand and gravel deposits ranging up to 20 feet in thickness were deposited in this channel, which was infilled with glacial drift by a later ice advance.

Water may be obtained in ~~some~~ economic quantities wherever porous and permeable strata ~~commonly termed an aquifer~~ are encountered in a well. ~~At Hanna,~~ At Hanna there are ~~three~~ two potential aquifers or water bearing horizons: (1) the unconsolidated sand and gravel deposits along the Hanna channel, and (2) the basal sandstone strata of the Edmonton formation (~~into~~ in which the former supply wells are completed.

Constants Commonly Encountered in Aquifer and Well Testing

Any self-consistent system			Numerical value of constant part				
Fundamental quantity	Variable part	Constant part	Any self-consistent system	IGDF system	IGMF system	USGDF system	USGMF system
$\frac{Tt}{r_w^2 S}$	$\frac{Tt}{r_w^2 S}$	1	1,000	1.605×10^{-1}	1.115×10^{-4}	1.337×10^{-1}	9.283 x 1
$\frac{r^2 S}{4Tt}$	$\frac{r^2 S}{Tt}$	$\frac{1}{4}$	2.500×10^{-1}	1.557	2.242×10^{3}	1.870	2.693 x 1
$\frac{4Tt}{e^{\gamma} r^2 S}$	$\frac{Tt}{r^2 S}$	$\frac{4}{e^{\gamma}}$	2.246	3.605×10^{-1}	2.504×10^{-4}	3.002×10^{-1}	2.085 x 1
$\frac{2\pi T s_w}{Q}$	$\frac{T s_w}{Q}$	2π	6.283	4.363×10^{-3}			
$\frac{Q}{2\pi T s}$	$\frac{Q}{Ts}$	$\frac{1}{2\pi}$	1.592×10^{-1}	2.292×10^{2}			
$\frac{Q}{4\pi T s}$	$\frac{Q}{Ts}$	$\frac{1}{4\pi}$	7.958×10^{-2}	1.146×10^{2}			
$\frac{Q \ln 10 \log r_2/r_1}{\pi K(h_2^2 - h_1^2)}$	$\frac{Q \log r_2/r_1}{K(h_2^2 - h_1^2)}$	$\frac{\ln 10}{\pi}$	7.329×10^{-1}	1.055×10^{3}			
$\frac{Q \ln 10}{2\pi T m_m}$	$\frac{Q}{T m_m}$	$\frac{\ln 10}{2\pi}$	3.665×10^{-1}	5.277×10^{2}			
$\frac{Q \ln 10}{4\pi T s_w}$	$\frac{Q}{T s_w}$	$\frac{\ln 10}{4\pi}$	1.832×10^{-1}	2.639×10^{2}			

Well Location: #3 (South Well)
Status: observation well
r: 919' from pumping well.

Pumping Test: Hanna Drawdown Test #1
Conducted by:
Date: Aug 29
Page: 2

Date	Time	t minutes	$\frac{r^2}{t}$ / $\frac{r^2}{t/t'}$	Static water level	Depth to water	Draw-down	Volume	Q GPM	Remarks
	1:30 PM	210		45.14					
	2 PM	240		45.14					From 7–11 after pump off
	2:30	270		45.14					
	3 PM	300		45.14					
	3:40	340		45.14					
	4:20	390		45.15					
	5 PM	420		45.16					
	6	450		45.14					
	7	540		45.16		.02			
	8	600		45.17		.03			
	9	660		45.18		.04			
	10 PM	720		45.19		.05			
	11	780		45.18		.04			
Aug 30	1 AM	900		45.19		.05			
	4	1080		—		–			
	7	1260		—		–			
	10 AM	1440		45.23		.07			(one day of pumping)
	1 PM	1620		45.24		.08			
	4 PM	1800		45.25		.09			8 AM – 45.22
	7 PM	1980		45.28		1.14			9 AM – 45.22
Aug 31	12 M	2280		45.31		.17			10 PM – 45.31
	6 AM	2640		45.35		.21			
	12 Noon	3000		45.41	?	.27?			

Constants Commonly Encountered in Aquifer and Well Testing

Any self-consistent system			Numerical value of constant part				
Fundamental quantity	Variable part	Constant part	Any self-consistent system	IGDF system	IGMF system	USGDF system	USGMF system
$\frac{Tt}{r_w^2 S}$	$\frac{Tt}{r_w^2 S}$	1	1,000	1.605×10^{-1}	1.115×10^{-4}	1.337×10^{-1}	9.283×10
$\frac{r^2 S}{4Tt}$	$\frac{r^2 S}{Tt}$	$\frac{1}{4}$	2.500×10^{-1}	1.557	2.242×10^{3}	1.870	2.693×10
$\frac{4Tt}{e^{\gamma} r^2 S}$	$\frac{Tt}{r^2 S}$	$\frac{4}{e^{\gamma}}$	2.246	3.605×10^{-1}	2.504×10^{-4}	3.002×10^{-1}	2.085×10
$\frac{2\pi T s_w}{Q}$	$\frac{T s_w}{Q}$	2π	6.283	4.363×10^{-3}			
$\frac{Q}{2\pi T s}$	$\frac{Q}{Ts}$	$\frac{1}{2\pi}$	1.592×10^{-1}	2.292×10^{2}			
$\frac{Q}{4\pi T s}$	$\frac{Q}{Ts}$	$\frac{1}{4\pi}$	7.958×10^{-2}	1.146×10^{2}			
$\frac{Q \ln 10 \log r_2/r_1}{\pi K(h_2^2 - h_1^2)}$	$\frac{Q \log r_2/r_1}{K(h_2^2 - h_1^2)}$	$\frac{\ln 10}{\pi}$	7.329×10^{-1}	1.055×10^{3}			
$\frac{Q \ln 10}{2\pi T m_m}$	$\frac{Q}{T m_m}$	$\frac{\ln 10}{2\pi}$	3.665×10^{-1}	5.277×10^{2}			
$\frac{Q \ln 10}{4\pi T s_w}$	$\frac{Q}{T s_w}$	$\frac{\ln 10}{4\pi}$	1.832×10^{-1}	2.639×10^{2}			