HYDROGEOLOGIC INVESTIGATION:

LEBANON, OHIO

September 8, 1992

Prepared for:

LAYNE-OHIO COMPANY
4921 Vulcan Avenue
Columbus, Ohio 43228
(614) 876-1195

Prepared by:

LAYNE GEOSCIENCES, INC.
610 South 38th Street
Kansas City, Kansas 66106
(913) 321-6236

TABLE OF CONTENTS

Page No.

SECTION 1 INTRODUCTION 1

1.1 Purpose of Investigation 1
1.2 Site Hydrogeology 1

SECTION 2 DATA COLLECTION & ANALYSIS 6

2.1 Pumping Test Data Collection 6
2.2 Pumping Test Data Analysis 6

2.2.1 Transmissivity and Storativity 6
2.2.2 Apparent Safe Yield 14
2.2.3 Well Spacing 16

.SECTION 3 CONCLUSIONS AND RECOMMENDATIONS 17

REFERENCES 19
Figure 1.1 Study Area 2
Figure 1.2 Cross Section A - A . 3
Figure 1.3 Cross Section B - B 4
Figure 2.1 Drawdown vs. Time - TH9 9
Figure 2.2 Analysis of (A) - TH9 10
Figure 2.3 Analysis of (B) - TH9 11
Figure 2.4 Analysis of (D) - TH9 12
Figure 2.5 Analysis of Test Well Data 13
Figure 2.6 Recovery Data - Test Well 15

Appendix A Geologic Well Logs

Appendix B Pumping Test Data

SECTION 1

INTRODUCTION

1.1 PURPOSE OF INVESTIGATION

Layne GeoSciences, Inc. (LGI) was retained by Layne-Ohio Company for the purpose of performing a hydrogeologic investigation of an area of land near Lebanon, Ohio. The land is being acquired by the City of Lebanon, Ohio for water supply development. The main objectives of this hydrogeologic investigation were to provide recommendations on well yield and well spacing for the land being acquired.

Figure 1.1 shows the location of the area of land being acquired and the location of test holes which were drilled within this area. The test holes were drilled in order to provide information on the geology and hydrogeology of the site. This information was used to determine the best location for a test well, and to determine which test holes should be completed as monitoring wells. Based on this information, TH8, TH9, TH 10, and TH 11 were completed as monitoring wells, and a test well was drilled and completed at the location shown on Figure 1.1.

Drawdown and recovery data was collected from the monitoring wells (TH8, TH9, TH 10, and TH 11), a nearby irrigation well (Figure 1. 1), and the test well during a 48hour pumping test of the Test Well. This data was used to calculate various aquifer parameters. These aquifer parameters, along with the information on the geology and hydrogeology of the study area, were used to determine the recommended well yield and well spacing for this area.

1.2 SITE HYDROGEOLOGY

The aquifer under investigation is a buried channel aquifer system consisting of glacial deposits. This buried channel system was formed when a channel which had been cut into bedrock by an ancient stream was completely filled by glacial deposits. The two main types of glacial deposits in this area are glacial till and outwash deposits. Glacial till consists of poorly sorted clay, silt, sand, and gravel, whereas outwash deposits predominately consist of coarse sand and gravel.

Figures 1. 2 and 1 .3 are geologic cross-sections through the area under investigation. The locations of these cross-sections are shown in Figure 1.1, and the geologic logs of the test holes are given in Appendix A. The cross-sections and the geologic logs of the test holes show that some parts of the area are underlain by thick deposits *of* coarse sand and gravel (TH8, Test Well, & TH9) and other parts are underlain mainly by glacial till with thin layers *of* coarse sand and gravel (TH7 & TH 13).

The aquifer in this area is unconfined, although it may show some characteristics of a confined aquifer when the water table is within clay or till. This occurs at times when the water table is high due to large amounts of precipitation. This will be explained in more detail in Section 2.2.1 (Pumping Test Data Analysis - Transmissivity and Storativity) of this report. Recharge to the aquifer comes from the creeks in the area (Figure 1.1) and from precipitation. The main source of recharge to the aquifer is from Turtle Creek. Recharge from precipitation appears to be limited and delayed due to clay and till near the surface. Heavy rains occurred during the pumping test conducted for this investigation, but no recharge effects were seen during the pumping test.

The saturated thickness of the aquifer varies throughout the site with variations in the thickness of the sand and gravel and with fluctuations in the water table. The saturated thickness of the aquifer at various test hole locations was calculated using information from the geologic logs of the test holes and from depth to water measurements made on July 13, 1992. These calculated saturated thicknesses are as follows:

Location	Saturated Thickness

Test Well	65.15	
Irrigation Well	60	(approximated)
TH9	59.94	
TH10	43.80	
TH1 1	60.48	

SECTION 2

DATA COLLECTION AND ANALYSIS

2.1 PUMPING TEST DATA COLLECTION

A 48-hour pumping test was conducted using the Test Well as the pumping well. The pumping test was started at 08:50 A.M. on July 14, 1992. The discharge rate of the Test Well was monitored throughout the test using an orifice. The orifice was connected to temporary discharge hose and located so that the discharge would flow directly into the creek located to the west of the Test Well (Figure 1.1). The discharge rate remained constant throughout the test. The discharge rate was approximately 653 GPM.

During the pumping test, water level drawdown was monitored in the following wells: the Test Well, Irrigation Well, TH9, TH10, and TH11. Drawdown data was collected from TH9 using a pressure transducer and continuous data logger. Drawdown data was collected from the pumping well (Test Well), Irrigation Well, TH1 0, and TH1 1 using an electric well sounder. After approximately 5 hours of pumping, measurements could no longer be obtained from the pumping well because the electric well sounder became tangled on the pipe column and could not be lowered far enough into the well. No problems were encountered in collecting data from the other monitoring wells during the test. All data collected during the pumping test and recovery period is given in Appendix B.

At 08:50 A.M. on July 16, 1992, the pump was shut off and recovery began. Water level recovery data was collected from all wells in the same manner in which the drawdown data was obtained. Recovery data was collected for 24 hours. After 24 hours of recovery, water levels in the Test Well and the monitoring wells had not returned to pre-pumping levels. The significance of this will be discussed in Section 2.2.2 (Apparent Safe Yield) of this report.

2.2 PUMPING TEST DATA ANALYSIS

2.2.1 Transmissivity and Storativity

<u>Methodology:</u>

The Cooper-Jacob solution method (Cooper & Jacob, 1946) was used to determine the transmissivity and storativity of the aquifer from the drawdown versus time data. This solution method is based on the Theis equation (Theis, 1935). Cooper-Jacob (Cooper & Jacob, 1946) determined that after the pumping well has been running for some time, the Theis equation could be closely approximated by:

$$s_o = \frac{2.3Q}{\pi T} \log\left(\frac{2.25\ Tt}{Sr^2}\right) \qquad (1)$$

where,

s_o drawdown
Q well discharge
T aquifer transmissivity
r distance to observation well
S aquifer storativity
t time since pumping began

This equation is valid for large values of t or small values of r. If plotted on semi-log paper, drawdown versus time data will plot as a straight line if either of these conditions is met.

Before using the above equation on data from an unconfined aquifer, a correction must be made to the drawdown data (Kruseman & De Ridder, 1979). This is because the above equation was developed using confined aquifer conditions. The correction is as follows:

$$s' = s - \left(\frac{s^2}{2b}\right) \quad (2)$$

where,

s' corrected drawdown
s drawdown
b saturated thickness of aquifer

Once the above correction has been applied to the drawdown data, the analysis can proceed as normal. A straight line is drawn through the field data points and extended backward to the zero drawdown axis. The value of the intercept of the line with the zero drawdown axis (t_0) and the slope of the line (Δs_0) are used to calculate the transmissivity and storativity of the aquifer using the following equations:

$$T = \frac{2.3\ Q}{4\pi \Delta s_0} \quad (3)$$

and

$$S = \frac{2.25\ Tt_0}{r^2} \quad (4)$$

Analysis of Data-,

Figure 2.1 shows the corrected drawdown data versus time for TH9. The extensive amount of data collected from this monitoring well because of the use of the pressure transducer and data logger allows the complexity of the aquifer system to be clearly seen. Each distinct slope of the data represents a different transmissivity value or a hydrologic boundary which has been encountered. Each distinct slope in Figure 2.1 has been labeled, and the interpreted cause for each is given below:

A) The calculated transmissivity based on this portion of the data is 25.1 ft2/Min or 36,144 ft2 /day (270,357 gal/day/ft). The analysis of the data is shown in Figure 2.2. This is an extremely high value for transmissivity, and is representative of the transmissivity of the aquifer in the immediate vicinity of the pumping well.

B) The calculated transmissivity based on this portion of the data is 17.5 ft2/Min or 25,200 ft2 /day (188,496 gal/day/ft). The analysis of the data is shown in Figure 2.3. At this time the cone of depression has reached a slightly less permeable zone of the aquifer. The lower the permeability of the aquifer material, the harder it is for water to move through this material towards the well. This results in an increase in the rate of drawdown with time. This transmissivity value is still very high, and is most likely representative of the overall transmissivity of the aquifer.

C) This portion of the data is indicative of a recharge boundary. Drawdown remained relatively constant during this portion of the data due to induced recharge. This recharge boundary is assumed to be Turtle Creek to the south (Figure 1.1), but due to the other creeks in the area, this is not known for certain.

D) The calculated transmissivity based on this portion of the data is 18.0 ft^2/Min or 25,920 ft^2 /day (193,881 gal/day/ft). The analysis of the data is shown in Figure 2.4. This transmissivity is very similar to the calculated transmissivity for section (B) of the data, and indicates that pumping has exceeded the recharge capacity of the recharge boundary and the cone of depression has continued its expansion.

E) This portion of the data is indicative of a barrier boundary. The sharp increase in the rate of drawdown with time indicates that the cone of depression has reached the edge of the aquifer.

Analysis of the data collected from the pumping well (Test Well) is shown in Figure 2.5. The calculated transmissivity based on this data is 17.7 ft^2/Min or 25,488 ft^2/day (190,650 gal/day/ft). This transmissivity is very similar to the transmissivity values calculated from sections (B) and (D) of the data from TH9, and corroborates the belief that these values for transmissivity are representative of the overall transmissivity of the aquifer.

The calculated storativity of the aquifer is also listed on Figures 2.2 through 2.5. In an unconfined aquifer such as the one being studied here, the storativity is essentially equal to the specific yield of the aquifer. In this case though, the calculated storativities are extremely low (0.00003 to 0.00055) for values of specific yield of an unconfined aquifer. A typical value for specific yield of an unconfined aquifer is 0. 15. The calculated values for storativity are more typical for that of a confined aquifer. This is mostly due to the fact that at the time of this pumping test the water table had risen within clay and till due to the large amounts of precipitation in June and July, 1992.

2.2.2 Apparent Safe Yield

Figure 2.6 shows the recovery data from the Test Well. A line was drawn through the field data points and extended to the zero drawdown axis. From this analysis, it was estimated that a complete recovery of the water level in the aquifer at the Test Well would occur approximately 11,000 minutes after the pump was turned off. Because this value exceeds the total pumping time (2,880 min), the pumping rate (653 GPM) exceeded the apparent safe yield of the aquifer at the Test Well site. This occurs when the rate of recharge to the aquifer is exceeded by the rate of pumping from the aquifer.

The apparent safe yield of the aquifer is the amount of water which can be pumped from the aquifer without causing any long term drawdown. The apparent safe yield of the aquifer at the Test Well site is calculated using the following formula:

$$\text{apparent safe yield} = \left(\frac{t_0}{t_1}\right)Q \qquad (5)$$

where,

- $\mathbf{t_0}$ total pumping time
- $\mathbf{t_1}$ total time for recovery
- **Q** pumping rate

Based on this formula, the apparent safe yield of the aquifer at the Test Well site is 171 GPM or approximately 250,000 gallons per day. This is equivalent to pumping approximately 500 GPM for eight (8) hours per day.

The value for apparent safe yield only applies to the Test Well site. Determining the combined effect of all withdrawals from the aquifer was not part of the scope of work for this investigation. A comprehensive study has not been done which would calculate the safe yield for the entire aquifer system.

2.2.3 Well Spacing

The area of influence of the Test Well was greater than 1,000 feet after pumping 653 GPM for 48 consecutive hours. The exact extent of the area of influence could not be determined because the furthest well being monitored during the pumping test was approximately 900 feet from the Test Well.

Due to the large area of influence of the Test Well, the limited extent of the aquifer, and the apparent limited amount of recharge to the aquifer, it is recommended that one (1) 500 GPM capacity well be completed at the Test well site and possibly a smaller capacity well (200 GPM) be completed at TH 12. Based on the calculations made during this investigation, this would cause a limited amount of long term drawdown of the water level within the aquifer.

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

Results from the test drilling program and the pumping test analysis indicate that the area under investigation is suitable for water supply development. The saturated thickness of the aquifer is greater than 60 feet in some areas and the transmissivity of the aquifer is very high (approximately 190,000 gal/day/ft2). Limits to the potential for development of this area do exist, however, because of the limited extent of the aquifer and the limited amount of recharge to the area.

The high transmissivity of the aquifer means that the cone of depression of a pumping well will cover a large area, but the amount of drawdown within the cone of depression will be small. Evidence of this was seen from the pumping test data. The cone of depression of the Test Well extended to the edge of the aquifer after 48 hours of pumping, but the drawdown in the pumping well was less than 10 feet.

Recharge to the aquifer appears to be limited based on the recovery data. Water levels had not returned to pre-pumping levels after 24 hours of recovery. Based on the recovery data from the Test Well, the projected time for complete recovery was 11,000 minutes. This means that the apparent safe yield of the aquifer at the Test Well was exceeded by pumping 653 GPM. The calculated apparent safe yield of the aquifer at the Test Well was 171 GPM or approximately 250,000 gal/day. The apparent safe yield is the amount of water which can be pumped without causing long term drawdown. The value is only an approximation, and is only valid for the Test Well site. The calculation does not take into account other withdrawals from the aquifer, and is not the safe yield for the entire aquifer system.

Due to the large area of influence of the Test Well, the limited extent of the aquifer, and the apparent limited amount of recharge to the aquifer, it is recommended that one (1) 500 GPM capacity well be completed at the Test well site and possibly a smaller capacity well (200 GPM) be completed at TH 12. Based on the calculations made during this investigation, this would cause a limited amount of long term drawdown of the water level within the aquifer.

The above recommendations are based on a relatively short term pumping test (48 hours) and the desire to cause no long term de-watering of the aquifer. If the City of Lebanon, Ohio would prefer to complete more wells within the study area, it is recommended that permanent monitoring wells be installed to monitor the water level within the aquifer. If more than one (1) 500 GPM well is completed within this area, de-watering of the aquifer may occur. The amount of de-watering would depend on the pumping schedules and pumping rates of the wells, and the amount of recharge reaching the aquifer from nearby creeks and from infiltration of precipitation. Biweekly or monthly depth to water measurements from the monitoring wells could be used to monitor the amount of de-watering, if any, that is occurring. This information could then be used to adjust pumping rates in the short term, and would give the City long term data which would provide a better understanding of the actual potential of the aquifer.

REFERENCES

Cooper, H.H. and C.E. Jacob, 1946, A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History, Am. Geophys. Union Trans., Vol. 27, pp. 526-534.

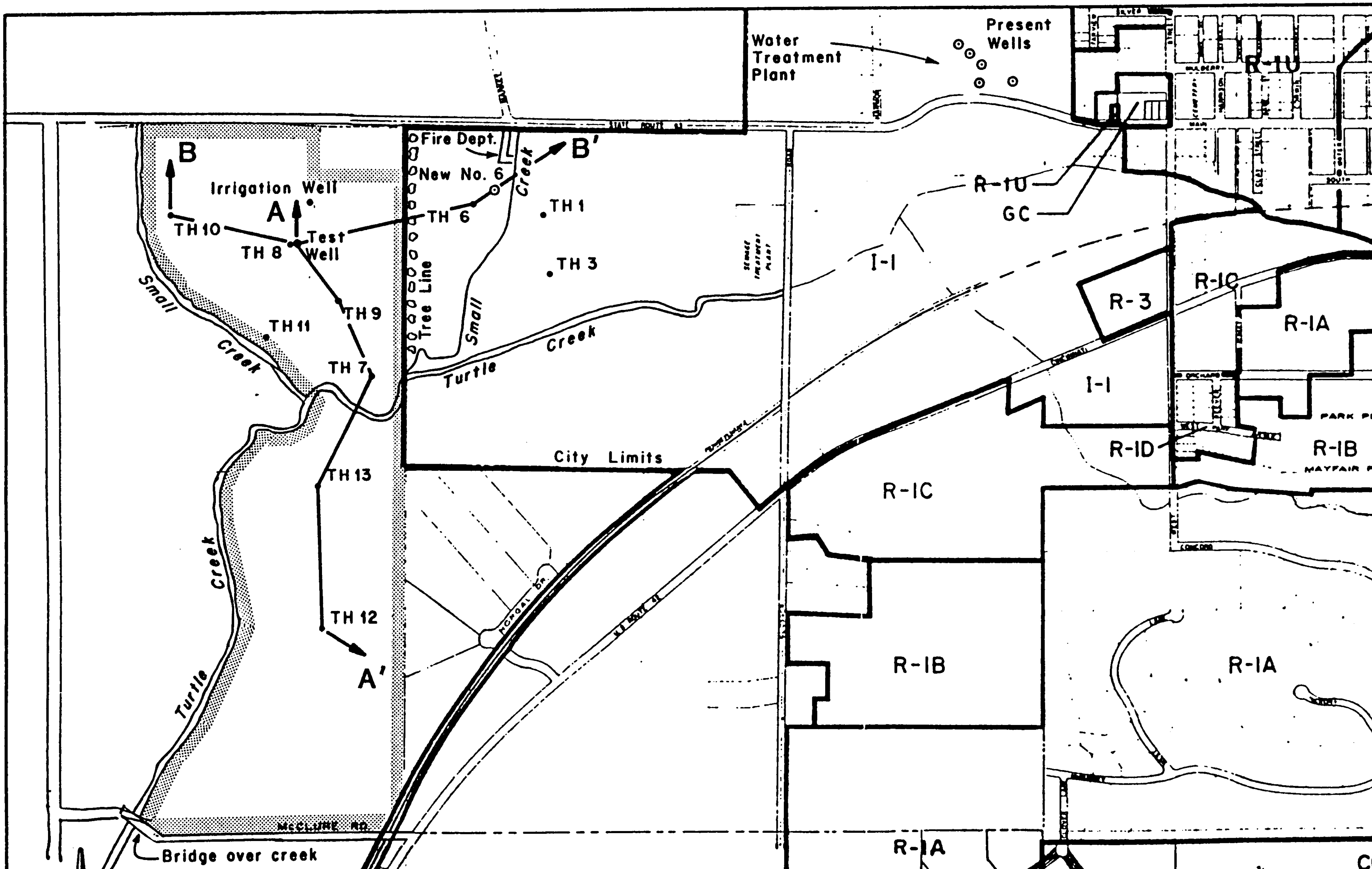
Driscoll, Fletcher G., 1986, Groundwater and Wells, 1089 pp.

Fetter, C.W., 1988, Applied Hydrogeology, 592 pp.

Kruseman, G.P. and N.A. De Ridder, 1979, Analysis and Evaluation of Pumping Test Data, Bulletin 11, Intern. Inst. for Land Reclamation and Improvements, Wageningen, Netherlands, 200 pp.

Theis, C.V., 1935, The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage, Am. Geophys. Union Trans., Vol. 16, pp. 519-524.

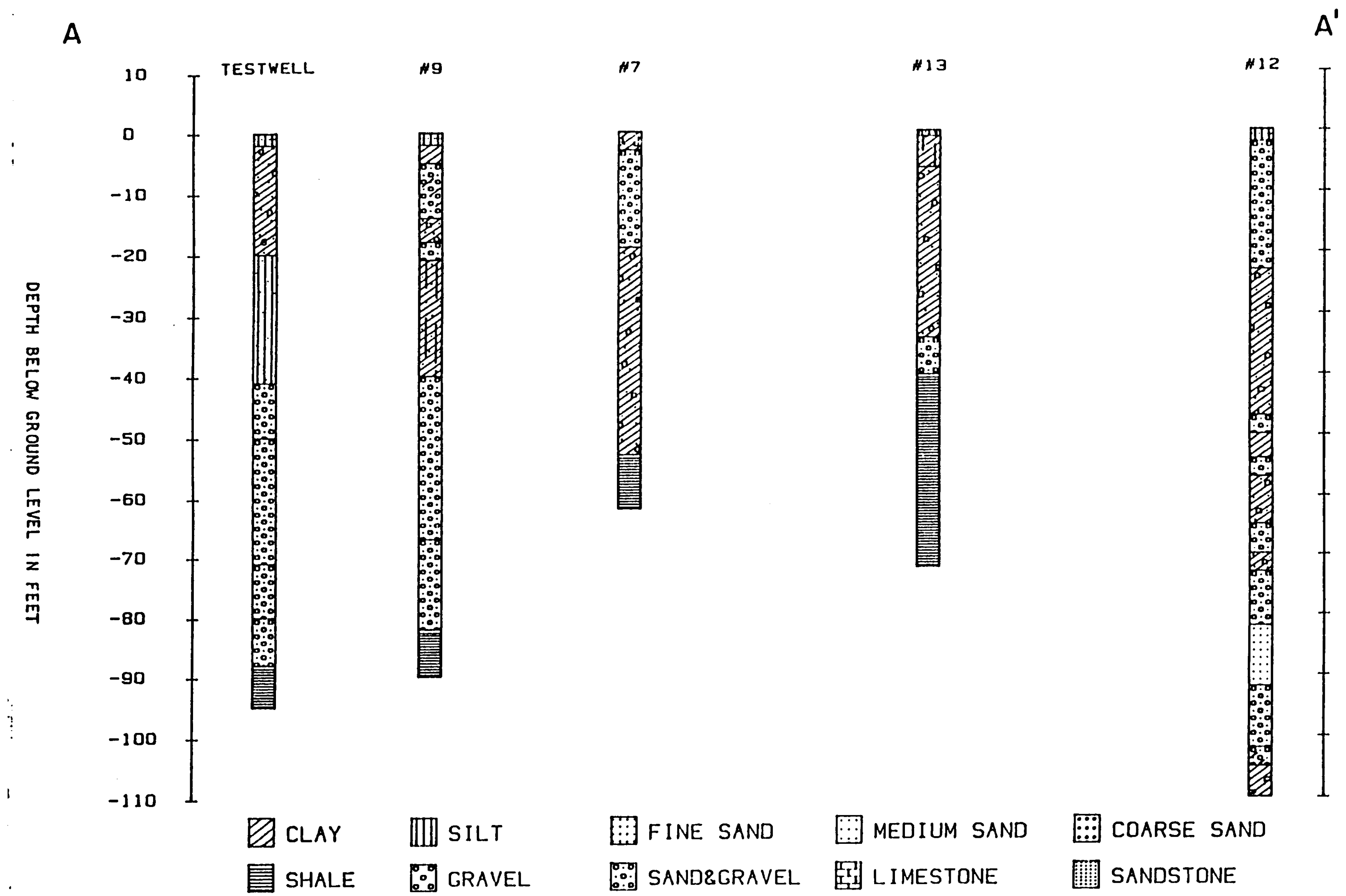
Walker, A.C., A Portion of the Lower Miami River Basin, Underground Water Resources, Ohio Department of Natural Resources, Ohio Water Plan Inventory, 1960.



STUDY AREA

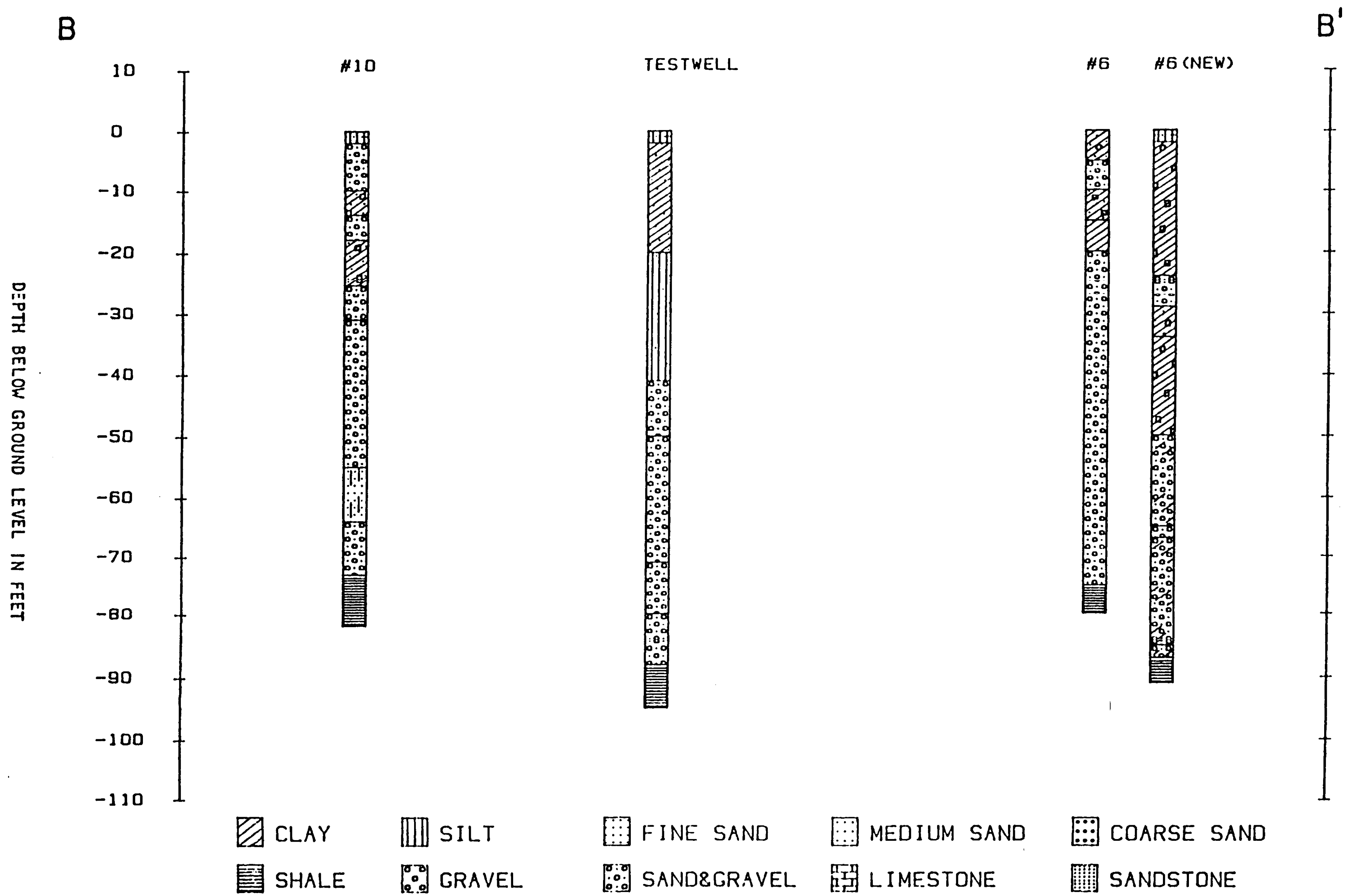
FIGURE 1.1

LAYNE GEOSCIENCES, INC.



GEOLOGIC CROSS SECTION

FIGURE 1.2



GEOLOGIC CROSS SECTION

FIGURE 1.3

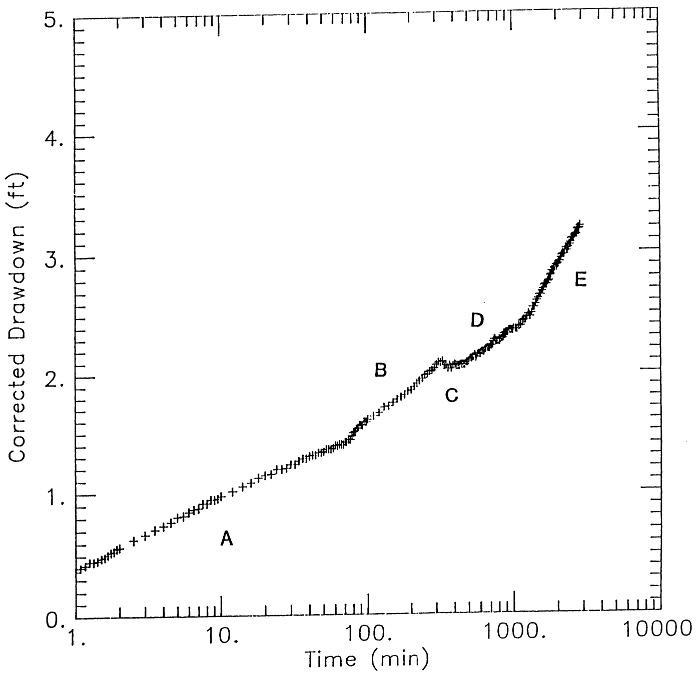
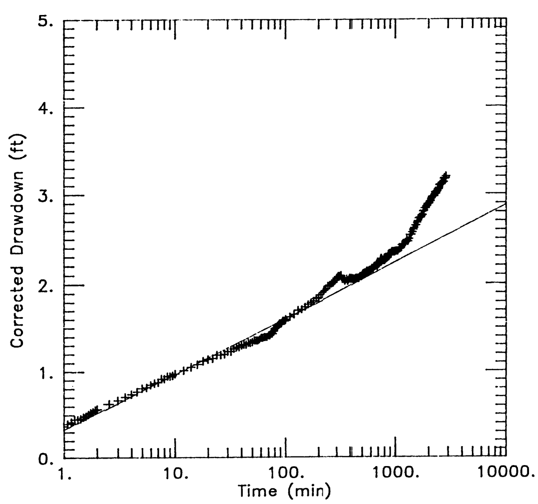


FIGURE 2.1

Layne GeoSciences, Inc.	Client: City of Lebanon, Ohio
Project No.: 39-2879	Location: Lebanon, Ohio

Figure 2.2 – Analysis of (A), TH9



DATA SET:
c:\leboh\9ddn.dat
09/08/92

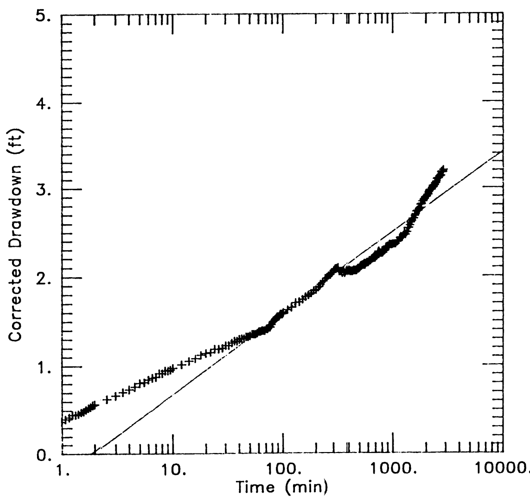
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
July, 1992
TEST WELL:
Test Well
OBS. WELL:
#9

ESTIMATED PARAMETERS:
T = 25.1 ft^2/min
S = 0.0001085

TEST DATA:
Q = 87.3 ft^3/min
r = 400. ft
b = 59.94 ft

Layne GeoSciences, Inc.	Client: City of Lebanon, Ohio
Project No.: 39–2879	Location: Lebanon, Ohio

Figure 2.3 – Analysis of (B), TH9



DATA SET:
c:\leboh\9ddn.dat
09/08/92

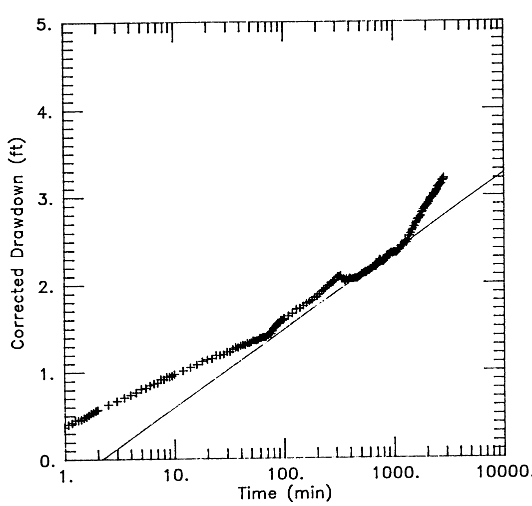
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
July, 1992
TEST WELL:
Test Well
OBS. WELL:
#9

ESTIMATED PARAMETERS:
T = 17.5 ft^2/min
S = 0.00045

TEST DATA:
Q = 87.3 ft^3/min
r = 400. ft
b = 59.94 ft

Layne GeoSciences, Inc.	Client: City of Lebanon, Ohio
Project No.: 39–2879	Location: Lebanon, Ohio

Figure 2.4 – Analysis of (D), TH9



DATA SET:
c:\leboh\9ddn.dat
09/08/92

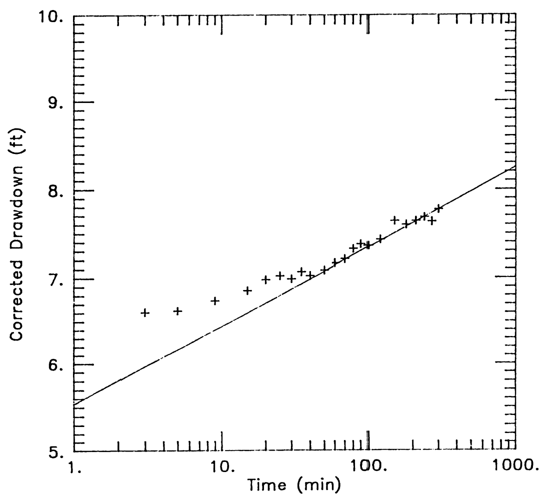
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
July, 1992
TEST WELL:
Test Well
OBS. WELL:
#9

ESTIMATED PARAMETERS:
T = 18. ft^2/min
S = 0.00055

TEST DATA:
Q = 87.3 ft^3/min
r = 400. ft
b = 59.94 ft

Layne GeoSciences, Inc.	Client: City of Lebanon, Ohio
Project No.: 39-2879	Location: Lebanon, Ohio

Figure 2.5 – Analysis of Test Well Data



DATA SET:
testddn.dat
09/08/92

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Cooper-Jacob

TEST DATE:
July, 1992

TEST WELL:
Test Well

OBS. WELL:
Test Well

ESTIMATED PARAMETERS:
T = 17.7 ft^2/min
S = 3.E-05

TEST DATA:
Q = 87.3 ft^3/min
r = 1. ft
b = 65.15 ft

TIME-DRAWDOWN SEMI-LOG PLOT