

CLEAR TECHNICAL REPORT NO. 97

HYDROLOGICAL CONSIDERATIONS FOR GOLF COURSE NO. 2 AT MUIRFIELD VILLAGE

Preliminary Report

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Introduction.

Muirfield Ltd. of Dublin, Ohio, in conjunction with James H. Bassett, Inc. and other consultants, is undertaking the design of a second golf course (No. 2) on the Muirfield Village site. The new golf course will be located on the western portion of the site, west of Muirfield Drive (Figure 1).

The existing golf course (No. 1) has experienced some problems in obtaining adequate supplies of good quality water for irrigation, particularly during periods of low rainfall. The purpose of this report is to explore alternative sources of surface water and groundwater to determine the best mix of sources to provide the new golf course (No. 2) with the sufficient quantity and quality water to maintain the aesthetic character of the course as well as provide adequate irrigation water during drought periods.

Character of Surface Water.

Three small streams traverse the Muirfield Village site, generally in a west to east direction. These include: 1) Deer Run in the northern part of the site, 2) an unnamed tributary to Deer Run near the mid-portion of the site, and 3) Indian Run at the southern boundary of the site. The streams have cut several deep and rather steep ravines in the Powell Moraine. Fairly high flow rates have been reported for these streams, but during periods of low rainfall, such as July and early August 1978, they can be intermittent with many pools of standing water.

The quality of the surface water in the vicinity of Muirfield Village is characterized in Tables 1, 2, and 3. With the exception of springs, surface water generally ranges from 500 to 700 $\mu\text{mhos}/\text{cm}$ (specific conductance) which is the equivalent of approximately 300 to 420 ppm of total dissolved solids (salinity). Conductivity values in this range are typical of surface waters in central Ohio and they are well within acceptable limits for golf course irrigation. The new lakes which will be constructed with-

in the golf course site, can be expected to have similar ranges. By way of comparison, a rainfall sample collected at Glick Road yielded values from 1500 to 2600 μ mhos/cm.

Character of Groundwater.

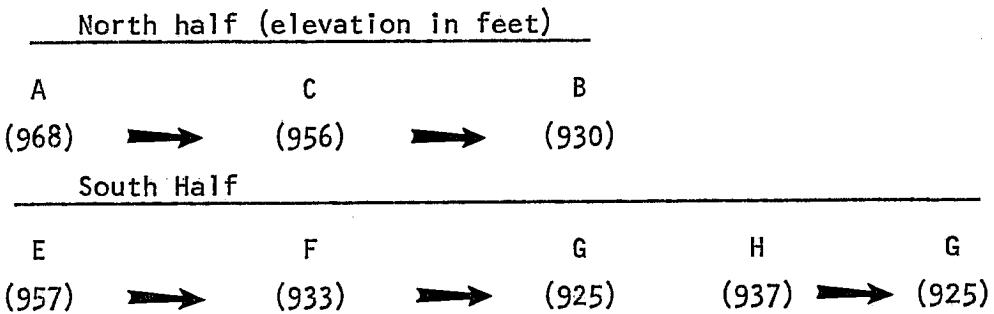
Groundwater sources within the new golf course site are of two types: 1) shallow lenses of sand and gravel associated with glacial action and 2) limestone bedrock deposited during the Devonian Period. Information on these sources comes primarily from water well records (Table 4) and chemical analyses of well water samples (Tables 3, 5, 6, 7, 8, and 9). The locations of the wells in the tables are shown on Figure 2.

Wells developed in the sand and gravel lenses accounted for 43 percent (12) of the 28 well records located for the vicinity of Muirfield Village. These wells were generally shallow and ranged from 33 to 92 feet deep with a mean depth of 66 feet. The static level of water in these wells ranged from 3 to 56 feet with a mean level of 29 feet (Table 10). Very little data is available on the quality of the water produced by the sand and gravel wells. Measurements of conductivity at the Headlee well (No. 11) on Brand Road yielded a mean value of 650 μ mhos/cm, similar to readings for surface water. However, water produced from sand and gravel beds farther north at Muirfield well No. 1 (Table 7) yielded dissolved ion concentrations very similar to bedrock water. It appears that the best quality groundwater from sand and gravel can be found in the buried valley which has its northern terminus near Brand Road and Indian Run.

Wells developed in the limestone bedrock accounted for 57 percent (16) of the 28 well records located for the vicinity of Muirfield Village. These wells generally were deeper than the sand and gravel wells, ranging from 60 to 355 feet deep with a mean depth of 184 feet. The static level of water in these wells ranged from 6 to 66 feet with a mean level of 35 feet, very similar to the values for the sand and gravel wells (Table 10). The dissolved salts in the bedrock water are approximately 3 to 5 times higher in concentration than in surface waters (Table 11). The quality of the bedrock water improves somewhat to the south with wells near Dublin showing the lowest values, while wells near the northwest part of the site yield the highest values.

Irrigation System.

The new golf course will contain a series of lakes (Figure 3), two of which will serve as irrigation lakes. Lakes B and G will each have a pump station and will serve the north and south halves of the golf course, respectively. The lakes will be interconnected in the following manner:



In this way all north lakes will flow into B and all south lakes will flow into G. The area, volume, storage capacity and elevation characteristics of each lake is given in Table 12.

The recommendations section of this report proposes a field of shallow sand and gravel wells between Brand Road and Indian Creek near No. 5 fairway, which will be used to supplement Lake G via a pipeline during draught periods. In a similar way the existing bedrock well at the Avery Road farm house can be used to supplement Lake E. These sources should develop a combined yield of over 300 gpm which should meet the dry weather needs of the south half of the golf course. The needs of the northern half of the course can be provided for by drilling bedrock wells adjacent to Lakes A and C to supplement them during low rainfall periods. These wells should also be expected to have a combined yield of approximately 300 gpm. All of the bedrock wells will require the dilution capacity of the surface lakes to lower the concentration of dissolved solids to acceptable limits.

Under drought conditions, assuming certain water requirements, the irrigation system outlined above will provide for approximately 25 days of no rainfall for the north half of the course and 50 days of no rainfall for the south half of the course. The following requirements were assumed for these calculations:

- 1) Volume of Lakes A, B, C = 21.8×10^6 gal.
- 2) Volume of Lakes E, F, G, H = 35.4×10^6 gal.

- 3) Each half of the golf course requires 400,000 gpm for irrigation
- 4) A 25 percent volume reduction in each lake acceptable (approximately 1-2 feet)
- 5) Conductivity of lake water = 600 $\mu\text{mhos}/\text{cm}$
- 6) Conductivity of bedrock water = 2500 $\mu\text{mhos}/\text{cm}$
- 7) Well pumping rate of up to 150 gpm required for bedrock wells (combined yield, north half)
- 8) Well pumping rate of up to 170 gpm for sand and gravel wells (combined yield, south half)
- 9) A 5-10 percent loss in lake volume due to evaporation during drought conditions
- 10) Maximum acceptable conductivity for irrigation water of 1200 $\mu\text{mhos}/\text{cm}$ (720 ppm dissolved solids)

Recommendations.

1. In order to develop sufficient irrigation water for the southern half of the new golf course, three (3) test wells are proposed in the shallow sand and gravel lens between Indian Creek and Brand Road, northeast of Muirfield Drive entrance. These wells should produce a combined yield of 150 to 200 gpm which will feed to Lake G through a buried pipeline. The proposed location of the three test wells are shown on Figure 3.
In addition, a pipeline is proposed to connect the existing well at the Avery Road farmhouse to Lake E, which in turn feeds to Lake F and then to Lake G by gravity.
2. In order to develop sufficient irrigation water for the northern half of the new golf course, a bedrock well is proposed 200 feet NNE of Lake A along golf course property line, which will be connected to Lake A via a pipeline which discharges near the bottom of the lake. This well should be tested at various horizons for adequate flow and minimal dissolved solids (100 gpm, 1000 to 1200 ppm).
If the well at Lake A proves to be inadequate, a second bedrock well is proposed at Lake C, near the NE end of the lake 600 feet W of

Muirfield Drive on Glick Road.

Wells at each lake will feed by pipeline to the lake, Lake A will feed by gravity pipeline to Lake C which in turn feeds by gravity pipeline to Lake B.

TABLES

TABLE 1
CHEMICAL ANALYSIS OF SURFACE WATER
AT MUIRFIELD VILLAGE

PARAMETER	CONCENTRATION			
	SAMPLE STATION			
	1	2	3	4
Hardness (total as CaCO_3 , ppm)	1190	240	380	760
Hardness (carbonate as CaCO_3 , ppm)	700	150	260	460
Chloride (as Cl , ppm)	35	10	25	25
Sulfate (as SO_4 , ppm)	1200	124	380	850
Phosphate (ortho as PO_4 , ppm)	0.02	0.01	5.5	---
pH (units)	6.6	7.7	7.9	7.3
Turbidity (JTU)	38	7	6	38
Conductivity ($\mu\text{mhos}/\text{cm}$)	2600	510	800	1550

Test Data: Samples collected on July 8, 1973 and analyzed on July 10, 1973.

Station Location:

- Sample 1. Spring near the south branch of Deer Run 600 feet west of Ohio Route 745 (Dublin Road).
- Sample 2. Deer Run at relocation crossing of Ashbaugh Road 600 feet south of Glick Road.
- Sample 3. At outlet to large lake 250 feet northwest of golf course fairway for hole no. 2.
- Sample 4. At outlet to pond on north branch of Deer Run 200 feet northwest of Ohio Route 745 highway bridge.

TABLE 2

CHEMICAL ANALYSIS OF SURFACE WATER
IN LAKE AT MUIRFIELD CLUB HOUSE AND NO. 4
POND AT RIVIERA COUNTRY CLUB

PARAMETER	CONCENTRATION		Units
	Muirfield*	Riviera**	
Alkalinity, total (CaCO ₃)	274	262	ppm
Alkalinity, phenol (CaCO ₃)	0	0	ppm
Hardness, total (CaCO ₃)	320	860	ppm
Hardness, carbonate	274	-	ppm
Hardness, non-carbonate	46	-	ppm
Calcium (CaCO ₃)	210	550	ppm
Magnesium (CaCO ₃)	110	310	ppm
Chlorides (Cl)	3.3	-	ppm
Iron (Fe)	1.8	1.2	ppm
Manganese (Mn)	0	0	ppm
Sulfates (SO ₄)	21	640	ppm
Nitrates (NO ₃)	4.4	-	ppm
Total Solids	302	-	ppm
Conductivity	480	1380	μmhos/cm
pH	7.8	7.7	units

*Samples collected on October 17, 1972

**Samples collected on September 25, 1972

TABLE 3

SPECIFIC CONDUCTANCE FOR SURFACE WATER AND WELL SAMPLES
IN THE VICINITY OF MUIRFIELD VILLAGE

Sample No.*	General Location	Conductivity** (μ mhos/cm)	Dissolved*** Solids (ppm)
1	Avery Rd. well (no log)	2850	1710
2	Rainwater (Glick Rd)	40	24
3	Glick Rd. well (No. 1)	2020	1212
4	Deer Run at Glick Rd.	665	400
5	Deep Lake (B) site	700	420
6	Spring at Tee no. 3	1510	906
7	Stream at Hole no. 2	1235	741
8	Brand Rd. well (No. 11)	650	390
9	Indian Run at Muirfield Dr.	510	306
10	Stream above Hole no. 12	920	552
11	Well at Hole no. 12 (no. 28)	1800	1080

*Samples taken July 1978

**Mean value for two readings

***Estimated from conductivity (μ mhos/cm \times 0.6 = dissolved solids in ppm)

TABLE 4

LOGS FOR WATER WELLS IN THE VICINITY OF MUIRFIELD VILLAGE

WELL NO. 1 Elevation: 968 ft. Driller: Plummer
 Owner/Location: Rovert Billingsley/Glick Rd.
 Date: July 28, 1953 Static Level: 56 ft.
 Pumping rate: 10 gpm Duration: - Drawdown: none
 Well log: Casing length/dia: 88 ft/4 1/4 in
 1) clay 0-85 ft
 2) sand & gravel 85-88 ft

WELL NO. 2 Elevation: 973 ft. Driller: Plummer
 Owner/Location: Robert Billingsley/Glick Rd.
 Date: July 30, 1953 Static Level: 56 ft.
 Well log: Casing length/dia: 88 ft/4 1/4 in
 1) clay 0-85 ft
 2) gravel 85-88 ft

WELL NO. 3 Elevation: 940 ft. Driller: DeWitt
 Owner/Location: Ohio Promotions, Inc./Ashbaugh Rd.
 Date: Sept. 5, 1967 Static Level: 36 ft.
 Pumping rate: 100 gpm Duration: 8 hrs Drawdown: 12 ft.
 Well log: Casing length/dia: 111 ft/6 in
 1) clay 0-35 ft
 2) lime shell 35-35.5 ft
 3) sand clay 35.5-50 ft
 4) dry course sand 50-99 ft
 5) clay 99-109 ft
 6) sand 109-111 ft
 7) limestone 111-215 ft
 chemical analysis: (see Table 5)

WELL NO. 4 Elevation: 930 ft. Driller: Plummer
 Owner/Location: Albert Seely/10407 Concord Rd.
 Date: March 5, 1969 Static level: 38 ft.
 Pumping rate: 15 gpm Duration: - Drawdown: none
 Well log: Casing length/dia: 56 ft/4 1/4 in
 1) clay 0-46 ft
 2) sand & gravel 46-56 ft

WELL NO. 5 Elevation: 940 ft. D Driller: DeWitt
 Owner/Location: America Italian Golf Assoc/Avery Rd.
 Date: April 17, 1969 Static level: 34 ft.
 Pumping rate: 518 gpm Duration: 10 hrs Drawdown: 59 ft.
 Well log: Casing length/dia: 70 ft/13 3/8 in
 1) yellow, blue & red clay 0-70 ft
 2) brown, blue & gray limestone 70-235 ft

TABLE 4 (continued)

WELL NO. 10 Elevation: 955 ft Driller: Burlingle
Owner/Location: J.L. Waisman/Avery Rd.
Date: Dec. 14, 1956 Static level: 45 ft.
Pumping rate: 15 gpm Duration: 1 hr Drawdown: none
Well log: Casing length/dia: 79 ft/6 in
1) clay 0-18 ft
2) sandy clay & gravel 18-21 ft
3) clay 21-65 ft
4) sandy gravel 65-76 ft
5) gravel 76-79 ft

TABLE 4 (continued)

WELL NO. 11 Elevation: 915 ft. Driller: Plummer
 Owner/Location: Melvin Headlee/Brand Rd.
 Date: May 2, 1956 Static level: 3 ft.
 Well log: Casing length/dia: 38 ft/4 1/4 in
 1) clay 0-18 ft
 2) sand 18-35 ft
 3) gravel 35-38 ft

WELL NO. 12 Elevation: 900 ft. Driller: Plummer
 Owner/Location: Jim Haley/Brand Rd at Ashbaugh Rd
 Date: July 3, 1957 Static level: 8 ft
 Pumping rate: 8 gpm Duration: - Drawdown: none
 Well log: Casing length/dia: 67 ft/4 1/4 in
 1) clay 0-20 ft
 2) sand 20-22 ft
 3) clay 23-36 ft
 4) sand 36-58 ft
 5) clay 58-65 ft
 6) gravel 65-67 ft

WELL NO. 13 Elevation: 930 ft Driller: Plummer
 Owner/Location: Charles Mand/5570 Indian Hill Dr.
 Date: June 18, 1964 Static level: 66 ft
 Pumping rate: 10 gpm Duration: - Drawdown: 4 ft
 Well log: Casing length/dia: 84 ft/4 1/4 in
 1) clay 0-65 ft
 2) limestone, broken 65-83 ft
 3) limestone, solid 83-88 ft

WELL NO. 14 Elevation: 910 ft Driller: Plummer
 Owner/Location: David Kessler/6205 Brand Rd
 Date: July 24, 1964 Static level: 5 ft
 Pumping rate: 20 gpm Duration: - Drawdown: none
 Well log: Casing length/dia: 33 ft/ 4 1/4 in
 1) clay 0-18 ft
 2) sand & gravel 18-33 ft

WELL NO. 15 Elevation: 930 ft Driller: plummer
 Owner/Location: Fred Grant/Indian Hill Dr
 Date: August 1, 1966 Static level: 55 ft
 Pumping rate: 20 gpm Duration: 4 hrs Drawdown: 1 ft
 Well log: Casing length/dia: 232 ft/6 in
 1) soil 0-2 ft
 2) yellow clay 2-39 ft
 3) blue clay 39-70 ft
 4) clay & gravel 70-74 ft
 5) blue clay 74-84 ft
 6) sand & gravel 84-97 ft
 7) blue clay 97-142 ft
 8) sand & gravel 142-165 ft
 9) gray limestone 165-255 ft
 10) light brown limestone, broken 255-265 ft
 11) gray limestone 266-287 ft
 12) bluish gray limestone 287-302 ft

TABLE 4 (continued)

WELL NO. 16 Elevation: 925 ft Driller: Columbus Testing Lab
 Owner/Location: Ira Southern/5655 Indian Hill Dr.

Date: August 17, 1962 Static level: 61 ft

Pumping rate: 14 gpm Duration: 3 hrs Drawdown: 1/3 ft
 Well log: Casing length/dia: 75 ft/6 in

- 1) brown clay 0-10 ft
- 2) gray clay with some gravel 10-72 ft
- 3) coarse gravel and fine gray sand, water bearing 72-75 ft
- 4) brown limestone 75-86 ft
- 5) gray limestone 86-110 ft

WELL NO. 17 Elevation: 925 ft Driller: Plummer

Owner/Location: V.J. Sebo/5654 Indian Hill Rd

Date: June 21, 1957 Static level: 52 ft

Well log: Casing length/dia: 66 ft/5 in

- 1) clay 0-60 ft
- 2) sand & clay 60-63 ft
- 3) sand & gravel 63-66 ft

WELL NO. 18 Elevation: 941 ft Driller: Plummer

Owner/Location: Fred Mills/Concord Rd.

Date: July 21, 1954 Static level: 48 ft

Pumping rate: 10 gpm

Well log: Casing length/dia: 84 ft/4 1/4 in

- 1) clay 0-80 ft
- 2) sand & gravel 80-85 ft

WELL NO. 19 Elevation: 895 ft Driller: Baker

Owner/Location: Ashland Oil Co./Lipert Farm, Dublin, Ohio

Date: October 4, 1968 Static level: 8 ft

Pumping rate: 350 gpm Duration: 24 hrs Drawdown: 31 ft

Well log: Casing length/dia: 58 ft/12 in

- 1) clay & gravel: 0-57 ft
- 2) clay & limestone 57-87 ft
- 3) shale & limestone 87-98 ft
- 4) blue limestone 98-155 ft

chemical analysis: (see Table 9)

WELL NO. 20 Elevation: 880 ft Driller: Baker

Owner/Location: Midwestern VW Corp./Dublin, Ohio

Date: Sept. 5, 1968 Static level: 49 ft

Pumping rate: 345 gpm Duration: 10 hrs Drawdown: 113 ft

Well log: Casing length/dia: 40 ft/10 in

- 1) clay 0-2 ft
- 2) clay & boulders 2-8 ft
- 3) limestone 8-183 ft
- 4) laminated limestone & shale 183-210 ft
- 5) limestone 210-225 ft

chemical analysis: (see Table 9)

TABLE 4 (continued)

WELL NO. 21 Elevation: 925 ft Driller: -
 Owner/Location: City of Hilliard/
 Date: June 11, 1970 Static level: 50 ft
 Pumping rate: 250 gpm Duration: 12 hrs Drawdown: 94 ft
 Well log: Casing length/dia: 200 ft/12 in
 1) red and gray clay & gravel 0-44 ft
 2) gravel 44-45 ft
 3) gray clay and gravel 45-50 ft
 4) brown limestone 50-125 ft
 5) brown limestone & red/brown shale 125-180 ft
 6) blue & brown limestone 180-230 ft
 7) gray limestone & gray shale 230-252 ft
 chemical analysis: (see Table 9)

WELL NO. 22 Elevation: 860 ft Driller: -
 Owner/Location: Columbus Zoo/Rt. 257
 Date: - Static level: 34 ft
 Well log: Casing length: 92 ft
 1) soil 0-3 ft
 2) clay 3-10 ft
 3) clay, sand & gravel 10-41 ft
 4) broken limestone 41-59 ft
 5) gray & blue limestone 59-185 ft
 6) brown limestone 185-200 ft
 chemical analysis:

	pH (units)	Hardness ... (ppm)	Fe ... (ppm)	Mn ... (ppm)	SO ₄ ... (ppm)
well 1	7.4	480	2.2	0.1	155
well 2	7.2	800	0.0	0.0	254
well 4	7.0	980	0.4	0.0	550

WELL NO. 23 Elevation: 900 ft Driller: Plummer
 Owner/Location: Helen Geese/5966 Brand Rd.
 Date: October 21, 1963 Static level: 8 ft
 Pumping rate: 15 gpm Duration: - Drawdown: 7 ft
 Well log: Casing length/dia: 92 ft/4 1/4 in
 1) clay 0-9 ft
 2) sand 9-18 ft
 3) clay 18-72 ft
 4) sand & gravel 72-92 ft

WELL NO. 24 Elevation: 900 ft Driller: Plummer
 Owner/Location: Barbara Sherwood/5777 Brand Rd.
 Date: April 13, 1966 Static level: 23 ft
 Pumping rate: 15 gpm Duration: - Drawdown: 14 ft
 Well log: Casing length/dia: 40 ft/4 1/4 in
 1) clay 0-38 ft
 2) limestone 38-107 ft

TABLE 4 (continued)

WELL NO. 25 Elevation: 935 ft Driller: M & S
 Owner/Location: Robert Erwin/Avery Rd.
 Date: December 17, 1975 Static level: 51 ft
 Pumping rate: 12 gpm Duration: 2 hrs Drawdown: none
 Well log: Casing length/dia: 99 ft/4 1/2 in
 1) yellow clay 0-20 ft
 2) fine sand 20-21 ft
 3) sand clay 21-80 ft
 4) red clay 80-99 ft
 5) limestone 99-107 ft

WELL NO. 26 Elevation: 915 ft Driller: Dublin Drilling
 Owner/Location: Sheaf/8040 Avery Rd.
 Date: February 13, 1973 Static level: 14 ft
 Pumping rate: 10 gpm Duration: 1 1/2 hrs Drawdown: -
 Well log: Casing length/dia: 71 ft/4 in
 1) clay 0-17 ft
 2) sand & gravel 18-75 ft

WELL NO. 27 Elevation: 950 ft Driller: Baker
 Owner/Location: Muirfield Ltd./Muirfield Village
 Date: September 25, 1972 Static level: 27 ft.
 Pumping rate: 520 gpm Duration: 8 hrs Drawdown: 20 ft
 Well log: Casing length/dia: 76 ft/12 in
 1) top soil 0-3 ft
 2) brown clay & gravel 3-15 ft
 3) gray clay 15-24 ft
 4) gravel 24-27 ft
 5) gray clay 27-50 ft
 6) sand & gravel 50-58 ft
 7) gravel & water 58-75 ft
 8) brown limestone 75-100 ft
 9) broken brown limestone 100-133 ft
 10) gray limestone 133-145 ft
 11) brown limestone 145-180 ft
 12) broken brown limestone & gray shale 180-250 ft
 13) gray shale 250-263 ft
 14) gray limestone 263-290 ft
 chemical analysis: (see Tables 6 and 7)

WELL NO. 28 Elevation: 950 ft Driller: Dunbar
 Owner/Location: Muirfield Ltd./Muirfield Village
 Date: April 17, 1975 Static level: -
 Pumping rate: - Duration: - Drawdown: -
 Well log: Casing length/dia: 222 ft/10 in
 1) top soil 0-1 ft
 2) yellow and gray clay 1-33 ft
 3) clay with gravel 33-56 ft
 4) sand & gravel 56-59 ft
 5) clay with gravel 59-103 ft
 6) brown & gray limestone 103-355 ft
 chemical analyses: (see Table 8)

TABLE 5
CHEMICAL ANALYSIS OF BEDROCK WATER
FROM A WELL AT MUIRFIELD SITE*

PARAMETER	CONCENTRATION
Alkalinity (total as CaCO_3)	414 ppm
Hardness (total as CaCO_3)	1200 ppm
Hardness (carbonate as CaCO_3)	414 ppm
Calcium (as CaCO_3)	750 ppm
Calcium (as Ca)	300 ppm
Magnesium (as CaCO_3)	450 ppm
Magnesium (as Mg)	109 ppm
Chlorides (as Cl)	7 ppm
Iron (as Fe)	1.9 ppm
Sulfates (as SO_4)	837 ppm
Sodium (as Na)	34 ppm
Solids (total)	1760 ppm
Specific Conductance	1400 $\mu\text{mhos}/\text{cm}$
Phenol	negative

*Well Data: Located in southeastern portion of site, 500 feet east of Ashbaugh Road near cemetery at ground elevation of 940 feet; drilled in September 1967 to a depth of 215 feet, lower 104 feet in Columbus Limestone; test in September 1967 indicated well capable of 100 gpm pumping rate for 2 hours with an 11.3-foot drawdown from 33.0 to 44.3 feet below ground level; above water sample analysis by Burgess & Nippe, Ltd., September 29, 1967.

Well No. 3 on Table 4 and Figure 2

TABLE 6

CHEMICAL ANALYSIS OF BEDROCK WATER FROM
MUIRFIELD WELL NO. 1* AND RIVIERA COUNTRY CLUB**

PARAMETER	CONCENTRATION***					
	9/25/72	9/26/72	10/11/72	3/9/73	7/10/75	Riviera 9/25/72
Alkalinity, total (CaCO ₃)	356	358	318	362	362	336
Alkalinity, phenol. (CaCO ₃)	0	0	0	-	0	0
Hardness, total (CaCO ₃)	1240	1280	1120	748	1000	1720
Hardness, carbonate (CaCO ₃)	-	358	318	362	302	336
Hardness, non-carbonate (CaCO ₃)	-	922	802	386	698	1384
Calcium (CaCO ₃)	720	700	650	-	600	880
Magnesium (CaCO ₃)	520	580	470	-	400	840
Chlorides (Cl)	-	-	8.0	7.6	7.5	31
Iron (Fe)	4.2	4.0	1.5	1.6	1.4	3.3
Manganese (Mn)	0	0	1.1	-	-	0
Sulfates (SO ₄)	960	770	860	320	690	1300
Sodium (Na)	-	-	30	-	-	-
Nitrates (NO ₃)	2.66	-	0	1.1	-	-
Total solids	-	-	1674	1089	1622	2170
Conductivity	1850	1780	1800	1210	1850	1925
pH	7.0	7.0	7.7	7.0	7.3	7.0

*Well no. 27 on Table 4 and Figure 2

**Well no. 5 on Table 4 and Figure 2

***All values in ppm except pH (units) and conductivity (μ hos/cm)

TABLE 7
CHEMICAL ANALYSIS OF WATER FROM VARIOUS HORIZONS
IN MUIRFIELD WELL NO. 1*

PARAMETER	CONCENTRATION**				
	Gravel Water @ 75 ft	Rock Water @ 140 ft	Rock Water @ 190 ft	Rock Water @ 235 ft	Rock Water @ 290 ft
Alkalinity, total (CaCO ₃)	426	428	-	-	358
Alkalinity, phenol. (CaCO ₃)	0	0	-	-	0
Hardness, total (CaCO ₃)	1500	1460	1440	1272	1280
Calcium (CaCO ₃)	780	800	-	724	700
Magnesium (CaCO ₃)	720	660	-	-	580
Iron (Fe)	10.0	9.6	8.0	1.6	40
Sulfates (SO ₄)	860	820	770	600	770
Chlorides (Cl)	127	-	-	-	-
Nitrates (NO ₃)	3.2	-	-	-	-
Conductivity	-	-	-	-	1780
pH	6.9	6.8	6.8	-	7.0
Total solids	2239	-	-	-	-

*Well No. 27 on Table 4 and Figure 2

**All values in ppm except pH (units) and conductivity ($\mu\text{mhos}/\text{cm}$)

Samples collected on September 26, 1972

TABLE 8

CHEMICAL ANALYSIS OF BEDROCK WATER
FROM MUIRFIELD WELL NO. 2*

PARAMETER	CONCENTRATION	
	April 16, 1975	June 23, 1975
Calculated CO ₂	6 ppm	150+ ppm
Phenol. Alkalinity (CaCO ₃)	0 ppm	0 ppm
Total Alkalinity (CaCO ₃)	180 ppm	260 ppm
Caustic Alkalinity (CaCO ₃)	--	0 ppm
Total Hardness (CaCO ₃)	582 ppm	1220 ppm
Carbonate Hardness	180 ppm	--
Non-carbonate Hardness	402 ppm	--
Calcium Hardness (CaCO ₃)	362 ppm	600 ppm
Calcium (Ca)	145 ppm	240 ppm
Magnesium Hardness (CaCO ₃)	220 ppm	620 ppm
Magnesium (Mg)	63 ppm	178.5 ppm
Chlorides (Cl)	22 ppm	27 ppm
Total Iron (Fe)	0.85 ppm	0.31 ppm
Manganese (Mn)	--	0.0 ppm
Sodium (Na)	--	43.5 ppm
Sulfates (SO ₄)	--	640 ppm
Total Solids	--	1476 ppm
pH	7.74 units	7.04 units
Conductivity		1750 μ hos/cm

*Well No. 28 on Table 4 and Figure 2, located near Golf Course Hole No. 12

TABLE 9
CHEMICAL ANALYSIS OF BEDROCK WATER FROM WELLS IN DUBLIN, HILLIARD AND MARYSVILLE

PARAMETER	CONCENTRATION			
	WELL NO. 19 (Ashland Oil Co. Dublin, Ohio)	WELL NO. 20 (Midwestern Ww Dublin, Ohio)	WELL NO. 21 (City of Hilliard, Ohio)	WELL (Marysville, Ohio)
Carbon Dioxide (CO ₂)	45 ppm	64 ppm	--	--
Phenol. Alkalinity (CaCO ₃)	0 ppm	0 ppm	0 ppm	0 ppm
Total Alkalinity (CaCO ₃)	302 ppm	232 ppm	312 ppm	248 ppm
Caustic Alkalinity (CaCO ₃)	0 ppm	0 ppm	--	--
Total Hardness (CaCO ₃)	520 ppm	336 ppm	600 ppm	950 ppm
Carbonate Hardness (CaCO ₃)	302 ppm	232 ppm	--	248 ppm
Non-carbonate Hardness (CaCO ₃)	218 ppm	104 ppm	--	702 ppm
Calcium Hardness (CaCO ₃)	290 ppm	228 ppm	--	582 ppm
Calcium (Ca)	116 ppm	91.2 ppm	200 ppm	--
Magnesium Hardness (CaCO ₃)	230 ppm	108 ppm	--	370 ppm
Magnesium (Mg)	66.2 ppm	31.1 ppm	25 ppm	--
Chlorides (Cl)	6 ppm	35 ppm	2 ppm	10 ppm
Total Iron (Fe)	2.15 ppm	0.29 ppm	1.65 ppm	1.5 ppm
pH	7.0 units	7.2 units	7.2 units	7.3 units
Turbidity			15 JTU	4 Pt-Co units
Color			903 ppm	1360 ppm
Total Solids			233 ppm	610 ppm
Sulfates (SO ₄)			0 ppm	
Nitrates (NO ₃)			1.32 ppm	
Fluorides (F)			33 ppm	
Sodium (Na)			0.10 ppm	
Nanganese (Mn)				

TABLE 10
CHARACTERISTICS OF WATER WELLS IN THE
VICINITY OF MUIRFIELD VILLAGE

Well No.	Depth		Static Level (ft)	Water-Bearing Material*
	Total	To Rock		
1	88	--	56	S&G
2	88	--	56	G
3	215	111	36	Ls
4	56	--	38	S&G
5	235	70	34	Ls
6	72	32	6	Ls
7	60	34	8	Ls
8	85	68	14	Ls
9	90	--	20	S
10	79	--	45	G
11	38	--	3	G
12	67	--	8	G
13	88	65	66	Ls
14	33	--	5	S&G
15	302	165	55	Ls
16	110	75	61	Ls (water in S&G at 72 ft)
17	66	--	52	S&G
18	85	--	48	S&G
19	155	57	8	Ls
20	225	8	49	Ls
21	252	50	50	Ls
22	200	41	34	Ls
23	92	--	8	S&G
24	107	38	23	Ls
25	107	99	51	Ls
26	75	--	14	S&G
27	290	75	27	Ls
28	355	103	--	Ls

*S = sand, G = gravel, Ls = limestone

TABLE 11
SPECIFIC CONDUCTANCE AND HARDNESS VALUES
FOR WATER WELL SAMPLES

Well Name/No.	Water-Bearing Material*	Conductivity ($\mu\text{mhos}/\text{cm}$)	Total Hardness (ppm)
1	Ls	2020	--
3	Ls	1400	1200
5	Ls	1925	1720
11	S&G	650	--
19	Ls	--	520
20	Ls	--	335
21	Ls	--	600
22	Ls	--	750
27 (75 ft)	S&G	--	1500
27 (29 ft)	Ls	1700	1280
28	Ls	1750	1220
Avery Rd. Marysville	Ls	2850	--
	Ls	--	950

*S&G = sand and gravel, Ls = limestone

TABLE 12

LAKE CHARACTERISTICS FOR
GOLF COURSE NO. 2, MUIRFIELD VILLAGE

Lake	Area (acres)	Volume		Storage Capacity (acre ft)	Elevations (feet)
		(cubic yards)	(gallons)		
A	2.7	31,000	6.26×10^6	3	968
B	2.7	28,000	5.66×10^6	-	930
C	3.2	49,000	9.90×10^6	5	956
D	neg.	negligible	-	-	-
E	2.5	54,500	10.91×10^6	3	957
F	2.5	50,000	10.10×10^6	5-6	933
G	2.5	32,000	6.46×10^6	-	925
H	2.4	39,000	7.88×10^6	3	937
TOTAL	18.5	283,000	57.08×10^6		

FIGURES

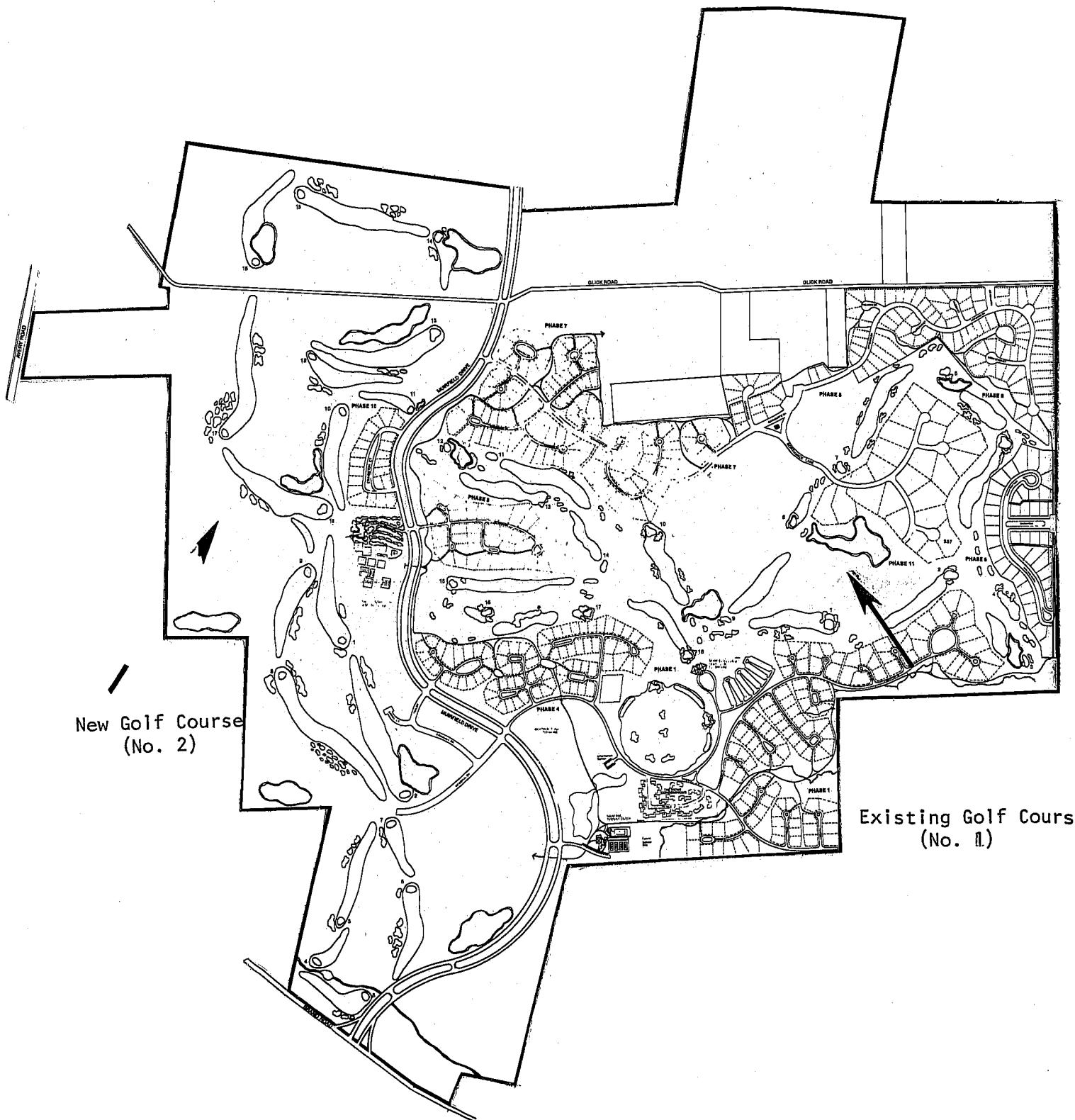


FIGURE 1. Map of Muirfield Village Showing Location of New Golf Course (No. 2).

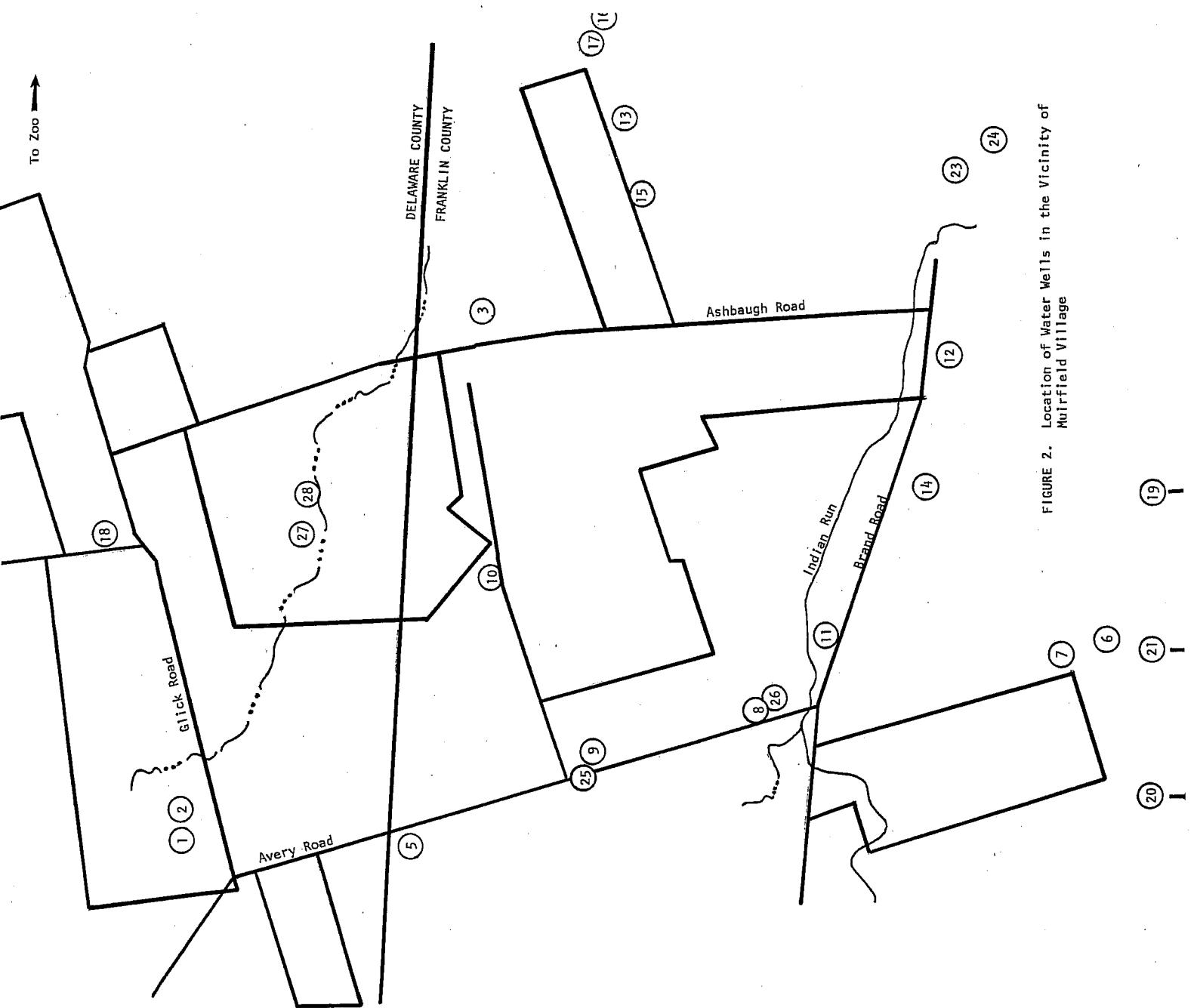
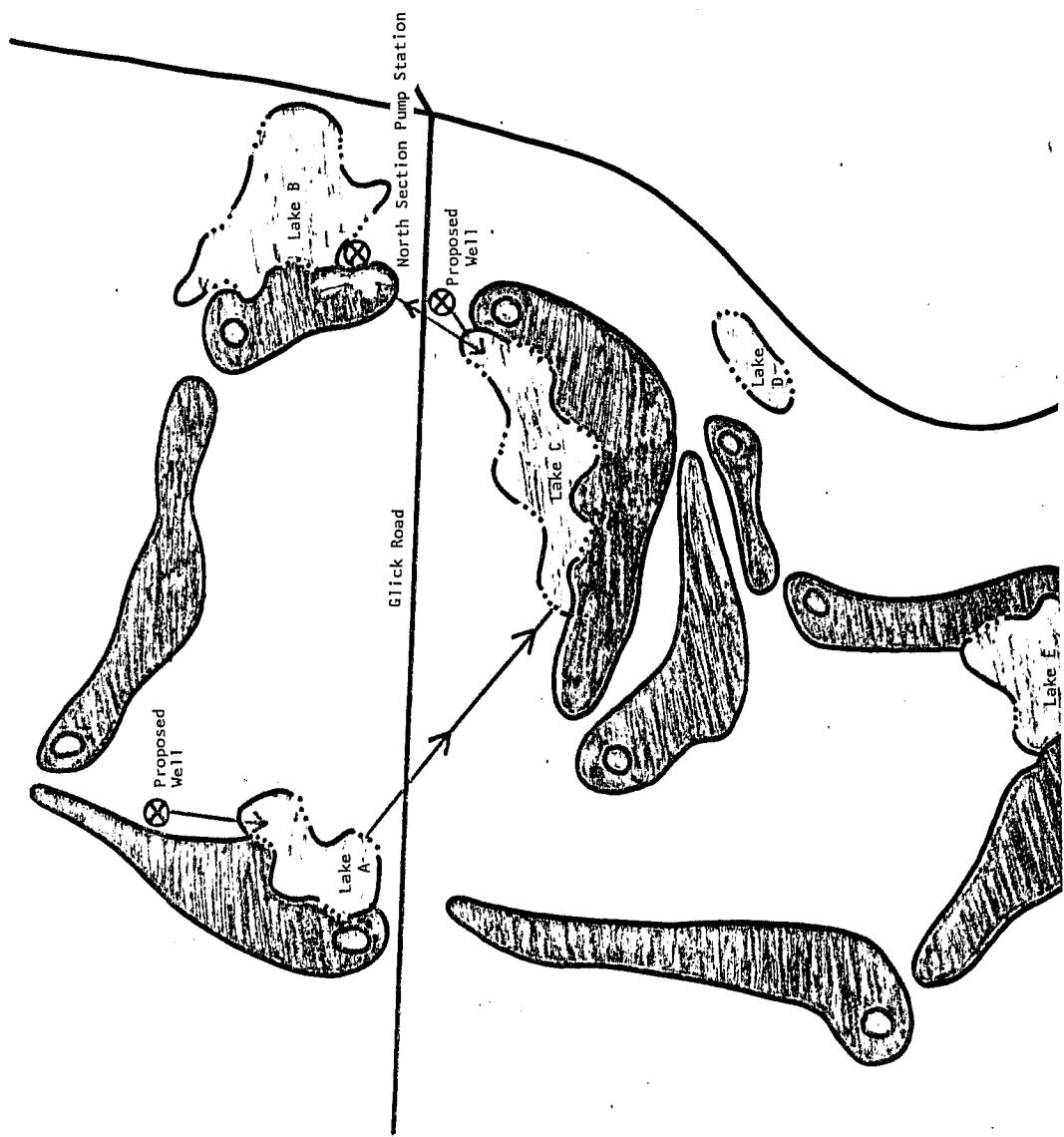
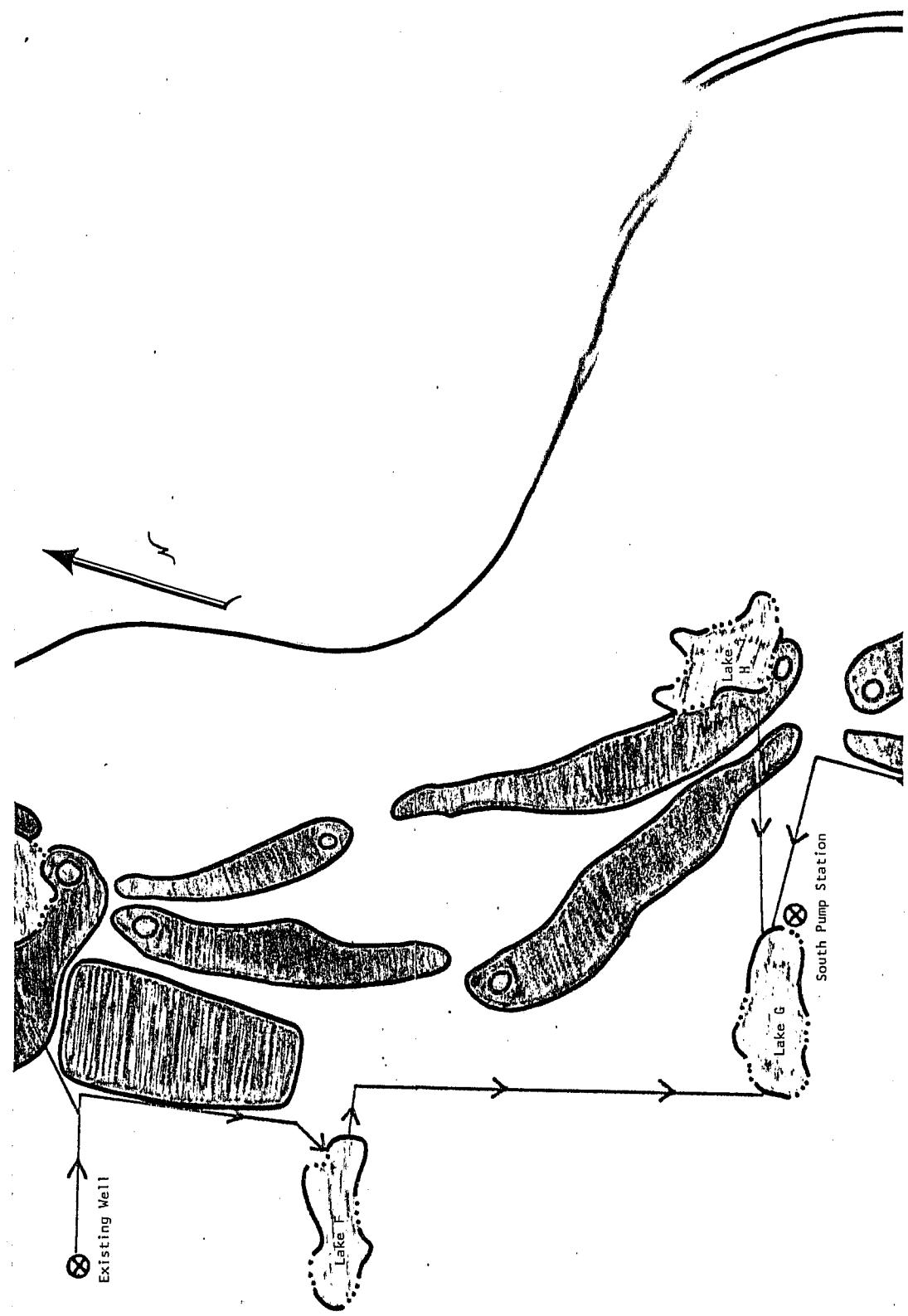


FIGURE 2. Location of Water Wells in the Vicinity of
Muirfield Village





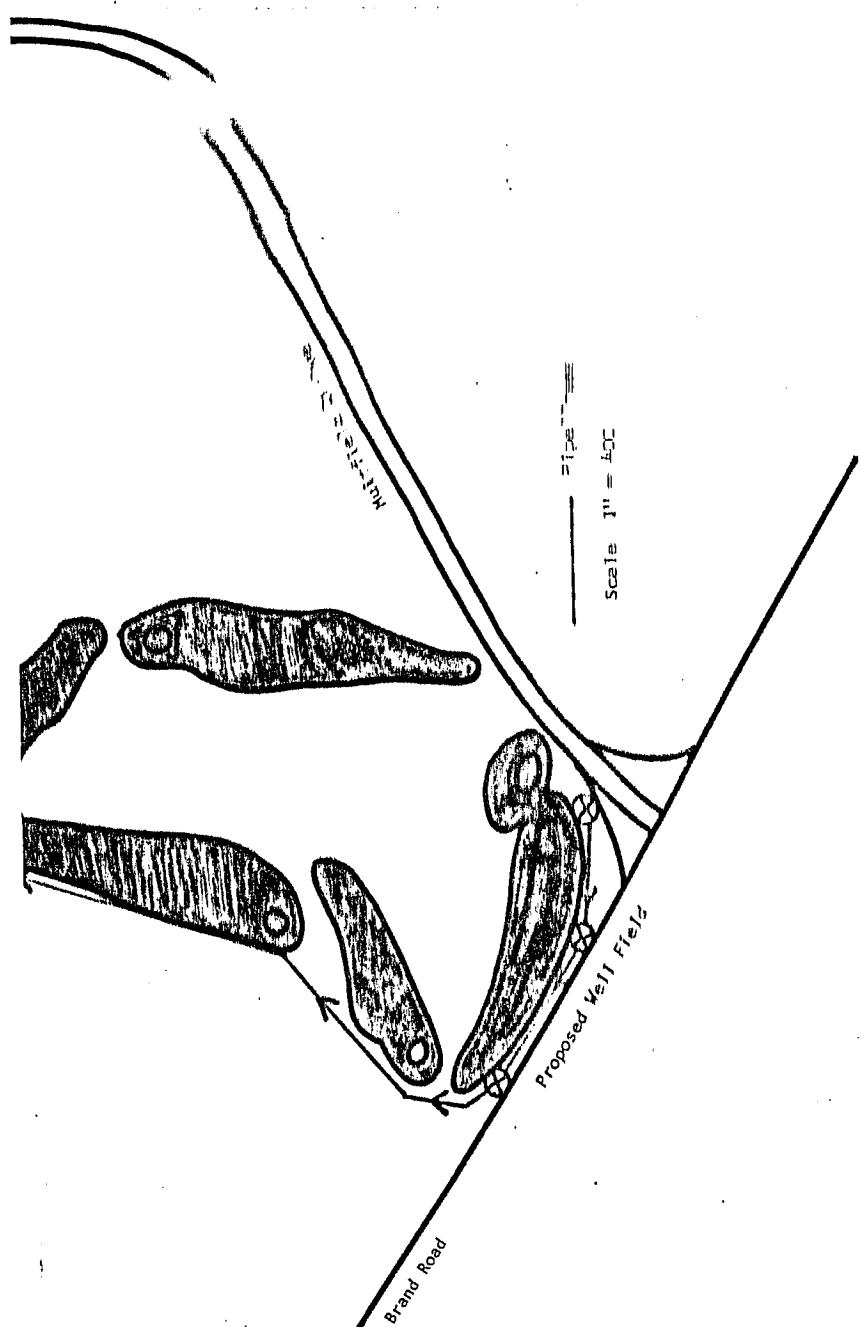


FIGURE 3. Irrigation System for New Irrigation Course (No. 2)