1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

TRIP BLANK

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1702

Sample wt/vol: 5.00(g/mL) G Lab File ID: 1702B61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5		U
75-01-4	Vinyl Chloride	5		U
74-83-9	Bromomethane	5		U
75-00-3	Chloroethane	5		U
75-35-4	1,1-Dichloroethene	5		U
75-15-0	Carbon disulfide	5		U
67-64-1	Acetone	13	8	JB
75-09-2	Methylene Chloride	5	0.9	JB
156-60-5	trans-1,2-Dichloroethene	5		U
1634-04-4	Methyl-tert-butyl ether	5		U
75-34-3	1,1-Dichloroethane	5		U
156-59-2	cis-1,2-Dichloroethene	5		U
78-93-3	2-butanone	13	1	JB
67-66-3	Chloroform	5		U
71-55-6	1,1,1-Trichloroethane	5		U
56-23-5	Carbon Tetrachloride	5		U
71-43-2	Benzene	5		U
107-06-2	1,2-Dichloroethane	5		U
79-01-6	Trichloroethene	5		U
78-87-5	1,2-Dichloropropane	5		U
75-27-4	Bromodichloromethane	5		U
10061-01-5	cis-1,3-Dichloropropene	5		U
108-10-1	4-Methyl-2-pentanone	13		U
108-88-3	Toluene	5	1	JB
10061-02-6	trans-1,3-Dichloropropene	5		U
79-00-5	1,1,2-Trichloroethane	5		U
127-18-4	Tetrachloroethene	5		U
591-78-6	2-hexanone	13		U
124-48-1	Dibromochloromethane	5		U
108-90-7	Chlorobenzene	5		U
100-41-4	Ethylbenzene	5		U
100-42-5	Styrene	5		U
75-25-2	Bromoform	5		U

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

TRIP BLANK

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1702

Sample wt/vol: 5.00(g/mL) G Lab File ID: 1702B61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5		U
1330-20-7	Xylene (total)	15		U

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1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBALCS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 268

Sample wt/vol: 5.00(g/mL) G Lab File ID: 268B61_17

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5	52	
75-01-4	Vinyl Chloride	5	56	
74-83-9	Bromomethane	5	55	
75-00-3	Chloroethane	5	56	
75-35-4	1,1-Dichloroethene	5	60	
75-15-0	Carbon disulfide	5	61	
67-64-1	Acetone	13	130	B
75-09-2	Methylene Chloride	5	53	B
156-60-5	trans-1,2-Dichloroethene	5	56	
1634-04-4	Methyl-tert-butyl ether	5	58	
75-34-3	1,1-Dichloroethane	5	58	
156-59-2	cis-1,2-Dichloroethene	5	56	
78-93-3	2-butanone	13	140	B
67-66-3	Chloroform	5	55	
71-55-6	1,1,1-Trichloroethane	5	54	
56-23-5	Carbon Tetrachloride	5	56	
71-43-2	Benzene	5	60	
107-06-2	1,2-Dichloroethane	5	56	
79-01-6	Trichloroethene	5	54	
78-87-5	1,2-Dichloropropane	5	56	
75-27-4	Bromodichloromethane	5	53	
10061-01-5	cis-1,3-Dichloropropene	5	59	
108-10-1	4-Methyl-2-pentanone	13	150	
108-88-3	Toluene	5	57	B
10061-02-6	trans-1,3-Dichloropropene	5	61	
79-00-5	1,1,2-Trichloroethane	5	63	
127-18-4	Tetrachloroethene	5	56	
591-78-6	2-hexanone	13	140	
124-48-1	Dibromochloromethane	5	60	
108-90-7	Chlorobenzene	5	57	
100-41-4	Ethylbenzene	5	56	
100-42-5	Styrene	5	58	
75-25-2	Bromoform	5	55	

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBALCS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 268

Sample wt/vol: 5.00(g/mL) G Lab File ID: 268B61_17

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5	59	
1330-20-7	Xylene (total)	15	170	

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBLKBA

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 265

Sample wt/vol: 5.00(g/mL) G Lab File ID: 265B61_17

Level: (low/med) LOW Date Received: 07/03/03

% Moisture: not dec. _____ Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5		U
75-01-4	Vinyl Chloride	5		U
74-83-9	Bromomethane	5		U
75-00-3	Chloroethane	5		U
75-35-4	1,1-Dichloroethene	5		U
75-15-0	Carbon disulfide	5		U
67-64-1	Acetone	13	8	J
75-09-2	Methylene Chloride	5	1	J
156-60-5	trans-1,2-Dichloroethene	5		U
1634-04-4	Methyl-tert-butyl ether	5		U
75-34-3	1,1-Dichloroethane	5		U
156-59-2	cis-1,2-Dichloroethene	5		U
78-93-3	2-butanone	13	1	J
67-66-3	Chloroform	5		U
71-55-6	1,1,1-Trichloroethane	5		U
56-23-5	Carbon Tetrachloride	5		U
71-43-2	Benzene	5		U
107-06-2	1,2-Dichloroethane	5		U
79-01-6	Trichloroethene	5		U
78-87-5	1,2-Dichloropropane	5		U
75-27-4	Bromodichloromethane	5		U
10061-01-5	cis-1,3-Dichloropropene	5		U
108-10-1	4-Methyl-2-pentanone	13		U
108-88-3	Toluene	5	0.6	J
10061-02-6	trans-1,3-Dichloropropene	5		U
79-00-5	1,1,2-Trichloroethane	5		U
127-18-4	Tetrachloroethene	5		U
591-78-6	2-hexanone	13		U
124-48-1	Dibromochloromethane	5		U
108-90-7	Chlorobenzene	5		U
100-41-4	Ethylbenzene	5		U
100-42-5	Styrene	5		U
75-25-2	Bromoform	5		U

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBLKBA

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 265

Sample wt/vol: 5.00(g/mL) G Lab File ID: 265B61_17

Level: (low/med) LOW Date Received: 07/03/03

% Moisture: not dec. _____ Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5		U
1330-20-7	Xylene (total)	15		U

FORM I VOA 8260B

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBLKZS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: WG25276-2

Sample wt/vol: 5.00(g/mL) G Lab File ID: WG25276-2B61

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5		U
75-01-4	Vinyl Chloride	5		U
74-83-9	Bromomethane	5		U
75-00-3	Chloroethane	5		U
75-35-4	1,1-Dichloroethene	5		U
75-15-0	Carbon disulfide	5		U
67-64-1	Acetone	13	10	J
75-09-2	Methylene Chloride	5	1	J
156-60-5	trans-1,2-Dichloroethene	5		U
1634-04-4	Methyl-tert-butyl ether	5		U
75-34-3	1,1-Dichloroethane	5		U
156-59-2	cis-1,2-Dichloroethene	5		U
78-93-3	2-butanone	13	1	J
67-66-3	Chloroform	5		U
71-55-6	1,1,1-Trichloroethane	5		U
56-23-5	Carbon Tetrachloride	5		U
71-43-2	Benzene	5		U
107-06-2	1,2-Dichloroethane	5		U
79-01-6	Trichloroethene	5		U
78-87-5	1,2-Dichloropropane	5		U
75-27-4	Bromodichloromethane	5		U
10061-01-5	cis-1,3-Dichloropropene	5		U
108-10-1	4-Methyl-2-pentanone	13		U
108-88-3	Toluene	5	0.6	J
10061-02-6	trans-1,3-Dichloropropene	5		U
79-00-5	1,1,2-Trichloroethane	5		U
127-18-4	Tetrachloroethene	5		U
591-78-6	2-hexanone	13		U
124-48-1	Dibromochloromethane	5		U
108-90-7	Chlorobenzene	5		U
100-41-4	Ethylbenzene	5		U
100-42-5	Styrene	5		U
75-25-2	Bromoform	5		U

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VBLKZS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: WG25276-2

Sample wt/vol: 5.00(g/mL) G Lab File ID: WG25276-2B61

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5		U
1330-20-7	Xylene (total)	15		U

FORM I VOA 8260B

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VZSLCS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: WG25276-5

Sample wt/vol: 5.00(g/mL) G Lab File ID: WG25276-5B61

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5	58	
75-01-4	Vinyl Chloride	5	54	
74-83-9	Bromomethane	5	57	
75-00-3	Chloroethane	5	57	
75-35-4	1,1-Dichloroethene	5	58	
75-15-0	Carbon disulfide	5	63	
67-64-1	Acetone	13	280	B
75-09-2	Methylene Chloride	5	52	B
156-60-5	trans-1,2-Dichloroethene	5	55	
1634-04-4	Methyl-tert-butyl ether	5	53	
75-34-3	1,1-Dichloroethane	5	57	
156-59-2	cis-1,2-Dichloroethene	5	55	
78-93-3	2-butanone	13	300	B
67-66-3	Chloroform	5	55	
71-55-6	1,1,1-Trichloroethane	5	55	
56-23-5	Carbon Tetrachloride	5	55	
71-43-2	Benzene	5	63	
107-06-2	1,2-Dichloroethane	5	54	
79-01-6	Trichloroethene	5	56	
78-87-5	1,2-Dichloropropane	5	55	
75-27-4	Bromodichloromethane	5	53	
10061-01-5	cis-1,3-Dichloropropene	5	55	
108-10-1	4-Methyl-2-pentanone	13	310	
108-88-3	Toluene	5	59	B
10061-02-6	trans-1,3-Dichloropropene	5	61	
79-00-5	1,1,2-Trichloroethane	5	64	
127-18-4	Tetrachloroethene	5	57	
591-78-6	2-hexanone	13	310	
124-48-1	Dibromochloromethane	5	60	
108-90-7	Chlorobenzene	5	59	
100-41-4	Ethylbenzene	5	60	
100-42-5	Styrene	5	63	
75-25-2	Bromoform	5	56	

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

VZSLCS

Project: Date Sampled:

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: WG25276-5

Sample wt/vol: 5.00(g/mL) G Lab File ID: WG25276-5B61

Level: (low/med) LOW Date Received: _____

% Moisture: not dec. _____ Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5	58	
1330-20-7	Xylene (total)	15	190	

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

WMSOIL-0
63003-002

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1701

Sample wt/vol: 5.43(g/mL) G Lab File ID: 1701B61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. 12 Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5		U
75-01-4	Vinyl Chloride	5		U
74-83-9	Bromomethane	5		U
75-00-3	Chloroethane	5		U
75-35-4	1,1-Dichloroethene	5		U
75-15-0	Carbon disulfide	5	1	J
67-64-1	Acetone	13	36	B
75-09-2	Methylene Chloride	5	1	JB
156-60-5	trans-1,2-Dichloroethene	5		U
1634-04-4	Methyl-tert-butyl ether	5		U
75-34-3	1,1-Dichloroethane	5		U
156-59-2	cis-1,2-Dichloroethene	5	2	J
78-93-3	2-butanone	13	8	JB
67-66-3	Chloroform	5		U
71-55-6	1,1,1-Trichloroethane	5	0.7	J
56-23-5	Carbon Tetrachloride	5		U
71-43-2	Benzene	5	5	
107-06-2	1,2-Dichloroethane	5		U
79-01-6	Trichloroethene	5	10	
78-87-5	1,2-Dichloropropane	5		U
75-27-4	Bromodichloromethane	5		U
10061-01-5	cis-1,3-Dichloropropene	5		U
108-10-1	4-Methyl-2-pentanone	13	2	J
108-88-3	Toluene	5	14	B
10061-02-6	trans-1,3-Dichloropropene	5		U
79-00-5	1,1,2-Trichloroethane	5		U
127-18-4	Tetrachloroethene	5	6	
591-78-6	2-hexanone	13	2	J
124-48-1	Dibromochloromethane	5		U
108-90-7	Chlorobenzene	5		U
100-41-4	Ethylbenzene	5	4	J
100-42-5	Styrene	5	0.3	J
75-25-2	Bromoform	5		U

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

WMSOIL-0
63003-002

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1701

Sample wt/vol: 5.43(g/mL) G Lab File ID: 1701B61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. 12 Date Analyzed: 07/04/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5		U
1330-20-7	Xylene (total)	16	6	J

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

WMSOIL-06
3003-002RE

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1701

Sample wt/vol: 6.24(g/mL) G Lab File ID: 1701RB61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. 12 Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
74-87-3	Chloromethane	5		U
75-01-4	Vinyl Chloride	5		U
74-83-9	Bromomethane	5		U
75-00-3	Chloroethane	5		U
75-35-4	1,1-Dichloroethene	5		U
75-15-0	Carbon disulfide	5	0.6	J
67-64-1	Acetone	11	26	B
75-09-2	Methylene Chloride	5		U
156-60-5	trans-1,2-Dichloroethene	5		U
1634-04-4	Methyl-tert-butyl ether	5		U
75-34-3	1,1-Dichloroethane	5		U
156-59-2	cis-1,2-Dichloroethene	5	0.5	J
78-93-3	2-butanone	11	6	JB
67-66-3	Chloroform	5		U
71-55-6	1,1,1-Trichloroethane	5	0.5	J
56-23-5	Carbon Tetrachloride	5		U
71-43-2	Benzene	5	3	J
107-06-2	1,2-Dichloroethane	5		U
79-01-6	Trichloroethene	5	2	J
78-87-5	1,2-Dichloropropane	5		U
75-27-4	Bromodichloromethane	5		U
10061-01-5	cis-1,3-Dichloropropene	5		U
108-10-1	4-Methyl-2-pentanone	11		U
108-88-3	Toluene	5	7	B
10061-02-6	trans-1,3-Dichloropropene	5		U
79-00-5	1,1,2-Trichloroethane	5		U
127-18-4	Tetrachloroethene	5	4	J
591-78-6	2-hexanone	11	1	J
124-48-1	Dibromochloromethane	5		U
108-90-7	Chlorobenzene	5	0.4	J
100-41-4	Ethylbenzene	5	2	J
100-42-5	Styrene	5	0.3	J
75-25-2	Bromoform	5		U

1ACC
VOLATILE ORGANICS ANALYSIS DATA SHEET

EPA SAMPLE NO.

WMSOIL-06
3003-002RE

Project: Date Sampled: 06/30/03

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Matrix: (soil/water) SOIL Lab Sample ID: 1701

Sample wt/vol: 6.24(g/mL) G Lab File ID: 1701RB61

Level: (low/med) LOW Date Received: 07/01/03

% Moisture: not dec. 12 Date Analyzed: 07/05/03

GC Column: RTX-VMS ID: 0.18 (mm) Dilution Factor: 1.0

Soil Extract Volume:_____(uL) Soil Aliquot Volume: _____(uL

CAS NO.	COMPOUND	REPORTING LIMIT	CONC UNITS: UG/KG	Q
79-34-5	1,1,2,2-Tetrachloroethane	5	0.4	J
1330-20-7	Xylene (total)	14	4	J

FORM I VOA 8260B

FORM 2
SOIL VOLATILE SYSTEM MONITORING COMPOUND RECOVERY

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Level: (low/med) LOW

	CLIENT SAMPLE NO.	SMC1 (DBF) #	SMC2 (DCE) #	SMC3 (TOL) #	SMC4 (BFB) #	TOT OUT
01	VBLKZS	105	102	114	113	0
02	VZSLCS	110	108	118	106	0
03	WMSOIL-06300	113	128	133*	148*	2
04	TRIP BLANK	100	102	109	101	0
05	VBLKBA	113	108	118	115	0
06	VBALCS	108	107	110	105	0
07	WMSOIL-06300	94	99	106	103	0
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		QC LIMITS
SMC1 (DBF)	= Dibromofluoromethane	(71-141)
SMC2 (DCE)	= 1,2-Dichloroethane-d4	(70-139)
SMC3 (TOL)	= Toluene-d8	(72-123)
SMC4 (BFB)	= Bromofluorobenzene	(65-131)

Column to be used to flag recovery values

* Values outside of contract required QC limits

D System Monitoring Compound diluted out

3B
SOIL VOLATILE LAB CONTROL SAMPLE

VBALCS

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Level: (low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Chloromethane	50.00	52.34	105	50-150
Vinyl Chloride	50.00	55.58	111	50-150
Bromomethane	50.00	54.78	110	50-150
Chloroethane	50.00	55.97	112	50-150
1,1-Dichloroethene	50.00	59.63	119	50-150
Carbon disulfide	50.00	60.82	122	50-150
Acetone	125.0	125.5	100	50-150
Methylene Chloride	50.00	52.55	105	50-150
trans-1,2-Dichloroethen	50.00	56.39	113	50-150
Methyl-tert-butyl ether	50.00	58.08	116	50-150
1,1-Dichloroethane	50.00	57.96	116	50-150
cis-1,2-Dichloroethene	50.00	56.22	112	50-150
2-butanone	125.0	137.5	110	50-150
Chloroform	50.00	55.38	111	50-150
1,1,1-Trichloroethane	50.00	54.00	108	50-150
Carbon Tetrachloride	50.00	55.88	112	50-150
Benzene	50.00	60.07	120	50-150
1,2-Dichloroethane	50.00	56.41	113	50-150
Trichloroethene	50.00	54.39	109	50-150
1,2-Dichloropropane	50.00	56.41	113	50-150
Bromodichloromethane	50.00	53.16	106	50-150
cis-1,3-Dichloropropene	50.00	58.67	117	50-150
4-Methyl-2-pentanone	125.0	146.5	117	50-150
Toluene	50.00	56.89	114	50-150
trans-1,3-Dichloroprope	50.00	61.23	122	50-150
1,1,2-Trichloroethane	50.00	63.13	126	50-150
Tetrachloroethene	50.00	55.58	111	50-150
2-hexanone	125.0	144.6	116	50-150

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

COMMENTS:

3B
SOIL VOLATILE LAB CONTROL SAMPLE

VBALCS

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Level:(low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Dibromochloromethane	50.00	59.72	119	50-150
Chlorobenzene	50.00	57.29	114	50-150
Ethylbenzene	50.00	55.67	111	50-150
Styrene	50.00	58.36	117	50-150
Bromoform	50.00	54.73	109	50-150
1,1,2,2-Tetrachloroetha	50.00	59.19	118	50-150
Xylene (total)	150.0	174.5	116	50-150

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

Spike Recovery: 0 out of 35 outside limits

COMMENTS:

3B
SOIL VOLATILE LAB CONTROL SAMPLE

VZSLCS

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Level: (low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Chloromethane	50.00	58.24	116	50-150
Vinyl Chloride	50.00	53.73	107	50-150
Bromomethane	50.00	57.19	114	50-150
Chloroethane	50.00	56.89	114	50-150
1,1-Dichloroethene	50.00	57.88	116	50-150
Carbon disulfide	50.00	62.67	125	50-150
Acetone	250.0	275.4	110	50-150
Methylene Chloride	50.00	51.95	104	50-150
trans-1,2-Dichloroethen	50.00	55.39	111	50-150
Methyl-tert-butyl ether	50.00	52.64	105	50-150
1,1-Dichloroethane	50.00	57.13	114	50-150
cis-1,2-Dichloroethene	50.00	55.09	110	50-150
2-butanone	250.0	296.6	119	50-150
Chloroform	50.00	55.46	111	50-150
1,1,1-Trichloroethane	50.00	54.81	110	50-150
Carbon Tetrachloride	50.00	55.05	110	50-150
Benzene	50.00	63.19	126	50-150
1,2-Dichloroethane	50.00	54.21	108	50-150
Trichloroethene	50.00	55.91	112	50-150
1,2-Dichloropropane	50.00	55.34	111	50-150
Bromodichloromethane	50.00	52.65	105	50-150
cis-1,3-Dichloropropene	50.00	55.13	110	50-150
4-Methyl-2-pentanone	250.0	308.5	123	50-150
Toluene	50.00	59.49	119	50-150
trans-1,3-Dichloroprope	50.00	61.39	123	50-150
1,1,2-Trichloroethane	50.00	64.03	128	50-150
Tetrachloroethene	50.00	57.45	115	50-150
2-hexanone	250.0	314.4	126	50-150

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

COMMENTS: _____

3B
SOIL VOLATILE LAB CONTROL SAMPLE

VZSLCS

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Level:(low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Dibromochloromethane	50.00	59.77	120	50-150
Chlorobenzene	50.00	59.26	118	50-150
Ethylbenzene	50.00	60.49	121	50-150
Styrene	50.00	62.82	126	50-150
Bromoform	50.00	55.85	112	50-150
1,1,2,2-Tetrachloroetha	50.00	57.80	116	50-150
Xylene (total)	150.0	187.1	125	50-150

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

Spike Recovery: 0 out of 35 outside limits

COMMENTS:

FORM 4
VOLATILE METHOD BLANK SUMMARY

CLIENT SAMPLE NO

VBLKBA

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Lab File ID: 265B61_17 Lab Sample ID: 265

Date Analyzed: 07/05/03 Time Analyzed: 1759

GC Column: RTX-VMS ID: 0.18 (mm) Heated Purge: (Y/N) Y

Instrument ID: 5973HP61

THIS METHOD BLANK APPLIES TO THE FOLLOWING SAMPLES, MS and MSD:

	SAMPLE NO.	LAB SAMPLE ID	LAB FILE ID	TIME ANALYZED
01	VBALCS	268	268B61_17	1824
02	WMSOIL-06300	1701	1701RB61	1916
03				
04				
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COMMENTS:

FORM 4
VOLATILE METHOD BLANK SUMMARY

CLIENT SAMPLE NO

VBLKZS

Lab Name: COMPUCHEM Contract: 8260B

Lab Code: LIBRTY Case No.: 17 SAS No.: SDG No.: 17

Lab File ID: WG25276-2B61 Lab Sample ID: WG25276-2

Date Analyzed: 07/04/03 Time Analyzed: 1741

GC Column: RTX-VMS ID: 0.18 (mm) Heated Purge: (Y/N) Y

Instrument ID: 5973HP61

THIS METHOD BLANK APPLIES TO THE FOLLOWING SAMPLES, MS and MSD:

	SAMPLE NO.	LAB SAMPLE ID	LAB FILE ID	TIME ANALYZED
01	VZSLCS	WG25276-5	WG25276-5B61	1801
02	WMSOIL-06300	1701	1701B61	2108
03	TRIP BLANK	1702	1702B61	2129
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30				

COMMENTS:

EPA Region 5 Records Ctr.
349911

COMPUCHEM

a division of Liberty Analytical Corp.

08-Jul-03

LISA SMITH
EARTH TECH
4135 TECHNOLOGY PARKWAY

Sheboygan, WI 53083

Subject:
Report of Data-Project: ET03044 DCX- DAYTON THERMAL

Attn.: LISA SMITH

Enclosed are the results of analytical work performed in accordance with the referenced account number.

This report covers sample(s) appearing on the attached listing.

Thank you for selecting CompuChem for your sample analysis. If you should have questions or require additional analytical services, please contact your representative at 1-800-833-5097.

Sincerely,

CompuChem
A Division of Liberty Analytical

Attachment

TOTAL NUMBER
OF PAGES 17

501 Madison Avenue ■ Cary, N.C. 27513 ■ Tel: 919-379-4100 ■ Fax: 919-379-4050

CompuChem, a division of Liberty Analytical

Hsn	Client ID	Wordorder	Matrix	Account	Project	Report
1701	WMSOIL-063003-00	17	S	CHRYSLER	ET03044	7/7/2003
1702	TRIP BLANK	17	W	CHRYSLER	ET03044	7/7/2003

CompuChem
a division of Liberty Analytical Corporation
501 Madison Avenue
Cary, N.C. 27513
Tel: 919/379-4100 Fax: 919/379-4050

SDG NARRATIVE

SDG # 17
CONTRACT # 8270C

SAMPLE IDENTIFICATION: WMSOIL-063003-002

The one (1) solid sample listed above was received intact, properly refrigerated at a temperature of 5.4°C, with proper documentation, in sealed shipping containers, on July 1, 2003. The samples were scheduled for the requested analyses of the semi-volatile fraction. The samples were prepared and analyzed following the SW846 8270C method for the TCL3 list of compounds.

Extraction and analysis holding time requirements were met for these samples.Several Target Compound List (TCL) analyte were identified above the Contract Required Quantitation Limit (CRQL) in this sample. Tentatively Identified Compounds (TICs) were not requested for this SDG. Manual quantitations were performed on one or more of the process files associated with this SDG. The reasons have been coded with explanations provided in the notice included in the narrative section of the SDG.

All decafluorotriphenylphosphine (DFTPP) abundance criteria were met for tunes associated to this SDG. Overall QC criteria were met for all initial and continuing calibration standards associated to this SDG. The surrogates met the recovery criteria. All of the internal standards met response and retention time criteria. The associated method blank met all quality control criteria. No matrix spikes were prepared for this SDG. A laboratory spike was performed with these samples and passed all QC criteria.

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data submitted on diskette has been authorized by the Laboratory Manager or his/her designee, as verified by the following signature.

Susan W Bass

Susan W. Bass
Director of Laboratory Operations
July 7, 2003

Profile 1221

COMPUCHEM a Divison of Liberty Analytical
COMMERCIAL RECEIVING LOG

Page ___ of ___

Client: Earth Tech / Chrysler
Project: Dayton Thermal soil
~~Quote:~~ work order # 17
Login No.
Subcontract? Y / (N)
TAT Verbal ___ Report 6 days

Rec'd Date: 7-1-03
Courier: Fed Ex
Airbill No. 841550721512

PPS/(RFA) ET03044

Lab Instructions
VOC TCL3Cl + MTBE sub
SVOC TCL3
PCB 8082

2

Cooler Rec'd By: C. Pierce
Sample Login By: Cathy Dorr
Temperature: 5.4 °C
Cyanide Samples checked for sulfide & chlorine? Y / (NA)
Phenol Samples checked for chlorine? Y / (NA)
Received in Good Condition? (Y) / N
If no, explain: * Received 6 Trip Blanks not listed on C-O-C!!

CompuChem ID	Client ID	QC	Matrix	Date 20 03	Military Time	Parameters: VOC's No. & Type	pH	VOC's % moist. No. & Type	pH	SVOC's PCB's No. & Type	pH	No. & Type	pH	No. & Type	pH	No. & Type	pH	No. & Type	pH	No. & Type	pH
1701	WMSOIL-063003-002 (7/1/03)		Soil	6/30	10:00	3-5g Encore		1-2oz		1-8oz											
1702	TRIP BLANK		H_2O	✓	—	4-40ml															

7/1/03

Container Type Abbreviations: 40ml.(40ml. vial) AL(Amber Liter) PL(Plastic Liter) 500P(500mL Plastic) 250P(250mL Plastic) OTHER ___

rll - 6/28/03 dce

DAIMLERCHRYSLER — Chain-of-Custody

№ 00553 A

CompuChem
501 Madison Avenue
Cary, NC 27513
Phone Number: (919) 379-4100
Fax Number: (919) 379-4040

Project Name: DCX - DAYTON THERMAL
Site Location: DAYTON, OH
Site Code:
RFA Number: ET 03044
DaimlerChrysler PM: GARY STANCZUK

Consultant: EARTH TECH
Address: 4135 TECHNOLOGY PARKWAY
SHEBOYGAN, WI 53083
Consultant PM: ROB STENSON
Phone: 920-451-2407 Fax: 920-458-0550

Turn-around Time Request: (circle)
24 calendar hrs.
48 calendar hrs.
7 calendar days
14 calendar days

Data Package Deliverables: (circle)
DaimlerChrysler Level 1
DaimlerChrysler Level 2
CLP

Matrix Codes
S - Soil, SW - Surface Water, GW - Groundwater, A - Air, Sed - Sediment, O - Other (specify)

Are aqueous samples field filtered for metals? Yes No

Field Sample Identification	Date Collected	Time Collected	Grab (G) or Composite (C)	Matrix Code	Total # of Containers	VOCs (5g Encore)	VOCs (1 - 2oz)	SVOCs /PCBs (1 - 8oz)							Remarks
WMSOIL-063003-002	6/30/03	1000hr	G	S	~~4~~ 5	3	1	1							* Received 6 Trip Blanks not listed on COC! analyze trip blank per Jim Smith @ Earth Tec recd 4 w/o air bubbles will use 1 of these for analysis. 7/1/03

Sampler(s): SC

Cooler ID #

Samples Relinquished under Airbill No.

Temperature (corrected) 5.4 C

Relinquished by:	Date:	Time:	Received by:	Date:	Time:	Custody Seal Intact?
STEVE CERVI	6/30/03	1330	C. Pierce	7-1-03	9:00	Yes No
Relinquished by:	Date:	Time:	Received for Laboratory by:	Date:	Time:	Custody Seal Intact? Yes No

Is RFA sampling complete? Yes No

DaimlerChrysler Corporation 800 Chrysler Drive, CIMS 482-00-51, Auburn Hills, Michigan 48326-2757

Distribution: White copy: Data package Yellow: Retained by laboratory Pink: Retained by sampler

Custody Seals #1 & 2

Revision No. 3
Created: July 9, 1999

CompuChem
501 Madison Avenue
Cary, NC 27513
Phone (919) 379-4100
Fax (919) 379-4040

DAIMLERCHRYSLER CORPORATION BOTTLE REQUEST AND SHIPMENT FORM

№ 00455A

6/26 AM

PARAMETER	NO. OF BOTTLES NEEDED FOR TEST	NO. OF BOTTLES SENT	CHEMICAL PRESERVATIVE	PRESERVATIVE LOT NO.	BOTTLE TYPE	BOTTLE LOT NO.
Volatiles (H2O)	2		HCl		Vials (40 ml)	
Semivolatiles (H2O)	2*		None	N/A	Amber Liter	
PCBs (H2O)	2*		None	N/A	Amber Liter	
Metals (H2O)	1		HNO3		500 ml Plastic	
Cyanide (H2O)	1		NaOH		Plastic Liter	
TPH- 418.1 (H2O)	2*		HCl		Amber Liter	
TPH-GRO (H2O)	2		HCl		Vials (40 ml)	
TPH-DRO (H2O)	2*		HCl		Amber Liter	
Volatiles (Soil)	1	2	None	N/A	(2 oz. or 4 oz.) Jars	D/2 834040
Volatiles (Soil - Low Level)	3	6	None	N/A	5 g Encore Samplers	*K113 1040
Volatiles (Soil)	1		None	N/A	25 g Encore Samplers	
TPH-GRO (Soil)	2		None	N/A	5 g Encore Samplers	
Semivolatiles/PCBs/~~418.1~~/ ~~DRO/Metals~~/Moisture (Soil)	1	2	None	N/A	8 oz. Glass Jar	F208401K
DI Water - Carboy #	N/A		N/A	N/A	Amber Liter	
Trip Blank -Carboy # 3	2	4	HCl	Pre-pres.	Vials (40 ml)	
Temperature Blank	N/A	1 per cooler	N/A	N/A	N/A	N/A

Customer Service Rep: Cathy Dover Date 6/24/03

RFA Number ET03044

Ship To Address: ~~EARTH TECH~~
Extended Stay America
Guest: Jamie Dickson
6688 Miller Lane
Dayton, OH 45414
(937) 898-9221

pH strips? Yes / (No) Labels? (Yes) / No
DaimlerChrysler COCs (Yes) / No Custody seals? (Yes) / No
Site-specific MS/MSD Yes / (No)
Cooler No(s): 1-cooler

Packed/Shipped by: R Schiller Date 6/25/03

THIS SECTION COMPLETED BY ENGINEERING FIRM:

Recipient's Signature: [signature]
Date Received: 6/26/03
Was all glassware received? (Yes) / No Received in good condition? (Yes) / No
Explain

Sampling Notes:

* - Two one-liter bottles are recommended for collection of semivolatiles, PCBs and TPH-DRO to allow for sample reextraction.
However, if well volumes do not permit collection of this volume for each parameter, a minimum of 1 liter is required for each parameter.

IF SITE-SPECIFIC MS/MSD REQUESTED IN RFA: Additional bottles have been provided to permit collection of adequate volumes for SITE-SPECIFIC MS/MSD analyses for each analytical parameter. MS/MSD samples should be collected for each parameter and matrix at a rate of 1 in 20 samples or per sampling event if less than 20 samples are collected.

Additional Comments: *Our metal T-handles have not been returned this week yet! I guess because it is the busy time in the "sampling season" Spoke w/ Lisa Smith - She ck'd sending disposal 5g plungers.

Please return all unused glassware and coolers when sampling is complete. Please return this form with final sample shipment.

White copy - original - return to lab Yellow copy - retained by field Pink copy - retained by shipper

Revision 1 / July 9, 1999

6/24/03

CompuChem, a Division of Liberty Analytical

Workorder Summary Report

Workorder 17 | Account: CHRYSLE

Status: | Project: ET03044

SAMPLE ID	CLIENT	COLLECT DATE	RECEIVE DATE	DUE DATE	COMMENTS
1701	WMSOIL-063003-	6/30/2003	7/1/2003	7/7/2003	RFA ET03044**VOC TCL3CT + MTBE.SUB**SVOC TCL3**PCB 8082**LCS ONLY
S	DRY WEIGHT	Dry Weight			
S	VS8260L3CM	VOC LL 8260 TCL3CIS/TRANS/MTBE			
S	SS8270LTC3	SVOC LL 8270C TCL3 SOIL			
S	GS82PCB	PCB 8082 SOIL			
1702	TRIP BLANK	6/30/2003	7/1/2003	7/7/2003	RFA ET03044**TRIP BLK RUN WITH SOILS**VOC TCL3CT + MTBE.SUB**LCS ONLY
W	VW82-53CTM	VOC 8260 5ML TCL3CIS/TRANS+MTB			

1BCWC
SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: WMSOIL-063003-002

Lab Project Number: ET03044
Method: 8270C
Date Collected: 06/30/03

Lab Sample ID: 1701
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: 07/01/03
Lab File ID: 1701A60
Analyst: 2319

% Moisture: 12 decanted: (Y/N) N
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
108-95-2	Phenol	35	380	ND	U
111-44-4	Bis(2-chloroethyl)ether	30	380	ND	U
95-57-8	2-Chlorophenol	36	380	ND	U
541-73-1	1,3-Dichlorobenzene	34	380	ND	U
106-46-7	1,4-Dichlorobenzene	29	380	ND	U
95-50-1	1,2-Dichlorobenzene	33	380	ND	U
95-48-7	2-Methylphenol	29	380	ND	U
108-60-1	2,2'-oxybis(1-Chloropropane)	40	380	ND	U
106-44-5	4-Methylphenol	28	380	ND	U
621-64-7	N-Nitroso-di-N-propylamine	33	380	ND	U
67-72-1	Hexachloroethane	37	380	ND	U
98-95-3	Nitrobenzene	43	380	ND	U
78-59-1	Isophorone	30	380	ND	U
88-75-5	2-Nitrophenol	30	380	ND	U
105-67-9	2,4-Dimethylphenol	30	380	ND	U
111-91-1	Bis(2-chloroethoxy)methane	36	380	ND	U
120-83-2	2,4-Dichlorophenol	22	380	ND	U
120-82-1	1,2,4-Trichlorobenzene	42	380	ND	U
91-20-3	Naphthalene	35	380	ND	U
106-47-8	4-Chloroaniline	9.5	380	ND	U
87-68-3	Hexachlorobutadiene	33	380	ND	U
59-50-7	4-Chloro-3-methylphenol	31	380	ND	U
91-57-6	2-Methylnaphthalene	38	380	ND	U
77-47-4	Hexachlorocyclopentadiene	67	380	ND	U
88-06-2	2,4,6-Trichlorophenol	65	380	ND	U
95-95-4	2,4,5-Trichlorophenol	49	380	ND	U
91-58-7	2-Chloronaphthalene	33	380	ND	U
88-74-4	2-Nitroaniline	25	750	ND	U
131-11-3	Dimethylphthalate	21	380	ND	U
606-20-2	2,6-Dinitrotoluene	24	380	ND	U
208-96-8	Acenaphthylene	26	380	33	J
99-09-2	3-Nitroaniline	25	750	ND	U
83-32-9	Acenaphthene	22	380	120	J

ND = Not Detected
Q = Qualifier

FORM I SV-1

1BCWC
SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: WMSOIL-063003-002

Lab Project Number: ET03044
Method: 8270C
Date Collected: 06/30/03

Lab Sample ID: 1701
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: 07/01/03
Lab File ID: 1701A60
Analyst: 2319

% Moisture: 12 decanted: (Y/N) N
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
51-28-5	2,4-Dinitrophenol	160	1900	ND	U
100-02-7	4-Nitrophenol	51	750	ND	U
121-14-2	2,4-Dinitrotoluene	13	380	ND	U
132-64-9	Dibenzofuran	29	380	72	J
84-66-2	Diethylphthalate	15	380	ND	U
7005-72-3	4-Chlorophenyl-phenylether	23	380	ND	U
86-73-7	Fluorene	17	380	86	J
100-01-6	4-Nitroaniline	19	750	ND	U
534-52-1	4,6-Dinitro-2-methylphenol	34	750	ND	U
86-30-6	N-Nitrosodiphenylamine (1)	31	380	ND	U
101-55-3	4-Bromophenyl-phenylether	27	380	ND	U
118-74-1	Hexachlorobenzene	29	380	ND	U
87-86-5	Pentachlorophenol	46	750	ND	U
85-01-8	Phenanthrene	24	380	1500	
120-12-7	Anthracene	25	380	250	J
86-74-8	Carbazole	25	380	160	J
84-74-2	Di-n-butylphthalate	20	380	ND	U
206-44-0	Fluoranthene	16	380	2200	
129-00-0	Pyrene	27	380	2000	
85-68-7	Butylbenzylphthalate	21	380	ND	U
91-94-1	3,3'-Dichlorobenzidine	16	750	ND	U
117-81-7	bis(2-ethylhexyl)Phthalate	39	380	67	J
56-55-3	Benzo(a)anthracene	24	380	1000	
218-01-9	Chrysene	28	380	1000	
117-84-0	Di-n-octylphthalate	19	380	ND	U
205-99-2	Benzo(b)fluoranthene	24	380	860	
207-08-9	Benzo(k)fluoranthene	36	380	930	
50-32-8	Benzo(a)pyrene	26	380	840	
193-39-5	Indeno(1,2,3-cd)pyrene	30	380	490	
53-70-3	Dibenzo(a,h)anthracene	29	380	170	J
191-24-2	Benzo(g,h,i)perylene	33	380	400	

(1) - Cannot be separated from Diphenylamine
ND = Not Detected
Q = Qualifier

FORM I SV-2

1BCWC

SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: SLCSJP

Lab Project Number: ET03044
Method: 8270C
Date Collected: _____

Lab Sample ID: WG25304-2
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: _____
Lab File ID: WG25304-2A60
Analyst: 2319

% Moisture: 0 decanted: (Y/N) N
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
108-95-2	Phenol	35	330	1900	
111-44-4	Bis(2-chloroethyl)ether	30	330	1500	
95-57-8	2-Chlorophenol	36	330	1800	
541-73-1	1,3-Dichlorobenzene	34	330	1200	
106-46-7	1,4-Dichlorobenzene	29	330	1200	
95-50-1	1,2-Dichlorobenzene	33	330	1300	
95-48-7	2-Methylphenol	29	330	1800	
108-60-1	2,2'-oxybis(1-Chloropropane)	40	330	1500	
106-44-5	4-Methylphenol	28	330	3700	
621-64-7	N-Nitroso-di-N-propylamine	33	330	1500	
67-72-1	Hexachloroethane	37	330	1200	
98-95-3	Nitrobenzene	43	330	1200	
78-59-1	Isophorone	30	330	1600	
88-75-5	2-Nitrophenol	30	330	1800	
105-67-9	2,4-Dimethylphenol	30	330	2000	
111-91-1	Bis(2-chloroethoxy)methane	36	330	1700	
120-83-2	2,4-Dichlorophenol	22	330	1900	
120-82-1	1,2,4-Trichlorobenzene	42	330	1400	
91-20-3	Naphthalene	35	330	1600	
106-47-8	4-Chloroaniline	9.5	330	1500	
87-68-3	Hexachlorobutadiene	33	330	1400	
59-50-7	4-Chloro-3-methylphenol	31	330	2000	
91-57-6	2-Methylnaphthalene	38	330	1700	
77-47-4	Hexachlorocyclopentadiene	67	330	1600	
88-06-2	2,4,6-Trichlorophenol	65	330	2200	
95-95-4	2,4,5-Trichlorophenol	49	330	2100	
91-58-7	2-Chloronaphthalene	33	330	1700	
88-74-4	2-Nitroaniline	25	660	2100	
131-11-3	Dimethylphthalate	21	330	1700	
606-20-2	2,6-Dinitrotoluene	24	330	1800	
208-96-8	Acenaphthylene	26	330	1900	
99-09-2	3-Nitroaniline	25	660	1700	
83-32-9	Acenaphthene	22	330	1900	

ND = Not Detected
Q = Qualifier

FORM I SV-1

1BCWC
SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: SLCSJP

Lab Project Number: ET03044
Method: 8270C
Date Collected: _____

Lab Sample ID: WG25304-2
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: _____
Lab File ID: WG25304-2A60
Analyst: 2319

% Moisture: 0 decanted: (Y/N) N
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
51-28-5	2,4-Dinitrophenol	160	1700	2200	
100-02-7	4-Nitrophenol	51	660	2100	
121-14-2	2,4-Dinitrotoluene	13	330	1900	
132-64-9	Dibenzofuran	29	330	1900	
84-66-2	Diethylphthalate	15	330	1800	
7005-72-3	4-Chlorophenyl-phenylether	23	330	1800	
86-73-7	Fluorene	17	330	2000	
100-01-6	4-Nitroaniline	19	660	1800	
534-52-1	4,6-Dinitro-2-methylphenol	34	660	2000	
86-30-6	N-Nitrosodiphenylamine (1)	31	330	1800	
101-55-3	4-Bromophenyl-phenylether	27	330	1900	
118-74-1	Hexachlorobenzene	29	330	1900	
87-86-5	Pentachlorophenol	46	660	2600	
85-01-8	Phenanthrene	24	330	2100	
120-12-7	Anthracene	25	330	2000	
86-74-8	Carbazole	25	330	2200	
84-74-2	Di-n-butylphthalate	20	330	1900	
206-44-0	Fluoranthene	16	330	2100	
129-00-0	Pyrene	27	330	2000	
85-68-7	Butylbenzylphthalate	21	330	1900	
91-94-1	3,3'-Dichlorobenzidine	16	660	1300	
117-81-7	bis(2-ethylhexyl)Phthalate	39	330	1900	
56-55-3	Benzo(a)anthracene	24	330	2000	
218-01-9	Chrysene	28	330	2000	
117-84-0	Di-n-octylphthalate	19	330	1900	
205-99-2	Benzo(b)fluoranthene	24	330	2000	
207-08-9	Benzo(k)fluoranthene	36	330	2100	
50-32-8	Benzo(a)pyrene	26	330	2000	
193-39-5	Indeno(1,2,3-cd)pyrene	30	330	2100	
53-70-3	Dibenzo(a,h)anthracene	29	330	2100	
191-24-2	Benzo(g,h,i)perylene	33	330	2000	

(1) - Cannot be separated from Diphenylamine
ND = Not Detected
Q = Qualifier

FORM I SV-2

FORM 2
SOIL SEMIVOLATILE SURROGATE RECOVERY

Lab Name: COMPUCHEM Method: 8270C

Lab Code: LIBRTY Case No.: SAS No.: SDG No.: 17

Level: (low/med) LOW

	CLIENT SAMPLE NO.	S1 (2FP)#	S2 (PHL)#	S3 (NBZ)#	S4 (FBP)#	S5 (TBP)#	S6 (TPH)#	S7 #	S8 #	TOT OUT
01	SBLKJP	65	63	56	59	68	70			0
02	SLCSJP	38	39	33*	38	45	46			1
03	WMSOIL-06300	68	70	59	65	81	79			0
04										
05										
06										
07										
08										
09										
10										
11										
12										
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25										
26										
27										
28										

		QC LIMITS
S1 (2FP)	= 2-Fluorophenol	(35-110)
S2 (PHL)	= Phenol-d5	(38-110)
S3 (NBZ)	= Nitrobenzene-d5	(35-110)
S4 (FBP)	= 2-Fluorobiphenyl	(37-110)
S5 (TBP)	= 2,4,6-Tribromophenol	(22-139)
S6 (TPH)	= Terphenyl-d14	(43-114)

Column to be used to flag recovery values
* Values outside of contract required QC limits
D Surrogate diluted out

3D
SOIL SEMIVOLATILE LAB CONTROL SAMPLE

SLCSJP

Lab Name: COMPUCHEM Method: 8270C

Lab Code: LIBRTY Case No.: SAS No.: SDG No.: 17

Level:(low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Phenol	2667	1880	70	23-134
Bis(2-chloroethyl)ether	2667	1458	55	19-113
2-Chlorophenol	2667	1794	67	20-133
1,3-Dichlorobenzene	2667	1165	44	10-127
1,4-Dichlorobenzene	2667	1190	45	10-127
1,2-Dichlorobenzene	2667	1269	48	11-127
2-Methylphenol	2667	1790	67	21-125
2,2'-oxybis(1-Chloropro	2667	1486	56	18-114
4-Methylphenol	5333	3663	69	10-100
N-Nitroso-di-N-prop.(1)	2667	1548	58	12-140
Hexachloroethane	2667	1153	43	10-131
Nitrobenzene	2667	1226	46	18-127
Isophorone	2667	1574	59	21-117
2-Nitrophenol	2667	1773	66	20-128
2,4-Dimethylphenol	2667	2034	76	10-133
Bis(2-chloroethoxy)meth	2667	1674	63	22-141
2,4-Dichlorophenol	2667	1915	72	20-137
1,2,4-Trichlorobenzene	2667	1432	54	15-131
Naphthalene	2667	1628	61	14-113
4-Chloroaniline	2667	1522	57	10-107
Hexachlorobutadiene	2667	1352	51	11-137
4-Chloro-3-methylphenol	2667	1980	74	19-137
2-Methylnaphthalene	2667	1699	64	16-146
Hexachlorocyclopentadie	2667	1627	61	10-150
2,4,6-Trichlorophenol	2667	2161	81	21-148
2,4,5-Trichlorophenol	2667	2074	78	20-147
2-Chloronaphthalene	2667	1731	65	15-138
2-Nitroaniline	2667	2115	79	20-132

(1) N-Nitroso-di-n-propylamine
Column to be used to flag recovery and RPD values with an asterisk
* Values outside of QC limits

COMMENTS:

3D
SOIL SEMIVOLATILE LAB CONTROL SAMPLE

SLCSJP

Lab Name: COMPUCHEM Method: 8270C

Lab Code: LIBRTY Case No.: SAS No.: SDG No.: 17

Level: (low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Dimethylphthalate	2667	1670	63	20-129
2,6-Dinitrotoluene	2667	1751	66	18-131
Acenaphthylene	2667	1882	70	18-121
3-Nitroaniline	2667	1694	64	11-105
Acenaphthene	2667	1944	73	18-112
2,4-Dinitrophenol	2667	2191	82	10-150
4-Nitrophenol	2667	2126	80	10-145
2,4-Dinitrotoluene	2667	1878	70	18-128
Dibenzofuran	2667	1899	71	24-131
Diethylphthalate	2667	1791	67	18-128
4-Chlorophenyl-phenylet	2667	1762	66	18-130
Fluorene	2667	1979	74	15-123
4-Nitroaniline	2667	1789	67	10-113
4,6-Dinitro-2-methylphe	2667	2000	75	10-150
N-Nitrosodiphenylamine	2667	1834	69	23-123
4-Bromophenyl-phenyleth	2667	1863	70	21-131
Hexachlorobenzene	2667	1865	70	15-148
Pentachlorophenol	2667	2578	97	10-150
Phenanthrene	2667	2077	78	18-123
Anthracene	2667	1980	74	19-120
Carbazole	2667	2159	81	24-140
Di-n-butylphthalate	2667	1906	71	20-131
Fluoranthene	2667	2084	78	16-127
Pyrene	2667	2035	76	12-123
Butylbenzylphthalate	2667	1930	72	20-119
3,3'-Dichlorobenzidine	2667	1302	49	10-129
bis(2-ethylhexyl)Phthal	2667	1933	72	18-125
Benzo(a)anthracene	2667	2034	76	17-117

(1) N-Nitroso-di-n-propylamine
Column to be used to flag recovery and RPD values with an asterisk
* Values outside of QC limits

COMMENTS: _____

3D
SOIL SEMIVOLATILE LAB CONTROL SAMPLE

SLCSJP

Lab Name: COMPUCHEM Method: 8270C

Lab Code: LIBRTY Case No.: SAS No.: SDG No.: 17

Level: (low/med) LOW

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Chrysene	2667	2036	76	19-121
Di-n-octylphthalate	2667	1857	70	13-135
Benzo(b)fluoranthene	2667	1965	74	10-126
Benzo(k)fluoranthene	2667	2106	79	12-129
Benzo(a)pyrene	2667	2048	77	15-120
Indeno(1,2,3-cd)pyrene	2667	2139	80	15-127
Dibenzo(a,h)anthracene	2667	2066	77	10-130
Benzo(g,h,i)perylene	2667	2037	76	13-125

(1) N-Nitroso-di-n-propylamine

Column to be used to flag recovery and RPD values with an asterisk
* Values outside of QC limits

Spike Recovery: 0 out of 64 outside limits

COMMENTS: _____

FORM 4
SEMIVOLATILE METHOD BLANK SUMMARY

CLIENT SAMPLE NO

SBLKJP

Lab Name: COMPUCHEM Method: 8270C

Lab Code: LIBRTY Case No.: SAS No.: SDG No.: 17

Lab File ID: WG25304-1A60 Lab Sample ID: WG25304-1

Instrument ID: 5972HP60 Date Extracted: 07/01/03

Matrix: (soil/water) SOIL Date Analyzed: 07/06/03

Level: (low/med) LOW Time Analyzed: 1704

THIS METHOD BLANK APPLIES TO THE FOLLOWING SAMPLES, MS and MSD:

	SAMPLE NO.	LAB SAMPLE ID	LAB FILE ID	DATE ANALYZED
01	SLCSJP	WG25304-2	WG25304-2A60	07/06/03
02	WMSOIL-06300	1701	1701A60	07/06/03
03				
04				
05				
06				
07				
08				
09				
10				
11				
12				
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COMMENTS:

FORM IV SV

1BCWC
SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: SBLKJP

Lab Project Number: ET03044
Method: 8270C
Date Collected: _____

Lab Sample ID: WG25304-1
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: _____
Lab File ID: WG25304-1A60
Analyst: 2319

% Moisture: _____ decanted: (Y/N) ___
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
108-95-2	Phenol	35	330	ND	U
111-44-4	Bis(2-chloroethyl)ether	30	330	ND	U
95-57-8	2-Chlorophenol	36	330	ND	U
541-73-1	1,3-Dichlorobenzene	34	330	ND	U
106-46-7	1,4-Dichlorobenzene	29	330	ND	U
95-50-1	1,2-Dichlorobenzene	33	330	ND	U
95-48-7	2-Methylphenol	29	330	ND	U
108-60-1	2,2'-oxybis(1-Chloropropane)	40	330	ND	U
106-44-5	4-Methylphenol	28	330	ND	U
621-64-7	N-Nitroso-di-N-propylamine	33	330	ND	U
67-72-1	Hexachloroethane	37	330	ND	U
98-95-3	Nitrobenzene	43	330	ND	U
78-59-1	Isophorone	30	330	ND	U
88-75-5	2-Nitrophenol	30	330	ND	U
105-67-9	2,4-Dimethylphenol	30	330	ND	U
111-91-1	Bis(2-chloroethoxy)methane	36	330	ND	U
120-83-2	2,4-Dichlorophenol	22	330	ND	U
120-82-1	1,2,4-Trichlorobenzene	42	330	ND	U
91-20-3	Naphthalene	35	330	ND	U
106-47-8	4-Chloroaniline	9.5	330	ND	U
87-68-3	Hexachlorobutadiene	33	330	ND	U
59-50-7	4-Chloro-3-methylphenol	31	330	ND	U
91-57-6	2-Methylnaphthalene	38	330	ND	U
77-47-4	Hexachlorocyclopentadiene	67	330	ND	U
88-06-2	2,4,6-Trichlorophenol	65	330	ND	U
95-95-4	2,4,5-Trichlorophenol	49	330	ND	U
91-58-7	2-Chloronaphthalene	33	330	ND	U
88-74-4	2-Nitroaniline	25	660	ND	U
131-11-3	Dimethylphthalate	21	330	ND	U
606-20-2	2,6-Dinitrotoluene	24	330	ND	U
208-96-8	Acenaphthylene	26	330	ND	U
99-09-2	3-Nitroaniline	25	660	ND	U
83-32-9	Acenaphthene	22	330	ND	U

ND = Not Detected
Q = Qualifier

FORM I SV-1

1BCWC
SEMIVOLATILE ORGANICS ANALYSIS DATA SHEET

Client Project ID:
Client SDG No: 17
Client Sample ID: SBLKJP

Lab Project Number: ET03044
Method: 8270C
Date Collected: _____

Lab Sample ID: WG25304-1
Sample wt/vol: 30.0 (g/mL) G
Level: (low/med) LOW

Date Received: _____
Lab File ID: WG25304-1A60
Analyst: 2319

% Moisture: _____ decanted: (Y/N) ___
Concentrated Extract Volume: 1000(uL)
Injection Volume: 1.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: WG25304-1

Date Extracted: 07/01/03
Date Analyzed: 07/06/03
Dilution Factor: 1.0

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
51-28-5	2,4-Dinitrophenol	160	1700	ND	U
100-02-7	4-Nitrophenol	51	660	ND	U
121-14-2	2,4-Dinitrotoluene	13	330	ND	U
132-64-9	Dibenzofuran	29	330	ND	U
84-66-2	Diethylphthalate	15	330	ND	U
7005-72-3	4-Chlorophenyl-phenylether	23	330	ND	U
86-73-7	Fluorene	17	330	ND	U
100-01-6	4-Nitroaniline	19	660	ND	U
534-52-1	4,6-Dinitro-2-methylphenol	34	660	ND	U
86-30-6	N-Nitrosodiphenylamine (1)	31	330	ND	U
101-55-3	4-Bromophenyl-phenylether	27	330	ND	U
118-74-1	Hexachlorobenzene	29	330	ND	U
87-86-5	Pentachlorophenol	46	660	ND	U
85-01-8	Phenanthrene	24	330	ND	U
120-12-7	Anthracene	25	330	ND	U
86-74-8	Carbazole	25	330	ND	U
84-74-2	Di-n-butylphthalate	20	330	ND	U
206-44-0	Fluoranthene	16	330	ND	U
129-00-0	Pyrene	27	330	ND	U
85-68-7	Butylbenzylphthalate	21	330	ND	U
91-94-1	3,3'-Dichlorobenzidine	16	660	ND	U
117-81-7	bis(2-ethylhexyl)Phthalate	39	330	ND	U
56-55-3	Benzo(a)anthracene	24	330	ND	U
218-01-9	Chrysene	28	330	ND	U
117-84-0	Di-n-octylphthalate	19	330	ND	U
205-99-2	Benzo(b)fluoranthene	24	330	ND	U
207-08-9	Benzo(k)fluoranthene	36	330	ND	U
50-32-8	Benzo(a)pyrene	26	330	ND	U
193-39-5	Indeno(1,2,3-cd)pyrene	30	330	ND	U
53-70-3	Dibenzo(a,h)anthracene	29	330	ND	U
191-24-2	Benzo(g,h,i)perylene	33	330	ND	U

(1) - Cannot be separated from Diphenylamine
ND = Not Detected
Q = Qualifier

FORM I SV-2

EXTRACTION WORKSHEET

Low Level Soil S-V Method 3550B for 8270C

CompuChem

176

ASSIGNED TO: Kelly / Jim

EMP ID NUMBER: 253512543

DATE EXTRACTED/POSTED: 7/1/03

7-1-9

17

	SAMPLE NUMBER	QC SAMPLE TYPE	SAMPLE WEIGHT (g)	FINAL VOLUME (mL)	COMMENTS
1	M1822-19		30.0	1.0	Add 1.0 mL of validation spike to LCS and SSs unless otherwise noted
2	L-20		30.0	1.0	
3	WL-25304-3	SS	30.0	1.0	GPC (3640A) PERFORMED Y / N
4	L-4	SS	30.0	1.0	USE M-20 for SS
5	1701		30.0	1.0	
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23	WL-25304-1	BLK	30.0	1.0	
24	L-2	LCS	30.0	1.0	

		S-VOL	Acid	B/N	Sulfur
SURROGATE	NO.	393			
	AMT.	0.5 ml			
	LOT	5464	N/A		
SPIKE	NO.		3012	2021	VALID.
	AMT.		1.0 ml	1.0ml	1.0 ml
	LOT				254647

FINAL VOLUME VERIFIED: KP

SUPERVISOR REVIEWED: [signature]

SURROGATE & SPIKE ADDED BY: KP, 7-1-03 (Initials Date)

Witness KR, 7-1-03 (Initials Date)

Analyst initials. Extracted KP/JDS/JS KD KP/JDS/JS N2 KP/JDS/JS Bottle up KP/JDS/JS

Manufacturer and lot number of reagents/solvents used CH_2Cl_2: CH732 Na_2SO_4: 47405 Acetone: CE167

Rev. 2/28/00:mlj

EPA Region 5 Records Ctr.
349912

CompuChem

a division of Liberty Analytical Corp.

08-Jul-03

LISA SMITH
EARTH TECH
4135 TECHNOLOGY PARKWAY

Sheboygan, WI 53083

Subject:
Report of Data-Project: ET03044

Attn.: LISA SMITH

Enclosed are the results of analytical work performed in accordance with the referenced account number.

This report covers sample(s) appearing on the attached listing.

Thank you for selecting CompuChem for your sample analysis. If you should have questions or require additional analytical services, please contact your representative at 1-800-833-5097.

Sincerely,

CompuChem
A Division of Liberty Analytical

Attachment

TOTAL NUMBER
OF PAGES 8

501 Madison Avenue ■ Cary, N.C. 27513 ■ Tel: 919-379-4100 ■ Fax: 919-379-4050

CompuChem, a division of Liberty Analytical

Hsn	Client ID	Wordorder	Matrix	Account	Project	Report
1701	WMSOIL-063003-00	17	S	CHRYSLER	ET03044	7/7/2003
1702	TRIP BLANK	17	W	CHRYSLER	ET03044	7/7/2003

CompuChem

a division of Liberty Analytical Corporation
501 Madison Avenue
Cary, N.C. 27513
Tel: 919/379-4100 Fax: 919/379-4050

SDG NARRATIVE
SDG # 17
PROTOCOL: SW-846 8082

SAMPLE IDENTIFICATIONS: WMSOIL-063003-002

The soil sample listed above was scheduled for the requested analysis of the PCB fraction. SW-846, 3rd Edition, Update 3, Sonication extraction (Method 3550B), and Method 8082 were used to prepare and analyze the sample, with the exceptions and/or additions requested by the client. The percent moisture value of the soil sample was 12. All pertinent Quality Assurance notices are included in the narrative section and all pertinent Laboratory notices for SDG #17 are included in the sample data sections.

PCBs

Extraction and analysis holding time requirements were met for the sample.

Aroclor-1260 and Aroclor-1254 were confirmed by dual column analysis above the Quantitation Limit (QL) in the sample.

Manual quantitations were performed on one or more of the process files associated with this SDG, including sample WMSOIL-063003-002. The reasons have been coded with explanations provided in the notice included in the narrative section of the SDG.

All QC criteria were met for all initial and continuing calibration standards associated to this SDG.

All of the surrogates met recovery and retention time criteria in the analyses of these samples.

The associated method blank met all quality control criteria.

The associated Laboratory Control Sample (LCS) prepared and analyzed along with these samples met all recovery criteria.

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data submitted on diskette has been authorized by the Laboratory Manager or his/her designee, as verified by the following signature.

Kerry S. Hinshaw

Kerry S. Hinshaw
Senior Scientist
July 7, 2003

CompuChem

a division of Liberty Analytical Corporation
501 Madison Avenue
Cary, N.C. 27513
Tel: 919/379-4100 Fax: 919/379-4050

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Kerry S. Hinshaw

Kerry S. Hinshaw
Senior Scientist
July 7, 2003

1D
PESTICIDE ORGANICS ANALYSIS DATA SHEET

Client Project ID: ET03044
Client SDG No: 17
Client Sample ID: WMSOIL-063003-002
Lab Sample ID: 1701
Sample wt/vol: 30.0 (g/mL) G
% Moisture: 12 decanted: (Y/N) N
Concentrated Extract Volume: 5000(uL)
Injection Volume: 2.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: 70

Lab Project Number:
Method: 8082
Date Collected: 06/30/03
Date Received: 07/01/03
Lab File ID:
Extraction:(SepF/Cont/Sonc) SONC
Date Analyzed: 07/02/03
Dilution Factor: 1.0

Sulfur Cleanup: (Y/N) Y

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
12674-11-2	Aroclor-1016	6.0	38	ND	U
11104-28-2	Aroclor-1221	5.6	48	ND	U
11141-16-5	Aroclor-1232	2.2	38	ND	U
53469-21-9	Aroclor-1242	4.0	24	ND	U
12672-29-6	Aroclor-1248	3.6	24	ND	U
11097-69-1	Aroclor-1254	3.6	24	150	
11096-82-5	Aroclor-1260	3.7	38	29	P

ND = Not Detected
Q = Qualifier

FORM I PEST

1D
PESTICIDE ORGANICS ANALYSIS DATA SHEET

Client Project ID: ET03044
Client SDG No: 17
Client Sample ID: PBLKJR
Lab Sample ID: 70
Sample wt/vol: 30.0 (g/mL) G
% Moisture: _____ decanted: (Y/N) ___
Extraction: (SepF/Cont/Sonc) SONC
Concentrated Extract Volume: 5000(uL)
Injection Volume: 2.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: 70

Lab Project Number:
Method: 8082
Date Collected: _____
Date Received: _____
Lab File ID: _____

Date Extracted:07/01/03
Date Analyzed: 07/02/03
Dilution Factor: 1.0

Sulfur Cleanup: (Y/N) Y

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
12674-11-2	Aroclor-1016	6.0	33	ND	U
11104-28-2	Aroclor-1221	5.6	42	ND	U
11141-16-5	Aroclor-1232	2.2	33	ND	U
53469-21-9	Aroclor-1242	4.0	21	ND	U
12672-29-6	Aroclor-1248	3.6	21	ND	U
11097-69-1	Aroclor-1254	3.6	21	ND	U
11096-82-5	Aroclor-1260	3.7	33	ND	U

ND = Not Detected
Q = Qualifier

FORM I PEST

1D
PESTICIDE ORGANICS ANALYSIS DATA SHEET

Client Project ID: ET03044
Client SDG No: 17
Client Sample ID: PLCSJR
Lab Sample ID: 71
Sample wt/vol: 30.0 (g/mL) G
% Moisture: _____ decanted: (Y/N) ___
Extraction: (SepF/Cont/Sonc) SONC
Concentrated Extract Volume: 5000(uL)
Injection Volume: 2.0(uL)
GPC Cleanup: (Y/N) N
Method Blank: 70

Lab Project Number:
Method: 8082
Date Collected: _____
Date Received: _____
Lab File ID: _____

Date Extracted: 07/01/03
Date Analyzed: 07/02/03
Dilution Factor: 1.0

Sulfur Cleanup: (Y/N) Y

CAS NO.	COMPOUND	MDL	Reporting Limit UG/KG	Results UG/KG	Q
12674-11-2	Aroclor-1016	6.0	33	180	
11104-28-2	Aroclor-1221	5.6	42	ND	U
11141-16-5	Aroclor-1232	2.2	33	ND	U
53469-21-9	Aroclor-1242	4.0	21	ND	U
12672-29-6	Aroclor-1248	3.6	21	ND	U
11097-69-1	Aroclor-1254	3.6	21	ND	U
11096-82-5	Aroclor-1260	3.7	33	170	

ND = Not Detected
Q = Qualifier

FORM I PEST

2F
SOIL PESTICIDE SURROGATE RECOVERY

Lab Name: COMPUCHEM Contract: 8082

Lab Code: COMPU Case No.: SAS No.: SDG No.: 17

GC Column(1): CLPEST ID: 0.53 (mm) GC Column(2): CLPEST2 ID: 0.53 (mm)

	EPA SAMPLE NO.	TCX 1 %REC #	TCX 2 %REC #	DCB 1 %REC #	DCB 2 %REC #	OTHER (1)	OTHER (2)	TOT OUT
01	PBLKJR	94	88	110	90			0
02	PLCSJR	100	92	110	96			0
03	WMSOIL-06300	91	94	87	71			0
04								
05								
06								
07								
08								
09								
10								
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30								

ADVISORY
QC LIMITS

S1 (TCX) = Tetrachloro-m-xylene (43-135)
S2 (DCB) = Decachlorobiphenyl (43-144)

Column to be used to flag recovery values
* Values outside of QC limits
D Surrogate diluted out

3F
SOIL PESTICIDE LAB CONTROL SAMPLE

Lab Name: COMPUCHEM Contract: 8082

Lab Code: COMPU Case No.: SAS No.: SDG No.: 17

COMPOUND	SPIKE ADDED (ug/Kg	LCS CONCENTRATION (ug/Kg)	LCS % REC #	QC. LIMITS REC.
Aroclor-1016	170	180	110	50-145
Aroclor-1260	170	170	100	37-137

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

Spike Recovery: 0 out of 2 outside limits

COMMENTS: _____

FORM III PEST-2

4C
PESTICIDE METHOD BLANK SUMMARY

EPA SAMPLE NO.

PBLKJR

Lab Name: COMPUCHEM Contract: 8082

Lab Code: COMPU Case No.: SAS No.: SDG No.: 17

Lab Sample ID: 70 Lab File ID: 062W70

Matrix (soil/water) SOIL Extraction:(SepF/Cont/Sonc) SONC

Sulfur Cleanup (Y/N) N Date Extracted: 07/01/03

Date Analyzed (1): 07/02/03 Date Analyzed (2): 07/02/03

Time Analyzed (1): 1054 Time Analyzed (2): 1054

Instrument ID (1): VARIAN43 Instrument ID (2): VARIAN46

GC Column (1): CLPEST ID: 0.53(mm) GC Column (2): CLPEST2 ID: 0.53(mm)

THIS METHOD BLANK APPLIES TO THE FOLLOWING SAMPLES, MS and MSD:

	EPA SAMPLE NO.	LAB SAMPLE ID	DATE ANALYZED 1	DATE ANALYZED 2
01	PLCSJR	71	07/02/03	07/02/03
02	WMSOIL-06300	1701	07/02/03	07/02/03
03				
04				
05				
06				
07				
08				
09				
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25				
26				

COMMENTS:

FORM IV PEST

EPA Region 5 Records Ctr.
349913

MEMORANDUM

TO: Kenneth Vogel

FROM: Kenneth Taylor

DATE: May 28, 1998

SUBJECT: Calibration of the Ground-Water Flow Model

DRAFT

The following updates the preliminary ground-water flow model development since my last memorandum dated April 27,1998.

MODEL CALIBRATION

The process of adjusting the model input values to produce the best match between simulated and observed water levels is called calibration. The first step involved in calibrating the model is to ensure that the direction of ground-water flow can be accurately simulated. This was done by comparing simulated ground water-level elevation to measured water level data collected between December 1997 and March 1998.

Once the calibration targets were selected, steady-state model simulations were run. Data from these simulations were compared to water-level measurements from the monitor wells onsite. Initial simulations were run without including withdrawals for the Miami River and the Madd River well fields or withdrawals for nearby production wells. Results from these simulations indicate that direction of ground-water flow through the property was from east to west toward the Miami River. This result is in direct contrast to the field measurements which show ground water moving for west to east or from west to northeast. Because of this discrepancy, withdrawals from the Miami River and Madd River well fields as well as the withdrawal from regional production wells were added to the model. Pumping rates for these wells were derived from the regional ground water flow model developed by CH2M Hill (1988).

The subsequent model runs shows that the direction of ground-water flow matched the field data reasonably well.

Additional adjustments were made to the vertical and horizontal hydraulic conductivity to adjust vertical gradient between the upper and lower aquifers as well as adjust the horizontal gradient between MWB-1 and MWB-4 and between MWB-5 and MWB-3. This portion of the calibration proved to be difficult because of the flat ground water gradient across the site and the alternation of pumping between production well 1 and production well 2. However, after several simulations, the simulated data matched the data reasonably well.

Calibration Results

Table 1 is a list of simulated modeled heads versus measured heads. As shown in the table, all of the simulated water elevations are within x foot of the measured water elevation. The variance is well within acceptable limits and shows that the model matches the magnitude and direction of the study area relatively well.

The simulated water-table elevation map is shown on figure x. The figure shows that a ground water low point is located to the northeast of the Dayton Thermal Products Plants. The sink is the result of a discontinuation of the confining till unit in this area. Areas in which the confining unit does not exist are a primary means of recharge for the lower aquifer, thus, these areas cannot support ground-water elevations as high as areas where the confining unit exist. These areas are also the primary reason the water-table flow direction was reversed when pumping at the two well fields was added to the model. In addition, the figure shows that the Dayton Thermal Products Plants are located near a ground-water flow divide which matches recent monitor well data which suggested the presence of this divide, giving added confidence to the model calibration.

Because of the uncertainties inherent in model calibration, before a model can truly be considered calibrated, it needs to be verified against a known transient condition, i.e., a pumping test. The verification should be preformed to ensure the model will accurately represent the system under a different set of hydrologic stress and, thus instill more confidence in future

predictive simulations. At present, however, the model is adequately calibrated to provide the information required from it at this time.

PARTICLE TRACKING ANALYSIS

ModPath, a particle-tracking post-processor to MODFLOW, was utilized to evaluate potential contaminate migration paths. It should be noted that ModPath is not a solute transport model and does not account for dispersions and chemical reactions. Therefore, ModPath can provide only rough estimates of travel time of halogenated solvents in ground water, but good estimates of migration paths.

Two simulations were run to evaluate the direction contamination may have traveled over time. The goal was to determine optimal placement of monitor wells that could help quantify the potential offsite contaminate migration. It should be noted, that DAM is a preliminary model which requires additional calibration (primarily transient) if it is to be used as a final remedial design tool or upgraded to simulate solute transport. Each simulation was run for 2 years, the period representing 1992 through 1994, with production well 2 (the shallow well) operating the first quarter of each year and production well 1 (the deep well) operating the remainder of each year. The pumping rate selected for each well when in operation was 263 mgd.

The above referenced two-year time frame was selected because it represented a period in which water-level elevation, stream discharge data, and precipitation data are known for the study area. In addition, the two-year time frame shows a fluctuation in water-table elevations typical of the area. Withdrawal rates for the nearby production wells and the two well fields have been estimated based on published ground-water flow model data, precipitation and river stage. Figure x is a plot which shows a hydrograph of simulated water-level Gem City monitor well MW-1 versus measured water-level data. The agreement between the simulated data and field data indicate that the DAM can be reasonably used to simulate the two year period in question, or future simulated stresses if withdrawal rates are known.

The first simulation utilized the preliminary model to determine the potential migration paths of the ground water with elevated levels of PCE and TCA, near monitor wells MWA-1

and MWA-2. For this simulation, particles were placed in model nodes near and surrounding monitor wells MWA-1 and MWA-2 (area of highest PCE and TCA ground-water contamination). Figure x shows the flow paths of the particles which represent PCE and TCA for a period of two years. The figure shows that the particles move in a east or north east direction. The areas intersected by the flow paths lines highlight areas for placement of additional monitor wells. It is interesting to note that the areas intersected by the flow paths only encompass areas which have low or non-detectable concentrations of PCE and TCA. This is another confirmation that the model is simulating the aquifer reasonably well.

The purpose of the second simulation is to determine the migration paths of the ground water with elevated concentration of TCE near monitor well MWA-4. Particles were placed in the model node near and surrounding MWA-4, the well with the highest concentration of TCE. The flow paths of these particles are shown on figure x. The figure shows that the particles moved in an east-northeasterly direction and only intercepts monitor wells with detectable levels of TCE. As with the first simulation, the areas intersected by the flow path lines are ideal locations for the placement of additional monitor wells.

SENSITIVITY ANALYSIS

The calibration phase of the ground water development refined aquifer parameters such that modeled results adequately simulate field data. This does not, however, ensure that all aquifer and stream parameters defined by the model precisely equal existing aquifer characteristics or their lateral distribution. At present, a sensitivity analysis is being completed for the DAM. This sensitivity analysis is being conducted to interpret which aquifer parameters have a lower confidence level and what impact variations in these parameters will have on the model results.

The initial stages of the sensitivity analysis have shown that the magnitude and orientation of the water table on the property is very sensitive to changes in withdrawal rates at the Miami River and Madd River well field's nearby production wells. Because of this, additional withdrawal data should be obtained to further define the model. Other parameters

which will be examined for the sensitivity analysis are horizontal hydraulic conductivity, vertical hydraulic conductivity and recharge for flux boundaries.

LIMITATIONS AND RECOMMENDATIONS

It should be noted that the DAM is a preliminary model and is designed to be used for placement of monitor wells only. Before the model can be used for remedial design or solute transport, additional data are needed to further calibrate the model. A 3-day pumping test of the current shallow production well, with measurements of monitor wells onsite, would provide water-level and drawdown (calibration) data to fine tune the model. A detailed pumping test plan will be developed at a later date; however, it should be performed early in any design process.

In addition to the pumping test, additional withdrawal data for the two well fields and nearby production wells as well as, a monitor well located off the site to the east of MWA-5, is needed to further develop the ground-water flow model. The pumping data is necessary because the orientation of the water table is very sensitive to changes in pumping rate. The monitor well is needed to further define the shape of the water table at and adjacent to the site.

S:\WIP\TAYLOR\DAYTON2.WPD

LEGGETTE, BRASHEARS & GRAHAM, INC.

PROFESSIONAL GROUND-WATER AND ENVIRONMENTAL ENGINEERING SERVICES

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FAX COVER SHEET

DATE: 4/9/98

PLEASE DELIVER TO: Kenneth Vogel

COMPANY: LB

FAX NUMBER: ( )

FROM: Kenneth Tayla

TOTAL NUMBER OF PAGES (INCLUDING THIS PAGE): 2

SUBJECT: model

COMMENTS:

If you do not receive all the correct number of pages, please call: Melinda Beck at (203) 452-3100 Ext. 268, as soon as possible.

A hard copy of this transmission will follow by: ___ regular mail or ___ overnight service.
Please join us in observing this FAX courtesy.

MEMORANDUM

TO: Kenneth Vogel

FROM: Kenneth Taylor

DATE: April 9, 1998

SUBJECT: Data Requested for Development of The Ground-Water Flow Model

Per, your request, I have put together a short list of data that will be needed during model development as wells as model calibration. The following list is in no significant order.

1. All available well logs for onsite and offsite monitor and/or production wells. I am especially interest in screen settings for near by wells.

2. The pumping history of the onsite production wells as well offsite recovery wells. The history should include average pumping rate data as wells as periods of significant Inactivity.

3. Flood profile maps for the Mad River and Miami River published by the Federal Emergency Management Agency for city of Dayton. These data will provide streambed elevation information.

4. MODFLOW data files for the existing Dayton regional groundwater model.

5. Publications which show recharge to unconfined aquifer.

6. Estimated river stage and discharge when ground water elevation in the aquifer was measured.

Received: from connix by lbghq.com (UUPC/extended 1.12p/sm3) with UUCP
for lbghq!ktaylor; Thu, 26 Mar 1998 11:36:07 +0500
Received: from vortex.mm.com (uucp@vortex.mm.com [204.73.34.1])
by beast.connix.com (8.8.7/8.8.7) with ESMTP id LAA19179
for <ktaylor@lbghq.com>; Thu, 26 Mar 1998 11:24:58 -0500 (EST)
Received: (from uucp@localhost)
by vortex.mm.com (8.8.8/8.8.8) with UUCP id KAA12649
for ktaylor@lbghq.com; Thu, 26 Mar 1998 10:24:51 -0600 (CST)
Received: from Connect2 Message Router by lbgmn.lbgmn.com
via Connect2-UUCP v1.10.13; Thu, 26 Mar 98 10:18:29 -0600
Message-Id: <52661A3501FE430F@lbgmn.com>
Date: Thu, 26 Mar 98 10:02:33 -0600
Sender: Rebecca Carlson <rcarls@lbgmn.com>
From: Rebecca Carlson <rcarls@lbgmn.com>
Organization: LEGGETTE, BRASHEARS & GRAHAM, INC.
To: ktaylor@lbghq.com
Subject: Dayton
X-SMF-Conversation-ID: 52661A3502FE430F
X-Mailer: Connect2-UUCP v1.10.13
X-PMFLAGS: 33554560 0

Ken,
You should receive 2 Fed Ex packages today containing reports, USGS Studies, Maps for the Dayton area , etc.. A list of the available references for this project that we have located to date is attached to this e-mail. Please let me know if there is any other information you need. I'll be sending along information from the ERIIS investigation soon. I apologize in advance for the zerox copies of the maps, they were out of print.

FYI: One of the Miami Well field employees told me that they had installed 165 new monitoring wells and were tracking several plumes that have been impacting supply wells (this is in addition to the CH2MHill 1988 study). They should have a formal report by this summer. It would be interesting to see what is flowing under the Miami River.

Rebecca Carlson
****

Rebecca A. Carlson
Environmental Engineer I
Leggette, Brashears & Graham, Inc.
1210 West County Rd. E
St. Paul, MN 55112
(612) 490-1405
(612) 490-1006 (fax)

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Uuencoded File Attachment: DATASUM.WPD

LEGGETTE, BRASHEARS & GRAHAM, INC.

PROFESSIONAL GROUND-WATER
AND ENVIRONMENTAL ENGINEERING SERVICES

1210 WEST COUNTY ROAD E
SAINT PAUL, MN 55112

(612) 490-1405 FAX (612) 490-1006

DATE: 3/6/98

PAGES:
(Includes cover page) 4

TO: Ken Taylor **FAX #:** Trumbull

COMPANY: LBG

TO: **FAX #:**

COMPANY:

TO: **FAX #:**

COMPANY:

FROM: Dave Strand per Vogel

RE: 3 chrg4/dayton
Site map
GW Flow Nov 97 map
GW Flow Jan 98 map

Please contact Kathleen Weinrich (612) 490-1405 if transmission is incomplete or can not be read.

fax TRANSMITTAL

MAR-06-98 FRI 14:56 LEGGETTE BRASHEARS FAX NO. 6124901006 P.01

TO: KEN TAYLOR
RE: DAYTON THERMAL PRODUCTS PLANT
CATALOGUE/SUMMARY OF EXISTING REFERENCES AND INFORMATION

REPORTS COMPLETED BY OTHER CONSULTANTS/ USEFUL INFORMATION COMPILED:

- Site Investigations by **QSource Engineering, Inc.**, (1993) for Gem City Chemicals, Inc. Facility.
  1. Hydraulic conductivity of the shallow aquifer is approximately 200 ft/day with a transmissivity reported to be approximately 15,000 to 40,000 ft^2/day.
  2. Pumping test for Gem City Chemicals on Feb 21, 1990 the recovery well was pumped at 340 gpm and the water level at a piezometer installed 3.5 feet away from the pumping well was monitored. Drawdown was .57ft after 450 minutes of pumping. Transmissivity determined from this test was 52,900 ft^2/day or 395 gpd/ft , and hydraulic conductivity was reported to be .226 cm/s (755 ft/day). Storage coefficient was reported to be .001.
  3. Gem City Chemical Pumping Rates for RW-1: " The pumping system operated without interruption during April, May, and June 1997. The pumping rate, which is recorded daily by Gem City Chemicals, Inc. personnel was 300 gpm. As of June 30, 1997, the totally volume of water pumped from the recovery well is 1,177.2 million gallons.
- Quarterly Progress Report for April, May, June 1997 by **Parsons Engineering Science, Inc**. For Gem City Chemicals.
- Recon Investigation by **Mathes & Associates**, (1991) for Dayton Thermal Products Plant (DTPP) property.
- Environmental Site Assessment (1992) **Burlington Environmental.** DTPP
- Site Investigations for **Clean Tech**, (1993, 1994, 1995 Volumes I-III)) for DTPP.
  DTPP slug testing: December 15 and 16, 1994. Encountered extreme permeability at the well (which well?). This was minimally effective in determining aquifer characteristics.
- Solid Phase Bioremediation Technologies of Petroleum Contaminated Soils, (1995) **Clean Tech.** DTPP
- **CH2M Hill, Inc.** (1972, 1984) Miami Well Field and Surrounding Areas
- **CH2M Hill, Inc.** (1986) Miami Well Field Study
  CH_2M Hill determined aquifer parameters for the development of the Miami South Well Field. The analysis assumed a 50 foot thick saturated zone in the upper aquifer and variable thickness for till and lower aquifer.

Upper Aquifer	
Hydraulic Conductivity	.003 ft/sec (260 ft/day, 2021 GPD/ft^2)
Storativity	.2 ft/ft
Till Layers	
Hydraulic Conductivity	.44 x 10^{-6} ft/sec (.04 ft/day, .3 GPD/ft^2)
Storativity	0 ft/ft
Lower Aquifer	
Hydraulic Conductivity	.001 ft/sec (87 ft/day, 710 GPD/ft^2)
Storativity	. 00001 ft/ft

- **CH2M Hill, Inc.** (1988) Miami South Source Investigation.
  This report identified 7 VOC plumes in vicinity of Miami South Well Field. Recently, 165 additional monitoring wells were installed by the ODOR, Division of Waters to delineate other plumes and establish their points of origin and potential impact on the Miami South Well Field. A formal report will be issued during Summer 1999 listing their findings.
- **Battelle Columbus Division** (1987). Aquifer Tests CW-9, CW-18, and SWR-1, Slug Test Analysis, and Recovery Analyses of City Well #11, and Industrial Well #3. Prepared for Sherwin-Williams.
- **Woolpert Consultants**, Dayton, Ohio, 1977, Ortho-topographic photographos of the Rhorers Island area,

Dayton , Ohio.

GOVERNMENT PUBLICATIONS:

- Norris, S. E., and Spieker, A.M., 1959, Vertical Leakage Through Till as a Source of Recharge to a Buried -Valley Aquifer at Dayton, Ohio: State of Ohio, Department of Natural Resources, Division of Water Tech Report No. 2, 16 p.
- Norris and Spieker (1966) Ground-water Resources of the Dayton Area, Ohio. USGS Water Supply Paper 1808.
- Spieker, Andrew Ground-Water Hydrogeology and Geology of the Lower Great Miami River Valley Ohio.
- Schmidt, James J., 1986 Groundwater Resources map of Montgomery County. Ohio Dept. Of Natural Resources.
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- Stream flow data from two gauging stations and precipitation data from two stations in the Dayton area.
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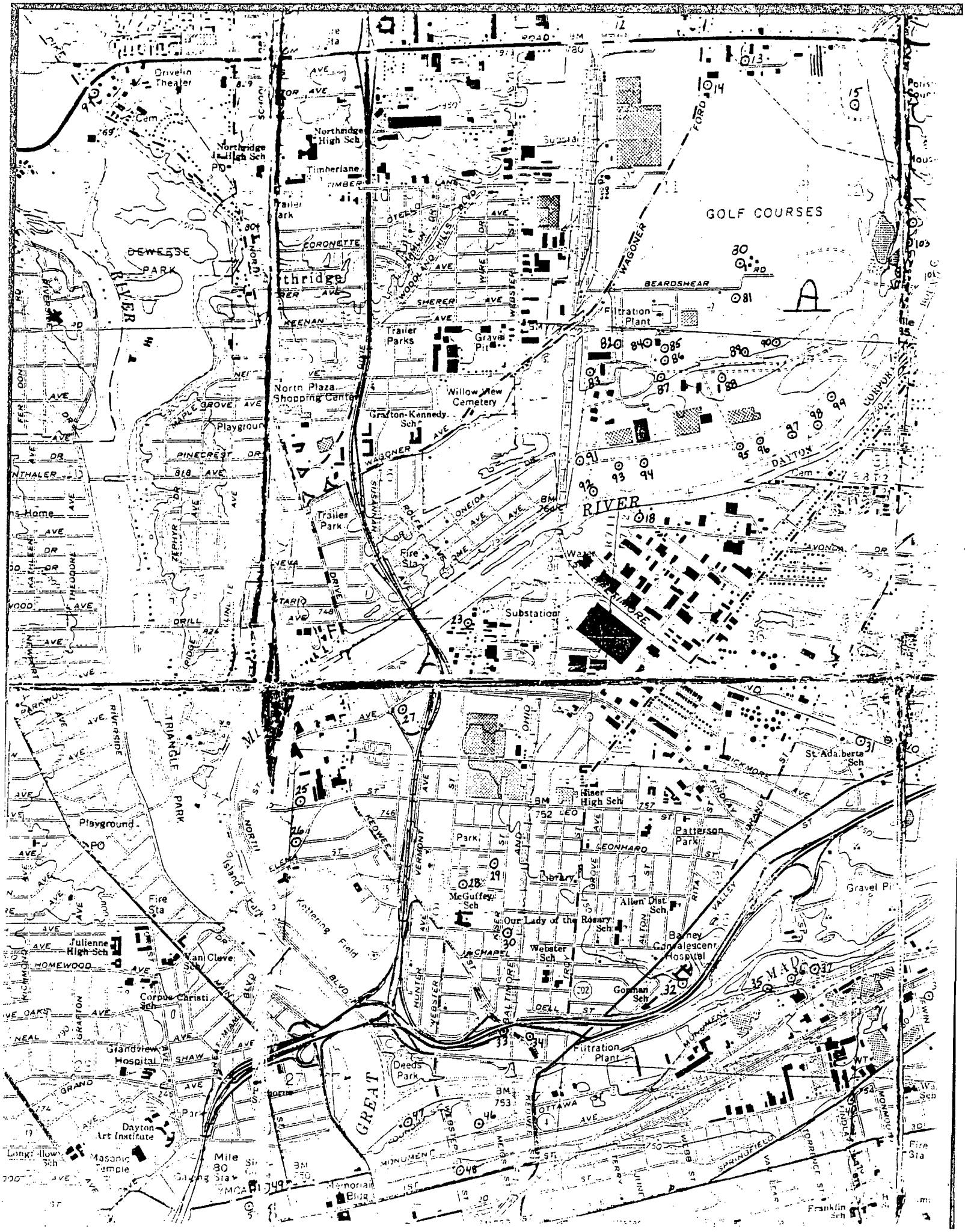
EPA Region 5 Records Ctr.
349914

Dayton - Groundwater / Modeling



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Filtration Plant
Trailer Parks
Gravel Pit
North Plaza Shopping Center
Willow View Cemetery
Grafton-Kennedy Sch
Playground
PINECREST DR
Trailer Park
Fire Sta
Substation
DAYTON
RIVER
TRIANGLE PARK
Playground
Fire Sta
Julienne High Sch
Van Cleve Sch
Corpus Christi Sch
Grandview Hospital
Dayton Art Institute
Masonic Temple
Mile 80
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Patterson Park
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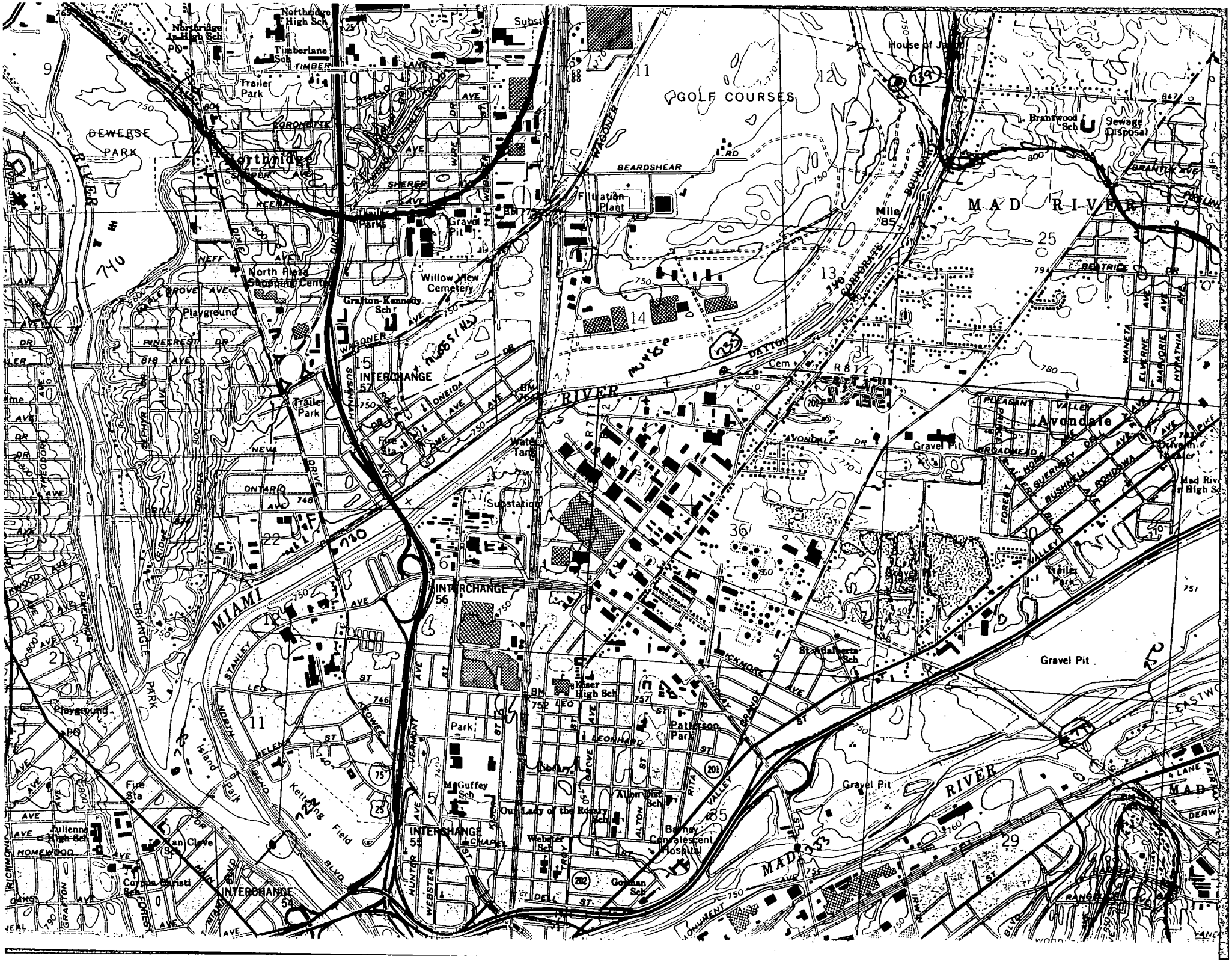

GOLF COURSES
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DEWEESE PARK
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Trailer Park
Filtration Plant
Gravel Pit
North Plaza Shopping Center
Willow View Cemetery
Grafton-Kennedy Sch
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Substation
Water Tank
Avondale
Gravel Pit
Mad River Jr High Sch
Kiser High Sch
Patterson Park
McGuffey Sch
Our Lady of the Rosary Sch
Barney Convalescent Hospital
Gorman Sch
Webster Sch
Alton Dist Sch
St Adalberta Sch
Brantwood Sch
Sewage Disposal
House of Jacob
Mile 85
Kettering Field
Island Park
Julienne High Sch
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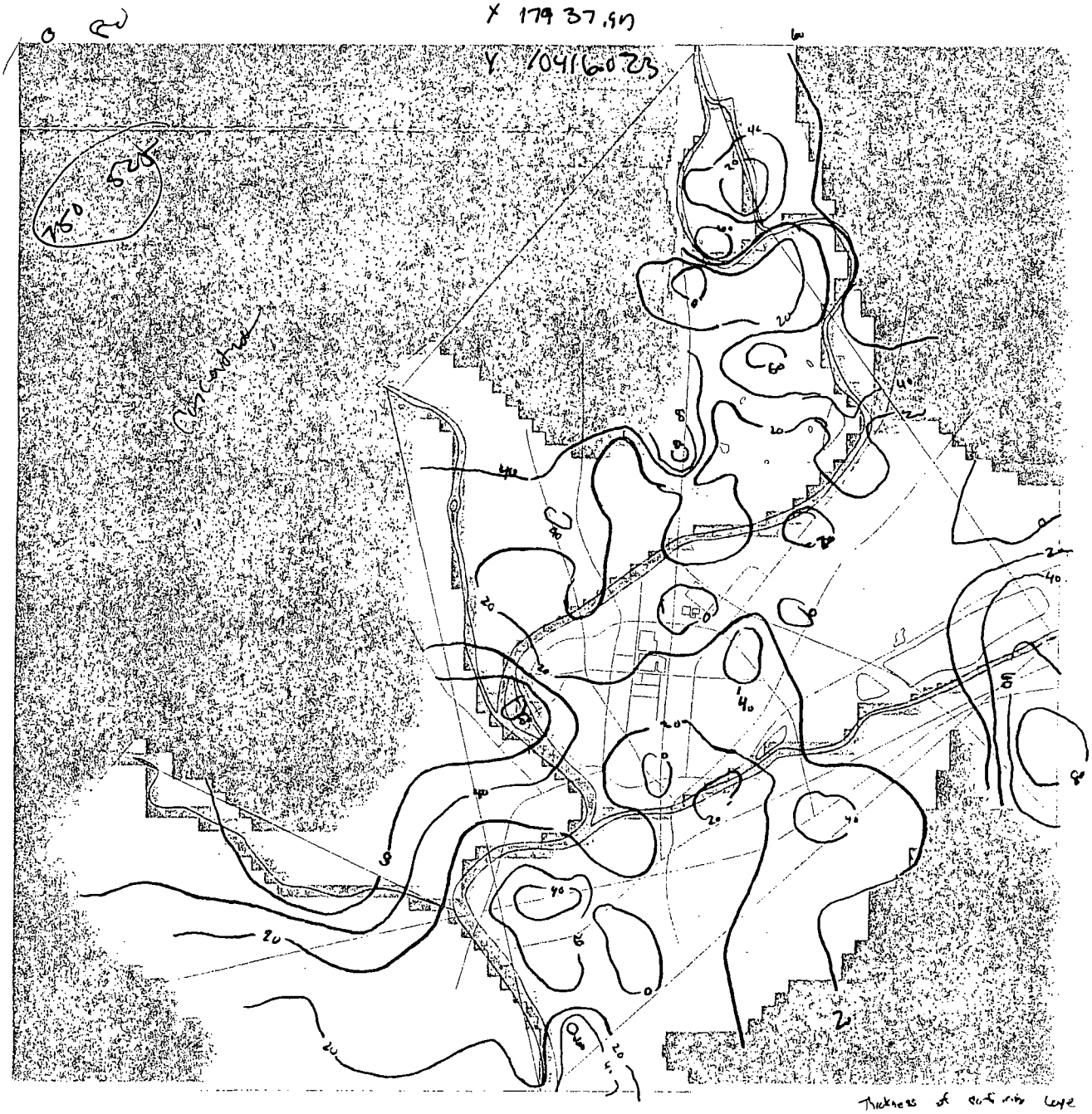
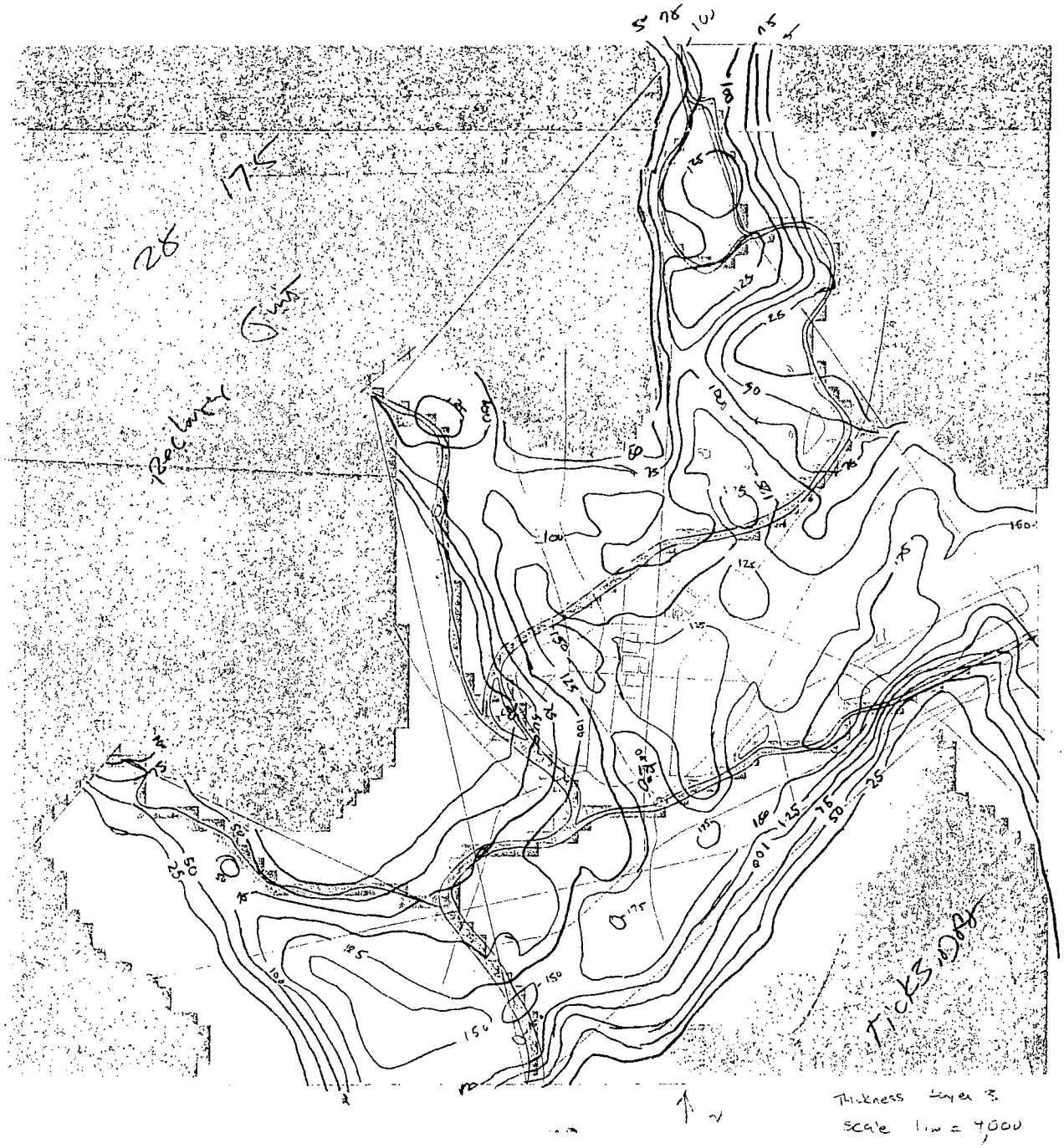


Thickness of [illegible] Layer

Scale 1in = 4000

BED ROCK ELEVATION
SCALE = 1/2 = 4,000 feet


Thickness Layer 3
Scale 1in = 4000

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(203) 452-3100 • FAX (203) 452-3111
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JOB STREAM - Segment map
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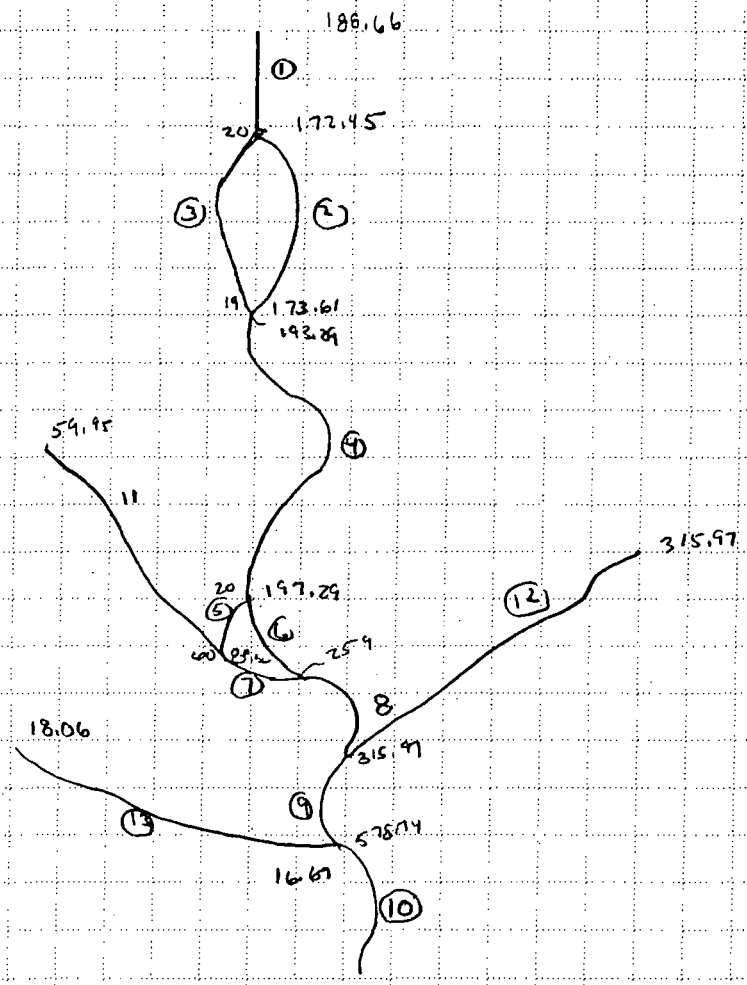

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PROFESSIONAL GROUND-WATER AND
ENVIRONMENTAL ENGINEERING SERVICES

126 MONROE TURNPIKE
TRUMBULL, CT 06611
203-452-3100
FAX 203-452-3111

FAX COVER SHEET

DATE: 4/27/98

PLEASE DELIVER TO:

NAME	COMPANY	FAX NUMBER
Kenneth Vogel		( )
		( )
		( )
		( )

FROM: Kenneth Taylor

TOTAL NUMBER OF PAGES (INCLUDING THIS PAGE): 7

SUBJECT: Dayton model

COMMENTS:

If you do not receive the correct number of pages, please call Melinda Beck or Stacy Didio at (203) 452-3100

Hard copy being send? _____No _____Regular Mail _____Overnight Service

MEMORANDUM

TO: Kenneth Vogel

FROM: Kenneth Taylor

DATE: April 27, 1998

SUBJECT: Development of The Ground-Water Flow Model

The following is a overview of the development of the Dayton Ground-Water Flow Model (DAM). The three-dimensional ground-water flow model was developed using the "Modular Three-Dimensional Finite-Difference Ground-Water Flow Model" (MODFLOW). MODFLOW was chosen because the model allows incorporation of leakage to and from surface water, impacts of model boundaries and variation in aquifer thickness. A Detailed review of the model's present structure is presented below.

MODEL DEVELOPMENT

Model Layers

DAM was developed as a three layer model. Layer 1 was modeled as a water-table aquifer or unconfined layer and is representative of the glacial and alluvium deposits. Layer 2 and Layer 3 were modeled as confined layers. The confined model designation was utilized for layers 2 and 3 because it is unlikely that the of the potentiometric water level will drop below the top elevation of the layer even under extreme drought conditions. Layer 2 is representative of the discontinuous till layer which acts as a confining layer through out the majority of the model and layer 3 is representative of the glacial and/or alluvium deposits.

The thickness and of the confining unit, layer 2 and lower aquifer (layer 3) were obtained for published data (CH2M Hill, 1988). The bottom of the model is the stratified-drift/bedrock contact. Bedrock elevation data were also obtained for published data (Spieker,1966).

Finite-difference Grid Design

Finite-difference models, such as MODFLOW, require that the area under investigation be divided into discrete subareas (nodes). The finite-difference grid developed for the Dayton Thermal Products Plant consists of 188 rows and 222 columns. The model utilizes a variable-spaced grid. Near the plant the spacing is finest, with node area dimensions of 20 feet by 20 feet. The distant areas have node area dimensions of up to 500 feet by 500 feet.

Boundary Conditions

A portion of, the eastern, western, northern and southern physical limits of the area modeled correspond to the bedrock-valley-fill contact. The portion of the boundary which corresponds to the contact were simulated as no simulated as no-flow boundaries. The portions of the boundaries not along the bedrock-valley-fill contact, mostly adjacent to rivers, were simulated as flux boundaries. A flux boundary was desirable along these boundaries to simulate ground-water entering and/or leaving the model aquifers as underflow. Flux boundaries, were simulated utilizing a general head boundaries. A general head boundary consists of a source of water outside the modeled area which supplies water (or takes water) to a cell in the modeled area at a rate proportional to the head difference between the source and the cell.

Please note, all of the model boundaries are sufficiently distance from a the plant so that they do not affect the model predictions.

The top boundary of the aquifer is the water-table and is treated in the model as a free-surface recharge boundary. Recharge from precipitation is applied uniformly to each cell in layer 1 of the model grid. The water table can move up and down depending upon the balance of stresses in the model area.

As stated above the bottom boundary is the to of bedrock. This contact was simulated as a no-flow boundary in the DAM. Some water, no doubt, flows upward or downward from the bedrock to the confined aquifer; however, the amount should be small enough such that no significant error is introduced by assuming the no-flow boundary.

MODEL INPUT

Recharge

Recharge rates are based on based on average annual recharge for the lower Miami River basin. Recharge currently being used in the model is 7.6 inches per year (CH2M Hill, 1988).

Stream Input

For the DAM, the stream package STR1 was used to simulate The Miami River, Mad River, Wolf Creek and Stillwater River. STR1 allows flow values to be entered, tracking of flow throughout the stream and allows stream cells to go dry during periods of the simulation. Stream conductance (c) values, in feet per day, for each node containing a stream. Conductance values for the stream bed are a function of the stream bed area, vertical hydraulic conductivity and stream bed thickness.

In calculating the stream bed conductance, the initial stream bed permeability for each of the simulated rivers was assumed to be 10 ft/d (feet per day) (Dumouchelle, 1993). This value will be change during calibration. The stream bed thickness was assumed to be 1 foot. Stream channel geometry and stream stage were obtained from topographic maps and stream gage data. Stream bed elevation were obtained for flood insurance studies published by the Federal Emergency Management Agency for the City of Dayton.

As stated above, STR1 requires that the initial discharge be input in the first cell of each stream and tributary. Initial discharges were obtained for USGS stream gage data.

Hydraulic Conductivity and Storage Coefficient

Assignment of the initial hydraulic conductivity and transmissivity values in the model was based upon published results (CH2M Hill, 1988 and Qsource, 1993) and evaluation of driller logs. Hydraulic conductivity in layer 1 (glacial deposits) currently vary from 99 ft/d to 700 ft/d. The conductivity values in layer 2 as of now range for 0.04 ft/d in areas where the confining unit exist and vary from 100 ft/d to 500 ft/d were the confining unit does not exist. The hydraulic conductivity in layer 1 is 90 ft/d.

As with the hydraulic conductivity, the assignment of the initial storage coefficient values were base upon published results (CH2M Hill, 1988). The Storage coefficient in layers 1, 2 and 3 were 0.2, 0.0001 and 0.0001, respectively.

Vertical Leakage

To simulate the vertical leakage between model layers 1 and 2 and model layers 2 and 3, a leakage term (VCONT) was calculated for each grid location. The VCONT is a function of the vertical hydraulic conductivity between the adjacent model layers and the thickness of the model layer. The DAM, vertical hydraulic conductivity was initially assumed to be 1:10 of the horizontal conductivity in each model node in layers 1, 2 and 3.

MODEL CALIBRATION AND VERIFICATION

The process of adjusting the model input values to produce the best match between simulated and observed water levels is called calibration . At present the DAM is being calibrate for a steady-state average condition. In the future the model will be calibrated to a pumping test.

DAM Steady-State Calibration

The first step necessary to calibrate the model is to ensure that the direction of ground-water flow was accurately simulated. This is being done by comparing simulated ground water-level elevations to measured water level data. In addition, simulated water-level elevations are being compared to measured water-level elevation for shallow and deep wells -

located within the study area. Attached is a plot of the current simulated water-table map in the study area. The map also shows the residual head difference between the model and the measured water level data. As you can see the magnitude of the water-level is close, but the direction of flow is currently incorrect this will be adjusted through further calibration.

CONCLUSION

Once the calibration process has been competed, PATH3D, a particle tracking program, will be used to evaluate potential contaminate migration paths. In addition, a sensitivity analysis will be completed to determine how varying aquifer parameters will impact plum migration.

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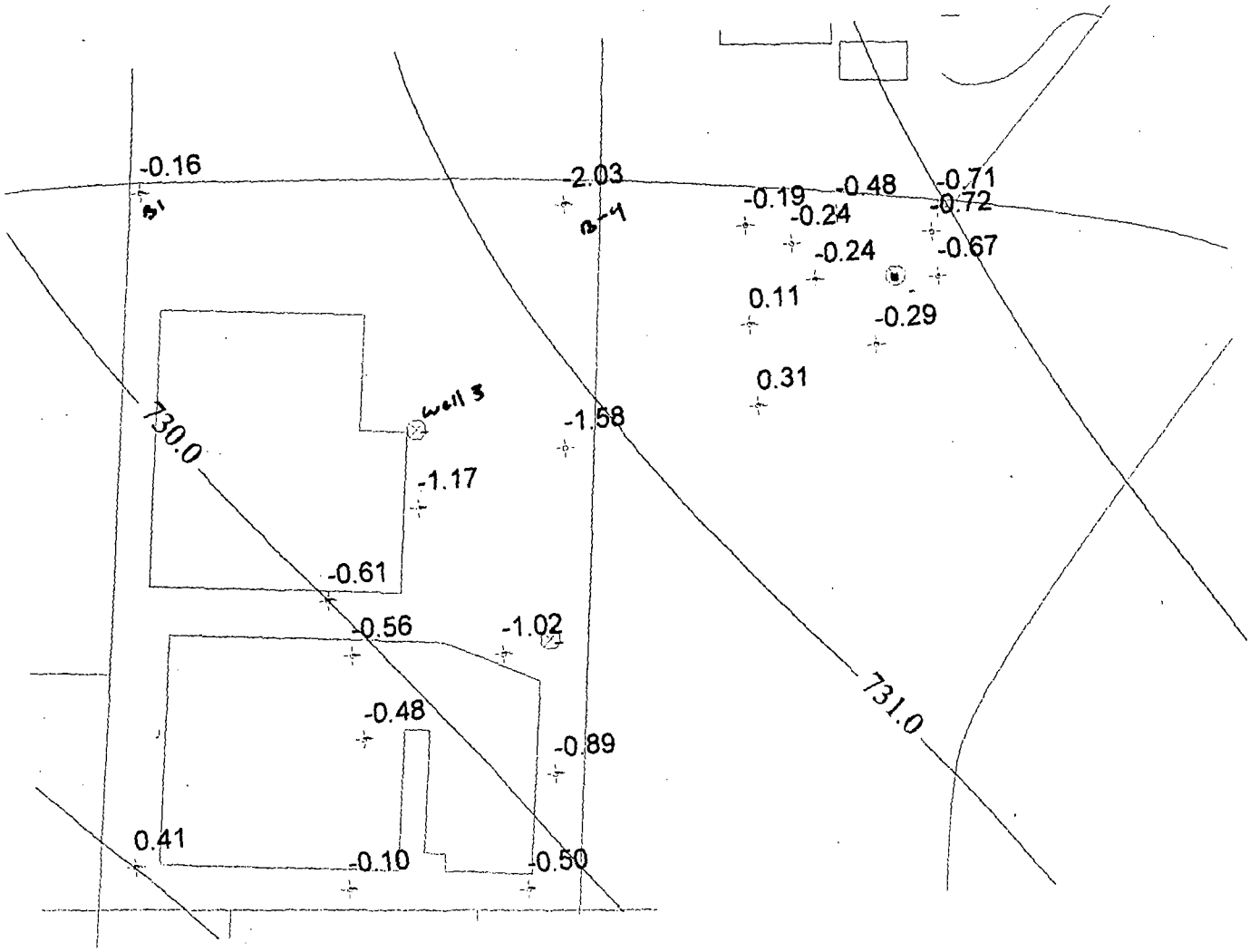
placement of monitoring wells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B1
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-0.10
-0.50

RECORD OF TELEPHONE CONVERSATION

DATE: 3/17 NAME: RJH ☐ INCOMING ☐ OUTGOING

NAME OF PERSON CALLING/CALLED: Jim Shoemaker

COMPANY/TITLE:

PHONE NUMBER:

CLIENT: TIME IN: TIME OUT:

DETAILS OF CONVERSATION:

CH2M Hill -

N. well Field

Model - assumptions →

Recharge lagoons -

Files → to Rebecca →

Avg 30-35 mgd → Miami - North
50-55 mgd Mad River - East

Mad River well Field -
west end of WHP - 3-4 wells on
west end of #47, #48, #49

Miami → Summer and when Mad is
70 mgd from Miami -
20-25 mgd from Miami -

Abe Martin - well field Supervisor (937) 333-2344

P:\DVS\TELEPHON.XLS

LEGGETTE, BRASHEARS & GRAHAM, INC.

Dayton, City of - Shoemaker, Jim
Jim Shoemaker, Environmental Scientist City of Dayton, Dept. of Water Division of Environmental Management 320 West Monument Avenue Dayton, OH 45402 (937) 333-3727 (937) 334-1417 cell (937) 333-6770 FAX

Called Jim on 3/5/02 8:20

8:40

He called back and left me a message

LEGGETTE, BRASHEARS & GRAHAM, INC.
Professional Ground-Water Consultants

JOB _____
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Dayton Model

Ken Vogel - model

Grid
Boundaries

Critical -

Look at data - Municipal wells - influence from these
Include - Cooling unit into model

Geology -

cooling unit has a hole

River -

Pumping Test Near River
River Bed - Package - River Package - We used Stream Package
10 stream reaches - Easier to calculate

Segment → The layers

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SCALE _____

Recharge → Varied precipitation Data seasonally

Pumping Wells → Locate wells across property
* How much are they pumping
* where are they located

Sensitivity Analysis → Pumping Rates in confined aquifer had the most impact on any head

Steady State Avg. Condition — Using Avg. Needs

Flow Map

① Avg. - all parameters

② Avg - all parameters → Fluctuate pumping rates

UISTAS → PURCHASE it!

City Pumping Rates — GET THESE!

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FactSheet Extension

Ohio State University Extension

Food, Agricultural and Biological Engineering

590 Woody Hayes Dr., Columbus, Ohio 43210

Water Resources of Montgomery County

AEX-480.57-98

Herbert M. Lane
Extension Agent
Agriculture and Natural Resources
Montgomery County

N'Deye-Marie N'Jie
Graduate Associate
Environmental Science
Food, Agric. and Biol. Engineering

Larry C. Brown
Associate Professor
Extension Agricultural Engineer
Food, Agric. and Biol. Engineering

Water is a resource often taken for granted. In recent years, water availability and quality have become important public concerns in Montgomery County. The county's population of 572,137 is predominantly urban, and 100 percent of the households rely on ground water for their water supply. This fact sheet provides a brief overview of Montgomery County's water resources, and is intended to help increase public awareness and understanding about this vital resource. By understanding where water is obtained and how it is used in the county, residents can gain a better appreciation for their water supply. Water resources terminology used in this publication is included in *Surface and Ground Water Terminology*, Fact Sheet AEX 460, which provides a listing of generally accepted water resource definitions. Ohio State University Extension publications are available through all Ohio county Extension offices.

Precipitation

An average of approximately 39 inches of precipitation falls on Montgomery County annually. Figure 1 illustrates the average monthly precipitation for the county for the period 1961 to 1990. Based on this 30-year record, the average precipitation is 3.3 inches per month, with January (2.3 inches) typically being the driest month, and May (4.2 inches) the wettest. However, there can be extreme variations in some years and in certain months within a year. Such seasonal and yearly extremes may have serious consequences and are not always apparent from the long-term precipitation information.

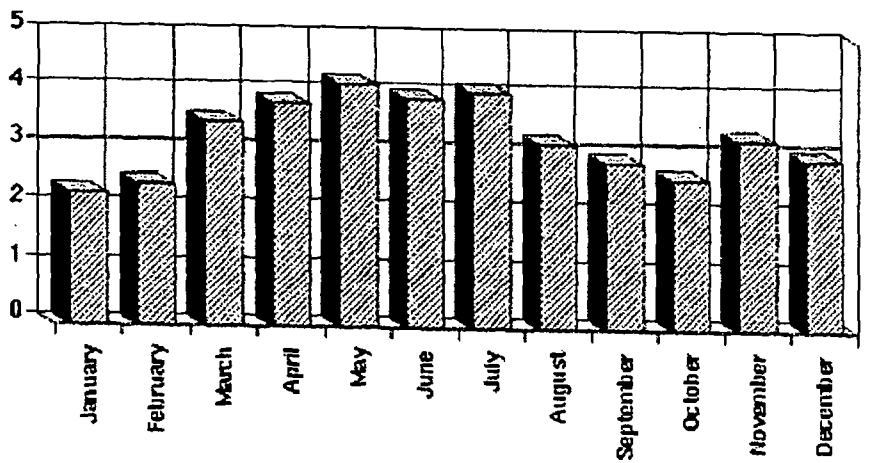

Figure 1. Average monthly precipitation (in inches) in Montgomery County, Ohio (1961-1990); data collected at Dayton.

Surface-Water Resources

Approximately 90 percent of the county lies in the Great Miami River basin, which flows south to the Ohio River. A narrow strip along the

southern half of the eastern county line lies in the Little Miami River basin, which also drains to the Ohio. A generalized surface-water map of Montgomery County is given in Figure 2.

Montgomery County
28.7.98 - KW

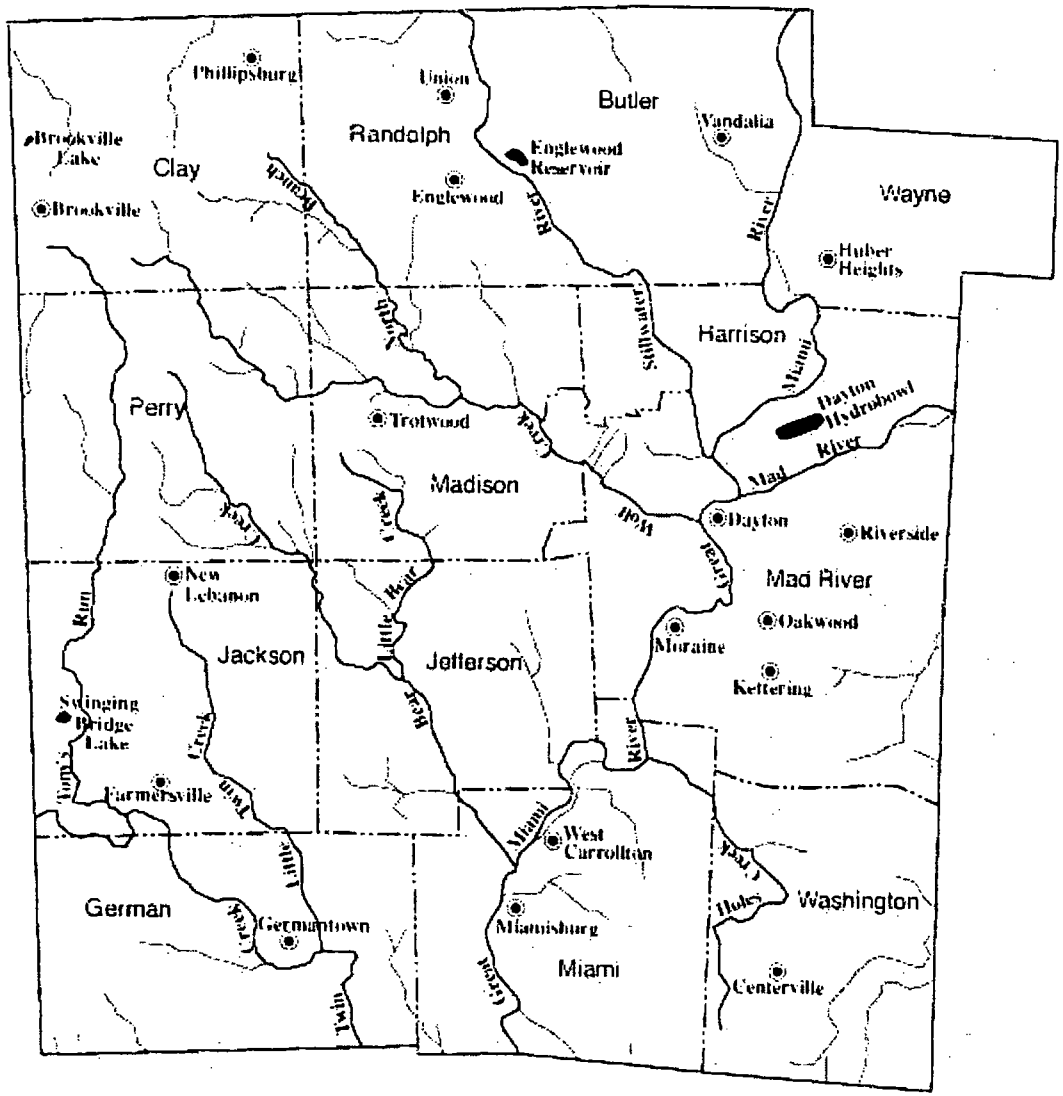

Figure 2. Surface-water resources in Montgomery County, Ohio (adapted

from ODNR Division of Water river basin maps; illustration prepared by K. A. Weber).

Surface water quantity and quality are affected by the soil type, geology, the topography of adjacent land, and the way people use the land. Changes in land use, such as residential development and agricultural production, may increase the amount of sediment and other pollutants entering a body of water. The soils and terrain also influence the amount of runoff because of infiltration, percolation, and water holding characteristics. With some soils, rainfall is more likely to run off, while other soils allow water to infiltrate more readily.

The county contains approximately 297,000 land acres, of which 40 percent is farmland. Forty-three soil types have been identified in the county and vary in drainage quality from very poorly-drained to well-drained. A large portion of the soils are moderately well-drained.

The county water acreage consists of about 612 acres of lakes of five or more acres, the largest being 170-acre Eastwood Lake. Smaller ponds number more than 100. The county contains approximately 255 linear miles of major streams and rivers (estimated from river basin maps, Ohio Department of Natural Resources [ODNR] Division of Water). In addition, 16.5 miles of county-maintained ditches and numerous miles of privately-maintained ditches are used for land drainage.

Ground-Water Resources

Montgomery County's primary ground-water source is the Great Miami Buried Valley aquifer, consisting of sand and gravel glacial outwash deposits. The aquifers below the Great Miami and Mad River Valleys can produce well yields of 2,500 gallons per minute (gpm) or more, and those under Twin, Little Twin, Wolf, and Bear Creeks as well as the Stillwater River, may yield over 500 gpm. Upland aquifers of clay till over non-water-bearing shaly limestone bedrock underlie as much of the county as the high-yielding aquifers, producing extreme variations in local ground water yields. A 115-foot deep municipal well drilled into the buried valley aquifer produces 2,500 gpm, while a 180-foot deep well one mile away can only draw 2 gpm from the shaly limestone bedrock. Concentrations of 300 to 500 parts-per-million (ppm) of calcium carbonate are common, making the local ground water extremely "hard." Softening is recommended for water containing over 150 ppm of $CaCO_3$, and iron is also often found at levels sufficient to be a nuisance. An overview of the ground-water resources in the county is given in *Montgomery County Ground-Water Resources*, AEX-490.57.

The yield of a well will vary considerably depending on the age and depth of the well, well construction, the diameter of the casing, pump capacity and age, and more importantly, properties of the geologic formation. Specific information on ground-water availability and wells can be obtained by contacting the ODNR Division of Water.

Where Does the Water Go?

Based on long-term statewide weather records, Ohio receives an average of 38 inches of precipitation per year. These 38 inches move through a complex path called the hydrologic cycle. Of these 38 inches, about 10 inches (26 percent) become runoff, which moves immediately to surface-water bodies like streams and lakes. Two inches are retained at the ground surface and evaporate back into the atmosphere in a

relatively short period of time. Twenty-six of the 38 total inches enter the soil surface through infiltration. Twenty of these 26 inches go into soil storage and later are returned to the atmosphere by the combination of evaporation and transpiration (evapotranspiration). The remaining 6 inches of precipitation (16 percent of the total) have the potential to recharge the ground-water supply. Two of these 6 inches eventually move to springs, lakes, or streams as ground-water discharge. The remaining 4 inches either return to the atmosphere by evapotranspiration or are withdrawn to supply water needs. For further reading, refer to *Ohio's Hydrologic Cycle*, AEX 461.

Statewide averages applied to the county's average annual precipitation provide a rough estimate of how many inches will result in runoff and how many inches have the potential to reach aquifers. Based on statewide averages of runoff and ground-water recharge, Montgomery County's 39 inches of average annual precipitation result in the same 10 inches of runoff to streams and lakes, and about 6 inches with the potential to recharge aquifers annually. Values for particular locations will differ according to local conditions.

Water Use

Water use for each of Montgomery County's public water-supply systems is given in Table 1. For each water system, this table presents an estimate of the population served, water source, estimated daily usage, service connections, and treatment plant capacity. The county's largest public-water system is the Dayton system, which uses 91 wells for its supply. All of the other public-water systems also use ground water as their source.

Ground water is a major water source for rural households in Montgomery County. Approximately three percent of all households obtain their water from private wells. Based on an estimated usage of 75 gallons per person per day, 1.6 million gallons per day (gpd) from private wells are used. Additional private water uses include industry (6 million gpd), quarrying (1.9 million gpd), and livestock use (11 million gpd), mostly from ground-water supplies. The remaining 97 percent of households use public-water supplies with ground water as the source, as identified in Table 1.

Table 1. Water Use in Montgomery County, Ohio.[1]

Public Water System	Population Served	Primary Water Source	Service Connections	Water Usage (gpd)[2]	Treatment Plant Capacity (gpd)
Brookville	4,880	PG	1,797	445,000	-
Cains MHP	70	G	62	15,500	130,000
Catalpa Grove MHP	74	G	34	10,200	27,000
Brookville Lake Estates	220	G	133	19,000	388,000
Dayton-Miami Plant	184,000	G	24,000	29,990,000	96,000,000
Dayton, Ottawa Plant	236,000	G	41,000	40,180,000	96,000,000

Englewood	12,500	G	3,452	1,140,000	2,200,000
Farmersville	932	G	383	73,800	432,000
Germantown	4,916	G	1,903	392,000	1,728,000
Miamisburg	17,900	G	6,373	2,096,000	4,300,000
Montgomery Co. System 1	150,000	PG	48,391	18,659,000	-
Montgomery Co. System 2	109,000	PG	31,336	11,916,000	-
New Lebanon	4,320	G	1,550	473,000	1,010,000
Oakwood	9,500	G	3,650	1,315,000	4,500,000
Huber Heights Plant 1	29,250	G	10,074	3,146,000	4,460,000
Huber Heights Plant 2	9,750	G	4,649	1,321,000	1,440,000
Phillipsburg	644	G	260	65,000	172,000
Pineview Estates MHP	400	G	204	30,000	360,000
Trotwood	8,816	PG	2,740	760,000	-
Union	5,800	G	1,800	468,000	576,000
Vandalia	15,000	PG	4,465	1,860,000	15,000,000
Voyager Village MHP	300	G	149	30,000	82,000
West Carrollton	12,000	G	3,250	1,286,000	3,600,000
Jefferson TWP	2,500	G	1,327	243,000	540,000
Shady Acres MHP	40	G	20	2,200	-

PG = purchase groundwater from Dayton and/or Montgomery County
1 Estimates from Ohio EPA using adjusted 1995-1997 data; information is based on data available at time of publication.
2 gpd = gallons per day.
3 Includes mobile home parks, nursing homes, and homeowners associations.

Some water users in Ohio must register their withdrawals with the ODNR Division of Water. Through the Water Withdrawal Facility Registration Program, owners of facilities capable of withdrawing 100,000 gpd (70 gpm) or more must register those facilities. Information collected through this program includes withdrawal capacity, ground- or surface-water sources, location and type of water use, and location of discharge points. The program is for registration only, and not for allocation or permission. Registered withdrawers file annual reports of their water use. This information helps planners at ODNR to determine the availability of water for projected needs and to better manage and

protect Ohio's water resources. Documenting water use also provides official records for individual uses. For more information, contact the ODNR Division of Water.

Water Quality

Human activities and natural processes affect the quality of our water supplies. Throughout Ohio, human activities contribute to both point and nonpoint source pollution. Point source pollution is the introduction of impurities into water (ground water or surface water) from an identifiable, known location. Examples of point sources can include industrial plants, power plants, commercial businesses, and wastewater treatment facilities.

Nonpoint source pollution also involves the introduction of impurities into a surface-water body or an aquifer, except the route is usually non-direct and the sources are diffuse in nature. A major portion of the sediment and nutrients enter the state's water resources through nonpoint source pollution, affecting both ground and surface water. Examples include automobile emissions, runoff and drainage from agricultural fields, home lawns and gardens, residential development, construction, mining, and logging activities.

Natural processes such as precipitation also have an impact on surface water and, to a lesser extent, ground water. For example, rainfall that is acidic ("acid rain") may alter the quality of a stream, lake, or other water resource that receives the rainfall.

Ground Water

As water moves through the glacial outwash, deposits or the bedrock formations underlying Montgomery County, it dissolves the minerals contained in these formations and carries them in solution. Publication AEX 490.57 summarizes some of the county's natural ground-water quality aspects.

Human activities, such as agricultural production, domestic waste disposal, and lawn and turf care, may have some influence on the county's ground-water quality. In a 1987 study by Heidelberg College, 249 wells in the county were sampled for nitrate-nitrogen content, an indicator of water quality. Results showed that 167 wells (67 percent of total) contained nitrate-nitrogen concentrations in the range of 0 to 0.3 ppm. This range is assumed to represent natural background levels. Thirty-seven wells (15 percent) tested in the range of 0.3 to 3.0 ppm, values that may or may not indicate human influence. The 34 wells (14 percent) that tested in the range of 3.0 to 10 ppm, may indicate elevated concentrations resulting from human activities. Only 10 wells (4 percent) tested at over 10 ppm nitrate-nitrogen, which exceeds the safe drinking-water standard. The average nitrate-nitrogen concentration for the 249 wells tested was 1.8 ppm. The design, location, and condition of a well, combined with the characteristics of the soils and geologic formations in which the well is constructed, influence the potential for pollutants to enter the well. The Montgomery County Combined Health District provides bacteriological water sampling for local citizens. For more information contact the health district at 614-225-4362.

Surface Water

Runoff and sediment from residential development, construction sites, and agricultural lands may enter the county's streams and lakes. Also, runoff may carry other pollutants, such as lawn and agricultural chemicals (pesticides and fertilizers), oil and gas from spills, and industrial wastes.

Through the Ohio Nonpoint Source Assessment and Water Resources Inventory, the Ohio Environmental Protection Agency (Ohio EPA) has identified 13,000 stream miles in Ohio that have been affected by nonpoint source pollution. Based on the findings of the Assessment and Inventory, the Ohio Nonpoint Source Management Program has been implemented to help improve the quality of the state's waters.

Water quality monitoring indicates that all or parts of the following Montgomery County streams are impaired by nonpoint source (NPS) pollution: Stillwater River, Little Beaver Creek, Little Twin Creek, Wolf Creek, Great Miami River, and Mad River. These streams are impaired by one or more of the following NPS pollution categories: agriculture, storm sewers, on-site wastewater treatment, or habitat alteration. Other county streams are impaired by point source pollution (municipal and/or industrial wastewater). Point source impaired streams include the Great Miami River, Stillwater River, Wolf Creek, and Bear Creek. Montgomery County also contains streams that have good water quality and are attaining chemical and biological water quality standards. Monitoring has shown that all or parts of the following streams have good water quality: Twin Creek and Opossum Creek. For specific information about the streams listed in the Assessment and Inventory documents, and details about the Nonpoint Source Management Program for the county, contact the Ohio EPA Southwest District Office, 401 East Fifth St., Dayton, OH 45402; Phone: 419-285-6357. Information about nonpoint source pollution is also discussed in Nonpoint Source Pollution: Water Primer, AEX 465, available from your county Extension office.

It is important to note that as of June 1998 less than half of Ohio's streams have been evaluated by the Assessment. As water quality monitoring continues statewide, the list of Montgomery County affected streams and streams with good water quality will change. Residents have a major challenge to protect water resources from pollutants that could affect the quality of the water supply.

Summary

Water availability and quality are important public concerns. Water problems can be both costly and inconvenient. While the present availability of water is good for Montgomery County, water is a precious resource that must be conserved and protected. We must all work together to maintain an adequate supply of good quality water.

This fact sheet provides information about the water resources in Montgomery County. For more information concerning water resources and drinking-water quality in the county, contact the Montgomery County office of Ohio State University Extension (1001 S. Main St., Dayton, OH 45409). In addition, the following agencies may be able to provide information on other water resources topics for the county: Montgomery Soil and Water Conservation District; Montgomery County combined Health District; ODNR Division of Water (Fountain Square, Columbus, OH 43224); U.S. Geological Survey (USGS), Ohio District (975 W. Third Ave., Columbus, OH 43212); Ohio EPA (P.O. Box 1049, Columbus, OH 43216-1049); and Ohio Department of Health (ODH; P.O. Box 118, Columbus, OH 43226).

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| Ohioline | Search | Fact Sheets | Bulletins |

1. Late Tertiary Period

B. Interglacial Activity
1. Early Quaternary Period
2. Early Pleistocene Epoch
a. Damming of Teays River
b. Intermittent Lakes
c. New Flow Direction of Teays River
d. Teays River Deep Stage Drainage
e. Glacial Drift
1.) General Location
2.) General Stratrigraphy
3.) General Location Extent
4.) General Thicknesses

C. Post-Glacial Activity
1. Mid to Late Pleistocene Epoch
a. Glacial Regerssion / Melting
b. Outwash Deposits
c. Valley-Train Deposits
1.) General Location
2.) General Stratigraphy
3.) General Location and Extent
4.) General Thicknesses
2. Resulting Topography
a. Upland Walls
b. Buried Valley

V. Aquifers.....5
A. Buried Valley
1. General Stratigraphy
2. General Location and Extent
3. General Thicknesses
4. Confining Units / Flow Impedance
a. General Aquifer Property Values
b. General Yields

B. Bedrock
1. Carbonate / Shale
2. General Location and Extent
3. General Thicknesses
a. Ranges of Yield
b. Ranges of Conductivity Values

C. Other possible Sources
1. Carbonate vs. Shale
2. Glacial Till
a. Lodgement
b. Ablation

D. Recharge
1. Infiltration
2. Factors Affecting Recharge
a. Precipitation
b. Vegetation Cover
c. Streams / Induced Infiltration

d. Subsurface Flow
e. No-flow Zones

VI. Curent Groundwater Usages and Conclusions.....6
1. Groundwater Quality
2. Demands on Water Supply
3. Action Taken
4. Future Needs and Situation

WORKS CONSULTED

Introduction

According to Edward Deeds, many people living in the Miami Valley Region had coined this area the "Fortunate Valley", as it was a highly fertile and productive area within the state of Ohio (Morgan, 1951, Foreword). People originally flocked to the area during the nineteenth century because of its favorable climate, its profitable soil, its suitability to construction and development, and its proximity to the rivers.

Nestled in southwest Ohio, approximately fifty miles north of Cincinnati, lies the city of Dayton, the largest city within the Miami Valley Region. As the paper industry and other industries expanded within the city, and as agricultural boomed along the city outskirts, population began to rise, with Butler, Hamilton, Montgomery, and Warren Counties alone having a combined population of over 600,000 people by 1900. Word of this incredibly productive valley spread fast across the country, eventually bringing more people—both Americans and foreigners alike—to the area. With this population boom came many new businesses, some of which would eventually remain in the area for decades to come.

However, this new attraction was not free of troubles. The people of the Miami Valley Region have undergone events which many would consider grounds for never returning to the area. Numerous floods devastated the area on more than one occasion throughout the late nineteenth and early twentieth centuries, with the worst of them all occurring in 1913. The rivers that had until now provided the hydroelectric power crucial to the flourishing businesses had become the valley's worst enemy, wiping out property and taking many lives in the process. These events heightened the area's awareness of the river's capabilities, and caused many people and organizations to obtain a better understanding of the regional climate, hydrology, geology, and any other factors necessary for protecting the city and preventing further loss of life and property. It was during the aftermath of the flood of 1913 that the Miami Conservancy District (MCD) was established.

This report describes the hydrogeology of the Miami Valley Region, and more importantly, the Great Miami River Drainage Basin. This basin is the drainage basin for the Great Miami River, the largest river in the region, and the one responsible for the most damage during the flood of 1913. All information and data contained herein were obtained from existing sources, as no new studies or tests were performed for the purpose of this report.

For further information on the MCD, please visit the website at www.miamiconservancy.org, or consult Arthur Morgan's *The Miami Conservancy District* (1951).

Physical Setting

The Great Miami River, with its headwaters at Indian Lake in Logan County, Ohio, flows through seven southwestern Ohio counties until it joins the Ohio River below the City of Cincinnati. This winding river

extends for approximately 157 river miles, and ranges in width anywhere from 20 ft. to 400 ft. (Dames & Moore, 1971). Although the Great Miami River flows through only seven counties, there are sixteen counties--fifteen in southwestern Ohio and one in southeastern Indiana--either partially or fully located within the river's drainage basin. The Great Miami River Basin is bordered by the Little Miami River Basin and the Scioto River Basin on the east, the Maumee River Basin on the north, the Wabash River Basin on the west, and the Mill Creek Basin and the Ohio River on the south.

Although the Great Miami River is the largest stream within this basin, other streams and tributaries within the drainage network include Twin Creek, Fourmile Creek, Dicks Creek, Elk Creek, Sevenmile Creek, Indian Creek, Stillwater Creek, the Mad River, and the Whitewater River. Twelve of the sixteen counties in the Great Miami River Basin subsequently lie within the Miami Conservancy District's program area, where information and data are gathered regularly for reasons pursuant to the district's mission. The drainage area for the basin above the mouth of the Whitewater River is 4,000 sq. miles, 3,670 sq. miles above the City of Hamilton, and 2,600 sq. miles above the City of Dayton (Morgan, 1951, p. 1). At its widest point, the drainage basin stretches to around 70 miles and to around 120 miles at its longest point.

General topography of the Great Miami River Basin is flat to gently rolling. The Great Miami River is situated in a Pleistocene buried valley that follows the course of the river and reaches up to a width of two miles within the basin. The Great Miami River Valley and the adjoining upland areas are situated in the Till Plains Region of the Central Lowland physiographic province, with the southern edge of the valley defining the boundary with the northern portion of the Bluegrass Section of the Interior Low Plateau (Spieker, 1968, p. A3). The till plains range in altitude from around 900' to 1200' mean sea level (msl), where the valley floor and flood plains range in altitude from about 650' to 900' msl (Norris and Spieker, 1966, p. 11). Excluding all valleys, other glacial features such as kames and moraines account for the variations in topography throughout the Great Miami River Drainage Basin.

Bedrock Geology

Bedrock underlying the entire Great Miami River Drainage Basin consists of interbedded Ordovician-age shale and limestone, originally deposited in a shallow marine shelf environment. Deposition occurred on the rise of the gently sloping ridge along the Cincinnati Arch, the only significant structural feature within the Great Miami River Drainage Basin. This arch was a north-to-south trending structure extending from Cincinnati to Dayton, at which point it took a northwest route, eventually joining the Kankakee Arch in east-central Indiana (Casey, 1996). Bedrock within this region consequently dips slightly to the northeast. The Ordovician marine environment, deepening towards the east, was located between the north-south reach of the arch and the Appalachian uplift areas still farther to the east. Sediment from these eastern orogenic processes served as the source for the limestone, dolostone, and shale later deposited along the Cincinnati Arch (Center for Groundwater Management and ODNR, 1992, Report No. 17, p. 23).

These interbedded limestone and shale deposits are frequently listed as undifferentiated and undivided bedrock units. Lithologically, the various groups, formations, and members are very similar. However, many interpretations on splitting these units have been offered. Bedrock across the Great Miami River Drainage Basin is most often associated with the Richmond Group of the Upper Cincinnatian Series. This unit is comprised of soft, highly plastic shale, mixed with dense, fossiliferous limestone layers, which account for 25% - 50% of the whole unit (Norris and Spieker, 1966, p. 14). Average thickness of the Richmond Group across the basin ranges anywhere from 800 ft. to 980 ft. thick (Spieker, 1968, p. A7 and GeoTrans, 1985, p. 11). In other isolated locations, the underlying Mayesville Group limestone and shale, also of the Upper Cincinnatian Series, is listed as the regional bedrock along with the Richmond Group.

Above these Ordovician deposits lie the Silurian limestone and dolostone deposits. Silurian rocks are the youngest rocks found within the Great Miami River Drainage Basin, and they too are sometimes classified simply as undifferentiated deposits, depending on the amount of information available at that specific location. Rocks within the Lower Silurian Alexandrian Series and the Upper Silurian Niagran Series are commonly found across the basin. In more recent classifications, the Sub-Lockport and Lockport Groups have been listed as separate divisions under the Alexandrian and Niagran Series, respectively.

The number of formations observed depends on one's location within the basin. Sub-Lockport formations include the Brassfield Limestone, the Dayton Limestone, the Osgood Shale, and the Laurel Dolostone. These units are exposed very nicely in the area of the drainage divide between the Great Miami River and the Little Miami River, particularly in Greene County near Clifton Gorge. These different formations are also fairly continuous across the entire basin, with some of the southern counties, such as Hamilton County, showing lesser traces of as many Silurian deposits. For a more detailed description of these Sub-Lockport and Lockport Group formations, consult The Center for Groundwater Management (Wright State University) and ODNR's *Groundwater Pollution Potential of Greene County*, Report No. 30, published by ODNR in April, 1995.

Within the Great Miami River Basin, the Brassfield Limestone plays the greatest role in the Silurian geology. This light gray to brown, relatively pure limestone exhibits massive and irregular bedding, and can reach up to 30 ft. thick (GeoTrans, 1985, p. 11). At depths of only a few feet in places, this dense limestone is best studied in the northeastern portion of the Great Miami River Drainage Basin, particularly around Dayton and the communities to the north of the city. Many of the other Sub-Lockport formations are observed in outcrops and along roadcuts in other portions of Montgomery, Greene, and Clark Counties. These units are typically not as thick or as extensive as the Brassfield Limestone. In other northern sections of the basin, Lockport dolostone formations are also found, specifically around the Greenville, Piqua, and Versailles areas. In some specific locations in Clark County, outcroppings of the Upper Silurian-age, Cayugan Series Greenfield Dolostone Formation are observed. This formation, a microcrystalline to fine-grained, light brown dolostone, is the youngest formation exposed within the Great Miami River Basin (Center for Groundwater Management and ODNR, 1995, Report No. 38, p. 26).

The Brassfield Limestone, the oldest of the Silurian deposits, often occurs at shallow depths from the land surface along the walls of the Great Miami Valley and in the upland regions, and serves as a source of water for many domestic wells across the basin. Most of the Ordovician and Silurian deposits are best located on the upland areas within the basin, for in the valley bottoms, they are buried underneath a few hundred feet of glacial material. A stratigraphic column for the local geology of the Great Miami River Drainage Basin is included at the end of the report.

Glacial History

Well after the Early Paleozoic seas had finally regressed, and the limestone and shale had been deposited, the topography and hydrology of southwestern Ohio resembled nothing of current conditions. Even during the Late Tertiary Period, the Great Miami River did not yet exist, but rather a pre-glacial river, known as the Teays River, served as the main stream in this regional drainage network. Entering near Portsmouth, this river's course traversed a northwest route across Ohio, flowing through the northernmost portion of the current Great Miami Basin, across the remainder of the state, and into Indiana. Its headwaters were located in the Piedmont Plateau in Virginia, and its final destination was the Mississippi Embayment, on the western edge of Illinois (Norris and Spieker, 1966, p. 18). This river, resembling the present Ohio River, had numerous tributaries, all of which combined to create a terraced landscape. These terraces, noticeable even today, are often labeled as the valley floor to the ancient

Teays River.

With the close of the Tertiary and the beginning of the Quaternary Period came the first wave of glaciers that would eventually be the catalysts for the change in drainage and topography across the region. About one million years ago, in the early Pleistocene Epoch, glaciers began advancing from the Arctic, extending south across much of Ohio and the rest of the Midwest. Numerous major glacial events would advance and retreat over the next few hundred thousand years until the Holocene Epoch. In the state of Ohio, two majors events are given substantial consideration--the Illinoian (300,000 – 130,000 years ago), and the Wisconsinan (24,000 – 14,000 years ago) (Hansen, p.1). Any glacial activity before the Illinoian is simply classified as pre-Illinoian glaciation (>300,000 years ago). Speculation exists over the exact boundaries and lobes of the numerous glacial events, but the Illinoian and Wisconsinan events are known to have been responsible for the bulk of the current glacial formations throughout the Great Miami River Basin. In other parts of the Midwest, these dates may differ by a few thousand years, and the extent of the glaciers may have been much greater or much less than in Ohio alone. For example, the entire Wisconsinan event in North America lasted from 70,000 – 10,000 years ago (Hansen, p.1). It is uncertain if the pre-Illinoian events reached farther south than the City of Dayton, but the Teays River was first affected by these glaciers sometime well before the Illinoian advance.

The pre-Illinoian glaciers, as they advanced from the north, brought with them large amounts of drift, composed chiefly of fine-grained silt and clay, which in turn dammed the Teays River and many of its tributaries. Although the actual natural damming of the river occurred outside of the present Great Miami River Basin, the effects it later had on the basin topography and hydrology were great. As the Teays River began to dam up, large intermittent lakes formed around the areas of its tributaries. It would be some time before these lakes would be drained, and in the meantime, large silt and lake clay deposits, sometimes up to 80 ft. thick, were laid in the valleys of the old Teays River and its tributaries (Norris and Spieker, 1966, p. 23). After the pre-Illinoian glaciers retreated, the lake water eventually began to cut through the drift, carving new drainage patterns.

In the glacial history of the Great Miami River Basin, the formation of these new drainage patterns is referred to as the Deep Stage drainage network. As the lakes drained, new valleys were incised into the limestone and shale bedrock, with water flowing towards the south, eventually exiting the area at the Pleistocene Ohio River. These valleys, including that of the future Great Miami River, were carved to depths of 200 ft. or more into the bedrock (Spieker, 1968, p. A7). These new V-shaped valleys were much deeper than those of the Teays River and its tributaries; thus this segment of overall geologic history in southwestern Ohio has been called the Deep Stage Drainage.

The damming of the Teays and the drainage of the intermittent lakes were both complete by the time the Illinoian glaciers advanced far into the current Great Miami River Basin. As these glaciers and the later Wisconsinan glaciers advanced, large amounts of lodgment till were deposited on top of the existing bedrock, blanketing the entire area. As these younger glaciers began to retreat during the mid and late Pleistocene Epoch, meltwater running off them carried large amounts of sand, silt, clay, and gravel, which in turn filled many of the newly formed valleys, some to the point of obscurity (Norris and Spieker, 1966, p. 26). The ice sheets accumulated these particles as they moved towards southern Ohio, scraping bedrock and eroding anything in their paths. The newly created drainage patterns of the Deep Stage Drainage were now disrupted by the huge amounts of meltwater and alluvium coming into the area.

At best, the stratigraphy of these valley-fill alluvial deposits can only be generalized, as thicknesses and occurrences of each type of material can vary per square mile or on an even smaller scale. One generalization is that the valley-fill deposits consist of unstratified, poorly graded, medium-sized sand and gravel deposits. With ranges typically from 120 ft. to 270 ft. thick throughout the Great Miami River

Basin, these deposits are the best local source for groundwater (GeoTrans, 1985, p. 13). However, the stratigraphy of the area is not even as simple as the generalizations suggest. During periods of glaciation, which last for tens of thousands of years, climate and temperatures fluctuate irregularly. This fluctuation causes the glaciers to advance or retreat at irregular rates. Many times during a period of regression, if temperatures drop for an extended period of time, the glacier may begin to grow, or advance, again for a while. Such activity immensely affects the deposition of sand, gravel, till, silt, and other glacier-related sediments, causing the end result to be a wide mix of materials at varying thicknesses, distributions, and depths. The Great Miami Valley is no exception to this process.

During the periods of Illinoian and Wisconsinan glaciation, the V-shaped valleys of the Deep Stage Drainage were being filled with the outwash deposits. By now, the upland areas were covered with a blanket of lodgment tills of generally low conductivity and permeability. As the rates of continued glacial advances and retreats fluctuated, lodgment till was often deposited directly in the valleys, or meltwater would bring eroded till with it from the upland areas into the valleys below. Thus, these unstratified sand and gravel valley-fill deposits are mixed with till layers of varying thicknesses, distributions, and depths as well. Many of these tills are then subsequently a mixture of other materials, whether it be clay, silt, sand, or some combination of these sediment sizes. Other ablation till deposits from the irregularly retreating glaciers occur throughout the valley, and may contain higher amounts of sand and gravel, as opposed to their lodgment counterparts. Attempting to correlate these till lenses is nearly impossible across the entire river valley.

As is the case with the outwash deposits, only rough generalizations can be made with the till deposits located within this region. Many till layers are more extensive than others, sometimes reaching 50 ft. thick and occurring at locations of 30 ft. - 50 ft. below the land surface (GeoTrans, 1985, p. 13). Other till layers are only a few feet thick and cannot even be observed in two neighboring wells. Both unstratified and stratified tills alike are found mixed in with the valley-fill deposits, making it even harder to correlate identical layers. Nevertheless, these complex tills play an integral role in the groundwater resources of the Great Miami River Basin. Depending on their compositions and extents, these tills may hinder utilization of groundwater in any given location, as they often impede groundwater flow.

After the final traces of the Wisconsinan glaciation left southwestern Ohio, the topography and hydrology of the area were drastically different than when the Teays River was winding its way across the state. A completely new drainage network was established, and topography had conformed to this new network, while still showing signs of the Late Tertiary drainage network of the Teays River. Now included in this new drainage network was the north-to-south trending Great Miami River and its numerous tributaries. The outwash and surficial deposits were laid down, burying the V-shaped valleys of the Deep Stage Drainage network, and elevations resembled those of current conditions, as described in this first section of this report.

Aquifers

Many of the Deep Stage valleys were buried beyond recognition, as Norris and Spieker (1966) had described. Although still recognizable, the Great Miami River Valley is usually described in terms of a buried valley. This buried valley, with its complex array of outwash and surficial deposits, has become a tremendous and priceless resource for groundwater in the southwestern Ohio region. Numerous "sub-aquifers" are housed in these deposits, providing an umpteen number of counties, cities, farmers, factories, and residents with essential water.

The predominant aquifer system in these deposits is commonly called the Great Miami Buried Valley Aquifer (GMBVA, or just BVA, colloquially). This extensive aquifer provides the bulk of the water to

the area, and is the focus of many hydrogeologic studies and protection plans. Since the stratigraphy of the outwash deposits--ignoring momentarily the surficial deposits--is extremely complex, the aquifer locations and extents are also difficult to determine at times. Much of the blame for this rests with the numerous forms, shapes, and sizes of the till and clay lenses located in this area. Since these fine-grained till layers are at times tens of feet thick, they often divide the BVA into numerous smaller aquifers. Many of these sub-aquifers are confined or unconfined,

depending on their location relative to the till and clay layers. However, this broad classification does not even begin to hint at the complexity behind determining the locations, yields, and availability of each of these smaller aquifers.

Previous research by Norris and Spieker (1966) has concluded that there are eleven hydrogeologic environments in the Great Miami River Valley. Ten of these environments are located within the GMBVA itself, with the last one as the adjoining upland areas. Within these ten environments, numerous aquifer classifications have been made, each one independent of the other, and each one classified on the basis of the geology in which it is located, its relative thickness, and the type of recharge available to the aquifer. For a complete, in-depth analysis of each of these environments—a task beyond the scope of this report—Norris and Spieker (1966) have provided such an explanation.

Since each one of these environments has different factors affecting the entire GMBVA, the aquifer properties of each environment will differ from each other as well. In addition, values given for aquifer properties will also be generalizations, as they are determined from specific sites throughout an aquifer. Although values may be quite accurate, slight variations in aquifer properties may still exist even on a scale of a square foot. However, numerous values obtained from a small location can provide useful information on the aquifer in that immediate area. Such reasoning is used by anyone wishing to obtain groundwater from a location within the BVA. The following table illustrates general ranges of values for different aquifer properties across the buried valley sand and gravel aquifers.

LOCATION	TRANSMISS. gPD/ ft.	hydraulic k gPD/ sq. ft	infiltration mgd / acre	storage coefficient	thickness ft.	average yield gpm
DAYTON AREA	40,000 – 350,000	750 – 3,000	.06 – 1.7	.20	50 – 150	100 – 4,500
VENICE / HAMILTON CO. AREA	285,000 – 345,000	2,380 – 2,780	.02 – .17	.20	50 – 150	500 – 5,000
UPPER GREAT MIAMI RIVER BASIN AREA	100,000 – 200,000	1,000 – 5,500	.02 – 1.3	.01 - .20	50 – 150	1,000 – 3,000
TIPP CITY AREA	158,000	1,130	*n/s	.15	50 – 150	350 – 1,200
HAMILTON / BUTLER CO.	350,000 – 700,000	2,000 – 4,000	.3 – 2.0	.20	50 – 150	10 – 12,000

AREA						

* Information not specified in documents reviewed for this summary

These data, collected at isolated locations throughout the BVA, provide a sense of magnitude and amounts for the different properties necessary in evaluating an aquifer. As a comparison, till properties vary greatly from those of sand and gravel. Ranges of hydraulic conductivity for this regional till confining unit are anywhere from .03 to .13 gpd/sq. ft. (GeoTrans, 1985, p.17). These properties may vary to any extent within the basin, thus forcing companies to perform pump and aquifer tests each time new wells are proposed or drilled. Data included in the previous table were obtained from the following sources: Miami Valley Regional Planning Commission (1993), Fang (1992), GeoTrans, Inc. (1985), Sieco, Inc. (1979), Fred H. Klaer & Associates (1966), Norris and Spieker (1966), and Shaefer & Walton (1956).

Unquestionably, the various aquifer properties are affected by the geology, location, and dimensions of the sand and gravel aquifers. One of the most important of these properties is the aquifer yield, as the amount of water from a well is essentially the purpose or goal of many studies conducted throughout the basin. The design of the wells and pumps, the layout of the well field, and the rates of infiltration play great roles in determining the amount of water obtainable from the various aquifers. Any yield obtained from a pump test is specific to that exact location, and just like the other aquifer properties, these values can vary on a very small scale.

In addition to the complex BVA system, other sources of water exist within the boundaries of the Great Miami River Drainage Basin. Bedrock aquifers are located throughout the region, although their yields are typically much lower than those of the sand and gravel aquifers. Cracks, fissures, and other secondary porosity features within the carbonate bedrock provide excellent channels for groundwater recharge, as these conduits allow groundwater to flow more freely through the subsurface. The Brassfield Limestone serves as the best bedrock aquifer in the area, as it is relatively pure, its shale content is much lower than that of the Richmond and Mayesville Groups, and it exhibits more massive bedding and greater thicknesses than many of the other Silurian carbonates. The dominant limestone and dolostone aquifers are typically located on the upland areas of the valley walls, as depth to the bedrock here is sometimes only a few feet, as opposed to the few hundred feet underneath the sand and gravel deposits inside the valley itself.

Within the Dayton area, the Brassfield Limestone exhibits a range of transmissivity values from 52 gpd/ft to 2,790 gpd/ft (GeoTrans, 1985, p. 20). The Ordovician Richmond Group exhibits a much smaller range, from 62 gal/ft/day to 428 gpd/ft, due to the higher amount of impeding shale present (GeoTrans, 1985, p.20). In other parts of the state of Ohio, the limestone aquifers are larger sources of potable water, and artesian springs often flow from the bedrock at constant rates of tens of thousands gallons per minute. However, in the southwestern portion of the state--specifically in the Great Miami River Drainage Basin--these aquifers do not produce high amounts of water.

Since yields from the bedrock aquifers are lower, smaller and shorter-screened wells are typically found drilled into the limestone. Most of these wells are used for domestic purposes, as the aquifers cannot adequately sustain production or municipal wells. This is in opposition to other portions of the state. For example, in northwestern Ohio, the majority of municipal well systems are completely housed in the carbonate bedrock. Typical yields for the limestone bedrock aquifers range from 250 GPM to 500 GPM, with the interbedded limestone and shale bedrock producing even lesser amounts—on the order of 100 GPM (Norris, 1967, p. 19). Water within these aquifers also tends to be of slightly lower quality, as sulfates, calcium, magnesium, and other heavier minerals are often present due to rapid dissolution of

the calcium carbonate and rapid movement of materials through the limestone (or dolostone), once in solution.

However, it should be mentioned that since some of the unconsolidated sediments comprising the BVA have their provenance in the limestone units, the geochemical signature of the water within both aquifers can be rather similar, with often only subtle differences at best. Water from the outwash deposits may also be rather hard, not just due to this reason, but also due to the fact that glacial meltwater often brings high concentrations of heavier minerals accumulated during the glaciers' advances over thousands of miles.

The glacial sand and gravel deposits and the Brassfield Limestone serve as the two dominant sources of water for the Greater Miami Area. Water supplies have been probed within the Richmond and Mayesville consolidated material, but were met with little success. In addition, other failed attempts were made within the glacial drift overlying the bedrock on the upland areas of the valley. Wide variation in transmissivity values and low yields made this material an unreliable source of water, as composition of the material itself also varied across the basin. Depending on the amount of till and clay, as well as the thickness of the drift, the amount of available water could possibly be enough to support a domestic well, or it may not provide enough for even these purposes. Based on 13 wells drilled in the Dayton area, a range of transmissivity for the upland glacial drift was determined to be 82 gpd/ft to 3,700 gpd/ft (GeoTrans, 1985, p. 20). When the pre-Illinoian glaciers deposited the first wave of drift in the area, this relatively impermeable material was deposited directly on top of the bedrock well before the Deep Stage Drainage would carve out the V-shaped valleys of the region. Over time, this material was eroded by the meltwater, thus causing it to be only slightly present in much of the upland areas. The remainder tends to be very clay-rich lodgment deposits.

Quaternary glacial sand and gravel deposits provide the most amount of water because the water can easily move through the unconsolidated material at relatively quick rates. The characteristic high porosity—often around 40% to 50%--allows infiltration and recharge to occur on a larger scale and at a quicker pace. Recharge keeps the aquifer replenished, but people begin to experience trouble when they remove more water than that which is coming back into the aquifer. Infiltration often provides the bulk of the groundwater recharge because water seeps into the ground directly from open channels of water, such as rivers, lakes, and streams. Many factors affect the recharge process, generally by altering the time it takes for an aquifer to replenish itself. Precipitation, vegetation cover, local streams, rates of infiltration, subsurface flow, and no-flow zones within or near the aquifer can severely affect the amount of recharge to an area. Another factor affecting recharge--one that has in recent years come to play a significant role--is the addition of housing developments and increased pumping from a single aquifer. Aquifers may not have as much time to replenish if suddenly more wells begin to tap into them, drawing substantial amounts of water from them each day.

Throughout the Great Miami River Drainage Basin, discharge amounts for the Great Miami River and its tributaries are measured regularly. Precipitation amounts are also collected across the basin, as both of these factors contribute immensely to the overall recharge of the area's groundwater supply. In addition to infiltration by streams and lakes, direct recharge by precipitation aids to replenish the aquifers in this region. The Miami Valley Area does exhibit a humid climate and receives a fair amount of precipitation, an average of 38 inches per year, so this variable is measured closely (Morgan, 1951, p. 3). Water that eventually works its way into the groundwater system moves through the subsurface as lateral flow, throughflow, or some other method of groundwater flow. All of these factors relate to each other, as well as to the geology of the area. For example, if there is a clay-rich zone within an aquifer, recharge to that aquifer may be hampered due to the presence of the clay-rich zone. Infiltration may not be strong enough to penetrate the zone, thus delaying recharge because the groundwater must find an alternate path around it. If the clay-rich zone allows water into it, the amount of time it will take for the

water to infiltrate downward through the zone will be too long for the aquifer to sustain a safe yield. If the clay-rich zone is too extensive or too thick, the aquifer underneath may be deprived of water for significant amounts of time. As mentioned earlier, many of the till deposits within the valley generally depict a hydraulic conductivity of only about .03 to .13 gpd/sq. ft.

Current Groundwater Usage and Conclusions

The groundwater and surface water within the Great Miami River Drainage Basin is typically hard, with a total dissolved solid content of around 400 ppm – 450 ppm (Spieker, 1968, p. A1). Groundwater obtained from bedrock aquifers exhibit hardness ranging between 300 ppm and 500 ppm (Norris, 1967, p. 19). Higher concentrations of calcium, calcium sulfate, and bicarbonates are typically found in the groundwater and surface water within this region, due to dissolution of the limestone bedrock and the speed at which the water moves through the entire drainage network. Previous research by Norris and Spieker (1966) has provided an extensive description of the various mineral constituents found in both the groundwater and surface water within this region.

Since the sand and gravel deposits possess higher conductivity and permeability values, pollution potential is also great in many locations around the Great Miami River Drainage Basin. In addition, the limestone bedrock allows for rapid movement of water and possible contaminants through the numerous cracks and fissures. The risk of pollution, combined with previous contamination problems in the basin, has heightened the awareness of people living and conducting business in the area. Wellhead protection plans and strategies have been performed and outlined by numerous municipalities in hopes of protecting their respective water supplies. Different regulatory agencies have also made strong efforts to educate people in the area on the groundwater system and how it is linked to many other factors across the basin.

With population rapidly rising around major cities within the basin, the demands on the water supplies will only continue to become greater. With this increased demand comes the task of locating new groundwater resources accessible to homeowners and others that need the water. This search for new water often causes disputes and creates tensions, only increasing the need to recognize the demands placed on these natural resources. Norris and Spieker (1966) predict that by the year 2000, the minimum amount of water removed from the BVA will be at least 210 MGD; in 1950, groundwater pumpage was only around 50 MGD (p.141). Understanding the groundwater and surface water interactions around the basin is essential to best utilizing and protecting these priceless resources. To date, legislature has been passed protecting groundwater resources, many groundwater recharge areas have been identified, possible contamination sites have also been identified around the region, and public access to information on groundwater and surface water across the Great Miami River Drainage Basin has increased. These steps have been taken in an on-going effort to ensure that the future of these priceless natural resources will be safe and that later generations will also be able to enjoy the benefits of an abundant water supply.

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Questions? Comments?

DAYTON THERMAL TRAILER INVENTORY
March 27, 2002 s:\tech\3chry\dayton\dayton thermal trailer inventory

DC's	**Glassware**
DC's	10 1-liter amber small neck
DC's	10 1-liter amber wide neck
DC's	37 4-ounce glass wide mouth
DC's	4 2-ounce glass wide mouth
DC's	35 40-mil HCl VOAs dated 3/21/01
DC's	40-mil HCl VOAs dated 09/01
DC's	40-mil HCl VOAs dated 12/01
DC's	40-mil HCl VOAs dated 03/02
DC's	55 40-mil VOAs unpreserved
DC's	100 40-mil HCL VOAs date unknown
DC's	**Sampling materials**
DC's	1 stainless steel mixing bowl
DC's	1 stainless steel sampling spoon
DC's	1 cheap painted trowel
DC's	2 one-gallon plastic jugs DI water
DC's	17 COCs as of August 2000
DC's	150 sample labels
DC's	gallon trash bags
DC's	Ziploc quart bags
DC's	½ package plastic cups
DC's	rolls of paper towels
DC's	2 or 3 55-gallon drums
DC's	7 5-gallon buckets with lids
DC's	1 roll packing tape
DC's	2 rolls duct tape
DC's	**Tools and Equipment**
DC's	1 sump pump
DC's	1 100-foot grounded power cord
DC's	1 50-foot garden hose
DC's	40 feet of 4-inch dryer vent hose
DC's	40 feet of 3-inch dryer vent hose
DC's	1 metal muffler adaptor to vent exhaust
DC's	1 spade
DC's	1 pickaxe
DC's	3 ratchet sets
DC's	2 adjustable wrenches for drum lids
DC's	1 hammer
DC's	1 crowbar
DC's	2 2-foot long screwdriver for well vaults
DC's	1 100-foot yellow tape
DC's	1 100-foot cloth tape on large reel
DC's	1 squeegy
DC's	1 2-gallon shop-vac
DC's	1 propane torch
DC's	2 6'x 8' plastic tarps

LBG's	35 disposable bailers
LBG's	3 boxes latex sample gloves
LBG's	~ 6 pair dishwashing gloves
LBG's	5 pair rubber work gloves
LBG's	2 pair leather work gloves
LBG's	1 box of Tyvek suits
LBG's	1 face shield
LBG's	1 baggie of Alconox
LBG's	1 spool of rope
LBG's	1 100-foot steel tape (Lufkin)
LBG's	1 LBG 24 qt cooler?
LBG's	3 orange safety vests
LBG's	2 magnehelics
LBG's	4 3.5"-computer disks
LBG's	1 clipboard
LBG's	2 hard hats
LBG's	5 pairs of safety glasses
LBG's	1 first-aid kit
LBG's	1 1-liter eye wash bottle
LBG's	misc. SVE well monitoring equipment
LBG's	1 5-gallon bucket tool organizer liner
LBG's	stapler

DAYTON THERMAL TRAILER INVENTORY

DC's	1 box absorbent hot dogs for free product in MWs
DC's	Spray Paint
DC's	1 purple soft side cooler
DC's	2 small insulated water jugs
DC's	1 small scrub brush with handle
DC's	1 broom and dustpan
DC's	1 bag 6" cable ties
DC's	1-bag earplugs
DC's	6-CO2 cylinders
DC's	2 Micro Purge backpack units
DC's	2 Micro Purge low-flow cell units
DC's	misc. pH/Conductivity solutions for low-flow calibration
DC's	1 poly cart with secondary containment
DC's	boxes of tygon tubing
DC's	1 tool box with misc. tools
DC's	1 well vault key for offsite MWs
DC's	1 small garbage can
DC's	2 whaler pumps
DC's	Haz/Non-haz waste stickers
DC's	pens/pencils/post its

Ground-Water Resources of the Dayton Area, Ohio

By STANLEY E. NORRIS *and* ANDREW M. SPIEKER

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CONTENTS

	Page
Abstract	1
Introduction	3
Purpose and scope of the investigation	3
Previous investigations	5
Personnel and acknowledgments	6
Methods of investigation	7
Well-numbering system	7
Early history of ground-water development	8
Geography	11
Location and areal extent	11
Topography and drainage	11
Climate	12
Population, industry, and transportation	13
Mineral resources	14
Geology	14
Consolidated rocks	14
Glacial (Pleistocene) deposits	15
Till	16
Outwash	17
Geologic history	17
Deposition and uplift of consolidated rocks	17
Preglacial (Teays Stage) drainage	18
Pleistocene glaciation	23
Pre-Illinoian glacier	23
Minford silt	23
Interglacial (Deep Stage) drainage	24
Illinoian and Wisconsin glaciers	26
Specialized investigational techniques	27
Static water-level changes	27
Electric (gamma-ray) logging	28
Temperature-depth relations	29
Seasonal temperature changes	32
Character of the valley-fill deposits	33
Miami River valley south of Dayton	36
Dryden Road well field of Montgomery County Sanitary Department	36
Miami Shores well field of Montgomery County Sanitary Department	37
Lamme Road well field of Montgomery County Sanitary Department	37
Frigidaire Division, General Motors Corp. well field	38
South Dayton	38
Dayton Power & Light Co. well field, Frank M. Tait Station	38
National Cash Register Co.–McCall Corp. area	42

Geology—Continued
Character of the valley-fill deposits—Continued — Page
Central Dayton — 43
Aetna Paper Co. (wells 301–304) — 43
Dayton Power & Light Co., Longworth Street Station (wells 23–26) — 43
Delco Products Division, General Motors Corp. (wells 28–35) — 43
Dayton Power & Light Co., Third Street Station (wells 13–21) — 44
North Dayton area — 44
Miami River well field area — 44
Mad River valley — 45
Keowee Street area — 45
Findlay Street area — 46
Rohrers Island area — 46
Hydraulic properties of the valley-fill deposits — 49
Artesian and water-table conditions — 49
Effects of interbedded till deposits — 50
Transmission and storage characteristics — 52
Yields of wells — 53
Construction and development of wells — 59
Controlled pumping tests — 65
Pumping test at Rohrers Island — 67
Pumping test at Miami River well field — 68
Pumping test at Frigidaire Division plant No. 1 at Taylor Street — 68
Pumping tests at Dayton Power & Light Co., Frank M. Tait Station — 69
Pumping tests at the Lamme Road well field of the Montgomery County Sanitary Department — 70
Pumping test at Dryden Road well field of the Montgomery County Sanitary Department — 71
Hydrology of the valley-fill deposits — 71
Ground water in storage — 71
Recharge — 72
Characteristics of streamflow — 75
Stream infiltration — 77
Infiltration rates at Dayton — 83
Rohrers Island well field — 83
Discharge measurements of September 7, 1951 — 88
Discharge measurements of October 4, 1960 — 88
Infiltration as related to stage, discharge, and area — 93
Ground water available from natural stream infiltration — 97
Leakage through the till-rich zone — 101
Artificial recharging methods — 101
Experiments in the Dayton area — 102
Experiments at Peoria, Ill — 105

Page
Ground-water pumpage in the Dayton area — 107
Central district — 112
East district — 113
North district — 115
West district — 115
South Park district — 116
Moraine district — 117
Ground-water levels in the Dayton area — 118
Water levels prior to intensive pumping — 119
Hydrographs of observation wells — 119
Observation wells:
Mt-1 — 121
Mt-2 — 121
Mt-3 — 122
Mt-5 — 123
Mt-6 — 123
Mt-49 — 123
Mt-51 (563) — 124
Mt-53 — 124
M-9 — 125
530 and 531 — 125
Piezometric-contour maps — 125
Chemical quality of surface and ground waters — 127
Constituents and properties of natural water — 127
Silica (SiO_2) — 131
Iron (Fe) — 131
Manganese (Mn) — 131
Calcium (Ca) — 132
Magnesium (Mg) — 132
Sodium (Na) and potassium (K) — 132
Bicarbonate (HCO_3) — 132
Sulfate (SO) — 132
Chloride (Cl) — 133
Fluoride (F) — 133
Nitrate (NO_3) — 133
Dissolved solids (residue at 180°C) — 133
Hardness — 134
Specific conductance — 134
pH — 135
Color — 135
Temperature — 135
Chemical quality of surface water and its relation to ground water — 135
Graphic presentation of chemical-quality data — 136
Summary — 139
Future ground-water needs — 139
Conclusions — 141
Records of wells in the Dayton area — 147
References — 159
Index — 163

ILLUSTRATIONS

[Plates are in pocket]

PLATE 1. Map of Dayton area showing distribution of glacial and alluvial deposits, bedrock contours, and location of geologic sections.
2. Hydrographs showing water-level fluctuations in wells, discharge of Miami River at Dayton, and monthly precipitation at Dayton airport.
3. Geologic sections.
4. Well-location map.
5. Map of Dayton area showing distribution of ground-water pumpage in 1958.
6. Hydrographs showing fluctuation of water levels in wells.
7. Map of piezometric surface, April 1959.
8. Map of piezometric surface, October 1960.
9. Graphic logs of wells.

		Page
FIGURE	1. Location map of Dayton area	12
	2. Map of Tenys Stage valleys	19
	3. Map of Deep Stage valleys	25
	4. Gamma-ray log of well	29
	5. Diagram showing idealized ground-water circulatory systems	31
	6. Drillers' logs of wells 530 and 531	40
	7. Graphs of water temperature at Tait Station	41
	8. Map of Rohrers Island showing shallow till deposits, wells of high specific capacity, and recharge ponds	48
	9. Graph theoretically relating 1-day pumping rate and drawdown	54
	10. Graph showing theoretical recharge from infiltrating stream	56
	11. Graph showing theoretical pumping rate and drawdown in an infinite aquifer	57
	12. Photograph showing installation of a well screen	60
	13. Photograph of a high-capacity turbine pump	62
	14. Photograph showing the Miami River and exposure of water table, Miami Shores area	80
	15. Hydrographs showing effect of riverflow on ground-water levels	82
	16. Photographs of Rohrers Island well field	84
	17. Photograph of intake structure near head of Rohrers Island	85
	18. Photographs of artificial recharge channels at Rohrers Island	86
	19. Hydrographs of Mt-2, Mt-3, Mt-6, and Miami River	94
	20. Graph showing water leakage through till-rich zone	102
	21. Graph showing ground-water pumpage in Dayton area, 1900–58	108
	22. Diagram showing comparison of recorder charts	122
	23. Logarithmic nomograph of chemical constituents in water	137
	24. Water-analysis diagram	138

TABLES

		Page
TABLE	1. Population, 1920–60	13
	2. Hydrologic coefficients obtained from pumping tests of wells in lower aquifer	67
	3. Characteristics of flow of the principal streams	76
	4. Miscellaneous discharge measurements, October 4, 1960	89
	5. History of ground-water pumpage, by districts, 1900–58	109
	6. Summary of average daily ground-water pumpage, and area and density of pumpage, 1958	110
	7. Pumpage of ground water by public-supply systems, industries, and commercial establishments, 1958	110
	8. Chemical analyses of ground-water samples	128
	9. Chemical analyses of surface-water samples	130

GROUND-WATER RESOURCES OF THE DAYTON AREA, OHIO

By Stanley E. Norris and Andrew M. Spieker

ABSTRACT

Use of ground water in Dayton and environs, in southwestern Ohio, amounted to 110 mgd (million gallons per day) in 1958 or about one-fourth of the State's total use of this resource. The Dayton area is highly industrialized and has a rapidly growing population of about 400,000, which is expected to double by the year 2000. Industrial and commercial growth also are expected to continue at a high rate, as is the attendant use of ground water. Concern over the ground-water situation at Dayton and the need for determining whether the sources of ground water are adequate to meet the anticipated future demand led to the investigation on which this report is based.

The area covered by this report includes the city of Dayton, which lies at the confluence of the Mad River, the Stillwater River, and Wolf Creek with the Miami River; the report also includes that part of the Mad River valley extending from the mouth of the river northeastward to Huffman Dam, a distance of about 5½ miles, and that part of the Miami River valley between Dayton and the mouth of Holes Creek about 3½ miles south of the city.

The principal streams in the Dayton area flow in wide valleys, which were cut deep into relatively impermeable bedrock by preglacial streams and partly filled by glacial deposition of sand, gravel, and till. The glacial deposits range in thickness from 150 to 250 feet and consist generally of an upper and a lower sand and gravel aquifer, each about 30–75 feet thick. The upper aquifer is extensively pumped only at the Rohrers Island well field of the city of Dayton, where water levels are kept high by artificial recharge. Elsewhere, this aquifer is not thick enough to allow sufficient drawdown for the development of high-capacity wells. The aquifers are separated horizontally by a till-rich zone, which occurs as an areally extensive layer of till or as closely associated till lenses and masses. This till-rich zone, which ranges in thickness from 10 to 50 feet and whose top is from 30 to 75 feet below the surface, is poorly permeable and confines water in the lower aquifer under artesian pressure. Recharge to the lower aquifer, in which most wells are screened, occurs largely by vertical leakage through the till-rich zone. The availability of ground water is not presently limited by the rate of leakage through the till-rich zone, as the difference between the piezometric or pressure-indicating surface of the lower aquifer and the water table in the upper aquifer is nowhere greater than about 20 feet. The till-rich zone is locally absent. Where it is absent, the two aquifers are hydraulically connected.

Wells in the Dayton area typically range in depth from 60 to 175 feet and commonly yield 250–2,500 gallons per minute. As determined by pumping tests, the coefficient of permeability of the lower aquifer ranges from 1,000 to 2,500 gpd (gallons per day) per sq ft, and its coefficient of transmissibility ranges from 40,000 to an estimated 250,000 gpd per ft. Where the till-rich zone is absent, the transmissibility may be as high as 500,000 gpd per ft. From pumping-test data, the leakage coefficient of the till zone at the municipal well field on Rohrers Island, in the Mad River valley, was computed as 0.001–0.012 gpd per cu ft and the coefficient of vertical permeability of the till of this zone as 0.03–0.13 gpd per sq ft.

Ground-water recharge in the Dayton area occurs chiefly because pumping induces infiltration of streamflow through the streambed into the upper aquifer. Thus, the availability of ground water depends not only on the physical properties of the aquifers but also on the character of the surface-water flow and the rate at which water can percolate through streambeds under various conditions. Discharge measurements made at several points along the Mad and Miami Rivers on October 4, 1960, at a time of very low flow, showed that the rate of infiltration through the streambeds averaged about 1.7 mgd per acre in artificially ponded areas on Rohrers Island and about 0.07 mgd per acre in the reach of the Miami River extending south from the Main Street Bridge in downtown Dayton to the city limits. The infiltration rate in this part of the Miami River channel was probably at a minimum when the discharge measurements were made. It is estimated to be much higher—averaging about 0.75 mgd per acre—when the discharge at the Main Street gage is equal to or greater than about 2,000 cfs (cubic feet per second). Flows of this magnitude occur about 20 percent of the time, during which ground-water levels consistently rise in this area.

Ground water is extensively withdrawn in three general areas. One of these areas is in the Mad River valley about 5 miles northeast of the center of town, in the vicinity of Rohrers Island. The other two areas are both in the Miami River valley; one includes most of the central and southern parts of Dayton, and the other is about 2 miles south of Dayton and includes the plants of the Frigidaire Division of General Motors Corp. and the well fields of the Montgomery County Sanitary Department.

Pumpage at the municipal well field on Rohrers Island averages nearly 35 mgd, mostly from the upper aquifer. The supply is maintained artificially by diverting river flow into specially constructed infiltration ditches and lagoons on Rohrers Island. These artificially flooded areas are drained periodically and dredged to remove the accumulated muck and silt so as to maintain a high rate of infiltration into the underlying aquifer. The Rohrers Island area has reached the practical limit of large-scale development, and the city is presently drilling new wells and developing another ground-water supply in the Miami River valley north of Dayton.

Pumpage by industrial and commercial establishments in the central and southern parts of Dayton averages about 40 mgd. Ground-water levels in three observation wells in these areas—at the Fourth Street Station of the Dayton Power & Light Co. (Mt-2), near the Stewart Street Bridge opposite the National Cash Register Co. (Mt-3), and at the Municipal Building near the center of town (Mt-6)—have been in fairly steady decline since the beginning of record. Some wells in this area have gone dry or have been deepened, and pumpage has been reduced locally because of low water levels. Recharge conditions are poor in the central and southern parts of Dayton, largely owing to the siltation of the riverbed and formation of a "channel seal," which retards the rate of stream infiltration. Water-supply development in the area as a whole is near its practical limit unless the rate of recharge can be increased.

Pumpage for industrial and public supply averages about 25 mgd in the third major area of concentrated pumpage, which centers at a point about 2 miles south of Dayton. Ground-water levels have not been lowered excessively in this area and additional large supplies can be developed. Favorable recharge conditions result from a relatively high rate of stream infiltration and, to a lesser extent, from the presence of permeable kame deposits, which form a group of high hills along the east side of the valley and contribute much ground-water runoff to the valley-fill deposits.

Ground water in the Dayton area, which is in a limestone terrane, is high in calcium and magnesium; the range of hardness as $CaCO_3$ of 44 samples analyzed is 269–516 ppm (parts per million). The iron content, 0–3.5 ppm in the samples analyzed, is troublesome. The iron problem is intensified by the presence of iron-precipitating "bacteria" in many wells. Chlorine treatment usually is required for the control of such organisms.

The demand for ground water in the Dayton area is estimated to rise from the 1958 total of 110 mgd to at least 140 mgd by 1975 and to at least 200 mgd by the year 2000. This last quantity is more than can be developed in the area under natural conditions, and an increasing incidence of local water shortages is forecast unless a comprehensive plan is evolved for conserving water and increasing the rate of infiltration to the aquifers.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The availability of ample supplies of water has been vital to the growth and industrial development of the Dayton area. Ground water, because of its purity and low temperature, has been of special value to industry, and comparatively few cities in Ohio are so abundantly endowed with ground-water resources as is Dayton. Nature's providence is reflected in the fact that nearly one-fourth of the total quantity of ground water used in Ohio is pumped from wells in the Dayton area. The Dayton municipal water system is one of the largest in the Nation where the entire supply is taken from wells.

The use of ground water in the Dayton area has grown enormously in recent years. Figures compiled by the U.S. Geological Survey in 1946 and by the Water Conservation Subdistrict of the Miami Conservancy District in 1954 reveal an increase in water use of about 40 percent in the intervening 8-year period. Indications are that the use of ground water for industrial and municipal purposes will continue to expand in future years. Forecasts by the Presidential Advisory Committee on Water indicate a probable doubling of the Nation's current demand for water for industrial use by 1975. The increase in water use at Dayton may be substantially above the national average if recent trends continue.

Although the demand for water will almost certainly increase, the supply is limited. Even prior to the drought of 1953–54, when com-

paratively little attention was being paid to water supply, some observers speculated that the growth of Dayton might be stunted eventually by the difficulty of obtaining water economically. These observers pointed to the fact that local shortages already had developed; some wells have been abandoned, and a few industrial plants appeared to have reached the maximum practical development of the ground-water resources in their respective areas. Fears of a widespread water shortage became more widespread during the ensuing 2-year drought and were intensified as water levels in observation wells dropped to record lows. Public officials and representatives of industry alike became concerned. Various plans to conserve water or to recharge aquifers were proposed; the principal plan called for the construction of control dams and retarding basins in the headwaters of the major tributary streams to provide for increased dry-weather flow in the Miami River. Increased riverflow during drought, it was asserted, would result in more recharge to the ground-water reservoirs. Systematic dredging of the stream channels in areas of heavy pumping also was proposed as a means of increasing the rate of infiltration to the underlying aquifers.

Thus, alarm caused by the drought and concern for the future resulted in the creation, in 1953, of the Water Conservation Subdistrict of the Miami Conservancy District, which was to study the feasibility of constructing control dams. The Subdistrict in 1956 retained a board of consultants to ascertain the benefits or liabilities of the proposal. The consultants, after collecting basic hydrologic data and making several experiments with artificial recharge, reported that increasing the base flow of the Miami River would not appreciably increase ground-water recharge. On the contrary, they found that reduction of the peak flows necessary to store water for augmenting low flows would inhibit recharge, inasmuch as most infiltration occurs during floods. Thus if flood peaks are reduced, so is much of the recharge.

In 1956 the Water Conservation Subdistrict entered into cooperation with the Branch of Ground Water of the U.S. Geological Survey to conduct the investigation forming the basis of this report, whose objective is a comprehensive review of the problems of greater Dayton's ground-water supply, with particular emphasis on future water requirements and how they can best be met. The scope of the report includes a detailed study of the geology and hydrology of the principal aquifers, a history of ground-water pumpage as related to water-level trends, a review of the quality of ground water, and, not least in importance, an estimate of Dayton's future water needs based on a continuation of present growth of population and industry.

No report is "final," inasmuch as ground-water requirements are constantly changing and are difficult to predict. Thus by 1975 the entire problem may have changed, rendering the present interpretation as obsolete as the old Miami and Erie Canal. It is the authors' purpose to present first the facts, and second their interpretation. Whether or not time alters the validity of the interpretation, the facts stand as a base for any future investigations.

PREVIOUS INVESTIGATIONS

The glacial-outwash aquifers of the Dayton area have been described in several reports covering various phases of the geology and ground-water resources of western Ohio. Fuller and Clapp (1912) reported on the Dayton area in their reconnaissance of the ground water of southwestern Ohio. Foerste (1915) wrote about the geology of the area and briefly mentioned the ground-water resources. Stout, Ver Steeg, and Lamb (1943) included a chapter on Montgomery County in their report on the geology of water in Ohio.

The most complete investigation of water resources of the Dayton area made prior to the present one was written by Norris, Cross, and Goldthwait (1948); it covers in much detail the geology of the consolidated rocks and of the glacial deposits and provides data on the hydraulic properties of the aquifers, yields of wells, water quality, and streamflow characteristics.

Walton and Scudder (1960) studied the ground-water resources of the valley-train deposits in the Fairborn area, immediately east of the area of this report.

Norris (1959) studied in detail the hydraulics and hydrology of the vally-fill deposits in the vicinity of the Dayton municipal well field on Rohrers Island, in the Mad River valley. His report, a byproduct of the present investigation, describes the separation of the valley fill into two aquifers by a clay-rich zone and gives the rate at which water leaks through this semiconfining bed to the lower aquifer.

Streamflow characteristics have been determined by a systematic stream-gaging program, maintained for nearly 50 years in the Dayton area by the U.S. Geological Survey, in cooperation with the Miami Conservancy District and Ohio Department of Natural Reasources, Division of Water. Flow characteristics have been tabulated and discussed by Cross (in Norris and others, 1948; Cross and Weber, 1950; Cross and Hedges, 1959). Cross (1950, p. 60–62) also gave a summary of the history of surface-water development, which centered around the Miami-Erie Canal system.

The disastrous flood of March 1913 and the formation of the Miami Conservancy District and construction of five flood-control reservoirs in the Dayton area were described by Morgan (1951).

PERSONNEL AND ACKNOWLEDGMENTS

This investigation was made under the supervision of the senior author. Cooperating agencies were the Miami Conservancy District, represented by Max L. Mitchell, chief engineer, and the Ohio Department of Natural Resources, Division of Water, represented by C. V. Youngquist, chief. All water analyses were made in the Columbus laboratory of the Branch of Quality of Water, U.S. Geological Survey under the supervision of G. W. Whetstone, district chemist. Data on streamflow were provided by the Branch of Surface Water, U.S. Geological Survey, represented by L. C. Crawford, district engineer.

A seismic-refraction survey to determine depths to bedrock was made in the spring of 1960 by R. M. Hazlewood of the Denver office of Branch of Geophysics, U.S. Geological Survey.

Mr. Robert E. Reemelin of the Miami Conservancy District collected much of the basic data incorporated in this report and periodically assisted the authors in making water-level measurements.

The authors regret that all the industrial and municipal representatives who furnished information for the report and cooperated in other ways cannot be mentioned here. The contributions of several, however, warrant special mention. Mr. John E. Eschliman of the Ralph L. Woolpert Co., Consulting Engineers of Dayton, furnished most of the information concerning the well fields of the Montgomery County Sanitary Department, including results of several pumping tests his firm had made. The firm of Schaefer & Walton, Consulting Ground Water Hydrologists, Columbus, made available all the basic data of a pumping test at the Miami River well field of the city of Dayton.

Messrs. W. T. Eiffert, director, and Robert Stout and Charles R. Stout, of the Dayton Water Department, supplied most of the information concerning the Dayton municipal well fields. Messrs. Loyd C. Huffman, sanitary engineer, and Earl Riber and Kenneth Hilton, of the Montgomery County Sanitary Department, were most cooperative in providing information.

Messrs. E. C. Webster, Glenn L. Herbst, and Gerald Doig of the Dayton Power & Light Co., E. K. Weisser and N. E. Siders of the National Cash Register Co, and G. E. Miller, E. R. Oda, and Doyle Mummert of the Frigidaire Division of General Motors Corp. provided information regarding the use of ground water by their respective industries. The authors are grateful to the many well drillers of the Dayton area who made information available. G. M. Baker & Sons, Inc., Messrs. Clay P. Garrison, Elbert Hays, Lewis C. Harman, A. E. Lotts, the Layne-Ohio Co., Messrs. O. O. Pegg, and Donald J. Roe were among those drillers most frequently consulted. Mr. Roe, of Vandalia, Ohio, was especially helpful in providing several gamma-ray logs of wells he had drilled and in giving information on pumping tests he had made in the Dayton area.

Mr. Wilbur Cotton, formerly executive secretary of the Miami Conservancy District, was instrumental in providing support for the investigation.

Finally, the authors express appreciation to Mr. O. B. Reemelin, vice president of the Dayton Power & Light Co., whose untiring efforts as chairman of the Water Conservation Committee of the Dayton Chamber of Commerce led to the formation of the Water Conservation Subdistrict of the Miami Conservancy District and ultimately to the support for the present cooperative investigation. Mr. Reemelin has been instrumental in fostering and maintaining interest in water conservation in the Dayton area. It is not an overstatement to say that his interest in Dayton's water problem was the largest single factor in making this report possible.

METHODS OF INVESTIGATION

During this investigation, records of 458 wells were collected and these wells were located in the field. Comprehensive inventories of ground-water pumpage in the Dayton area were made in 1955 and 1958. Water levels in about 60 observation wells were measured in 1955 and twice annually in 1958, 1959, and 1960; and contour maps were prepared of the piezometric surface of the lower aquifier. The results of seven pumping tests were analyzed, and chemical analyses of 44 water samples were made.

The presence of widespread sheets of till interbedded with the valley-train deposits led to the use of several specialized criteria for their recognition. These criteria are described in detail under the heading "Specialized Investigational Techniques."

WELL-NUMBERING SYSTEM

For purposes of well numbering and the inventory of ground-water pumpage, the Dayton area is divided into six districts. (See pl. 5.) Privately owned wells are assigned numbers by district according to the following plan:

District	*Well Nos.*
Central	1–100
East	101–200
North	201–300
West	301–400
South Park	401–500
Moraine	501 and up

All privately owned wells inventoried in the preparation of this report are listed in the section "Records of Wells in the Dayton Area."

Public-supply wells retain the numbers originally designated by waterworks officials. Wells of the Dayton Municipal Water Department are designated by the prefix C, wells of the Montgomery County Sanitary Department by the prefix M, and wells of the Oakwood Water Works by the prefix O. Test wells drilled by the Dayton Municipal Water Department are given their original number prefixed by the letter T. All public-supply wells inventoried in the preparation of this report are listed in the section "Records of Wells in the Dayton Area."

Observation wells in Montgomery County whose records are maintained by the Ohio Division of Water in cooperation with the U.S. Geological Survey are designated by the prefix Mt. These observation wells are not listed in the well-records section but are described in the section "Hydrographs of Observation Wells," beginning on p. 119.

EARLY HISTORY OF GROUND-WATER DEVELOPMENT

In 1880 pumpage at the Dayton waterworks amounted to about 1 mgd (million gallons per day), and total use of ground water in the Dayton area, including that from private wells, is estimated to have been no more than double this amount. By 1958, ground-water pumpage for municipal, industrial, and commercial use in the Dayton area had increased to 110 mgd. These pumpage figures, separated in time by no more than a human lifespan, document the growth of Dayton from little more than a country village to a vast complex of factories, stores, homes, airports, and other components of a modern metropolis. Water in abundance and at low cost was essential to this growth, and it is fully as essential to the preservation of today's industrial economy. Dayton's continued growth depends on the continued availability of ever larger quantities of pure, clean water. Truly, modern civilization has an insatiable thirst.

From the beginning of its settlement by a small band of pioneers, who in 1796 disembarked from flatboats at the confluence of what then were considered three navigable rivers, water has been of paramount interest and concern to Dayton's citizens. During the town's early years, attention was directed chiefly to surface-water sources of supply, to the building of milldams and levees, and to the use of the rivers for transportation.

The Miami and Erie Canal in 1829 linked Dayton to the rest of the world, by way of Cincinnati, and inaugurated Dayton's first significant growth. Canal traffic reached its peak about 1850 and then began its rapid decline, which was coincident with the growth of rail transportation.

The first well dug in Dayton was on the Newcom lot at the corner of Main Street and Monument Avenue, according to the Reverend A. W. Drury (1909, p. 526), who stated that:

> In the gravels underlying the original site of the city of Dayton and within a few feet of the surface an abundance of cool, wholesome water was readily secured. * * * wells, both public and private, were sunk in all parts of the original plat. Many thought that no other provisions would be necessary. When larger needs began to present themselves, attention was turned to Mad River as a source of supply. The clear, rapid current of this stream, with a fall double that of the Miami, was well calculated to capture the imagination and inspire the first efforts in securing an adequate water supply.

Reverend Drury went on to state that as early as June 2, 1826,

> the common council passed a resolution requesting Mr. E. Brabham and Mr. V. W. Van Cleve to survey and ascertain the practicability of conveying water from some point on the Mad River into the town of Dayton.

Events evidently moved slowly, however, and according to Reverend Drury not until March 1, 1845, was the Dayton Water Co. incorporated and authorized to "dig trenches, lay pipes, and in every way necessary install a complete plant by which should be secured good and wholesome water from Mad River." Despite this mandate there is no record of anything having been done; likewise, several other efforts to provide a waterworks between 1845 and 1869 failed.

By the 1860's, however, it was recognized that many shallow wells were being contaminated by the effluent from cesspools dug in the same sand-and-gravel formation. The need for sewers led to the establishment in 1868 of the first board of health. In 1869 a bond issue for a waterworks was passed by the voters. A committee was then formed to make recommendations for a water system; Conover (1932, p. 527) reported that:

> the Committee favored the "Holly system" or direct pressure (no standpipe) system. Council leased ground at Dutoit and Beacon Streets, and in September, 1869, sunk two wells, each 25 feet in diameter. These were unsatisfactory and the council purchased two acres at the corner of Keowee and Ottawa Streets for $5,000.

Wells were sunk at the new site. Conover reported (1932, p. 527–528) that:

> In 1871 a long trench was made in the vicinity of the wells to serve as a storage reservoir, but within a year it was found necessary to make a direct connection with Mad River in order to secure a sufficient supply, an extensive filter of gravel being relied upon to exclude all impurities.
>
> In 1874, a very dry year, the water supply proved insufficient and the water of Mad River was turned into the service pipe without any attempt to filter the same. This condition continued from July 10 to the latter part of September. The gallery filtration system proved to be a failure and large wells afterward sunk failed to meet requirements.

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In 1887, wells were driven in the bed of Mad River, which with various additions and improvements have given an abundant supply of pure water down to the present time.

Many of Dayton's earlier citizens recognized the relationship between ground water and the geology. Writing in the 1880's, Steele and others (1889, p. 33) stated:

But not the least of the advantages derived from the sand and gravel that underlies Dayton is the drainage it affords. It almost obviates the necessity of sewerage. * * * Underneath the City, at a depth of a few feet, runs a constant stream of water, removing impurities of all kinds and preventing disease. In the less densely populated parts of the City it acts as an admirable filter, and carries into wells pure and cold water for drinking and culinary purposes. Now that in parts of the City well water is no longer considered wholesome, the City is indebted to this same [sand and gravel] for the wells at the waterworks.

A more complete interpretation of the geology was written by Conover (1932, p. 214), who reported that:

Dayton's advantages and future prospects, as far as these depend upon an adequate water supply, are due to the geological formation of the valleys centering at Dayton. Great channels and extensive areas were grooved out of the solid rock and into these were borne from the north great quantities of drift in the form of clay and gravel and sand * * *.
The lower strata consist for the most part of clays impervious to water. In the vicinity of Dayton, the upper level of the clay is from 30 to 100 feet below the surface of the valleys. Above this clay floor are the strata of gravel and sand in which is the great reservoir of water ready to be tapped for the uses of man.

The "clay floor" to which Conover referred is the top of an extensive till deposit which generally separates the sand and gravel deposits into an upper and a lower aquifer. Evidently, Conover was unaware of the existence of the lower aquifer, in which most wells other than some of the municipal wells at Dayton now are screened.

Along with knowledge of the geological aspects of Dayton's ground-water supply, came the usual prognostications of the "inexhaustible" character of this vital resource. Steele (1889, p. 214) wrote: "The supply seems inexhaustible; however, should the growing population in the future require more water, additional wells can be added to the plant * * * the waterworks will (soon) have a capacity of 17 mgd." Another account (Conover, 1932, p. 214) stated: "Probably no city in the country is more highly favored than Dayton with an abundant supply of pure and delicious water. The wells are practically inexhaustible * * *."

In 1929, C. H. Paul, an engineer, stated in a publication of the Dayton Chamber of Commerce that: "Not only is the present supply adequate for some time to come, but undeveloped water resources, easily available, are controlled by the City, and the search for an adequate water supply will never be one of Dayton's problems. For and industrial city this is an asset whose value can hardly be overestimated."

Paul made this statement when ground-water pumpage in the Dayton area was about 40 mgd, a little more than one-third the 1958 total.

It is unlikely that Paul or anyone else in the 1920's, and certainly no one of a generation before him, could have foreseen the explosive increase in the rate of industrial expansion and in water use that has characterized the Dayton area in the past 20 years. He and his predecessors, therefore, may be excused for their unqualified optimism at a time when very few facts were available as to the amount of water in storage in the aquifers and the rate of natural replenishment.

And so it has been in this country with resource after resource—timber, mineral deposits, fertile soil, and wild game—to cite better known examples; the initial concept is that their supply is "inexhaustible." Only when actual depletion or sharp conflict between users becomes grim reality do the citizens bestir themselves and begin accurately to evaluate and conserve Nature's bounty. We owe it to some of Dayton's leading citizens, notably Mr. O. B. Reemelin, for pointing to the urgent need for an evaluation of our ground-water resources. Only when facts are at hand can this vital resource be intelligently developed, managed, and conserved.

GEOGRAPHY

LOCATION AND AREAL EXTENT

This report considers the greater part of the Dayton metropolitan area, which is in the eastern part of Montgomery County. A narrow strip of the report area lies along the west edge of Greene County (fig. 1). Dayton is in the southwestern part of Ohio, about 50 miles northeast of Cincinnati and 65 miles west of Columbus. The report area covers about 175 square miles, is rectangular, and comprises parts of six 7½-minute topographic quadrangles: Bellbrook, Dayton North, Dayton South, Fairborn, Miamisburg, and Trotwood.

TOPOGRAPHY AND DRAINAGE

The Dayton area is in the Till Plains section of the Central Lowland physiographic province (Fenneman, 1938, p. 499–518). The land surface is flat to gently rolling and is at an altitude of 900–1,100 feet. A mantle of glacial drift overlies the bedrock. The principal streams—the Miami, Mad, and Stillwater Rivers—are entrenched, and their generally flat flood plains range in altitude from 710 to 780 feet. The downtown part of Dayton is on the flood plain of the Miami River at an altitude of about 740 feet. Locally more

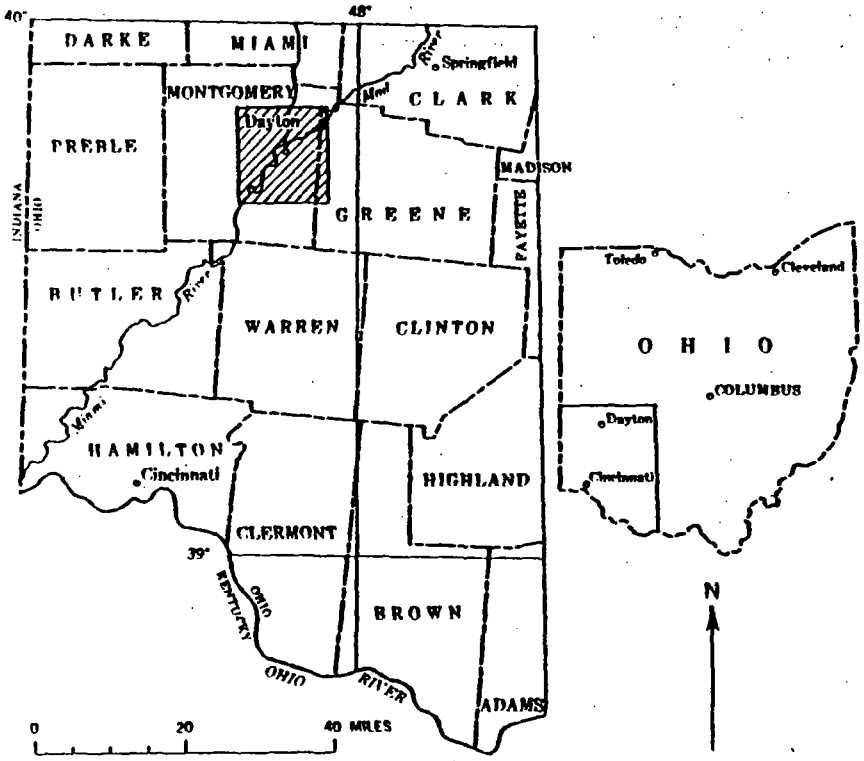

FIGURE 1.—Southwestern Ohio and the Dayton area.

pronounced relief is the result of kames and terminal moraines deposited by the Wisconsin ice sheet.

The area is largely in the drainage basin of the Miami River. Little Beaver Creek, a tributary of the Little Miami River, drains a small part of the city of Kettering, which is in the southeastern part of the area. The principal tributaries of the Miami River in the Dayton area are the Mad River, Stillwater River, Wolf Creek, and Holes Creek.

CLIMATE

The Dayton area has a humid temperate climate, a mean annual temperature of 52.7°F, and a mean annual precipitation of 36.75 inches. Normally precipitation is distributed evenly through the year. The average date of the first freezing temperature in the fall is October 21, and that of the last in the spring is April 20. Thus the average length of the growing season is about 6 months. Temperature extremes are rare and of short duration. The record high temperature is 108°F, in July 1901, and the record low temperature

is -28°F, in February 1899. About 1 year in 10 has temperatures above 100°F and 2 years in 3 have temperatures below zero. Snowfall is moderate; the maximum recorded accumulation is 16.5 inches, in January 1918.

Plate 2 shows the monthly precipitation at Dayton for 1942–60, the period of water-level record in this area. Detailed information on climate is available in a report by Norris, Cross, and Goldthwait (1948, p. 6–9) and in the publications of the U.S. Weather Bureau.

POPULATION, INDUSTRY, AND TRANSPORTATION

The population of the Dayton area is about 392,200, according to the 1960 census. This figure is approximate because the area includes fringes of townships bordering those here listed, whose population makes the actual total slightly greater than is shown. Dayton ranks as the 6th largest city in Ohio and the 49th largest in the United States.

Table 1 shows the population trend of the Dayton metropolitan area for the period 1920–60. It can readily be seen that the suburban area has grown relatively faster than the city itself. It is estimated that by the year 2000, the 1960 population will have doubled.

TABLE 1.—*Population of the Dayton area, 1920–60*

	1920	1930	1940	1950	1960
Montgomery County	209,532	273,481	295,480	398,441	527,080
Area of report:					
City of Dayton	152,559	200,982	210,718	243,872	262,332
City of Kettering (formerly Van Buren Township)	7,213	11,271	16,442	22,200	54,462
City of Moraine (formerly part of Van Buren Township)	-------	-------	-------	-------	2,262
City of Oakwood	1,473	6,494	7,652	9,691	10,493
Harrison Township	7,880	8,985	12,663	27,974	28,996
Mad River Township	3,283	4,371	4,642	17,860	33,644

The Dayton area is one of the major industrial centers of Ohio. In 1960 there were 738 industrial firms in Montgomery County, about 675 of which were in the area covered by this report. Among their principal products, valued at $875 million in Montgomery County, are automobile equipment, refrigerators and air-conditioning units, cash registers and related business machines, electrical equipment, paper products, books and printed material, rubber goods, machine tools, and precision instruments.

Industry has a long tradition in the Dayton area. Since 1910 Dayton has been a center of the automotive industry; in recent years the emphasis has been on automotive parts. Much of the industrial growth of the city can be attributed to its proximity to both the

source of raw materials and the markets. The excellent water resources of the area have enabled Dayton to sustain a high level of industrial activity.

The Dayton area is provided with excellent transport facilities. It is on the lines of the Baltimore & Ohio, Erie-Lackawanna, New York Central, and Pennsylvania Railroads and is served also by American, Delta, Lake Central, Trans World, and United Airlines. The area is served by 95 motor freight lines and 9 motor buslines. Several major State and Federal highways link Dayton with all nearby metropolitan centers. Route 75 of the new Federal interstate highway system passes through Dayton, and Interstate Route 70 passes 7 miles north of Dayton.

MINERAL RESOURCES

By far the most abundant mineral resources available in the Dayton area are gravel and sand, commercial quantities of which are available almost everywhere in the area shown on plate 1 as "Glacial outwash." Of special interest is the large area of kame moraine where sand and gravel easily can be removed from hillsides. Many large sand and gravel pits are located in all directions from the built-up central district of Dayton.

Limestone is available but is not now quarried in the area of this report, although several limestone quarries are operated in adjacent areas (Norris and others, 1948, p. 12). The limestone of this area probably will never be quarried, as it occurs largely in the densely populated urban area.

GEOLOGY

CONSOLIDATED ROCKS

The consolidated rocks underlying the valleys and lowlands in the Dayton area consist of shale and thin interbeds of limestone. The limestone layers are hard, coarsely crystalline to dense, and very fossiliferous. They are 1–5 inches thick and may make up 25–50 percent of the entire sequence. The intervening claylike shale is soft, puttylike, and sometimes has distinctive robin's-egg-blue color, which facilitates identification in drill cuttings. The sequence of shale and interbedded limestone was named the Richmond Group after exposures of these rocks near Richmond, Ind. The Richmond Group is of Ordovician age and was deposited as ocean sediments about 430 million years ago.

The Richmond Group is capped on the bedrock divides in the Dayton area by the Brassfield Limestone of Silurian age. The Brassfield Limestone is a light-gray to brown, relatively pure limestone, as much as 30 feet thick. It is quarried at Fairborn and used in the manufacture of cement. The contact between the Brassfield Limestone and shale of the underlying Richmond Group is well exposed in the railroad cut at the southeast end of Huffman Dam, in the northeastern part of the area.

The consolidated rocks are relatively unimportant as sources of ground water in the Dayton area. The shale and interbedded limestone of the Richmond Group yield barely sufficient water for household wells. Many wells drilled into these rocks are, for all practical purposes, dry. The Brassfield Limestone is a much better aquifer than the Richmond Group and is a generally dependable source of water for farm and home use. The water-yielding properties of the consolidated rocks have been described in detail by Norris, Cross, and Goldthwait (1948).

GLACIAL (PLEISTOCENE) DEPOSITS

About 1 million years ago worldwide climatic changes occurred that have resulted in the periodic formation of glacial ice sheets of continental magnitude. Four times, at least, at intervals separated by several tens of thousands of years, these glaciers have spread from centers of accumulation in northern Canada and elsewhere into the northern United States. The four glacial stages are named, from oldest to youngest, the Nebraskan, Kansan, Illinoian, and Wisconsin Stages. Weathered boulders of glacial origin in northeastern Kentucky and diversion of ancient drainage lines in Ohio and other States are evidence that at least one and possibly both of the first two glaciers reached the Dayton area. It is certain that the last two glaciers reached the Dayton area; the Illinoian glacier advanced southward to points a few miles south of Cincinnati, and the Wisconsin glacier stopped a few miles north of Cincinnati. The Illinoian glacier receded from the western Ohio area about 200,000 years ago. Ice of Wisconsin age covered much of Ohio as recently as 14,000 years ago. In a sense the Wisconsin glacier is still in retreat, the remnants of this last great ice sheet being confined now to the Arctic regions.

Each of the four principal glacial stages was influenced by relatively minor climatic fluctuations, and the glaciers alternately advanced and retreated over the area. These oscillations, less widespread than those that characterized the principal glacial advances, are known as substages. Evidence of Illinoian and older substages has not been recognized in Ohio. Wisconsin-age deposits in western Ohio have been related to two substages, corresponding to early and late Wisconsin time. Largely on the basis of radiocarbon-dating

methods, Goldthwait estimated (1958, p. 209) that the first Wisconsin advance reached western Ohio more than 37,500 years ago. The last major advance of the Wisconsin ice commenced between 25,000 and 19,500 years ago; the ice began to recede from its southern terminus, near Cincinnati, about 17,000 years ago, and it disappeared from Ohio about 14,000 years ago (Goldthwait, 1959, p. 198–199, 211, 215). The Wisconsin ice readvanced locally during its final retreat and in many areas deposited till on sand and gravel that had been but recently laid down. This is shown by extensive areas in which till overlies gravel near Dayton, generally on the higher land adjacent to the major valleys both north and south of the city (pl. 1; and Goldthwait, in Norris and others, 1948, p. 34).

The glaciers transported into western Ohio vast quantities of rock and soil, most of it brought from no great distance, but some of it originating as far away as Northern United States and Canada. When the glaciers melted, the soil and rock debris was left on the bedrock, either in the form of till or as sand and gravel, according to the way it was deposited.

TILL

Till was deposited directly by the ice as it moved over the area; it is a heterogeneous mixture of clay and stones and lacks assortment or stratification. It covers most of the upland areas (pl. 1) to depths of a few feet and is 80 feet thick or more where it fills depressions in the underlying bedrock surface. Locally, as at the limestone quarries near Fairborn, it is thin or absent.

Till of Wisconsin age weathers to a yellowish-brown to dark, silty clay loam, typical of glacial limestone soils. Below the soil zone downward to the base of the zone of oxidation, which may extend 10–20 feet below the surface, the till is light brown and is fairly easy to dig. Unoxidized till is blue gray and is relatively hard and tough. The well driller commonly reports it as blue clay or hardpan.

From time to time, as the glaciers advanced over or retreated from the Dayton area, tongues of ice lay in the valleys. When these ice tongues melted, the till they contained was deposited as widespread layers or, locally, as blocks and lenses. In some areas these till deposits were removed or cut through by melt water. In most places the till was buried by outwash sand and gravel and remains much as in its original form.

Till, being relatively impermeable, is a major factor in the hydrologic cycle in the Dayton area because it is generally interbedded with the sand and gravel deposits in the large valleys and it slows recharge to the underlying aquifers.

OUTWASH

When the glaciers melted and the ice fronts retreated, the waters derived from the melting ice poured down the valleys, filling them with vast quantities of sand and gravel, called outwash or valley train. The term "outwash" is appropriate, for the material literally was washed out of the glacier. Most of the outwash deposits in the Dayton area were left by ice of the two Wisconsin substages. The deposits of the earlier glaciers had been largely removed by erosion and transported to the sea by the rivers and creeks that occupied the valleys during the ensuing interglacial stages.

The outwash deposits in the Dayton area range in thickness from about 120 to 250 feet. They are the sole source of the large ground-water supplies that are pumped for municipal and industrial use. The deposits thus constitute, indirectly, a vital natural resource of inestimable worth.

GEOLOGIC HISTORY

DEPOSITION AND UPLIFT OF CONSOLIDATED ROCKS

A shallow sea occupied the Dayton area during much of the Paleozoic Era, which began more than 600 million years ago and ended about 230 million years ago. During that time sediments accumulated in the sea and gradually became compacted into the consolidated rocks. Shale of the Richmond Group was once chiefly mud brought to the sea by rivers heading in landmasses to the east and southeast. The limestone layers of the Richmond Group are made up largely of the calcareous remains of organisms that lived in the former sea. The overlying Brassfield Limestone also was derived from the limy remains of these organisms.

During much of the Paleozoic Era the Dayton area emerged above water as part of a low-lying landmass or chain of islands. These emergent lands were along the crest of the Cincinnati arch, whose axis traverses western Ohio along a generally north-south line that passes through Cincinnati and Toledo. According to Stout (1941, p. 13), the Cincinnati arch was formed by subsidence of the rocks along the flanks of a resistant core. This core possibly is formed of crystalline rocks (Lockett, 1947, p. 435). The crest of the Cincinnati arch stood at or near sea level for long intervals of geologic time. The strata thicken on both flanks of the arch and dip off the crest at low angles. In Montgomery County, which is on the crest of the arch, the consolidated rocks dip approximately 5 feet per mile to the northeast, parallel to the axis of the crest (Norris and others, 1948, p. 22).

The final emergence of the western Ohio area took place near the end of the Paleozoic Era. Streams formed on the new land and began their slow work of transporting sediment to the sea. In the millions

of years since the end of the Paleozoic Era erosion has removed many feet of younger sediments, to expose those that presently compose the bedrock. As erosion went on, the area more than once was reduced to a relatively flat surface, known as a peneplain. Typically, after a peneplain, or an incipient peneplain, had been developed, the area would be uplifted slightly, or for some other reason the base level of the streams would change, and dissection of the surface would begin anew. The bedrock surface in the Dayton area ranges in altitude generally between 900 and 1,000 feet. This surface represents a well-developed peneplain, the Lexington, which can be traced over much of western Ohio, eastern Indiana, and Kentucky. The Lexington peneplain was uplifted in several stages, according to Fenneman (1938, p. 441, 443). The last rise occurred in late Tertiary time, perhaps 10 or 15 million years ago, and resulted in the deep trenching of valleys.

In Logan County, about 50 miles north of Dayton, is a small area of higher terrain which reaches a general altitude of more than 1,200 feet and contains the highest point (1,550 ft) in Ohio. This higher area, known to geologists as the Bellefontaine outlier, is an erosional remnant of the Harrisburg peneplain, a well-developed surface in southeastern Ohio and adjacent States. Rocks of the Bellefontaine outlier include limestone and shale of Silurian and Devonian ages, which are younger than the bedrock in the Dayton area. These younger rocks are areally extensive in central and eastern Ohio, as they formerly were in much of western Ohio.

PREGLACIAL (TEAYS STAGE) DRAINAGE

The main streams draining the Central Lowland province flowed generally northwestward from at least the beginning of the Lexington cycle until the drainage was disrupted by glaciers early in the Pleistocene Epoch. The principal preglacial (actually late Tertiary) stream is called the Teays River. The Teays River, which compared in size with the present Ohio River, flowed from the Piedmont Plateau of Virginia and the Carolinas across West Virginia, Ohio, Indiana, and Illinois to the Mississippi embayment. It entered Ohio at a point near Portsmouth, flowed north to the vicinity of Chillicothe, and thence generally northwest past London, Springfield, Sidney, and St. Marys to the Indiana line (Stout and others, 1943, p. 52). The course of the Teays River lay about 30 miles northeast of Dayton at its nearest point (fig. 2).

South of Chillicothe, in the unglaciated part of Ohio, the Teays River valley is 1½–2 miles wide and lies about 200–250 feet below the hills on either side. The valley is choked with 50 feet or more of

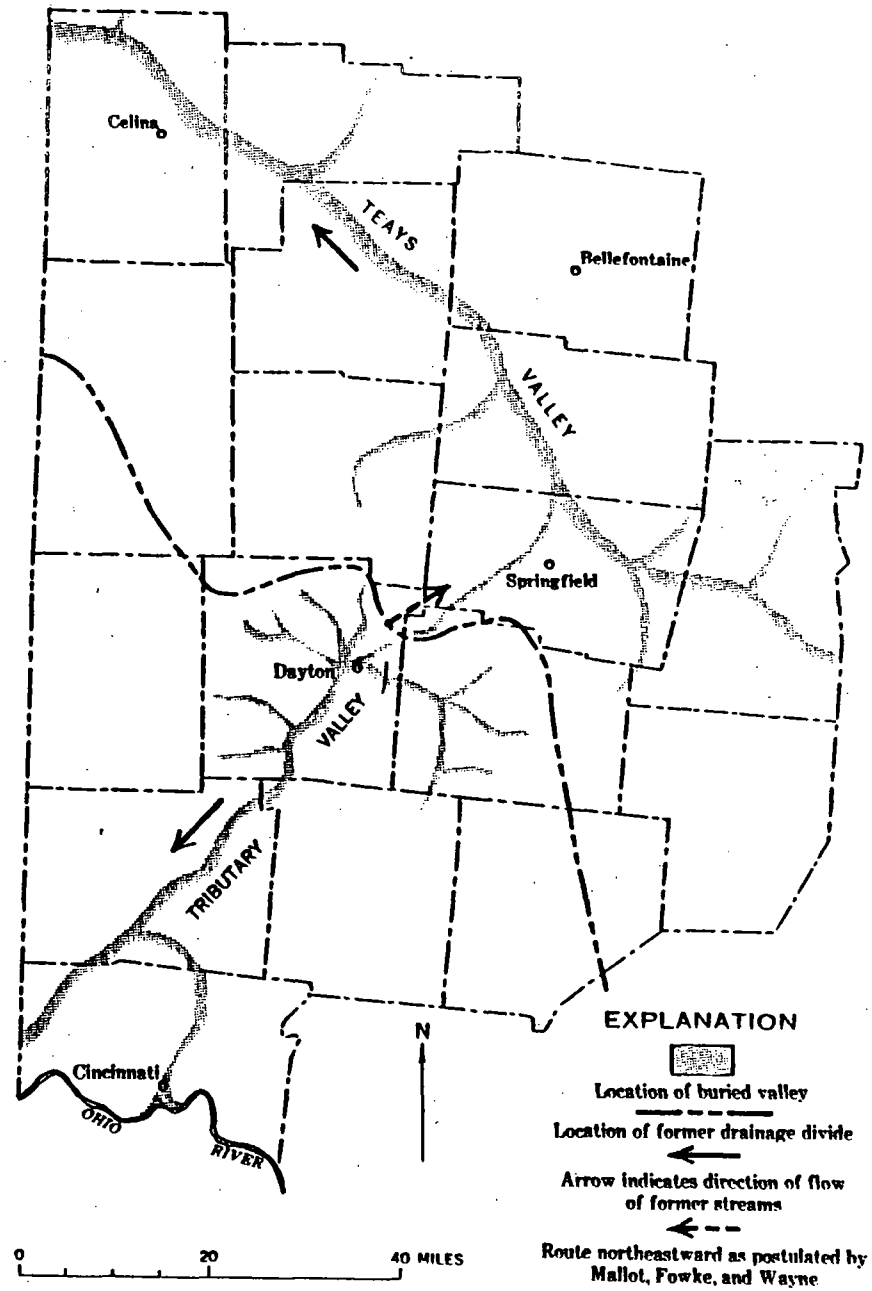

FIGURE 2.—Approximate location of Teays Stage valleys in western Ohio (modified from Stout and others, 1943).

lacustrine clay and alluvium, which forms a relatively flat floor upon which the modern streams flow. The courses and gradients of the modern streams bear little or no relation to those of the former Teays River.

The gradient of the Teays Valley between Wheelersburg, on the Ohio River, and a point near Lake St. Marys, in Mercer County, is about 10 inches per mile. The altitude of the valley floor is given by Stout, Ver Steeg, and Lamb (1943, p. 53) as 660 feet at Huntington, W. Va.; 650 feet near Wheelersburg, Scioto County; 630 feet at Omega, Pike County; and 590 feet at Chillicothe, in Ross County. North of Chillicothe the Teays River valley is buried by glacial drift, and its course is known only from well records and the results of geophysical investigations. The altitude of the buried Teays River valley, determined by test drilling, is 568 feet in the south-central part of Madison County; 556 feet near London, in Madison County; 548 feet near Springfield, in Clark County; and 538 feet in the southern part of Champaign County, west of Urbana (Norris and Spicer, 1958, p. 218). The altitude of the buried Teays River valley near the Indiana line is given by Stout, Ver Steeg, and Lamb (1943, p. 53) as 460 feet.

At various points along its course in Ohio the Teays River was joined by major tributaries (fig. 2), which, like the Teays River itself, carved broad deep valleys. The tributary valleys join the Teays River valley at accordant levels, and the entire system is well graded to the same regional base level. This stage in the peneplanation of a region is known as the strath stage and here marks the beginning of another peneplain at a lower level than the Lexington surface. The level represented by the bedrock floor of the Teays River valley and its major tributaries is called the Parker strath (Fenneman, 1938, p. 301). In southern Ohio the Teays River valley was abandoned as a major drainageway when the Parker erosional cycle was disrupted at the beginning of the Pleistocene Epoch. In other areas the Teays Stage valleys were used by streams of later drainage systems, some of which flowed in opposite directions to the Teays Stage streams. Where this occurred, the younger streams commonly cut below the levels established in Teays time, leaving remnants of the Parker strath as terraces along the valley walls.

The major valleys in the Dayton area were established, at least in part, by Teays River tributaries. Geologists are in general agreement on this point; however, opinions are sharply divided concerning the direction of flow of these tributaries and the level to which they cut their valleys during the Teays cycle. According to Stout, Ver Steeg, and Lamb (1943, p. 70), the Dayton area was a headwaters area in

Teays time and was drained by a south-flowing tributary, which they called the Hamilton River. They wrote (1943, p. 70) that the Hamilton River "gathered its headwaters south of the col [constriction in a valley; this one is at the site of a former divide from which streams flowed in opposite directions] at West Milton on the present Stillwater River, near Tadmor on the present Miami River, and above Harshman on the present Mad River. The stream thus formed by the convergence of tributaries at Dayton flowed southwestward past Miamisburg * * * Middletown * * * and Hamilton." The Hamilton River, according to these geologists, joined with larger tributaries that turned westward near Cincinnati and entered the Teays River somewhere in Indiana.

The altitude of the Teays tributary valley at Dayton was estimated by Stout, Ver Steeg, and Lamb to have been about 714 feet. This is approximately 175 feet higher than the Teays River valley in southern Champaign County; however, a wide difference in altitude between these valleys would be expected, if Dayton were part of a headwaters area as the aforementioned geologists believed. Norris (1948, p. 148), concurring with this interpretation, stated that in Montgomery County "remnants of the Teays valley floor occur as terraces along the sides of some of the more recent valleys at elevations ranging from 750 to 770 feet for former tributaries in the northern part of the county, to elevations as low as 650 feet along the main stream in the southern part of the county."

Stout, Ver Steeg, and Lamb's hypothesis of a south-flowing Teays tributary in the Dayton area was challenged by W. J. Wayne, who studied the buried Teays drainage system in Indiana. Wayne (1953, p. 575–585) favored the view advanced by Malott (1922, p. 136–138) and Fowke (1925, p. 87) that, prior to the formation of the Ohio River, the Kentucky River flowed northeastward through "the old Miami Valley" to a junction with the Teays River in northwestern Ohio. If this is true, the principal Teays tributary in Dayton flowed at a level only slightly above that of the master stream, which crossed the State only a few miles northeast of Dayton. The altitude of the valley of a hypothetical north-flowing Teays tributary would be about 570 feet in downtown Dayton. This figure was obtained by assuming a gradient of about 1 foot per mile for the tributary stream and the likelihood that such a stream would have joined the Teays River some 30 miles downstream in Champaign County, where the altitude of the Teays River valley floor is 538 feet (Norris and Spicer, 1958, p. 218).

Neither the hypothesis of Stout, Ver Steeg, and Lamb, nor that advanced by Wayne, Malott, and Fowke can be affirmed on the basis of evidence obtained in the area of this report. The generalized

character of the bedrock contours on the geologic map (pl. 1), which are based on records of wells, indicates that insufficient data are available with which to form an interpretation. The map, as it is drawn, does show a wide bench or terrace in the bedrock between altitudes of about 550 and 600 feet, occurring on both sides of a much narrower and deeper valley. This terrace level may represent the floor of an early valley, possibly of Teays age. The narrower and deeper channel represents the valley of a Deep Stage stream.

The direction of flow in the Dayton area of the Teays Stage streams (south, as Stout, Ver Steeg, and Lamb stated, or north as Wayne believed) is a matter of speculation for the time being. Stout, Ver Steeg, and Lamb's concept has been criticized on the basis that the divides supposedly located at West Milton, Tadmor, and near Harshman (at the site of Huffman Dam) are only about 25 miles from the Teays River valley, and two major drainage systems would not have coexisted so close together in similar geologic terrane at such widely divergent levels. Moreover, these divides, if there were such, must have been relatively narrow, perhaps much less than a mile wide, as judged from inspection of a topographic map. It would be indeed fortuitous, say the critics, if during the long Teays interval the tributaries of two major streams, the Teays River and the Hamilton River, rose within a few thousand feet of each other without one or the other being captured by stream piracy. And, finally, the critics point out, many of the bedrock valleys that relate to the so-called Hamilton River appear to have contained north-flowing streams, rather than south-flowing streams, as postulated by Stout, Ver Steeg, and Lamb.

In criticism of Wayne's hypothesis, on the other hand, insofar as the Dayton area is concerned, the cols at Tadmor and West Milton are much less than half a mile wide, which clearly seems too narrow to accommodate a major Teays tributary that Wayne said carried the drainage of the entire Kentucky River basin. The third col, at the site of Huffman Dam, is about 3,000 feet wide and could have served as outlet for the waters of a major stream. However, a way has not been found by which such a stream could have reached the Teays River valley in Champaign County. The route northeastward by way of the Mad River valley is blocked by a col, which is only about one-fourth of a mile wide near Springfield (Norris and others, 1952, pl. 1). Control on bedrock mapping in western Clark County is so complete as to virtually rule out passage of a major north-flowing Teays tributary, except possibly between Medway and New Carlisle. To enter the Teays River valley, such a stream would have had to turn west at New Carlisle and follow a circuitous route northward through

eastern Miami County and thence eastward to the Teays River valley in the vicinity of St. Paris in western Champaign County. Few wells have been drilled to bedrock in eastern Miami County, and the possibility that a buried valley having the course just described exists cannot be ruled out. What amounts to "negative" evidence, however, hardly seems a sound basis for the support of a far-reaching concept such as Wayne's.

Elements of both concepts may be correct. The Hamilton River may have come into being at the time of uplift of the Lexington peneplain and may have followed the course described by Stout, Ver Steeg, and Lamb. Eventual reduction of the col at Huffman Dam and headward erosion of a Teays tributary originating in Champaign County may have reversed the upper Hamilton River, which then followed a course northward as suggested by Wayne. Whatever the truth, and evidence may become available someday that will settle the issue, after several million or several tens of million years, the Teays drainage system was completely disrupted and obliterated by the great ice sheets of the Pleistocene Epoch.

PLEISTOCENE GLACIATION

PRE-ILLINOIAN GLACIER

The Teays drainage system was disrupted and a new stream system was started when an early glacier, possibly the first of the Pleistocene Epoch, advanced southward into the Central Lowland province. This early glacier dammed the Teays River by filling the valley with glacial drift, thus producing widespread lakes in the valleys of the Teays River and its principal tributaries. These lakes were in existence for a long time, as indicated by thick and extensive deposits of lake clay and silt which accumulated in the valleys. The lake deposits extend well to the north of the glacial boundary, indicating that the glacier that dammed the Teays River did not advance as far south as did the ice of later stages. The damming may have occurred in Ohio (Stout and others, 1943, p. 78) or in the area southwest of Ft. Wayne, Ind. (Norris and Spicer, 1958, p. 219–225).

MINFORD SILT

Stout and Schaaf (1931) named the aforementioned lake deposits the Minford Silt, from exposures in southern Ohio. In southern Ohio the formation attains a maximum thickness of more than 80 feet and is found at altitudes as high as 860 feet. In and near Madison County, in west-central Ohio, where the Teays River valley is competely buried by glacial drift, the Minford Silt at the sites of 12 scattered test holes ranges in thickness from 18 to 264 feet. (Nor-

ris and Spicer, 1958, p. 219). The highest altitude at which the Minford Silt was found in these test holes is 850 feet, at a site in south-central Madison County.

The Minford Silt is more a clay than a silt, as it is generally finer grained than a true silt. Typically, it is dull blue gray to reddish brown, soft, and, when wet, highly plastic. The constituent particles are so fine that when soaked in water they may stay suspended for days (Stout and Schaaf, p. 667, 668). The Minford Silt is not a source of ground water and, where it lies directly on relatively impermeable bedrock as it does over wide areas in west-central Ohio, it marks the lower limit of ground-water supplies.

The Minford Silt has not been identified in the Dayton area. If it occurs there at altitudes comparable to those reported for it in Madison County, it should be present well up on the sides of the major valleys, considerably above river level. Identification of the Minford Silt in the Dayton area would go far toward confirming Wayne's concept of a north-flowing Teays tributary in that area.

The lake stage in the Teays River valley ended when the lake waters, which had found outlets across low divides into adjacent drainage basins, cut through these divides and allowed the lakes to drain. When the lake stage ended is conjectural; it may have ended relatively soon (a few hundred or a few thousand years perhaps) after the retreat of the glacier that dammed the Teays River.

INTERGLACIAL (DEEP STAGE) DRAINAGE

After the Teays drainage system was disrupted, drainage was reestablished along radically different lines, somewhat similar to those of the present Ohio River system (fig. 3). The post-Teays drainage system is called Deep Stage because of the depth of the valleys. Deep Stage time was a period of valley entrenchment, and streams of the Deep Stage system in the Dayton area cut the bedrock valleys to their present depths, well below Teays levels.

Deep Stage streams in the Dayton area followed courses similar to those of the modern streams. The main stream flowed southward, along the courses now followed by the Mad and Miami Rivers, to the ancestral Ohio River (Stout and others, p. 78). In Deep Stage time, as at present, Dayton lay at the confluence of several large tributary streams. These Deep Stage streams, flowing on the Ordovician shales, cut to altitudes below 500 feet. The lowest point of record in the Dayton area is south of the city, at the Dryden Road well field of the Montgomery County Sanitary Department. At this place, near the mouth of Holes Creek, a test hole was drilled 229 feet to bedrock, which was reached at the altitude of 490 feet. Within the city the

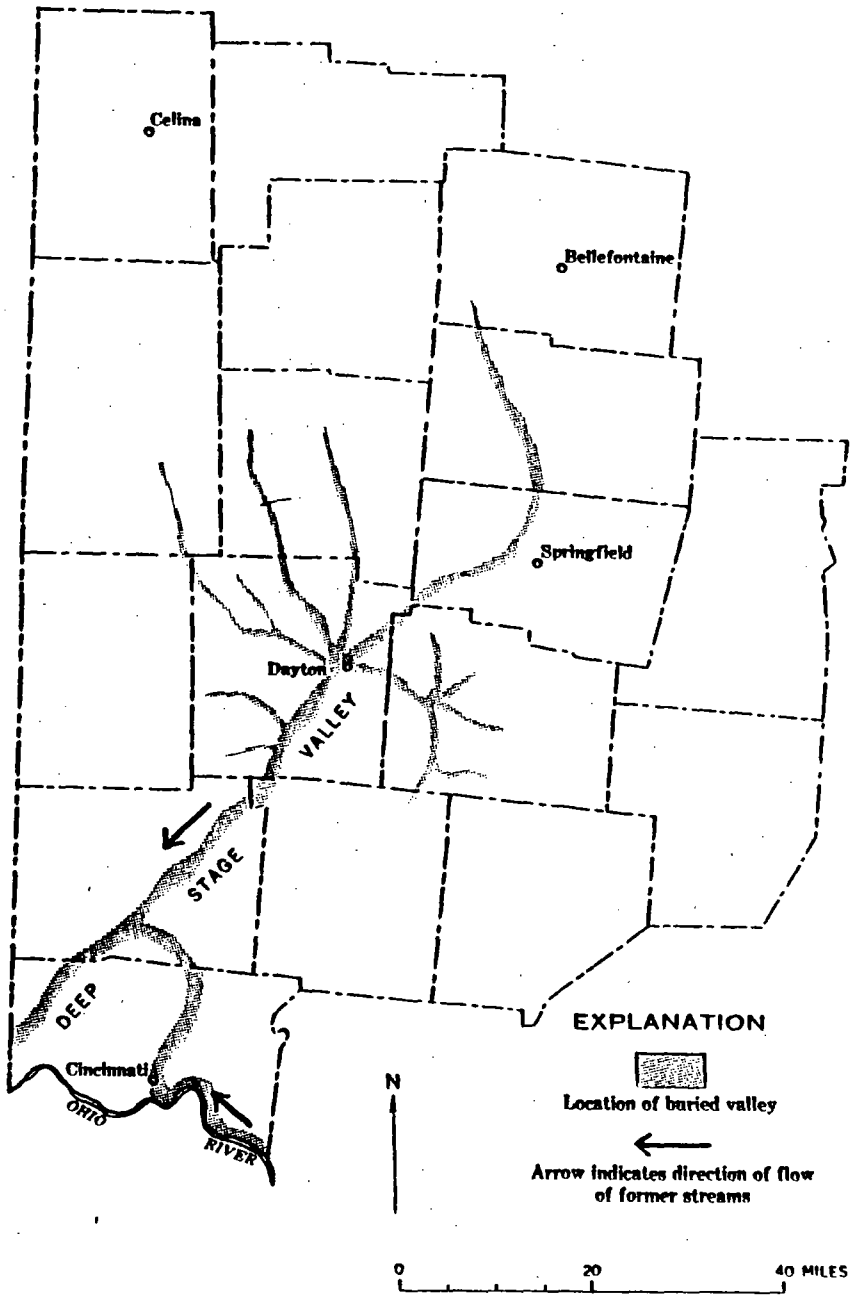

FIGURE 3.—Approximate location of Deep Stage valleys in western Ohio (after Stout and others, 1943).

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lowest known point on the bedrock is beneath the intersection of First and Findlay Streets, where a well drilled for gas or oil in 1887 reached bedrock at a depth of 247 feet, or at an altitude of approximately 500 feet. Only fragmentary data are available relative to the altitude of the floor of the buried Deep Stage valley south of Dayton. At Venice (Ross Post Office), 7 miles south of Hamilton, the altitude of the buried valley floor is 364 feet. If the altitude at Venice and the altitude of 500 feet determined at First and Findlay Streets in Dayton are the minimum for their respective locations, the Deep Stage valley between these points, 45 miles apart, has a gradient of about 3 feet per mile. This is about the same as the gradient of the Miami River valley between Dayton and the Ohio River. If the gradient of the bedrock floor of the buried valley is about 3 feet per mile, the test hole at the county-owned well field near the mouth of Holes Creek evidently was not in the deepest part of the channel in that area but bottomed on bedrock on the side of the valley, some 10 or 15 feet above the lowest point.

The shape of the lateral profile of the bedrock valley underlying Dayton cannot accurately be determined from available data. The shape of the valley can be inferred in a general way, however, from what is known about the Deep Stage cycle and the geometry of normal stream development. Deep Stage streams did not attain a graded condition and were still incising their valleys when the cycle ended. The lower part of the principal buried valley at Dayton—that due to Deep Stage cutting—can be assumed, therefore, to have a V-shaped cross section. The sides of the V are asymmetrical, and the slope at any point depends on the relation of the valley to the meanders of the former stream. Typically, a valley is steeper on the outside than on the inside of a meander. Additional generalizations concerning the valley profile are not warranted, owing both to the uncertainties regarding the Teays Stage level and to the scarcity of well records that reveal the depth to bedrock in the Dayton area. The minimum altitude of the bedrock floor of the buried valley in the greater part of downtown Dayton is at or a little below 500 feet. The depth to bedrock at any point in that area therefore approaches 250 feet as a maximum.

ILLINOIAN AND WISCONSIN GLACIERS

The Deep Stage drainage system was ended by the advance of the Illinoian ice sheet. Ice of the Illinoian and Wisconsin sheets advanced into and beyond the Dayton area, deranged the drainage lines, filled most of the valleys, some to the point of obscurity, and left the terrain with its present appearance.

The bedrock contours on the geologic map (pl. 1) show the configuration of the buried channels produced by the Teays and Deep Stage streams. Four Deep Stage tributaries to the ancestral Miami River came together in what is now downtown Dayton and formed a wide deep trough, which glacial-outwash materials later filled.

SPECIALIZED INVESTIGATIONAL TECHNIQUES

The widespread presence of relatively impermeable layers of till in the sand and gravel aquifers necessitated the development of criteria for their recognition as well as the use of specialized techniques, some of which are not widely understood and warrant discussion here.

The pronounced effects of interbedded till layers on the water-yielding properties of the valley-train deposits, and consequently the consideration that must be made of these layers when wells are located and when aquifers are artificially recharged, require that till and other relatively impermeable deposits be identified during drilling and that these deposits be traced laterally from well to well.

Drillers commonly report till in well logs as "hardpan" or "blue clay" (the second term refers to unweathered material; oxidized till is called "brown clay") and sometimes as "clay and stones" or "clay and gravel." Unfortunately, drillers often find it difficult to distinguish between till deposits, many of which may contain numerous stones and rock fragments in the clay matrix, and so-called "dirty" sand and gravel, which contains much silt and clay. Moreover, the driller's interpretation of the material in which he is drilling may be affected by the sharpness of the bit, the depth of the hole, and the amount of water in the hole. Thus, the accuracy of well logs varies considerably, and the logs of several closely spaced wells may suggest as many different interpretations of the sequence of deposits as there are records. Of course, glacial deposits commonly do change both laterally and vertically over short distances, further complicating the interpretation of drillers' logs. Several methods of identifying till layers are described in the next four sections.

STATIC WATER-LEVEL CHANGES

One of the greatest aids to the ground-water geologist in determining the hydrologic properties of the valley-fill deposits, and in identifying areally extensive till layers, is a record of changes in water level made while a well is being deepened. In areas of large ground-water withdrawal, the hydrostatic head in an aquifer overlying a till layer may be several feet higher than the head in a similar aquifer immediately below the till layer. Where this condition occurs the water level in a well being drilled usually changes abruptly when the casing

is driven through the intervening till into the lower aquifer. An illustrative example is shown by the records of several test wells (329–333) drilled in 1951 at the McCall Corp. plant in the west-central part of Dayton. Here abrupt changes in water level of as much as 20 feet are reported in wells drilled through a till layer at depths between about 75 and 105 feet. Unfortunately, these are the only available examples of such a striking change in water levels, since few drillers bother to note these changes as they deepen a well.

ELECTRIC (GAMMA-RAY) LOGGING

By far the best method of determining the sequence of beds in the valley-fill deposits and of tracing till layers laterally from well to well is by electric logging of wells, especially gamma-ray logging, which can be done in cased wells. Electric-logging equipment was not available for use in this investigation; however, a few gamma-ray logs, which were very helpful in the geologic interpretation, were furnished by Mr. D. J. Roe of Vandalia, Ohio. Because of the usefulness of gamma-ray logging in water-resources investigations of glacial terrane, a brief description of the method is appropriate here.

Gamma-ray logging techniques are based on the fact that all rocks contain radioactive materials, which emit gamma rays. Generally speaking, limestone and dolomite are much less radioactive than shale, silt, and clay. Glacial till, which in the Dayton area is composed chiefly of clay, is therefore much more radioactive than the associated sand and gravel, which is composed largely of limestone and dolomite fragments. An electrical probe sensitive to gamma-ray emission is lowered in a well. The probe is connected through a cable to a device at the surface that records a curve or log showing the radioactivity, and by interpretation the geologic characteristics, of the formations penetrated by the well. Tills are usually distinguishable from sand and gravel on the gamma-ray logs, and the correlation of formations with similar formations in nearby wells can be made with far more confidence than by the use of drillers' logs alone.

Figure 4 shows a representative gamma-ray log, made by Mr. Roe, of a test hole drilled at the site of production well 609, at the Frigidaire Division plant at Moraine City. A geologic interpretation of the gamma-ray log also is shown. On the basis of the gamma-ray log, well 609 was screened at depths of 92–108 feet and 134–150 feet. On test the well was pumped at the rate of 2,000 gpm and a drawdown of only 9 feet resulted, which indicates an exceptionally good capacity. Availability of more gamma-ray logs would have been very helpful to the authors during this investigation.

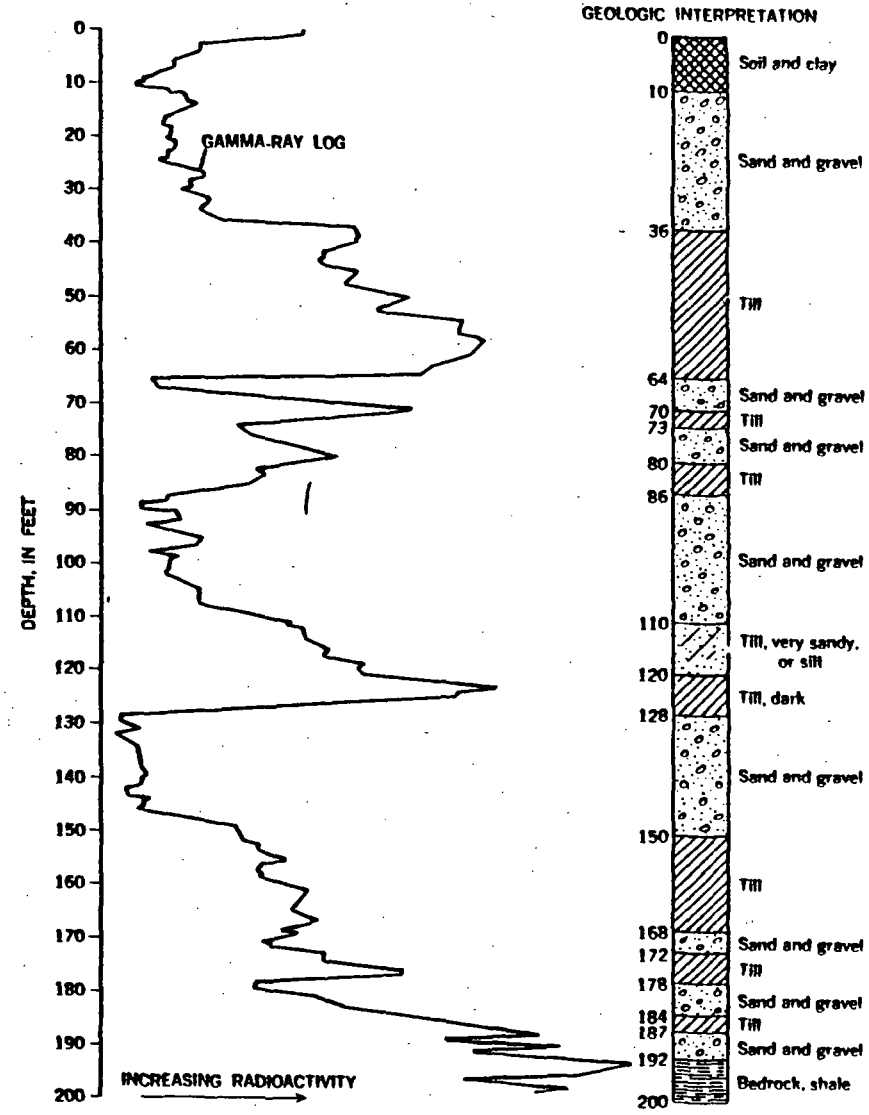

FIGURE 4.—Representative gamma-ray log and geologic interpretation of uncased test hole, drilled at the Frigidaire Division plant at Moraine City.

TEMPERATURE-DEPTH RELATIONS

A promising method for identifying interbedded till layers in the Dayton area is that of plotting water-temperature changes in wells at various depths and relating the shape of the resulting temperature-gradient curve to the local geology. Where the circulation of ground water is relatively rapid, such as near large centers of pumping or

sources of recharge, differences in temperature of water in aquifers that are separated, or partly separated, by till may be large enough to be detected by sensitive, thermistor-type thermometers. The basis of the method is most easily explained by considering examples of temperature gradients to be expected in hypothetical wells drilled under three idealized sets of flow conditions. The explanation is further simplified by specifying that the temperature of the water infiltrating from a source stream is higher than the temperature of the water in the aquifer. In Ohio this condition commonly occurs in late spring and summer.

The first of the three hypothetical flow systems considered is that occurring in a homogeneous heavily pumped sand and gravel aquifer traversed by an infiltrating stream. The temperature of the water in a fully penetrating observation well drilled between the source stream and the well being pumped will decline steadily from the top of the aquifer to the bottom. A plot of water temperature related to depth yields a straight line, as is indicated by the accompanying graph (fig. 5*A*). This is the simplest of the three hypothetical flow systems.

Consider next an otherwise homogeneous aquifer in which a horizontal layer of till of small areal extent occurs (fig. 5*B*), situated with respect to a large center of pumping so that some water enters the pumped wells after leaking vertically downward through the till, while the remainder of the water flows around the till layer and enters the wells by a more circuitous route. Under these conditions the temperature gradient in the observation well (fig. 5*B*) will be approximately linear both above and below the till. However, as the diagram shows, that part of the line representing temperatures below the till will be displaced, relative to the temperature-gradient line above the till, in the direction of lower temperature. The position of the till layer in this idealized flow system is indicated by a pronounced "blip" on the temperature-gradient line, caused by the colder water in the till.

The third hypothetical flow system considered is that of two aquifers hydraulicly separated by a laterally extensive till layer, through which all recharge to the deeper aquifer must pass (fig. 5*C*). Under these conditions that part of the temperature-gradient line depicting temperatures beneath the till will be displaced relative to that above the till by the colder water in the till and in the lower aquifer. However, unlike conditions shown in the second example (fig. 5*B*), the temperature of the water beneath the completely separating till layer will be no higher than that of the water in the till. Thus the temperature in the observation well will always decline with depth, but the rate of decline will increase significantly in the till.

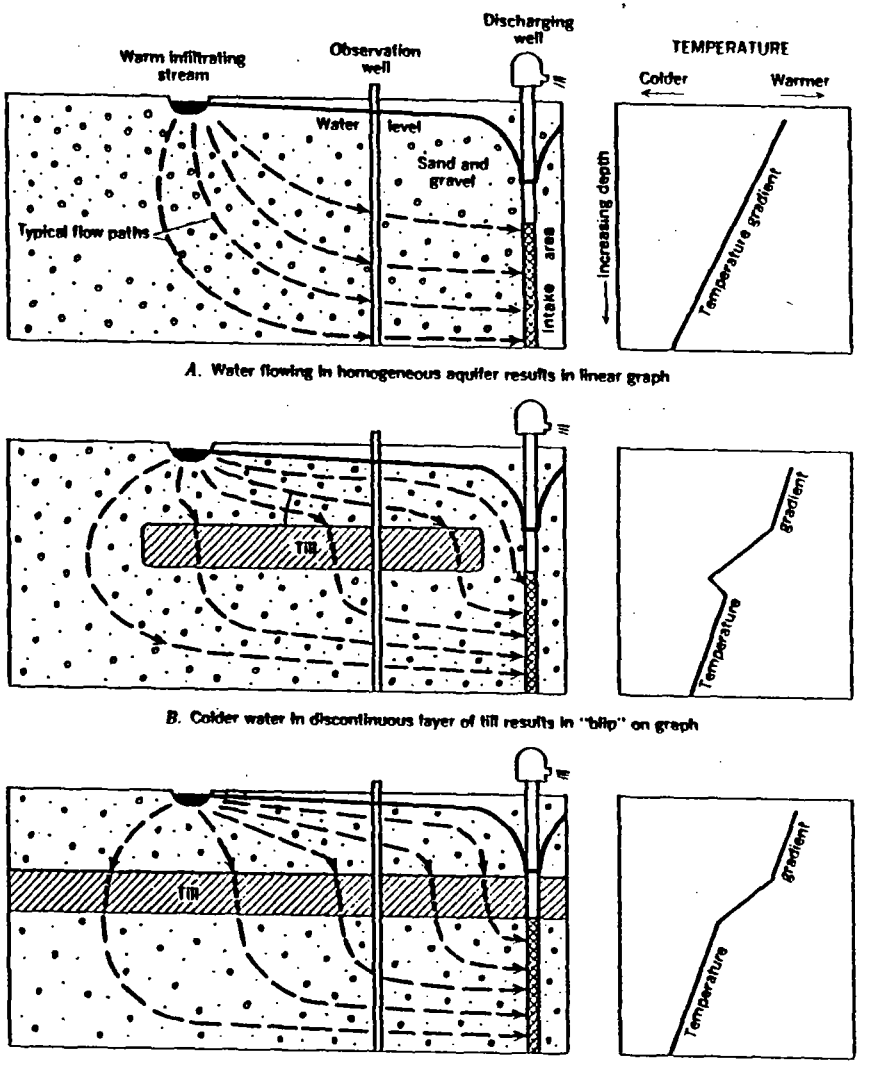

FIGURE 5.—Idealized ground-water circulatory systems, showing characteristic temperature-gradient curves resulting from infiltration of warm water into relatively cool aquifer under various geologic conditions.

The method of using temperature gradients in wells to identify hydrologic conditions has been tried at only one place in the Dayton area, at the Frank M. Tait Station of the Dayton Power & Light Co. in south Dayton. Temperatures were measured in two 2-inch observation wells (530 and 531) drilled in a well field yielding approximately 5 mgd at the time the measurements were made, in June 1957. At

this time the water in the Miami River was appreciably warmer than the ground water, a condition similar to that specified in the discussion of the hypothetical flow systems. The temperature gradients in the two observation wells at the Tait Station indicate that discontinuous layers of till interbedded with the valley-train deposits are present there. (See fig. 6.) This interpretation is borne out by other geologic and hydraulic evidence, described in the section "Character of the Valley-Fill Deposits" and elsewhere in this report.

The temperature-gradient method deserves further testing and refinement under a wide variety of hydrologic conditions and also in representative wells measured repeatedly during various seasons of the year. The growing use of highly sensitive, relatively inexpensive thermistor-type thermometers should result in rapid advancement of what may become a very useful hydrologic technique.

SEASONAL TEMPERATURE CHANGES

Another method of determining from water-temperature data the presence or absence of semiconfining beds is based on annual temperature fluctuations in wells. If two wells drilled in a homogeneous and isotropic aquifer and located at equal distances from a source stream receive replenishment principally from the stream, the temperature of the water pumped from the wells will vary with seasonal changes in stream temperature. Graphs relating temperature of water from wells and from streams to time will each have the same general shape. The amplitude of the fluctuations of well-water temperature will not be as great as that of the stream temperature, and the seasonal high and low temperatures of the ground water will lag behind those of the stream. If the two wells are of unequal depth, differences in amplitude of the temperature fluctuations and in time of arrival of seasonal highs and lows from the source stream will be apparent, but the curves will have the same general shape unless the inequalities of depth are very great.

The presence in the water-bearing deposits of a semiconfining bed through which the water must leak, or around which water must flow to reach the wells, will change the shape of the ground-water temperature curve. If at the site of one well the flow of ground water is impeded by a semiconfining bed, the annual-temperature graph for that well will be different from the annual-temperature graph for another well where there is no semiconfining beds. The semiconfining bed will, in general, dampen the seasonal temperature fluctuations, and a relatively flat curve will result. Differences in the annual temperature graphs caused by semiconfining beds were recorded in two wells at the Tait Station of the Dayton Power & Light Co. (fig. 7).

CHARACTER OF THE VALLEY-FILL DEPOSITS

The wide valleys at Dayton, which were cut deeply into the bedrock by streams of the Teays and Deep Stage drainage systems, were filled during the ensuing glacial stages principally with sand and gravel, laid down as valley train by melt water, and with till which occurs as lenses and layers interbedded with the sand and gravel deposits. Though constituting a relatively small part of the valley-fill deposits, the till is a major hydraulical factor because it slows recharge to the deeper wells.

Glacial ice melts unevenly and at varying rates. Moreover, periods of melting commonly are interspersed with intervals of relative cold during which glaciers may temporarily resume their growth. The valley-train deposits were laid down under variable conditions, and although at a distance they seem generally uniform, alternate layers of silt, sand, and gravel, representing a wide range of grain sizes, are visible up close. Layers of coarse gravel may be sharply bounded above and below by beds of markedly finer material, and, in many places, beds of coarse gravel may grade laterally into finer material over comparatively short distances.

Goldthwait (1959, p. 206) described as follows the way in which a typical valley-train deposit is formed:

> Wherever a glacier ends in a region which slopes away from the ice, the waters which issue from one or more tunnels in the ice edge head down the nearest valley lowland. Many million gallons are produced on warmest days. Coming from the basal ice, the water is milky with the rock flour of glacial till and it has a full bed load of sand and gravel. In fact, more tons of particles are fed into the stream at the glacier than ever reach the lake or sea, so there must be constant addition to the surface or the plain. Some load is dropped on each bar thus filling up the shallow channel and causing the water to spill over to the right or left and start an additional channel. All glacial outwash rivers become braided by dividing into many channels each ten to 100 feet wide and one to ten feet deep. The water runs nearly flush with the surface. Most of the coarsest cobble part of the load gets left on the first few upstream bars, but in their place the water gathers some smaller pebbles already there. * * * When one side of the valley plain builds ten to 20 feet higher, the braided currents shift to the low side of the valley. The resulting "valley-train" is smooth with only minor little scarps (five to 20 ft.) and abandoned channels. * * * This was the scene in most south-flowing valleys in Ohio as the ice retreated.

The events that Goldthwait describe were repeated several times in the Dayton area, at least once during each of the major glacial stages and substages. Each time the glaciers melted, the principal valleys were partly filled with sand and gravel, and during each of the long interglacial intervals—each lasting several tens of thousands of years—streams similar to those that now occupy these valleys began their slow work of erosion and removal of the deposits over which

they flowed. During the long interval between the Illinoian and Wisconsin glacial stages, which may have lasted more than 100,000 years (Goldthwait, in Norris and others, 1948, p. 28; Rubin, 1960, p. 289), most of the material deposited by the Illinoian and earlier glaciers probably was removed from the bedrock valleys by stream erosion.

With the onset of the Wisconsin glacial advance, conditions that had prevailed during the preceding interglacial interval changed. Except during the few warm days in summer, rivers dwindled or stopped flowing altogether, and their place was taken eventually by tongues of ice, which moved southward in advance of the main ice mass. These ice tongues, or valley glaciers, are mainly responsible for the extensive deposits of till that occur nearly everywhere in the valley-train deposits. In central Dayton, where four valley glaciers coalesced, the interbedded till deposits are relatively thick and extensive.

In some parts of the Dayton area, well-defined till sheets, buried by 30–60 feet of sand and gravel, extend almost entirely across the major valleys and separate the valley-train deposits into two or more distinct aquifers. For example, at Rohrers Island, in the Mad River valley, wells of the Dayton municipal well field tap two aquifers, one lying above and the other below a layer of till that ranges in thickness from about 11 to 50 feet (Norris, 1959, p. 3).

Drillers' logs, gamma-ray logs of wells, and water-level data show that conditions similar to those at Rohrers Island prevail generally in the major river valleys of the Dayton area. The valley-train deposits, in most places, are separated into an upper aquifer and a lower aquifer. Section *A–A′* (pl. 3), extending along the middle of the Miami River valley from the mouth of Holes Creek northward to north Dayton and thence up the Mad River valley to Huffman Dam, and sections *B–B′*, *C–C′*, *D–D′*, and *D–D″* (pl. 3), extending across the valley, show clearly a zone as much as 80 feet thick, predominantly of till, interbedded with sand and gravel deposits. (See pl. 1 for location of geologic sections.) In places, this till-rich zone is made up of well-defined areally extensive till sheets; elsewhere it consists of numerous lenses and irregular masses of till grouped closely together at approximately the same altitude. The till is more irregular in distribution near the sides of the valleys than in the central part.

In small areas, notably in the Mad River valley immediately below Eastwood Park, the till either is absent from the sand and gravel deposits or consists only of a few scattered lenses. Elsewhere, there are small openings in otherwise extensive till sheets; these probably represent stream channels cut through the till when it was exposed at the surface. These openings or channels are indicated by the absence of till in one or two records of several closely spaced wells.

The upper surface of the till-rich zone lies generally 30–50 feet below the land surface in downtown Dayton. The base of the zone, which is much more irregular than the upper surface, ranges from about 60 to 125 feet below land surface. These levels are somewhat arbitrary, as the sand and gravel deposits both above and below the till-rich zone contain scattered lenses and masses of till that make it difficult in places to correlate the deposits from well to well.

Locally in the Miami River valley in central and northern Dayton, and more extensively in the Mad River valley downstream from Findlay Street, the till-rich zone consists of two till layers, separated by several feet of sand and gravel. The upper till layer generally is thinner and less extensive than the lower till layer. Athough locally the intervening sand and gravel constitutes a separate aquifer, it is herein considered part of the upper aquifer.

The sequence of late Pleistocene events described by Goldthwait indicates that the till-rich zone and the overlying sand and gravel probably are associated with the late Wisconsin substage. Therefore, the sand and gravel that underlies the till-rich zone was probably deposited during the retreat of the early Wisconsin glacier. The early Wisconsin glacier also deposited till on or only slightly above the bedrock in most of the Dayton area, except in the relatively narrow Deep Stage channels, which in a few places probably contain sand and gravel left by a still earlier glacier.

The interval between the end of the early Wisconsin substage and the beginning of the late Wisconsin substage was not long enough for the streams to erode from the valleys much of the early Wisconsin sand and gravel deposits. Thus, when the late Wisconsin ice sheet advanced to the Dayton area, it moved down the valleys over early Wisconsin sand and gravel deposits of considerable thickness.

The relatively shallow till layer, which composes part of the till-rich zone in the Miami River valley in certain areas in central and northern Dayton and in the lower Mad River valley, probably was deposited during the local readvance of the late Wisconsin glacier, described by Goldthwait (Norris and others, 1948, p. 34). In most places these shallower till deposits are thinner and less extensive than those associated with the main advance of the late Wisconsin glacier. The glacier moved a relatively short distance when it readvanced, and, generally, the ice transported less material than it did during the main advance. However, in central Dayton the shallower till is thicker and more extensive than the lower till.

The till-rich zone cannot be separated into an upper and a lower till layer in two areas of the Miami River valley: (1) central Dayton and (2) between Dayton and the mouth of Holes Creek. However, the till-rich zone in these areas may actually consist of two tills, one lying directly upon the other. This is suggested by color changes in the till, noted in several drillers' logs. These color changes indicate not only the usual sequence of yellow, oxidized till overlying blue, unweathered till, but also the presence in a few places of yellow till beneath blue till. The latter sequence could have resulted from the deposition of younger till on the surface of slightly older, oxidized till. However, the yellow color of the till at the base of the till-rich zone also could have resulted from chemical changes caused by the circulation of ground water.

The log of a typical drilled well near the Miami River in the Dayton area shows a few feet of soil and alluvial material[1] near the surface. Beneath the soil and alluvium is 30–50 feet of sand and gravel, overlying about 30 feet of till. The till, which most drillers would call either clay and gravel or hardpan, overlies 50 or 60 feet, perhaps more, of sand and gravel. The lower sand and gravel stratum also overlies till, and this basal till, 10–20 feet thick, overlies the shale and limestone bedrock. This hypothetical and highly generalized well log reflects a simplified geologic section through the valley-fill deposits.

MIAMI RIVER VALLEY SOUTH OF DAYTON

DRYDEN ROAD WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT

South of Dayton near the mouth of Holes Creek, at the Montgomery County Sanitary Department well field on Dryden Road, four wells (M–10, M–11, M–12, M–13) penetrate deposits of till as much as 15 feet thick interbedded with the sand and gravel deposits. The till deposits range in depth from 45 to 75 feet and probably consist of a group of closely spaced lenses rather than a continuous layer. The till generally separates the sand and gravel deposits into an upper and a lower aquifer; however, recharge to the lower aquifer in this area would be expected to be relatively rapid, from water percolating downward through openings between the individual till masses. The Dryden Road well field is favorably located above the Deep Stage channel, where the sand and gravel deposits are relatively thick. Bedrock is about 230 feet below land surface and about 490 feet above sea level.

[1] Alluvium consists chiefly of sand, clay, and muck, deposited by present-day streams when they overflow their banks.

MIAMI SHORES WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT

The Montgomery County Sanitary Department is developing a new well field on the west side of the Miami River just below the mouth of Holes Creek in the Miami Shores area. In 1960 three production wells (M–14, M–15, and M–16) were drilled to depths ranging from 150 to 176 feet. A till deposit about 5 feet thick at a depth of about 68 feet was reported in all three well logs. This till is correlative with the till interbedded with the sand and gravel deposits at the nearby Dryden Road well field.

LAMME ROAD WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT

Less than a mile northeast of the Dryden Road well field is the Lamme Road well field, also part of the water-supply system of the Montgomery County Sanitary Department. Here till deposits of various thicknesses are reported at depths ranging from 40 to 81 feet, corresponding generally to the position of the till-rich zone. The till deposits are discontinuous; they are reported in the logs of only five of the nine drilled wells in the area (wells M–1 to M–9). Some logs report "dirty gravel" at the altitude of the till-rich zone.

Above the till-rich zone the sand and gravel deposits are relatively fine grained and are mixed with clay. Below the till-rich zone the deposits are "cleaner" and coarser grained, ranging from sand to coarse gravel and boulders. The deeper sand and gravel deposits enclose a lens of clay, the top of which is reported in the logs of several wells at depths ranging from about 90 to 125 feet. This clay bed, though not reported in all the logs, is 35 feet thick in places. A sample taken from well M–6, between depths of 91 and 126 feet, was described by Mr. John Eschliman of the Ralph L. Woolpert Co. as a very dense clay free of stones. This clay probably was deposited in the waters of a small lake. Though of limited extent, the clay adversely affects the yields of wells at the Lamme Road well field.

The sand and gravel deposits in both the upper and the lower aquifers at the Lamme Road well field contain a high proportion of fine-grained material, which has contributed to problems of well development and maintenance. In the 10-year life of the well field two wells have been redrilled and all the other wells have been redeveloped. Specific capacities of the wells originally ranged between about 40 and 85 gpm per ft. The specific capacities of two wells were increased to more than 100 gpm per ft by redrilling them and installing longer well screens.

Geologic section *B–B'* (pl. 3), which is drawn across the Miami River valley through the Lamme Road well field and the area of the Moraine plants of the Frigidaire Division, General Motors Corp.

shows the general character of the valley-fill deposits. Recharge from the upper aquifer to the lower aquifer is relatively rapid at the Lamme Road well field, as it is at the Dryden Road well field, because of the discontinuity of the deposits in the till-rich zone.

FRIGIDAIRE DIVISION, GENERAL MOTORS CORP. WELL FIELD

West of the Lamme Road well field, in the vicinity of the Frigidaire Division plants, the till deposits of the till-rich zone are continuous over a large area. At the Frigidaire plants all but 1 or 2 of 25 well logs show relatively thick till within a zone whose upper surface ranges in depth from about 30 to 40 feet and whose lower surface ranges in depth from about 80 to 90 feet. The till in this zone ranges in thickness from about 5 to 70 feet; the median thickness is about 30 feet. (See pl. 3.) The till, which occurs chiefly as a widespread sheet, significantly reduces recharge to the lower aquifer at the Frigidaire plant.

Evidence of the hydraulic separation of the upper and lower aquifers is shown by differences in water level in wells open above and those open below the till-rich zone. This evidence was obtained indirectly in March 1959 during repair of well 553, which was temporarily taken out of service because of a hole in the casing. The well is screened between depths of 95 and 125 feet, immediately below the till-rich zone. The hole in the well casing, which was detected by plant engineers when the well began yielding warmer water, was 44 feet below the land surface, at or near the top of the till-rich zone. In repairing the well a plug was placed in the casing a few feet below the hole to stop flow between the upper and lower parts of the well. The plug was left in place overnight, during which time the water level rose to 25.1 feet below the top of the casing, or 4.3 feet higher than it had been before the plug was put in. This shows that the water table in the upper aquifer was a few feet higher than the piezometric surface in the lower aquifer. Water pumped from the lower aquifer at the Frigidaire Division plants must either leak downward through the till of the till-rich zone or flow laterally to the wells from more distant areas where the till deposits are discontinuous or absent.

SOUTH DAYTON

DAYTON POWER & LIGHT CO. WELL FIELD, FRANK M. TAIT STATION

The Frank M. Tait Station of the Dayton Power & Light Co. (formerly the Miller's Ford Sta.) is just within the southern limits of Dayton, on the south bank of a wide meander in the Miami River not far from Carillon Park. Till, corresponding in altitude to the till-rich zone, is reported in 10 of 12 logs of wells drilled in the vicinity of

the Tait Station; however, there is wide variation in the reported depths of the till deposits and a range of 3–20 feet in their thickness. The till-rich zone evidently consists chiefly of closely grouped, irregular lenses of till, rather than a continuous and widespread sheet. (See geologic section *A–A'*, pl. 3.) The logs of well 524 and the preliminary test hole (well 607) drilled at the same site show almost no till at the position of the till-rich zone.

Graphs of temperature gradients measured in wells 530 and 531 provide additional evidence of local gaps in the till-rich zone. The graphs show that some water flows through these openings in moving from the upper to the lower aquifer. Figure 6 shows drillers' logs of wells 530 and 531, beside which are plotted the respective temperature-gradient curves. Except for the somewhat anomalous lower part of the temperature-gradient curve for well 531, which suggests the presence of an unlogged till deposit, zones of colder water closely correspond in depth to deposits of till as logged by the driller, while warmer water is associated with the intervening or underlying sand and gravel deposits. The temperature in the wells was measured in June 1957, when the water in the stream was warmer than the ground water. The water in the till had not been affected as much by circulation of water derived from stream infiltration as had the water in the permeable sand and gravel deposits, indicating that much water flowed around the till to reach the lower aquifer. Had all the water entered the lower aquifer by leakage through the till it would have been no warmer than the water in the till itself. The zones of warmer water in well 530 reach nearly the same maximum temperatures, while of the two warmer zones in well 531 the lower zone is much cooler than the upper zone. This indicates that the movement of water from the upper to the lower aquifer was taking place more rapidly in the vicinity of well 530, where the till is absent locally, than in the vicinity of well 531, where the flow was chiefly by leakage through the till.

Despite the fact that openings occur locally in the till-rich zone at the Tait Station, this zone is generally effective in retarding the movement of water from the upper to the lower aquifer. A pumping test made on well 524 in April 1956 showed that the till was highly effective in hydraulically separating the upper and lower aquifers.

Annual temperature graphs of ground water from two wells at the Tait Station, compared to a similar graph of temperature in the Miami River, also show that the till-rich zone is hydraulically effective in separating the upper and lower aquifers. The graph (fig. 7) of the annual water temperature in well 521, which is 65 feet deep and screened near the bottom of the upper aquifer, reveals seasonal fluctu-

ations much like those occurring in the Miami River. In contrast, the annual temperature graph of water from well 524, which is 155 feet deep and screened in the lower aquifer, is nearly flat. If no semi-confining bed existed in the area, seasonal fluctuations would be ap-

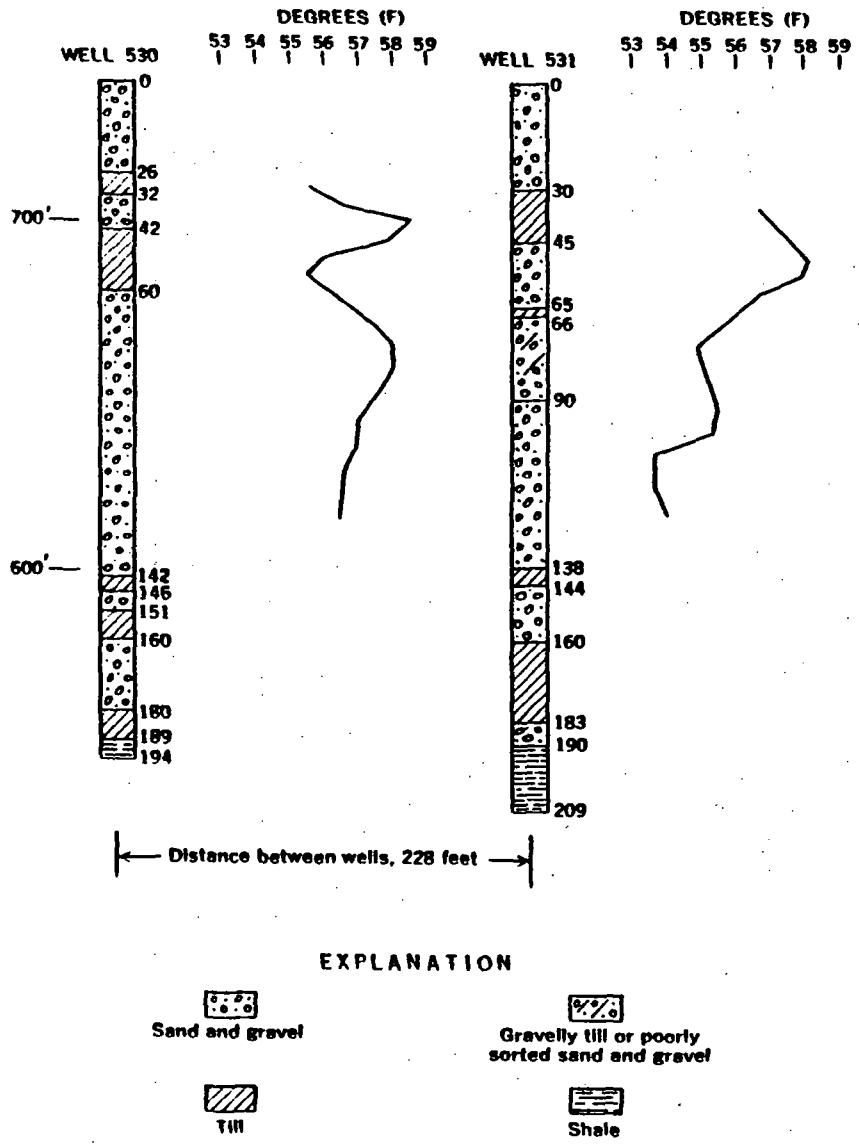

FIGURE 6.—Drillers' logs and accompanying temperature graphs of wells 530 and 531 at the Tait Station of the Dayton Power & Light Co. Temperature fluctuations show that part of the ground water flows around discontinuous deposits of till in moving from the upper to the lower aquifer.

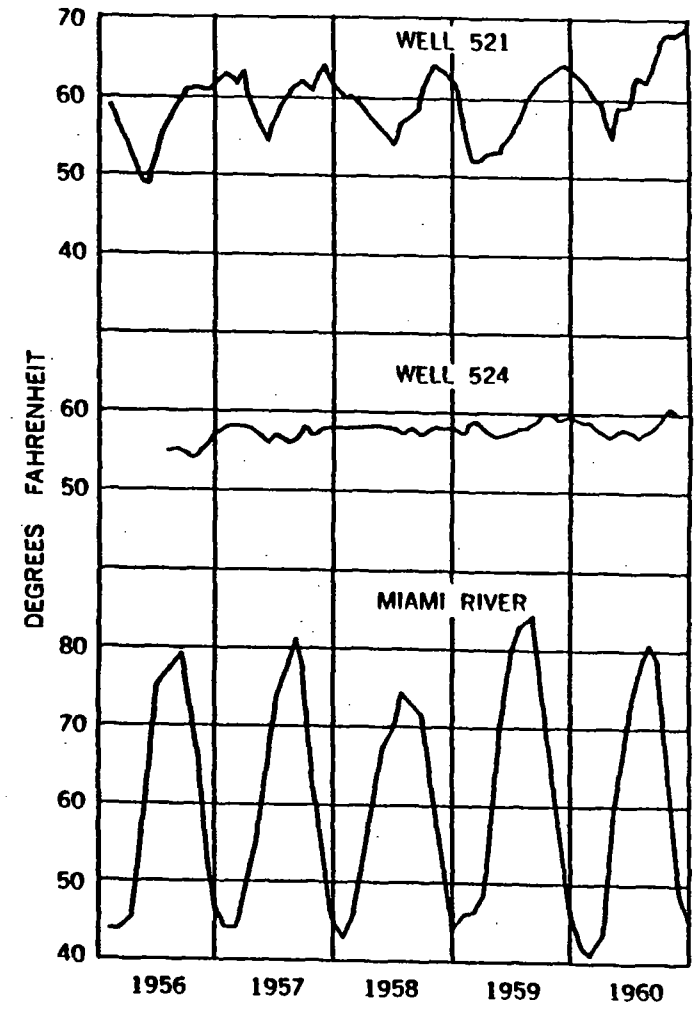

FIGURE 7.—Graphs of annual temperature of water in wells at the Tait Station of the Dayton Power & Light Co., compared with that of the Miami River.

parent in the graph from well 524, which is much closer to the river than is well 521.

In summary, at the Tait Station of the Dayton Power & Light Co., the till-rich zone consists chiefly of lenses and discontinuous masses of till. Some wells have been drilled nearly to bedrock without cutting any significant till deposits. Recharge to wells screened below the till-rich zone is by leakage through the till deposits and by the flow of water around and between the lenses and masses of till. The area has

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proved an excellent one for the development of large ground-water supplies.

NATIONAL CASH REGISTER CO.-McCALL CORP. AREA

Geologic section *C–C′* (pl. 3) shows the character of the valley-fill deposits along an east-west line extending across the Miami River valley from the vicinity of the McCall Corp. plant in southwest Dayton to a point east of the National Cash Register Co. plant.

The till-rich zone in the vicinity of the McCall Corp. plant is about 30 feet thick and lies between the approximate depths of 75 and 105 feet. Large differences are noted between water levels in wells open above the till and in wells open below the till.

In five test holes (329–333) drilled at the McCall Corp. plant in 1951, the water level during drilling ranged between 32 and 40 feet below the surface until the wells were deepened below the till-rich zone. When this was done the level dropped abruptly to depths ranging between 50 and 58 feet. Thus, the till-rich zone is highly effective hydraulically, in separating the valley-fill deposits into two principal aquifers. There is evidence that the till may contain a lens of sand and gravel, as indicated on the cross section.

The till-rich zone shown in geologic section *C–C′* is projected laterally across the valley largely on the basis of records of wells drilled at the Himes Bros. Dairy (well 321), the Dairy Division of the Kroger Co. (well 324), the Sunshine Biscuit Corp. (well 360), and the National Cash Register Co. plant. At the Sunshine Biscuit Corp., for example, wells are screened in the lower aquifer between depths of 75 and 115 feet, beneath a till-rich zone approximately 25 feet thick.

At the National Cash Register Co. plant, which lies near the east side of the Miami River Valley and also near the east side of the underlying bedrock valley, till constitutes a large part of the valley-fill deposits. The till deposits range widely in depth and thickness, occurring mainly as irregularly distributed lenses and masses. Nearly all the company-owned wells are screened below the till; however, the separation of the sand and gravel deposits into an upper and a lower aquifer probably is not as clear cut as is indicated on plate 3. Most recharge to the wells is by percolation between or around the till deposits. This is shown by the fact that the water level in observation well Mt–3, at the northwest corner of Stewart Street and Patterson Boulevard, on the east bank of the Miami River, quickly responds to changes of stage in the nearby river as well as to variations in the pumping rates at the plant.

CENTRAL DAYTON

In much of the central part of Dayton the till-rich zone is composed of two tills—an upper, relatively thick bed, and a lower, thinner bed, separated by 20–35 feet of sand and gravel. The upper till is more extensive than the lower, though both can be correlated from well to well over considerable distances. A few wells have been screened between the two tills in what is considered, somewhat arbitrarily, to be part of the upper aquifer.

AETNA PAPER CO. (WELLS 301–304)

The upper till of the till-rich zone is about 25 feet thick and lies between depths of 40 and 65 feet. The lower till is approximately 15 feet thick and lies between depths of about 95 and 110 feet. Thus, the tills are separated by about 35 feet of sand and gravel. Both tills correlate closely with similar till deposits at the Longworth Street Station of the Dayton Power & Light Co., more than a third of a mile east of the Aetna Paper Co. wells.

The Aetna Paper Co. formerly had eight wells 40–42 feet deep screened above the upper till. These wells went dry, and deeper wells were drilled 80–100 feet deep and screened between the upper and lower tills. Still later, the present wells were drilled through the lower till and screened in the lower aquifer.

DAYTON POWER & LIGHT CO., LONGWORTH STREET STATION (WELLS 23–26)

The upper till of the till-rich zone is approximately 30 feet thick and occurs between depths of about 40 and 70 feet. The lower till is reported between depths of about 100 and 110 feet. These till deposits, which together constitute the till-rich zone, correlate closely with similar deposits at the Aetna Paper Co. plant.

The two principal production wells (23 and 24) at the Dayton Power & Light Co. plant are screened in the lower aquifer between depths of 144–172 feet and 120–135 feet, respectively. Temperature measured in well 24, the shallower well, in June 1957, at 5-foot-depth intervals, showed a slight, though abrupt, decrease below the depth of 110 feet, corresponding to the base of the till-rich zone.

DELCO PRODUCTS DIVISION, GENERAL MOTORS CORP. (WELLS 28–35)

Conditions at the Delco plant are unlike those that prevail generally in central Dayton in that here there are no well-defined till layers. Of the logs of seven wells drilled at this site, five show till deposits of varying thickness at depths of 40–95 feet, the approximate position of the till-rich zone. Till is not reported in the other two well logs, which suggests that the till-rich zone is composed either of discontinuous

lenses or of an irregular sheet through which channels were cut before deposition of the upper sand and gravel aquifer.

The north-central downtown area, in which the Delco plant is located, lies at the confluence of three buried valleys. At various times in the Pleistocene Epoch, valley glaciers coalesced in this area, and the rock materials that they carried were commingled to form a complex mass of till. Likewise, when the glaciers retreated, melt waters may have produced at their junction a variety of unusual erosional and depositional features. For example, some of the well logs at the Delco plant report deposits of fine sand of considerable thickness. In the log of well 35, fine to very fine sand is reported below the depth of 126 feet, extending nearly to the bedrock surface at the depth of 200 feet. Fine sand, often called "quicksand" by well drillers, is rarely more than 15–25 feet thick in the Dayton area and occurs most commonly just beneath the till-rich zone.

DAYTON POWER & LIGHT CO., THIRD STREET STATION (WELLS 18–21)

Interbedded till deposits of variable thickness are reported in the logs of wells drilled at the Third Street Station. Till occurs in the sand and gravel deposits at depths of about 25–60 feet and 80–110 feet. One or two early wells were screened between the tills, at depths of 60–80 feet, but the present wells are screened beneath the lower till in the lower aquifer at depths of 115–145 feet.

NORTH DAYTON AREA

Geologic sections *D–D′* and *D′–D″* (pl. 3) illustrate the character of the valley-fill deposits in the northern part of Dayton. Section *D–D′* is based on meager data, chiefly that from wells drilled at the plants of the Dayton Castings Co., Premier Rubber Co., and Chrysler Airtemp Sales Corp., but it is presented to show that in this area, too, the valley-fill deposits evidently are separated by till into an upper and a lower sand and gravel aquifer, similar to generally prevailing conditions in the Dayton area.

MIAMI RIVER WELL FIELD AREA

Geologic section *D′–D″* is drawn northward from the corner of Troy and Valley Streets through the Miami River well field of the city of Dayton, on the west bank of the Miami River approximately 3½ miles northeast of the center of Dayton. Logs of wells drilled at the Miami River well field clearly show the till-rich zone, which separates the sand and gravel deposits into an upper and a lower aquifer. The upper aquifer, lying immediately beneath the soil and river alluvium, consists of 30–40 feet of coarse sand and gravel, into which the Miami River has cut its channel. Beneath the upper aquifer are deposits of till, reported in nearly all the well logs, constituting a well-defined till-rich zone between depths of about 40 and 90 feet.

Beneath the till-rich zone at the Miami River well field are 50–70 feet of coarse sand and gravel. The lower sand and gravel aquifer is generally underlain by till, which in turn overlies the shale bedrock. Most wells are screened between depths of about 65 and 130 feet, as the test-hole records show that in this interval the sand and gravel deposits are coarsest.

MAD RIVER VALLEY

Geologic section *A–A′* (pl. 3) shows that in the Mad River Valley the till-rich zone consists of two tills, the thickest and most extensive of which lies about 40–60 feet below the land surface. A minor, less extensive till zone lies a few feet below the riverbed and, in a small area above the Keowee Street Bridge, constitutes a local confining bed, similar to that formed generally by the deeper till deposits. Elsewhere in the Mad River Valley, the upper till is represented chiefly by scattered lenses.

KEOWEE STREET AREA

In the Mad River Valley in the vicinity of Keowee Street, the upper till forms a local confining bed, similar to that formed by the deeper and more widespread till which generally separates the upper and lower aquifers. Evidence of this relatively shallow confining bed is shown by the fact that water in several wells of the waterworks "old main group" or "river wells" occurs under sufficient artesian pressure to flow. These river wells range in depth from 30 to 88 feet and are screened above the deeper till layer. When the wells were drilled in 1887, artesian pressure was great enough that the wells flowed 3 feet above river level. In an early history of Dayton, Steele and others (1889, p. 214) stated that:

> During the months of July and August 1887 the board of waterworks trustees constructed, in the bed of Mad River, east of Keowee Street, a series of tube wells, 30 in number, eight inches in diameter, and at an average depth of 40 feet. The water from these wells flows of its own accord, rising above the tops of the wells and above the level of Mad River an average height of three feet.

According to Mr. Charles Stout, well-field superintendent, some of these old wells were opened in 1960 during the laying of a pipeline near Keowee Street, and water still flowed from the wells after 73 years, although under much less artesian pressure.

The artesian head producing flow in the old river wells cannot be derived from the head in the lower aquifer, as the piezometric surface in that aquifer, shown by water-level measurements in well C–47 at the municipal softening plant, fluctuates between about 20 and 25 feet

below the land surface. The river wells tap a local artesian aquifer in which water is confined by the shallow layer of till. Till exposed in the bed of the Mad River about 1½ miles above Keowee Street and about half a mile below Eastwood Park, near the Baltimore & Ohio Railroad bridge, may represent the edge of the till sheet that forms the confining bed in the vicinity of Keowee Street. If so, the artesian pressure in the old wells probably originates in the area of Eastwood Park, where the river is about 5 feet higher than it is in the vicinity of Keowee Street.

FINDLAY STREET AREA

The valley-fill deposits in a mile-long segment of the Mad River Valley centering near the Findlay Street Bridge are worthy of special note relative to the availability of ground water. Near the Mad River in much of this area the till-rich zone evidently is absent. This is shown by the records of city-owned wells C-44, C-45, and C-46, drilled on or near the levee on the south bank of the Mad River, and the record of well 217, which is 141 feet deep, drilled at the Dayton Rust Proof Co. The driller's report on well 217 states simply, "gravel all the way," which is interpreted to mean that no till deposits were cut.

Although this meager evidence can hardly be called conclusive, it clearly points to the possibility that the Findlay Street area may become important in future water-resources development involving either the withdrawal or the artificial recharging of large quantities of ground water. If the till-rich zone is absent over a sizable part of this mile-long area, water can percolate from the surface to the deeper parts of the aquifer much more readily than at most other places in the Dayton area. The presence of numerous gravel pits from which, as from the Mad River, infiltration can originate makes the area doubly attractive as a possibility for large-scale water-resources development.

ROHRERS ISLAND AREA

Test drilling on and near Rohrers Island was begun in 1923, and since that time the Dayton municipal water department has drilled scores of test holes and production wells. About 1946, Mr. W. W. Morehouse, then director of the Dayton Water Department, estimated the number of test holes and wells drilled on Rohrers Island at more than 400. Since 1946 several additional test holes and production wells have been drilled on or near the island.

Judging from the large number of drill-hole records available, one might assume that the character of the valley-fill deposits in the Rohrers Island area is known in great detail. This is indeed true compared to our knowledge of the deposits in many other areas of

comparable size in the Miami River and Mad River valleys. Significant gaps in our knowledge remain, however, because most of the wells and test holes drilled on and near Rohrers Island were relatively shallow and did not penetrate into the lower aquifer. Moreover, nearly all the drilling was concentrated in a few small areas near the river, leaving untested relatively large areas between the Mad River and the edges of the valley. Also, many of the drillers' logs are sketchy and inadequately describe the formations. Despite these deficiencies, there remains a wealth of information on which to base a description of the valley-fill deposits in the Rohrers Island area.

In that part of the Mad River valley extending from the vicinity of Huffman Dam down at least as far as Tates Hill, the valley-fill deposits are effectively separated by a till-rich zone into an upper and a lower aquifer, typical of conditions generally in the Dayton area. (See geologic section *A–A′*, pl. 3.) This fact has been recognized by waterworks officials for many years. Indeed, it is probable that the aforementioned area was the first in which the separation of the sand and gravel deposits into an upper and a lower aquifer was considered as a factor in well development. The water in the lower aquifer was known to be harder and higher in iron content than the water in the upper aquifer, and before Dayton had a municipal water-treatment plant few wells were drilled to the lower aquifer and these were seldom pumped. After 1953, when Dayton built a treatment plant, more wells were drilled in the lower aquifer near Rohrers Island and these became major sources of supply. The drilling of the deeper wells also yielded much valuable information on the character of the valley-fill deposits.

In the vicinity of Rohrers Island the upper aquifer is about 65 feet thick and the lower, about 50 feet thick. The till-rich zone which separates the aquifers ranges in thickness from about 11 to 50 feet (Norris, 1959, p. 3; Norris and others, 1948, p. 52). The upper aquifer contains interbedded lenses of till in the vicinity of Rohrers Island. Farther downstream, between Harshman Road and Tates Hill, the shallow till deposits can be correlated from well to well and evidently constitute a widespread, nearly continuous sheet lying 20–30 feet below the land surface. The till sheet that forms the shallow confining bed in the vicinity of Keowee Street is no doubt correlative with the shallow till deposits at Rohrers Island.

At Rohrers Island the shallow till deposits impede recharge from the Mad River to wells drilled in the upper aquifer. The wells of highest specific capacity are located in areas where these till deposits are thin or absent (fig. 8).

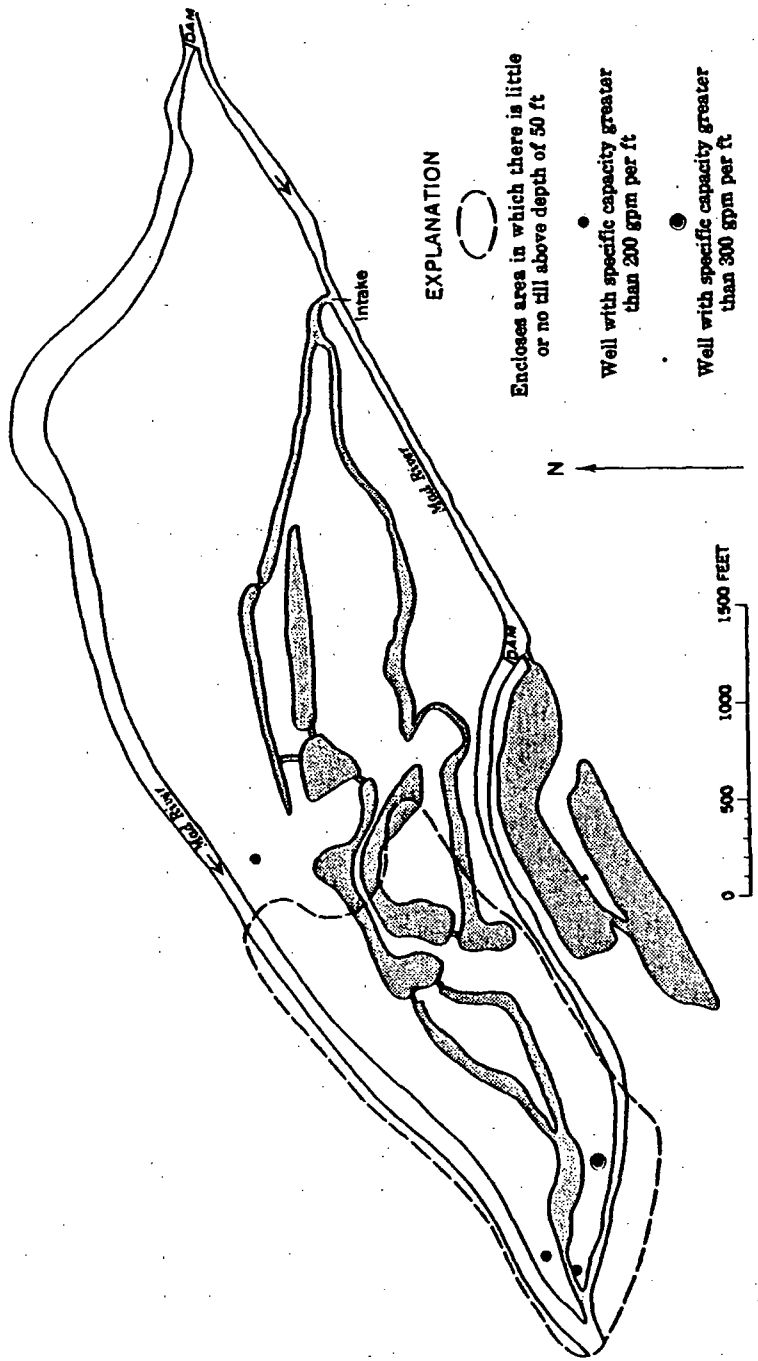

FIGURE 8.—Shallow till deposits, wells of high specific capacity, and recharge ponds, Bohrers Island.

HYDRAULIC PROPERTIES OF THE VALLEY-FILL DEPOSITS

The functioning of the natural hydraulic system, of which the valley-fill deposits are a principal component, is basically simple. Partly filling the preglacial bedrock valley that passes through the heart of Dayton is some 150–250 feet of glacial deposits, consisting chiefly of sand and gravel, over which the Miami River and its tributaries flow. Below the depth of a few feet the sand and gravel generally are saturated, and wells drilled into these permeable deposits yield large quantities of water. As water is pumped from storage in the deposits it is replenished principally by infiltration through riverbeds. Some recharge is derived also from rainfall that enters the ground in the vicinity of the pumped wells, and from ground water diverted to the wells by interception or capture of its natural flow from the uplands into the streams.

Although simple in principle, the mechanics of this hydraulic system are complicated in detail. Differences in permeability of the sand and gravel deposits from place to place both laterally and vertically, and variations in streamflow and in the rate of stream infiltration, as well as the distribution of pumpage, are among the factors that must be considered in evaluating the ground-water resources.

Of considerable importance too are the effects of the till-rich zone, which generally separates the valley-fill deposits into an upper and a lower aquifer and impedes recharge to the lower aquifer, in which nearly all the wells are screened. The till-rich zone confines water in the lower aquifer under artesian pressure. In the upper aquifer the water generally is not under pressure but occurs under water-table conditions.

ARTESIAN AND WATER-TABLE CONDITIONS

The upper aquifer is similar to a surface reservoir such as a lake, and the water table or upper surface of the saturated part of the aquifer is analogous to the water surface in the lake. In the lower (artesian) aquifer no true water table or free surface exists. However, the levels to which water will rise above the semiconfining bed in tightly cased wells form an imaginary, piezometric (pressure-indicating) surface, which in a sense is analogous to the water table in the upper, unconfined aquifer.

When a well is pumped, the water level is drawn down in the well and in a cone-shaped area of the aquifer around the well. If the aquifer is homogeneous and of large areal extent, water flows to the well from all directions in response to the hydraulic gradients created by pumping. If the well is drilled in an unconfined aquifer, water

flows toward the well by gravity and drains from storage as the cone of influence spreads. Dewatering the aquifer slows the effects of pumping, and the drawdown that occurs within any specified time is smaller than it would have been had little or no stored water been available. When a well in an artesian aquifer is pumped the aquifer is not drained by gravity, except perhaps in the immediate vicinity of the well if the water level is drawn below the upper confining bed. As only a little water is made available from storage, by elastic compression of the aquifer and expansion of the water, the cone of influence must extend over a greater area to induce the amount of water being pumped to flow into the well, and the effects of pumping are quickly transmitted from one part of the aquifer to another.

Consider the effects of pumping each of two identical wells screened in sand and gravel deposits having permeabilities and thicknesses typical of such deposits in the Dayton area. Our hypothetical aquifers are of large areal extent and differ only in that one is an artesian aquifer, in which water is under pressure, and the other is an unconfined aquifer, in which water-table conditions prevail (that is, the water is under atmospheric pressure only). Assume that each well is pumped at 1,000 gpm for a period of 1 day, during which time the wells receive no replenishment from any source. Under these conditions, the drawdown at the end of the pumping period in observation wells located 300 feet from each of the pumped wells would be about 1 foot in the unconfined, water-table aquifer and about 7 feet in the artesian aquifer. A drawdown of 1 foot, such as would have occurred 300 feet from the well being pumped in the water-table aquifer, would occur about 1½ miles from the well being pumped in the artesian aquifer.

EFFECTS OF INTERBEDDED TILL DEPOSITS

The till-rich zone that generally confines water in the lower aquifer in the Dayton area is an imperfect confining bed. Water will leak through the till as soon as a difference is established between water levels in the upper and lower aquifers. Recharge by leakage into the lower aquifers usually begins soon after pumping starts, slowing the rate of drawdown in this aquifer and eventually stopping it entirely. Observations have shown that recharge from leakage through the confining bed may begin to take effect at any time from a few minutes to several hours after pumping starts in the lower aquifer.

The till-rich zone is absent locally in the Dayton area, and in these areas there is actually only one aquifer and water-table conditions prevail. In other places the till-rich zone consists of discontinuous layers and lenses of till which imperfectly separate the sand and gravel deposits into two aquifers. When wells in the lower aquifer

are pumped in such areas, they may respond initially as though artesian conditions prevailed and then the response changes very quickly to water-table characteristics as flow becomes established between and around the till masses. The effect is the same as though the lower aquifer were ideally artesian and the rate of leakage through the confining bed were very high.

Conditions in the upper aquifer, where water-table conditions generally prevail, also are far from ideal. Because of the horizontal layering of the deposits, and the local presence of interbedded till deposits, the permeability measured parallel to the bedding is generally much higher than the permeability measured normal to the bedding. As a result, the aquifer exhibits artesian properties to some extent, and the water level in a well being pumped responds initially as it would in an artesian aquifer. However, as the cone of influence grows, vertical drainage of the saturated sediments becomes a greater factor in sustaining the yield of the well, and water-table conditions are eventually established.

In a few places in the Dayton area, especially those in which little or no ground water is pumped, the water table in the upper aquifer is within a few feet of the land surface, in the zone of soil and alluvium. The surficial deposits in this zone are relatively impermeable and in places may act as an imperfect confining bed, producing local semiartesian conditions in the upper aquifer.

The recognition of and distinction between artesian and water-table conditions are of major concern to those engaged in pumping-test analysis in the Dayton area. Pumping tests are being used more and more by hydrologists and by some well drillers to determine the characteristics of aquifers, sources of recharge, and yields and proper spacing of wells. However, the difference between artesian and water-table conditions is much less a factor in determining the yield of wells drilled in the valley-fill deposits than are variations in permeability and thickness of the aquifers, choice of well screens, and degree of development of the wells. Moreover, yield is determined to a greater extent by the location of wells relative to sources of recharge than by all the aforementioned factors. Wells screened in the upper aquifer will yield much more water per unit of drawdown if they are close to an infiltrating stream than if they are some distance from the stream, other factors being equal. Wells drilled in the lower aquifer will yield most in areas where the rate of leakage through the confining bed is highest for a given head differential. The ideal place to drill wells in the Dayton area, for largest yields, is as close as practicable to a large infiltrating stream, in an area where the till-rich zone is absent or ineffective as a confining bed and where, as a consequence, there is

virtually one sand and gravel aquifer extending from river level downward to the bedrock surface. A further requirement would be to drill the wells where ground-water levels have not been appreciably lowered by pumping.

TRANSMISSION AND STORAGE CHARACTERISTICS

Properties of the valley-fill deposits enabling them to act as a storage reservoir and to transmit water to pumped wells under various hydraulic gradients rank in importance next to the availability of recharge in determining the magnitude of ground-water supplies in the Dayton area. The amount of water taken into or released from storage is important because it usually sets limits on rate of withdrawal between periods of replenishment. The permeability and the saturated thickness of the deposits (the product of these is called the transmissibility) together determine the rates at which water will move in the aquifers under various hydraulic gradients.

The specific yield of an aquifer is the ratio, usually expressed as a percentage, of the volume of water that will drain by gravity from the material to the total volume of the saturated material. For sand and gravel deposits the specific yield commonly ranges from 10 to 25 percent, the exact figure depending partly upon the length of time the sediments are allowed to drain. If a specific yield of 20 percent is assumed for the valley-fill deposits at Dayton, then an estimated 1½ gallons of water would drain from each cubic foot of the material during dewatering. The valley-fill deposits underlying an area of 1 square mile—roughly the size of Dayton's downtown district—would thus yield from storage nearly 42 million gallons of water if the water table were lowered an average of 1 foot over the entire area. Obviously, a very large quantity of water is in storage in the valley-fill deposits.

A commonly used measure, or coefficient, of permeability is defined as the number of gallons that will flow in 1 day through a 1-foot-square vertical section of an aquifer under a hydraulic gradient of 1 foot per foot; that is, under a vertical drop in water level of 1 foot for each foot of horizontal flow. The coefficient of permeability of a typical clay or till may be 0.1 gpd per sq ft or less, whereas that of a well-sorted sand and gravel may be 2,500 gpd per sq ft or more. As computed from pumping tests, the coefficient of permeability of the sand and gravel deposits in the Dayton area typically ranges between about 1,000 and 3,000 gpd per sq ft. The coefficient of permeability of the till-rich zone in the vicinity of Rohrers Island ranges between 0.03 and 0.13 gpd per sq ft (Norris, 1959, p. 12).

The rate of flow of ground water is governed not only by the permeability of the aquifer but also by the thickness; the thicker the aquifer, the greater the quantity of water it will transmit in a specified time under a given hydraulic gradient. The product of the coefficient of permeability of an aquifer and the thickness is termed the coefficient of transmissibility and is usually expressed as the number of gallons of water that will flow in 1 day through a 1-foot-wide vertical strip whose height equals the full saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per foot. A sand and gravel deposit whose coefficient of permeability is 2,000 gpd per sq ft and whose saturated thickness is 50 feet would thus have a coefficient of transmissibility of 100,000 gpd per ft (2,000 gpd per sq ft × 50 ft). The coefficient of transmissibility is a more useful term in describing the water-yielding properties of an aquifer than is the permeability alone. The coefficient of transmissibility of the valley-fill deposits, as determined from pumping tests, ranges from 125,000 gpd per ft for the lower aquifer in the vicinity of Rohrers Island to about 250,000 gpd per ft for the lower aquifer in the vicinity of the Tait Station of the Dayton Power & Light Co., in south Dayton.

In areas where the till-rich zone is absent, the transmissibility may be as much as 600,000 gpd per ft, although a value this high has not been computed from an aquifer test during this investigation. Such a high value is theoretically possible, however, as a coefficient of permeability of 3,000 gpd per sq ft has been computed for glacial outwash gravels similar to those in the Dayton area. Where such deposits are 200 feet thick, the transmissibility would be 600,000 gpd per ft. A maximum transmissibility of 500,000 gpd per ft for the valley-train deposits in the Dayton area is more likely, however, since these deposits probably do not have a uniform permeability of 3,000 gpd per sq ft through their entire thickness.

YIELDS OF WELLS

Typical industrial, commercial, and municipal wells drilled in the valley-fill deposits in the Dayton area range in depth between 60 and 200 feet and yield 100–3,000 gpm. The largest recorded yield is 4,500 gpm, from a 90-foot well (C–29) drilled by the Dayton Water Department on Rohrers Island. Most of the municipal wells tapping the upper sand and gravel aquifer on and near Rohrers Island yield 1,500–2,500 gpm from depths of about 65–90 feet. In the same area 10 deeper wells (C–1—C–6, and C–32—C–35) screened in the lower aquifer yield 2,000 gpm each; the total yield of these wells is about 15 mgd.

Typical industrial wells, such as those at the Frigidaire Division plant at Moraine City, yield 500–2,000 gpm and range in depth

from 110 to 150 feet. Well 524, which is 155 feet deep and is located at the Tait Station of the Dayton Power & Light Co., in southern Dayton, yielded 3,000 gpm during a pumping test.

To help convey a better understanding of the significance of various coefficients of transmissibility and other measurements used to evaluate the water-yielding properties of aquifers, figures 9–11 are provided. These graphs show the yields of idealized aquifers of three types: those receiving no recharge, those receiving recharge from a line source, and those receiving recharge by leakage through a slightly permeable confining bed.

The drawdown-yield graph (fig. 9) for a 12-inch well shows the theoretical relationship between yield and drawdown in ideal aquifers of various transmissibilities when the well is pumped steadily for 1 day. The drawdowns on the graph are those that would occur if the aquifers were homogeneous and of infinite areal extent, if the water pumped were all from storage, and if the well were 100 percent efficient.

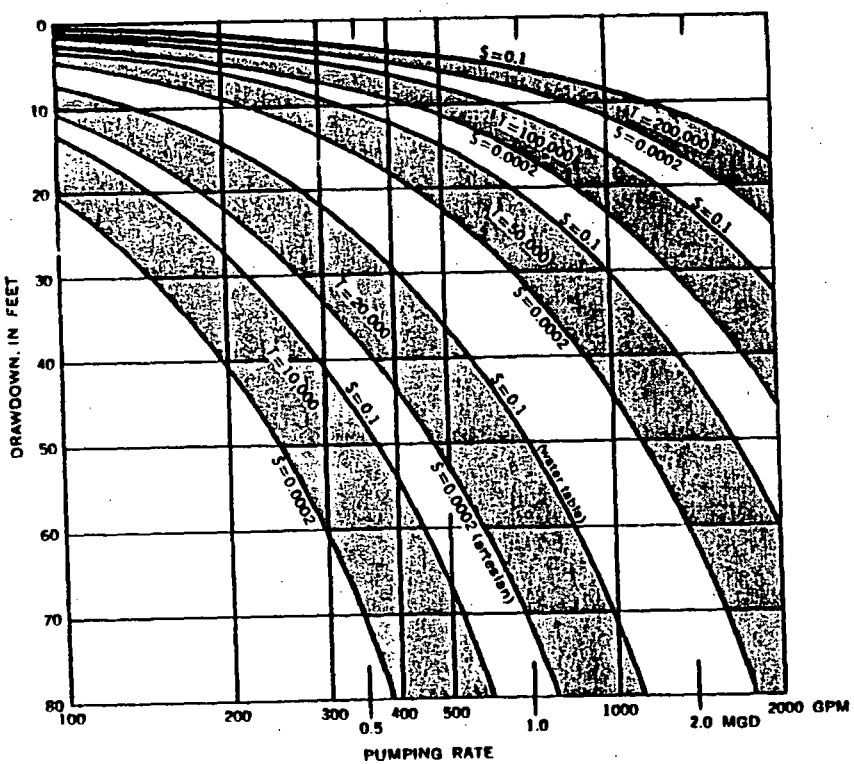

FIGURE 9.—Theoretical relationship between pumping rate and drawdown after 1 day of pumping a 12-inch-diameter well tapping an infinite aquifer receiving no recharge. T=coefficient of transmissibility, in gallons per day per foot. S=coefficient of storage.

As the aquifers are assumed to be of infinite extent, no boundary effects are shown.

The graph is intended to convey a general idea of the significance of various coefficients of transmissibility. If it were used to determine the transmissibility of a sand and gravel aquifer from field data or, conversely, as a basis for predicting the drawdown in a well tapping an aquifer whose transmissibility is known, only a very general approximation could be expected. One reason for this is that the efficiencies of wells screened in sand and gravel deposits vary greatly. The drawdown in a poorly developed well may be many times greater, for a given pumping rate, than the drawdown in a properly developed well tapping the same aquifer.

The principal reason, however, why the drawndown-yield graph would give misleading results if used with field data from the Dayton area is that recharge to a well usually becomes effective in a matter of minutes or within a few hours after pumping starts. Recharge slows the rate of drawdown or stops it altogether, and the drawdown after 1 day's pumping is less than it would have been if no recharge had reached the well.

Recharge most commonly is derived from an infiltrating stream if the wells tap the upper aquifer, or it is derived from leakage through the till-rich zone if the wells are drilled into the lower sand and gravel aquifer. The infiltration graph (fig. 10) shows the specific capacities to be expected of wells 12 and 24 inches in diameter drilled at various distances from an infiltrating stream and in aquifers of various transmissibilities. The specific capacity of a well is the ratio of the yield to the drawdown and is usually expressed in gallons per minute per foot of drawdown. Thus a well having a specific capacity of 50 gpm per ft might yield 1,500 gpm with 30 feet of drawdown, or 2,000 gpm with 40 feet of drawdown, or any specified quantity so long as the ratio of the yield to the resulting drawdown is 50 gpm per ft.

Comparison of the infiltration graph (fig. 10) with the drawdown-yield graph (fig. 9) shows no great difference in drawdown for a given pumping rate in a well drawing from storage in an infinite aquifer and in a well receiving recharge from stream infiltration. For example, the drawdown-yield graph shows that after 1 day a drawdown of 8 feet would occur in a 12-inch well pumped at 1,000 gpm and tapping an infinite aquifer whose coefficient of transmissibility is 200,000 gpd per ft. The infiltration graph shows that under similar conditions, except that the well receives recharge from a stream 200 feet away, the specific capacity would be about 133 gpm per ft and hence, at a pumping rate of 1,000 gpm, the drawdown would be about 7.5 feet. In comparing the two graphs, it must be remembered that

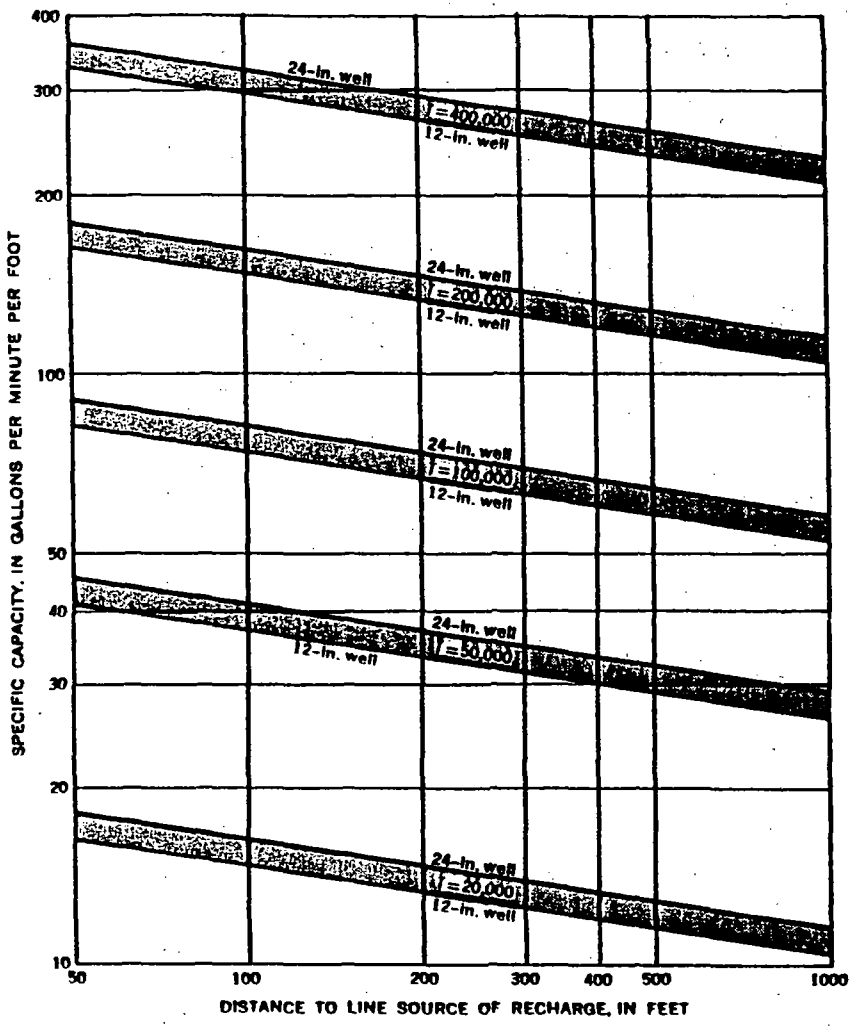

FIGURE 10.—Theoretical relationship between specific capacity of wells and distance to line source of recharge, such as an infiltrating stream. T=coefficient of transmissibility, in gallons per day per foot.

the drawdown-yield graph shows the drawdown after only 1 day's pumping. If pumping continued for more than 1 day in the hypothetical example, as it almost certainly would in reality the drawdown also would continue and would be greater after some other specified time than is indicated by the graph. The infiltration graph, on the other hand, shows conditions for a stabilized hydraulic system, in which recharge from an infiltrating stream has halted further growth of the cone of depression. Thus, a drawdown of 7.5 feet, determined

in the hypothetical example, is the maximum that would occur, no matter how long the well was pumped. Of course the graph, like any such nomograph, is based on (1) theoretical flow in a homogeneous aquifer, (2) the assumption of a fully penetrating and efficient well, and (3) the existence of a perfect hydraulic connection between the aquifer and the infiltrating stream. This last condition is seldom met in nature, as the permeability of the streambed is usually less than that of the underlying aquifer. The infiltration graph should be used only as a general guide in considering the effects of infiltration on the yields of wells.

Another graph showing the significance of major hydraulic properties of the valley-fill deposits is the "leaky-aquifer" graph (fig. 11).

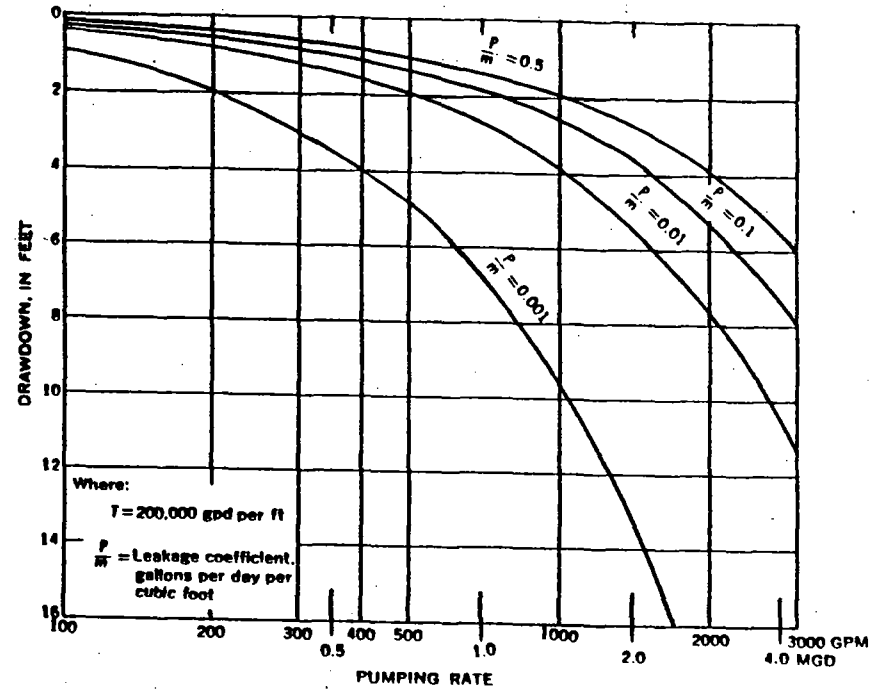

FIGURE 11.—Theoretical relationship between pumping rate and drawdown in a 24-inch-diameter well tapping an infinite aquifer receiving recharge by a leakage through a semiconfining bed.

This graph shows, for a 24-inch well in an artesian aquifer having a coefficient of transmissibility of 200,000 gpd per ft, the effects of recharge derived by leakage through a semiconfining bed. The several curves on the graph show the relationship between the yield of

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the well and the drawdown for various values of the leakage coefficient $\frac{P'}{m'}$, where P' is the coefficient of permeability of the confining bed and m' is its thickness. If the confining bed through which leakage is occurring has a coefficient of permeability of 0.1 gpd per sq ft and a thickness of 10 feet, its leakage coefficient is $\frac{0.1 \text{ gpd per sq ft}}{10 \text{ ft}}$, or 0.01 gpd per cu ft. The graph shows that under the conditions specified, the drawdown in a 24-inch well pumped at 1,000 gpm will be about 4 feet.

The leakage coefficient of the till-rich zone in the vicinity of Rohrers Island ranges from 0.001 to 0.012 gpd per cu ft, and the coefficient of permeability of the till ranges from 0.03 to 0.13 gpd per sq ft, as determined from a pumping test (Norris, 1959, p. 12). Walton (1960, p. 18) determined that the leakage coefficient for glacial tills and clays at seven places in Illinois ranged from 0.005 to 0.23 gpd per cu ft and that the coefficient of permeability of these beds ranged from 0.08 to 1.6 gpd per sq ft. The range in permeability determined by Walton for six of the seven confining beds in Illinois was from 0.08 to 0.63 gpd per sq ft, the same order of magnitude as that determined for the till-rich zone in the vicinity of Rohrers Island.

More data on the permeability of glacial till and clay were obtained from laboratory tests of four samples of till and one sample of varved finely laminated clay collected in the Dayton area and analyzed by the U.S. Geological Survey in Denver. The coefficient of permeability of the clay sample, as determined by permeameter methods, was 0.1 gpd per sq ft. For three of the four till samples the coefficient of permeability ranged from 0.01 to 0.5 gpd per sq ft, which compares closely with the range of till permeabilities determined at Rohrers Island and in Illinois. The coefficient of permeability determined for the other till sample from the Dayton area was very high and is believed to be in error.

According to the evidence, a typical coefficient of permeability of glacial till is about 0.1 gpd per sq ft. If such a till is 25 feet thick and confines water in an underlying aquifer, the leakage coefficient of the confining bed $= \frac{0.1 \text{ gpd per sq ft}}{25 \text{ ft}} = 0.004$ gpd per cu ft. Thus, as indicated by the "leaky-aquifer" graph (by interpolation), the theoretical drawdown in a 24-inch well pumping 1,000 gpm from an underlying artesian aquifer whose coefficient of transmissibility is 200,000 gpd per ft is about 6 feet. Such a well would have a specific capacity of about 160 gpm per ft, corresponding to that of a similar well in a water-table aquifer of the same coefficient of transmissibility located about 100 feet from an infiltrating stream. (See infiltration graph, fig. 10.)

CONSTRUCTION AND DEVELOPMENT OF WELLS

The construction and development of wells in the Dayton area have evolved in recent years into fairly standard methods and procedures. Typically, when wells are drilled for a factory, the choice of the drilling site is restricted by the property lines to a plot of perhaps an acre or less. The well site is selected by the plant engineer, who is guided by the general layout of the plant, the location of any existing wells, and the accessibility to existing power-distribution lines. Test holes are usually, though not always, drilled at the chosen site before the production well is put down. Results of the test drilling, together with records of existing wells, may dictate a different site for the production well.

Proposed well sites are usually rejected if the aquifer contains excessive amounts of silt or clay, or if layers or masses of till are present that locally replace the permeable sand and gravel. In a very few instances, the results of test drilling have been so discouraging to drillers and plant officials that no attempts were made to drill supply wells. Where the plant grounds cover a relatively large area, say 10–20 acres, several test holes may be put down for each production well drilled. Usually, the test holes are drilled by cable-tool or percussion-type equipment, similar to that used in drilling the production wells. In recent years use of rotary equipment has become more common and is generally acknowledged to give better results in test-hole drilling than does percussion-type equipment. One driller uses a mechanical separator during drilling to remove the sand and gravel particles from the drilling mud for inspection, and he logs the hole by means of a portable electric logger, which makes gamma-ray, resistivity, and self-potential logs of the formations. Use of these geophysical tools usually gives a far better picture of geologic conditions at the site than can be obtained from drillers' logs alone.

When the production well has been drilled to the selected depth, a brass or bronze well screen is lowered to the bottom of the casing (fig. 12) and the casing is then pulled back, exposing the screen to the sand and gravel aquifer. The diameter of a typical production well is governed by the anticipated yield of the well; if the expected yield is large, the casing diameter also will be made relatively large, so as to accommodate the required pump. Wells yielding 100–300 gpm commonly are 6–8 inches in diameter; wells yielding 300–500 gpm are 8–10 inches in diameter; wells yielding 500–1,000 gpm may be 10–12 inches in diameter; and those yielding 1,000–3,000 gpm are 16–20 inches, or more, in diameter.

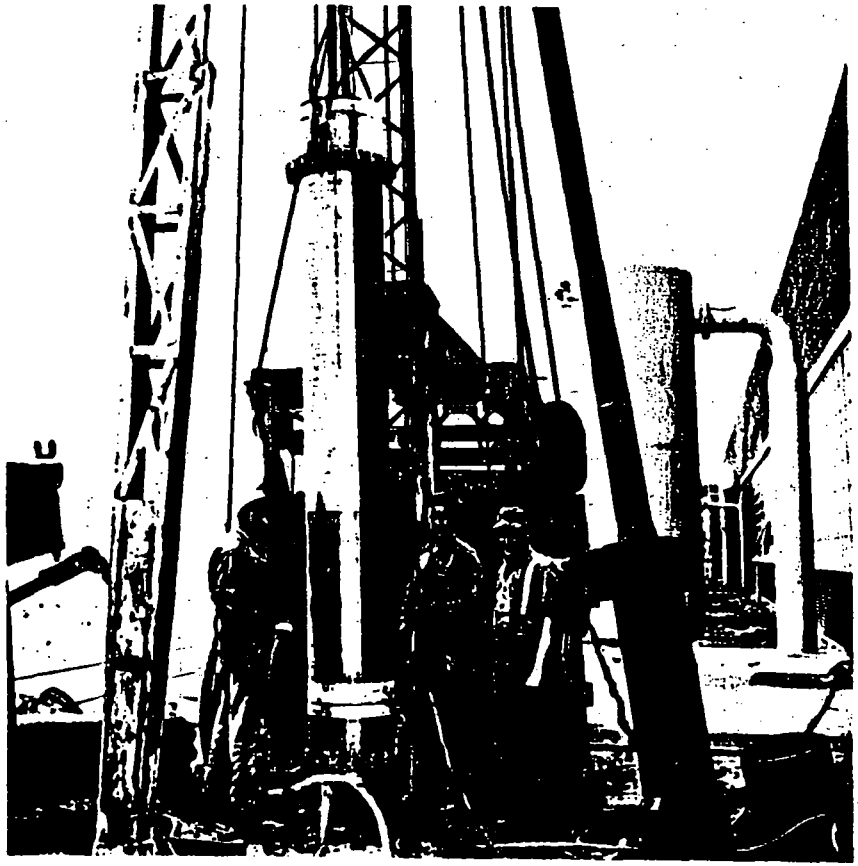

FIGURE 12.—Installation of a well screen at the Frigidaire Division plant at Moraine City. After screen is in place, casing will be pulled back to expose the screen to the sand and gravel aquifer.

Theoretically, increasing the diameter of a well does not increase its yield proportionately, and calculations show that under water-table conditions the yield of a 24-inch well is only 15–30 percent greater than the yield of a 3-inch well. In practice, however, well diameter usually has a very significant effect on the yield owing to comparatively large head losses through small-diameter well screens. In comparing the yields of 12- and 18-inch wells screened in sand and gravel deposits at Louisville, Ky., Rorabaugh (1953, p. 11) stated that for relatively low discharge rates the specific capacities of the wells differed by less than 5 percent, but for comparatively high rates they differed by more than 20 percent.

In the Dayton area there is a fairly close correlation between the diameters of wells and their specific capacities, according to pumping-

test data from approximately 150 wells. Most of these data are from drillers' acceptance tests, usually lasting 2–8 hours. Commonly such a test is ended when the water level in the well approximately stabilizes or "levels off," as determined by periodic measurements made with a steel tape or an air-line gage. Of the wells studied, 27 were less than 12 inches in diameter, and all but 3 of these had specific capacities of less than 50 gpm per ft. The rest of the wells studied were 12 inches in diameter, or larger; 65 percent of these larger wells had specific capacities greater than 50 gpm per ft.

Although the greater screen-intake area resulting from the increased well diameter is probably the major cause of the higher specific capacities of the larger wells, it may not be the only factor. When wells are pumped at relatively high rates, recharge effects occur more quickly than when the same wells are pumped at lower rates. During short periods of pumping, as in typical acceptance tests of wells, this fact becomes important. A well pumped at a relatively low rate may draw water entirely from storage in the aquifer during a pumping test of a few hours' duration, whereas the cone of depression formed around the same well when it is pumped at a higher rate is larger and may reach a source of recharge long before the test is over. Recharge slows or stops the drawdown, and the computed specific capacity of the well is therefore much greater at the higher pumping rate.

Modern pumps in the Dayton area are almost all the deep-well turbine type. In the turbine pump an electric motor, mounted on the casing and coupled to a long shaft, turns a series of impellers housed in the lower end of a vertical column suspended in the well below the water level. Water enters the column at the impellers, is forced upward, and is discharged through an orifice in the pump base. The discharge is governed principally by the number of impellers, called stages, used in the pump. These can be added or removed as the occasion demands. The design of the deep-well turbine pump eliminates the need for costly shelters or pumphouses, and most such pumps are placed in the open where they are readily accessible for servicing or maintenance (fig. 13).

The deep-well turbine pump has been in common use for about 30 years. Before its advent, displacement or cylinder-type pumps, centrifugal pumps, and a few air-lift pumps were used, and some of these types are still in service in the Dayton area. The jet or ejector-type pumps, in common use on rural and domestic wells, are seldom used in industrial wells because of their small capacity.

The first step in the development of an industrial well in the Dayton area is selection of the proper screen. Thirty or forty years ago screens were considered primarily as strainers whose function

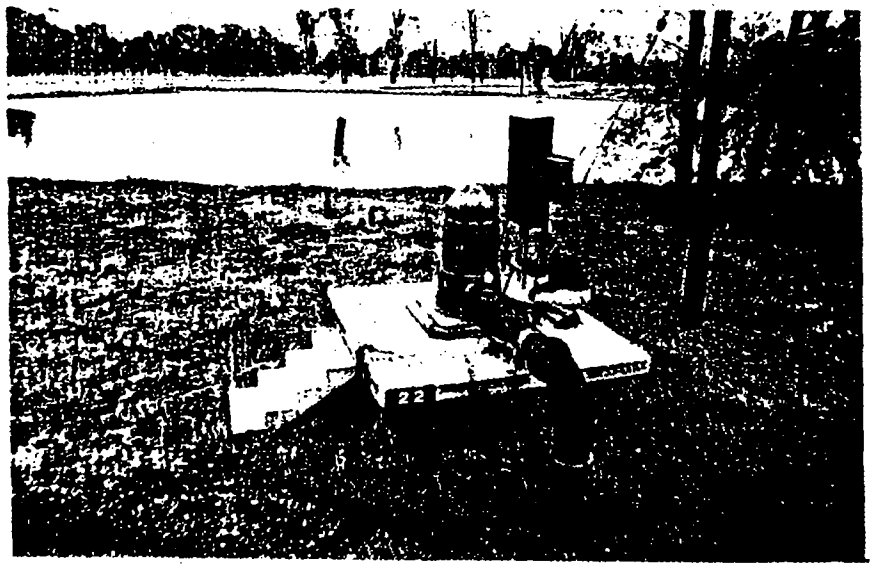

FIGURE 13.—High-capacity turbine pump installed on municipal well at Rohrers Island. Recharge pond in background. Photograph courtesy of the Dayton Daily News.

was to exclude from the well everything but the water. Consequently, the slots or openings in the screens were made small enough to keep out sand and other fine particles. This concept has changed, however; modern well screens are designed so that the openings are large enough to pass 40–60 percent of the aquifer materials. The size of the screen openings used in a typical production well is usually determined from a sieve analysis of sand and gravel samples collected in drilling the test hole. During development the finer grained material is washed through the screen and is removed from the well by pumping or bailing. This forms what is termed a natural "gravel pack" around the well screen and usually results in a much more efficient well than that obtained by earlier construction methods.

Artificial gravel packs also are used in some wells. These are constructing by first putting down a large-diameter casing, into which is inserted a casing of smaller diameter having a screen at its lower end. The annular space between the large-diameter casing and the well screen is filled with gravel of predetermined size and the outer casing then is withdrawn, exposing the gravel packing.

A few well screens in the Dayton area are of cemented gravel construction, in which graded gravel is mixed with cement and cast into a porous thick-walled screen reinforced by wire mesh and longitudinal

iron rods. The size of the gravel used in these screens is determined by analysis of samples of sand and gravel from the aquifer.

A few industrial wells in the Dayton area are not screened at all, except through perforations in the well casing. Most of these wells were drilled during World War II, when metal screens were scarce. Some, though not all, are of low efficiency or short life. A well driller informed the authors that he was replacing several wells, 12 years old, in which perforated casing was used in place of screens.

The yield of a well is roughly proportional to the length of the well screen, as the more fully a well penetrates an aquifer the smaller are the losses due to "partial penetration," which occur even in a perfectly homogeneous aquifer. (See Peterson and others, 1953.) In the sand and gravel aquifers at Dayton, horizontal layering of the deposits causes the permeability transverse to the bedding to be much less than the permeability parallel to the bedding. In some areas thin layers of clay or till interbedded with an otherwise homogeneous-appearing sand and gravel aquifer may further reduce the permeability in the vertical direction. Those factors greatly increase losses in wells that only partly penetrate the aquifers. The obvious solution to this problem is to use a long screen, which can "tie together" the more permeable parts of the aquifer. Moreover, the longer the well screen, the greater is the total area of the screen openings and the smaller is the head loss as the water flows through the screen into the well.

The screen lengths of about 60 wells in the Dayton area were plotted against their specific capacities. Wells whose screens were up to 10 feet in length had specific capacities up to 40 gpm per ft.; wells whose screens were 10–20 feet in length had specific capacities up to 160 gpm per ft.; and wells whose screens were 20–30 feet in length had specific capacities up to 320 gpm per ft. These are maximum or near-maximum capacities for the respective screen lengths. Some wells studied, whose screens were 20–30 feet long, had lower specific capacities than wells having 10-foot screens.

After a well is drilled and the screen is installed, the well is developed to permit water to flow more freely through the sand and gravel in the immediate vicinity of the well screen and thus to enter the well with minimum head loss. Development consists of removing part o the finer grained material from the aquifer; this causes rearrangement of the sand and gravel particles adjacent to the well screen Removal of the finer particles from the sand and gravel envelope surrounding the screen reduces the chance that the well will "sand up" "pump sand" when the pump is installed. The foregoing terms a commonly applied to the fouling of the pump or distribution lines fine sand pumped up with the water.

Sometimes wells are developed by introducing compressed air into the water through a long hose or pipe. This agitates and lifts the water until, laden with sand and other particles washed through the well screen, it overflows from the casing.

The most common method of developing wells in the Dayton area is by surging. In this method a tightly fitting surge block affixed to the drilling tool is worked up and down in the well like a ramrod in a gun. This forces water back and forth through the well screen at comparatively high velocity and brings the finer material into the well where it can be removed by bailing. Thorough development may require 1–2 days or even longer and is usually worth the expense on the basis of pumping costs alone. The difference in drawdown between wells that are properly developed and wells that aren't is commonly as much as 10 feet. For a pumping rate of 1,500 gpm, the cost of operating an improperly developed well may be as much as $1 per day more than for operating a properly developed well. After a few years the additional pumping cost could equal the original cost of the well. Moreover, added maintenance problems usually are associated with inadequate well development.

Some wells decline in efficiency after a few years and may require redevelopment at intervals. Several conditions may cause this decline. The most common is an incrustation of the well screen caused by either the deposition of limy materials in the screen openings and in the sand and gravel adjacent to the screen or by the growth of iron- or sulfate-forming bacteria in a slimy deposit, which clogs the well screen or the gravel around the well.

Iron-forming bacteria of the genus *Crenothrix* may grow in water containing iron in excess of about 0.2 parts per million. Methods of control include disinfection and regular treatment of the well and pumping equipment with hydrochloric acid or other chlorine compounds. Where contamination extends into the aquifer, some distance away from the well face, it is difficult to control and may eventually threaten an entire well field. Contamination of an aquifer over a large area is not known to occur anywhere in the Dayton area, though the problem locally is acute and should be carefully watched so that widespread control measures can be taken quickly if necessary.

Serious problems of well maintenance caused by iron-forming bacteria have occurred at the National Cash Register Co. plant and at the plants of the Delco-Moraine and Frigidaire Divisions of General Motors Corp. At the National Cash Register Co. plant a well drilled in 1950 was treated with acid in 1954 and again in 1958 in efforts to restore its efficiency, which had been appreciably reduced by the growth of iron-forming bacteria. At the Delco-Moraine Division

plant, a well (No. 338) drilled in 1948 to a depth of about 125 feet soon declined in yield and was deepened in 1950 to 200 feet. Since 1950 the well has twice been clogged by bacterial growth and both times was treated with acid. It has now been abandoned. No doubt the yield of many other wells in the Dayton area has been adversely affected by iron-forming bacteria. The problem warrants a more systematic study than was possible during this investigation.

CONTROLLED PUMPING TESTS

The method most commonly used to determine the storage and transmission properties of an aquifer is based on the nonequilibrium formula, which was introduced by Theis (1935). In this method the effects of pumping a well at a known constant rate are measured at several observation wells that tap the same aquifer. Graphs of drawdown versus distance from the pumped well, or of drawdown versus time since pumping started, are used to solve equations that express the relation between the coefficients of transmissibility and of storage of an aquifer and the lowering of water levels in the vicinity of a pumped well (Brown, 1953).

By methods based on the theory of images (Ferris, 1948), boundary effects are evaluated whereby the position, with respect to a pumped well, of a source of recharge (such as an infiltrating stream) or of an impermeable barrier (such as bedrock valley walls) can be determined. Effects of leakage through a semiconfining layer, such as a bed of glacial till, may be determined by methods described by Hantush (1955). Examples of pumping-test analysis were presented by Walton (1953, 1960) and by Norris (1959).

Control of pumping tests is made difficult in the Dayton area by interference from other wells and by the scarcity of observation wells. Technical difficulties hamper maintainance of constant pumping rates and precise measurement of ground-water levels in observation wells. Close control of a pumping test for periods longer than a few hours usually is not possible in the Dayton area. This difficulty, plus the heterogeneity of the aquifer, complicates interpretation of the test results.

One of the most difficult problems of interpretation is that of determining whether recharge to a well comes directly from an infiltrating stream or from vertical leakage through a till bed. The effects on ground-water levels observed during typical pumping tests are much the same for either source of recharge. Seldom are there enough properly spaced observation wells to indicate unequivocally the source of recharge; consequently, a great deal of judgment based principally upon a knowledge of the geology is involved in the analysis.

Serious error might result in attempting to predict the long-term yield of wells if the source of recharge was mistakenly identified as an infiltrating stream, whereas the actual source was vertical leakage through a confining bed of low permeability. Under the mistakenly identified condition, the growth of the cone of depression, ideally, would be halted by the infiltrating stream and recharge would be maintained at a relatively constant rate as long as flow occured in the stream. Under the actual condition, recharge would be from storage in the leaking bed. If replenishment to that bed were deficient, as perhaps it might be in periods of drought, the recharge to the underlying aquifer also would diminish, perhaps in critical amounts.

The problem of interpretation is compounded when recharge to a pumped well is principally from water that flows from the upper to the lower aquifer through openings in the till-rich zone. Under such conditions the growth of the cone of depresion is halted by a change in the aquifer from artesian to water-table conditions, and the effects on drawdown are similar to those caused by recharge from an infiltrating stream or by vertical leakage through a poorly permeable bed. An opening in the till-rich zone can be located by image-well methods if enough observation-well data are available, but the rate of recharge through the opening cannot be evaluated by ordinary field techniques.

Further complications arise where several openings occur in the till-rich zone as, for example, in an area where the till is in the form of closely spaced lenses or masses. Under these conditions it may be a practical necessity to consider that recharge originated as leakage through a confining bed having a relatively high leakage coefficient, because the amount of data required to define the hydraulic system more completely would be so great as to render unlikely its collection in the field. Unfortunately, a leakage coefficient approximated in this way can be applied only with caution, and only with respect to the pumped well. It would have a different value for almost any other well in the area whose location differed with respect to the individual openings in the till-rich zone.

Although pumping-test data are useful in determining initial pumping rate, well efficiency, and short-term drawdown in a pumped well, seldom do they constitute an adequate basis for predicting the yield of large ground-water systems. The perennial yield of an aquifer is determined not so much by its hydraulic properties as by the average annual recharge, just as for a surface-water reservoir.

Several of the better controlled and instrumented pumping tests made in the Dayton area are the basis for the computed values of the principal hydraulic properties—the coefficients of transmissibility and

permeability and the leakage factor—used in this report. These pumping tests are briefly described below, and the computed values of the hydraulic properties are listed in table 2. The analytical procedures are not described, and the water-level data are omitted. A pumping test made in 1953 by the U.S. Geological Survey at the Dayton municipal well field at Rohrers Island has been more exhaustively treated and is the subject of another publication (Norris, 1959). The interpretive procedures described in that report are generally similar to those used in analysis of the other tests in the Dayton area. The hydrologic coefficient given in the description of the pumping tests are the authors' unless otherwise stated.

The permeability of the lower sand and gravel aquifer is uniformly high in the Dayton area, except locally in the downtown district, where several large valley glaciers coalesced. As a consequence, the till-rich zone is unusually thick, and the sand and gravel deposits contain relatively large quantities of fine sand and silt, which reduce their permeability.

TABLE 2.—*Hydrologic coefficients obtained from pumping tests of wells in lower aquifer*

Test site	Date of test	Transmissibility of aquifer (gpd per ft)	Permeability (gpd per sq ft)	Confining bed	
				Leakage (gpd per cu ft)	Vertical permeability (gpd per sq ft)
Rohrers Island area	October 1953	215,000	2,500	0.001–0.012	0.03–0.13
Miami valley near Beardshear Rd	April 1956		2,300		
Frigidaire Div. plant No. 1, Taylor St	February 1951	40,000	1,000		
Tait Sts., Dayton Power & Light Co	April 1958	• 200,000–250,000	• 2,000		
Montgomery County Sanitary Dept., Lamme Rd. well field	April, June 1950		• 2,000–2,500		
Montgomery County Sanitary Dept., Dryden Rd. well field	April 1955	240,000	1,600		

• Estimated.

PUMPING TEST AT ROHRERS ISLAND

A test conducted in 1953 by the U.S. Geological Survey at the Rohrers Island well field of the city of Dayton was described by Norris (1959). The test was made in wells drilled in the lower aquifer, which is about 50 feet thick and is separated from the upper aquifer by 11–50 feet of till. At the test site the coefficient of permeability of the sand and gravel is 2,500 gpd per sq ft, and the coefficient of transmissibility of the lower aquifer is 125,000 gpd per ft. The permeability of the till confining bed ranges from 0.03 to 0.13 gpd per sq ft, on the basis of data from five observation wells, and the leakage coefficient of the

confining bed ranges from 0.001 to 0.012 gpd per cu ft. A median value of the leakage coefficient, 0.003 gpd per cu ft, was selected as generally representative of the well field. This value was checked by relating it to the quantity of water subsequently pumped at the well field, the observed drawdown in wells, and the areal extent of the cone of depression as estimated from the geologic data. Good agreement was obtained between the observed facts and the theoretical calculations which were based on the selected value of the leakage coefficient. Although this value probably cannot be applied elsewhere in the Dayton area, the range of permeability of the till may be useful in making approximations of well yield where the till is extensive and its thickness is known.

PUMPING TEST AT MIAMI RIVER WELL FIELD

Schaefer and Walton, consulting hydrologists, made a pumping test in April 1956 at the Miami River well field, in which well T-2 was pumped about 4 days at a rate of 1,200 gpm. The pumped well was screened in two places, at depths of 68–78 feet and 88–108 feet, and was open both above and below an 8-foot-thick till deposit, which evidently constitutes the hydraulically most effective part of the till-rich zone at the test site.

During the test the pumped well received recharge almost immediately from the upper aquifer. Schaefer and Walton noted in their report to water-department officials (written commun., 1956) that the water level in an observation well 19 feet deep located 80 feet from the pumped well "responded to the withdrawal of water 15 seconds after the pump was turned on or off." According to Schaefer and Walton, "water in the shallow aquifer was also confined under slight artesian pressure because the water table was above the base of the semiconfining alluvial materials." This would account for the very rapid response to pumping effects in the upper aquifer.

Schaefer and Walton determined the coefficient of permeability of the sand and gravel deposits at the test site to be approximately 2,300 gpd per sq ft. They stated (written commun., 1956):

> Recharge to the deeper materials, at least in the vicinity of the test site, will occur as leakage of water through the semiconfining bed. Relatively deep cones of depression will have to be created to induce large quantities of water to leak through the clayey materials. The effectiveness of artifically recharging the deeper sand and gravel by spreading water over the shallow deposits will be decreased by the presence of the relatively impermeable bed.

PUMPING TEST AT FRIGIDAIRE DIVISION PLANT NO. 1 AT TAYLOR STREET

In February 1951 the U.S. Geological Survey made tests in two 12-inch wells screened in the lower aquifer at the Frigidaire Division plant No. 1 in downtown Dayton. The till-rich zone, 80–90 feet thick, is thicker at the test site than at most other places in the Dayton area (pl. 3), and the upper and lower aquifers are correspondingly thin, each about 40 feet thick.

During the test, well 38, which is 181 feet deep and screened in the lower 20 feet, was pumped at a rate of approximately 500 gpm for 8 hours. Drawdown and recovery measurements were made in well 37, which is 193 feet deep and 130 feet distant from the pumped well.

Well-interference effects, caused by operation of wells at other downtown business places, were noted during the test, and only water-level data obtained during the first 2 hours of the drawdown and recovery periods were used in the test analysis. The computed coefficient of transmissibility was approximately 40,000 gpd per ft, and the coefficient of permeability was about 1,000 gpd per sq ft, less than half the value computed for the lower aquifer at Rohrers Island. The leakage coefficient could not be determined from the Frigidaire site test data, as recharge did not become effective during the first 2 hours of pumping.

The 1,000 gpd per sq ft coefficient of permeability calculated from the test of the Frigidaire Division wells may be lower than the true permeability of the lower aquifer at this site. A discrepancy may have resulted from distortion of the field data by noncontrolled pumping in nearby wells. However, the calculated value, which is based on data from the observation well, checks closely with that based on the actual drawdown observed in the pumped well during the test. The drillers' logs of wells 37 and 38 report "dirty gravel" at several places in the stratigraphic sequence. This may indicate that the aquifer material is not well sorted at this site and that it contains a high proportion of silt and clay, which would reduce its permeability. The computed permeability coefficient, 1,000 gpd per sq ft, probably is not representative of the permeability coefficient in the downtown area.

PUMPING TESTS AT DAYTON POWER & LIGHT CO., FRANK M. TAIT STATION

In April 1956 a pumping test was made at the Tait Station, of the Dayton Power & Light Co. by a board of consultants, assisted by Mr. Robert E. Reemelin of the Miami Conservancy District. Well 524, which is 155 feet deep and screened in the lower 50 feet, was pumped for about 6 hours at a rate of 3,050 gpm. The pumped well is 195 feet from the Miami River, on the east bank of the stream. Drawdown and recovery measurements were made in wells 531 and 530, respectively, 695 and 790 feet southeast of the pumped well, in a direction away from the river.

The specific capacity of the pumped well was approximately 110 gpm per ft, which suggests a coefficient of transmisibility in the range

of 200,000–250,000 gpd per ft and indicates a coefficient of permeability for the lower aquifer of about 2,000 gpd per sq ft.

The test data are partly anomalous, probably because of the inhomogeneity of the aquifer and possibly because of interference of nearby wells; therefore, they are not amenable to the rigorous methods of analysis based on commonly used equations of ground-water flow. Recharge effects were noted in the observation wells about 10 minutes after pumping started, but whether this recharge originated at the Miami River or resulted from vertical leakage through the till-rich zone could not be determined. Recharge from both sources probably influenced water levels during the test.

PUMPING TESTS AT THE LAMME ROAD WELL FIELD OF THE MONTGOMERY COUNTY SANITARY DEPARTMENT

Two pumping tests were made at the Lamme Road well field in 1950, when development of the field was begun. In April the Ralph L. Woolpert Co. pumped well M–4, which is 166 feet deep and screened in the lower 28 feet for 24 hours at the rate of 1,000 gpm. Drawdown measurements were made in wells M–1 and M–2, respectively 258 and 350 feet from the pumped well. Data from the test were furnished to the authors by Mr. John Eschliman of the Woolpert Co.

In June 1950, the U.S. Geological Survey pumped well M–3, which is 187 feet deep and screened in the lower 30 feet, for 24 hours at the rate of 1,000 gpm. Drawdown measurements were made in well M–4, which is 272 feet distant from the pumped well.

Results of the pumping tests indicate a relatively high coefficient of transmissibility for the lower aquifer and a coefficient of permeability of 2,000–2,500 gpd per sq ft. Stabilization of water levels occurred very rapidly during each of the tests, and there was almost no further drawdown in the wells after about 5 minutes of pumping. Distortion of the flow field, caused by a clay lens that lies just above the depth at which most wells are screened, precluded more rigorous analysis of the test data.

The effect of this clay lens in retarding the vertical movement of water is shown by the results of redeveloping well M–6 and installing a longer screen in it. When placed in service this well was screened between depths of 127 and 157 feet, immediately below the clay lens, and it had a specific capacity of about 40 gpm per ft. The specific capacity declined in about 1½ years to 18 gpm per ft. The well was redeveloped and an additional 15 feet of screen was installed between depths of 76 and 91 feet, immediately above the clay lens. After this [illegible], the specific capacity of the well was 113 gpm per ft, nearly [illegible]

PUMPING TEST AT DRYDEN ROAD WELL FIELD OF THE MONTGOMERY COUNTY SANITARY DEPARTMENT

In April 1955, the U.S. Geological Survey made a pumping test of well M–10, which was pumped at the rate of 380 gpm for about 24 hours. Drawdown and recovery of the water level were measured in well M–12, which is 273 feet from the pumped well. Results of the tests indicate a coefficient of transmissibility for the lower aquifer of about 240,000 gpd per ft and a coefficient of permeability of about 1,600 gpd per ft. The aquifer is highly artesian, and recharge effects were noted in the observation well approximately 1 minute after pumping started in well M–10.

HYDROLOGY OF THE VALLEY-FILL DEPOSITS

GROUND WATER IN STORAGE

The availability of ground water in the Dayton area depends in part upon the quantity of water in storage in the valley-fill deposits, even though this quantity cannot be entirely withdrawn through wells. The sand and gravel filled valleys, a major element of Dayton's physical geography, constitute a large natural reservoir which matches in capacity some of the world's largest manmade lakes. The total area underlain by sand and gravel in the Miami Valley between Holes Creek, south of the city, and Needmore Road, near the north boundary, together with the segment of the Mad River valley extending from its mouth to Huffman Dam, and including smaller areas near the mouths of the Stillwater River and Wolf Creek, is approximately 40 square miles. From this area is pumped all but a tiny fraction of the ground water used for industrial and municipal purposes at Dayton.

If the sand and gravel deposits in this area of 40 square miles average 200 feet in thickness, their total volume is about 1½ cubic miles, or about 15 times the volume of material excavated during construction of the Panama Canal. If the sand and gravel is uniformly saturated below the depth of, say, 30 feet and if the porosity of these deposits averages 30 percent, the total quantity of water in storage in the area under consideration is about 425 billion gallons. This enormous quantity of water, if it could all be extracted from the ground, would supply Dayton's water requirements for 10 years at present pumping rates. In the table that follows, the storage capacity of the valley-deposits can be compared with that of several manmade surface reservoirs.

Reservoir	Capacity, in billion gallons
Lake Mead	9,670
Valley-train deposits at Dayton	425
5 retarding basins of the Miami Conservancy District (total)	273
Hoover Reservoir (Columbus, Ohio)	19

The natural underground storage at Dayton is comparable to that provided by very large artificial reservoirs costing many millions of dollars. According to estimates made by a board of consultants, the cost of constructing proposed reservoirs at Covington and DeGraff and on Beaver and Elk Creeks would average $135 per acre-foot of capacity. On this basis, a surface-water reservoir having the storage capacity of the valley-fill deposits in the Dayton area would cost about $175 million to construct.

To carry such comparison further, the underground reservoir at Daton requires no maintenance, it is not readily subject to silting or pollution, and it yields water of good chemical and bacteriological quality and of generally low and uniform temperature. Moreover, the valuable land underlain by this natural reservoir is not taken out of use, as it would be if it held a surface reservoir, nor does the water have to be piped to most points where it is used, as is true of surface-water supplies.

The rate at which water can be withdrawn from the valley-train aquifers, as computed from pumping tests and as demonstrated by the high yields of wells, exceeds Dayton's presently foreseeable need for water. However, the amount that can be withdrawn on a perennial basis is not determined so much by the hydraulic properties of the aquifer as by the average annual recharge.

RECHARGE

Recharge to the valley-fill deposits has its origin principally in that portion of the precipitation which runs off or seeps into the streams above Dayton and enters the aquifers in the Dayton area by infiltration through streambeds. The water enters the ground where the water table in the deposits underlying the stream has been sufficiently lowered by pumping to reverse its natural slope. This is the process, called induced infiltration, by which all large ground-water developments in the Dayton area are chiefly replenished. In a sense, the valley-fill deposits function as vast natural filter beds into which water is drawn from the streams and purified before use.

A minor amount of recharge to the aquifers in the Dayton area is derived from precipitation which falls on the valley-fill deposits and

infiltrates directly to the water table in the vicinity of pumped wel The inflow of ground water from the uplands is a major factor local especially where the uplands consist of thick permeable deposits. T conditions are present south of Dayton in an area of 5 square mi on the east side of the Miami River vally between Southern Hills a the vicinity of Holes Creek, where kame deposits of sand and grav form high hills and rugged terrain and there is no well-develop surface drainage. Much of the precipitation in this area enters t ground and flows into the valley-fill deposits as ground water, so of which may briefly emerge as springs before reentering the grou farther down the valley slope.

Ground-water runoff intercepted by pumping wells may be high valuable to individual water users whose wells are comparatively f from infiltrating streams, near the sides of the valleys. For examp the Montgomery County Sanitary Department wells at Lamme Ro receive some recharge from the sand and gravel deposits on the adj cent upland. Similarly, wells at the Focke Packing Co., plant on t south side of the Mad River valley near Eastwood Park are replenish in part by ground water moving toward the Mad River from t sand and gravel deposits on the hill behind the plant.

Recharge to the ground-water reservoirs varies seasonally and, the Dayton area, occurs principally between late fall and early spri Beginning in late October or early November and continuing throu the winter and spring until the following April or May, ground-wat levels generally rise. During the rest of the year they usually declin however, rising trends as well as long-term declines in ground-wat levels are often interrupted and temporarily reversed by droughts floods, or by changes in pumping practices.

The hydrographs of wells Mt-2, Mt-3, and Mt-6 (pl. 2) show t fluctuations of ground-water levels, based on plottings of the lowe weekly water levels recorded in the wells. Wells Mt-2 and Mt-6 a in downtown Dayton, at the Fourth Street Station of the Dayt Power & Light Co. and in the basement of the Municipal Buildi at Second and Ludlow Streets, respectively. Well Mt-3 is sou of downtown Dayton at the intersection of Stewart Street and Pa terson Boulevard, opposite the National Cash Register Co. plant. T number of times that peak water levels occurred and that annual r charge began in specific months are shown for most of the period record in the table that follows.

Well	Period of record	Number of times—A: Peak water levels occurred B: Annual recharge began	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mt-2	1942-60	A		3	4	7		1	2					
		B	1	1						1	8	4	1	1
Mt-3	1945-60	A		3	1	4		2	1	3				
		B									1	3	5	4
Mt-6	1946-60	A	1	4	3	4	1	1						
		B								5	7	2		

The total amount of recharge derived from local precipitation, including that part directly received by the valley-fill deposits, as well as that part entering the aquifers as ground-water flow from the adjacent uplands, amounts to about one-fourth of Dayton's present water use. Party on the basis of calculations made by Walton and Scudder (1960, p. 35) in the Fairborn area, a little less than one-third of the precipitation received on the valley floor is estimated to infiltrate to the water table in areas outside the city. This amounts to about 12 inches per year, or approximately 15 mgd. Locally, recharge from direct precipitation probably differs greatly from the estimated annual rate, but data from which these rates can be calculated are not available.

Inflow of water to the valley-fill deposits from the adjacent uplands, including both surface runoff that infiltrates to the water table after it reaches the valley floors and ground-water inflow, is estimated to average about 10 mgd in the principal areas of pumpage. This rate, too, is subject to much local variation. Little surface runoff can reach the valley-fill deposits in paved areas of the city, and little subsurface flow occurs from the upland areas on both the east and west sides of Dayton, which are generally underlain by relatively impermeable Ordovician shale covered by a thin blanket of glacial till. In those areas ground-water inflow may amount to no more than about 0.1 mgd per mile of valley wall, about the same as the rate determined by Walton and Scudder (1960, p. 34) in the Fairborn area. However, ground-water inflow from the sand and gravel deposits that compose the upland on the east side of the Miami River valley between Dayton and Holes Creek is estimated at more than 1 mgd per mile of valley wall, or a total average inflow in that area of about 5 mgd.

Although recharge from local precipitation accounts for the replenishment of approximately one-fourth of the ground water presently pumped in the Dayton area, it cannot be increased appreciably, whereas recharge from the induced infiltration of streamflow, which sustains most of Dayton's pumpage, will increase as ground-water

development grows. Moreover, there are ways to increase the rate of stream infiltration artificially. For example, at the municipal well field at Rohrers Island infiltration takes place through the beds of artificial channels and lagoons, which are dredged periodically to maintain a rate of infiltration much higher than that which occurs naturally in the Dayton area.

CHARACTERISTICS OF STREAMFLOW

The most important hydrologic factor at Dayton, relative to water supply, is the regimen of flow in the Miami River and its principal tributaries. Significant flow characteristics of streams in the Dayton area were discussed by Cross and Hedges (1959, p. 139, 141, 144, 145, and 146) and are listed in table 3.

The flow that is equaled or exceeded 90 percent of the time is near the minimum flow recorded in most Ohio streams and is generally considered to come primarily from the discharge of ground water. The amount of ground-water discharge depends largely upon the natural storage properties of the formations within a drainage basin. Cross (in Norris and others, 1948, p. 64) stated:

> A river flowing from a basin of bare, impermeable rock would experience a flood following every substantial rain, and would carry little or no flow a few hours later. Another river with the same mean flow, but flowing over an area of thick, permeable sands and gravels, might have but a slight increase in flow after a rain, and high sustained flows between rains. Natural lakes and artificial reservoirs would have the same effect, but in the Miami River basin the storage is for the most part in the glacial deposits, and is ground-water storage.

For comparative purposes the flows equaled or exceeded 90 percent of the time are related to the areas of the respective drainage basins, and this ratio, usually expressed in cubic feet per second per square mile, is termed the dry-weather-flow index. The Mad River's dry-weather-flow index, 0.293 cfs per sq mi, is the highest in Ohio; it reflects the large amount of natural storage in the sand and gravel deposits in the drainage basin.

The mean flow of the Miami River at Dayton, 1,422 mgd, represents about 13 times as much water as is now being pumped in the area, and the flow equaled or exceeded 90 percent of the time 191 mgd, is more than 1½ times the present water use. However, neither of these figures is very meaningful as they reveal little about other significant characteristics of streamflow, especially the discharge available in extended periods of drought. Data on drought frequency or dry-weather flow are commonly used in surface-water studies to compute the size of proposed storage reservoirs so that a minimum flow of some selected magnitude will be obtained or, conversely, to calculate the yield

TABLE 3.—*Characteristics of flow of the principal streams in the Dayton area, Ohio*

Stream	Drainage area above Dayton (sq mi)	Station location	Mean flow		Flow equaled or exceeded 90 percent of the time		Unit discharge (cfs per sq mi)	Maximum daily discharge		Minimum daily discharge		Remarks
			cfs	mgd	cfs	mgd		cfs	mgd	cfs	mgd	
Miami River	2,318	1,000 ft downstream from Main Street Bridge in Dayton; ¾ mile downstream from Mad River.	2,203	1,422	296	191	0.118	58,800	38,600	109	70	Flood flow regulated at 4 retarding basins above station. Water is diverted above station by induced infiltration to well fields in vicinity of Beardshear Rd. (Miami River) and Rohrer's Island (Mad River) for use in Dayton; most return flow from diversions bypasses station in Dayton sewer system.
Mad River near Dayton.	632	600 ft downstream from Huffman Dam; 6 miles northeast of Dayton.	622	402	185	120	.238	17,400	11,220	94	61	Flood flow regulated by Huffman retarding basin (167,000 acre-ft).
Stillwater River at Englewood.	648 (above Englewood).	1,000 ft downstream from Englewood Dam; 8.3 miles upstream from mouth.	570	368	39.6	26	.061	9,910	6,400	4.8	3.1	Flood flow regulated by Englewood retarding basin (312,000 acre-ft).
Wolf Creek at at Dayton.	69.5	At West Riverview Avenue Bridge in Dayton; 1.3 miles upstream from mouth.	54.6	35.3	3.6	2.3	.052	3,080	1,990	1.1	.6	
Miami River at Taylorsville.	1,158	600 ft downstream from Taylorsville Dam; 9½ miles upstream from Stillwater River.	981	634	91.3	58.9	.079	24,600	15,892	39	23	Flow regulated as retarding basin on Miami River just above station (184,000 acre-ft; 1,158 sq mi) and on Loramie Creek at Lockington (70,000 acre-ft, 281 sq mi). Low and medium flow slightly regulated by Indian Lake (45,900 acre-ft, 110 sq mi).
Miami River at Miamisburg.	2,718	Miamisburg about 9 miles below Dayton sta.	2,217	1,432	386	249	.42	50,800	32,817	148	96	Diurnal fluctuation caused by powerplant above station. Flood flow regulated by 4 retarding basins above station.

available from a surface reservoir of given size. Such data may also be helpful in estimating the upper limit of magnitude of ground-water supplies in which stream infiltration is the principal means of replenishment. On the basis that there is no limit to the rate at which water from the stream can enter or be withdrawn from the ground-water reservoir, the theoretical yield from unit storage graphs (described by Cross and Webber, 1950, p. 4) can be estimated in a manner analogous to estimation of the yield of a surface-water reservoir. Thus, on the basis of the unit storage graph prepared by Cross and Webber (1950, fig. 123) for the Miami River at Hamilton (none was presented for the Dayton station) a surface-water reservoir at Dayton having the same storage capacity (approximately 425 billion gal) as the valley-fill deposits would provide a minimum flow, by regulation, of about 1,000 mgd, or about nine times the present water use. The ultimate yield of the ground-water reservoir in the Dayton area will be considerably less than 1,000 mgd, as the water must enter the reservoir principally through streambeds and then move laterally toward points of withdrawal. Entry losses through the streambed and resistance to flow within the aquifer are the principal factors that limit the rate of recharge; the first is more critical than the second. The infiltration rate is influenced by a number of variable factors and, therefore, is not constant; moreover, it can be increased artificially. Thus, within limits imposed by the regimen of streamflow, the yield of the ground-water reservoir at Dayton is largely determined by economic considerations, such as the cost of devising and utilizing methods for increasing the natural rate of recharge.

STREAM INFILTRATION

The critical factor in the development of ground-water supplies by inducing infiltration from streams is the rate at which water will "leak" through the streambed into the aquifer. The infiltration rate depends chiefly upon the permeability of the streambed, the permeability and thickness of the underlying aquifer, and the steepness of the hydraulic gradient between the source stream and wells tapping the aquifer. It also depends upon the depth of water in the stream and the temperature of the infiltrating water.

The permeability of the streambed is usually less than that of the underlying aquifer, and for infiltration to occur the water in the stream must be at a higher level than the water table immediately adjacent to the stream. This difference in head is a measure of the force required to move water through the interface between the channel and the body of sand and gravel in which the channel is cut. The relationship between the infiltration rate and the head difference is approxi-

mately linear so long as the water table is not lowered below the streambed. When the water table drops below the streambed and continues to fall, a corresponding increase in the rate of infiltration to the aquifer will not be produced. Until this condition is reached, however, the head available in the stream channel is a major factor affecting infiltration rates.

Seasonal variations in stream temperature may under certain conditions be a major factor in the yield of infiltration supplies (water's viscosity and resistance to flow are inversely related to temperature). The flow rate to a well, for a given drawdown, is decreased about 1.5 percent for each degree the water temperature is lowered. Theoretically, this can amount to as much as a 50 percent change in flow rate over the common range of stream temperature; however, once water enters the ground its temperature quickly approaches a median value and the practical effects of seasonal temperature variations usually are not significant.

The potential yield of wells drawing replenishment from a stream would be easy to evaluate if the rate of infiltration through the streambed could be readily ascertained. Unfortunately, infiltration rates, especially for large streams, are difficult to determine, whether by analysis of ground-water data or by direct measurement of seepage losses in the stream. Rorabaugh (1951, p. 170) stated:

> Determination of percolation rates for large streams in terms of rate per unit area is difficult. * * * When a well near a large river is pumped, the cone of depression extends beneath the river until sufficient head and area are developed to satisfy the needs of the system. In a highly permeable bed the cone may extend only part way across the river. Where low vertical permeability exists the cone may expand to include the full width of the stream and then extend up stream and down stream. Since the head distribution is logarithmic percolation rates in the area near the installation will be several times as large as the average over the effective area of percolation.

When sufficient data are available from observation wells in the vicinity of a discharging well or group of wells and an adjacent infiltration stream, contours drawn on the water table will define the size and extent of the cone of depression and show the area of the stream channel in which infiltration is occurring. When the system is in equilibrium and the pumping rate is known, the average infiltration rate can be determined for the area of the stream channel between the limiting or so-called neutral contours, which represent the boundaries of the area in which infiltration is occurring. This method is useful when the aquifer beneath the infiltrating stream is reasonably homogeneous and the shape of the cone of depression is not distorted. Distortion of the cone results from differences in permeability in the aquifer or from the effects of semiconfining beds through which the

water must pass in traveling from the stream to the wells. The complex hydrologic conditions in the Dayton area, particularly effects of the till-rich zone beneath which most wells are screened, together with widespread well-interference effects caused by uncontrolled pumping, generally rule out application of methods based on the areal extent of cones of depression.

The most practical method for determining infiltration rates in the Dayton area is by direct measurement of seepage losses in the streams. However, because of the minimum error of 2–5 percent considered present in all stream-discharge measurements, this method is reasonably accurate only when flows are relatively low and the seepage losses are a significant part of the total flow. The accuracy of the method depends also upon the adequacy of data relative to diversions between measurement points, such as the amount of inflow from storm sewers or tributaries.

The flow in the principal streams at Dayton usually is too high to permit accurate determination of seepage losses by direct measurement. This can be done only when the streams are near their minimum flows; that is, at discharges which are equaled or exceeded about 90 percent of the time. Infiltration rates determined under low-flow conditions many be very different from those which occur when the streams are at moderate to high stages, and this fact must be kept in mind when evaluating the results.

It is generally believed that under natural conditions the rate of infiltration through a streambed is greatest during or immediately after floods, when the silt and other fine-grained sediment, including organic matter, that have accumulated in slack water periods are being removed by channel scour. With reference to Dayton, a board of consultants (Abel Wolman and others, written commun., 1957) stated: "The relatively impermeable river bottom seal or crust that occurs in places in the Miami River greatly retards the vertical seepage of water." The consultants also commented on the indurated character of this "crust," the existence of which, they pointed out, is well known to construction engineers familiar with the river.

A striking illustration of the low permeability of the stream channel in periods of low and moderate flows is a photograph (fig. 14) which shows a difference of several feet between the level of the water in the Miami River and the water table in the Miami Shores area south of Dayton. If the stream channel were more permeable in this area the water table would eventually rise to about the level of the water in the stream.

FIGURE 14.—Excavation near the Miami River in the Miami Shores area, in 1960, showing difference in height between the water table (represented by the water surface in bottom of excavation) and river level. Photograph courtesy of the Miami Conservancy District.

The condition of the streambed depends largely upon the characteristics of flow in the stream, including velocity, sediment load, and erosion or deposition of material in the channel. A stream may scour its channel during rising stages, when the velocity of flow is increasing, and redeposit material during falling stages, when the velocity of flow is decreasing. Moreover, there may be considerable differences in velocity across a stream, and the stream may be eroding one part of its channel and building up another part. Consequently, streambed conditions vary widely from time to time and from place to place. Artificial channel controls such as retaining walls or levees that restrict the flow to a comparatively narrow part of the channel may increase the velocities sufficiently to prevent deposition in a particular reach, while low-head dams, commonly constructed in the major streams to provide for water-supply intakes or to keep the channels flooded for scenic or recreational purposes, increase the siltation of the channels.

Floods are major, still largely unevaluated factors in aquifer replenishment at Dayton. During flood stages in which the streams overflow their banks, water may cover land planted to various kinds of crops, including grass or trees, in various stages of tillage and having a wide range of permeability. Duration of floodflows and the antecedent condition of the ground are also factors determining the quantity of water entering the aquifer. Comparison of the hydrographs of observation wells Mt-2, Mt-3, and Mt-6 and graphs of the mean daily discharge in the Miami River (fig. 15) shows that in June 1958 mean daily flows up to 36,000 cfs lasting for several days raised ground-water levels more than did the well-publicized flood of January 1959, which produced a peak mean daily discharge of nearly 60,000 cfs. Not only were the high discharges of June 1958 of longer duration than those of January 1959, but also, and perhaps more significantly, the 1959 flood occurred when the ground adjacent to the stream channels was largely frozen. The duration of the floodflows and the condition of the ground at the time of the floods controlled the amount of water that infiltrated to the ground-water reservoirs. Still another factor in determining infiltration rates, though in this area probably a minor one, is the amount of soil moisture and the rate at which it is lost by evapotranspiration during flooding.

Stream infiltration rates under natural conditions generally are considerably below rates that have been achieved artificially in some areas by dredging or harrowing of the stream channels, or determined experimentally by allowing water to infiltrate through the bottoms of specially prepared recharge pits. This has led to adoption of artificial recharging methods, such as those used by the Dayton Water Department at Rohrers Island, and to consideration of the feasibility

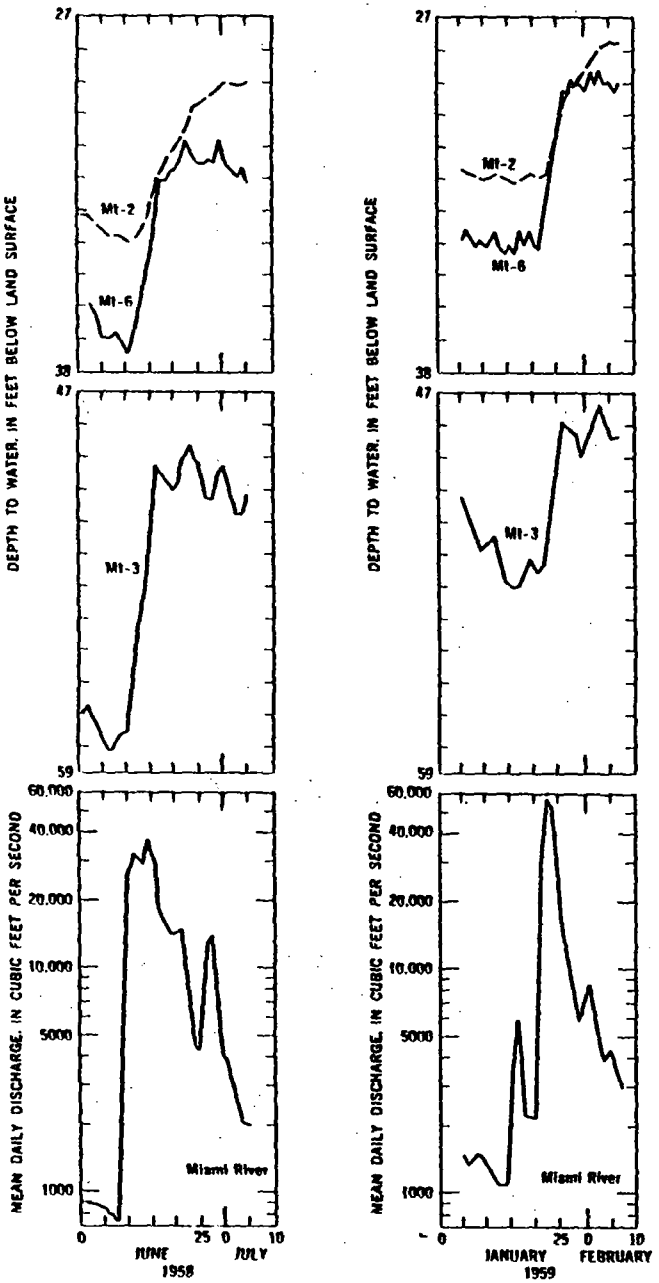

FIGURE 15.—Hydrographs of observation wells Mt-2, Mt-3, Mt-6 and of the Miami River at Dayton, showing effect of riverflow on ground-water levels. Ground-water levels rose more during sustained high flow in June 1958 than during the higher, shorter flow in January 1959.

of applying such methods generally in the Dayton area. The paragraphs that follow review some of the findings on natural recharge rates in other areas and the results of dredging experiments and low-flow studies at Dayton.

According to Rorabaugh (1951, p. 170), infiltration rates through the riverbed in a 2-mile reach of the Ohio River near Charleston, Ind., have averaged 0.15 mgd per acre during periods of intensive pumping. Walton and Scudder (1960, p. 35–36) reported that pumping from wells at the Wright-Patterson Air Force Base has induced infiltration through the bed of Hebble Creek at rates ranging from 0.17 to 0.33 mgd per acre, and through the bed of Mud Run at the rate of 0.34 mgd per acre. These rates are based on discharge measurements made in the summer of 1955 during periods of low streamflow. The rate of infiltration is greater, Walton and Scudder stated, when the flows in the streams are high.

Dove (1962, p. 64) stated that near Hamilton, where as much as 17 mgd is pumped from two large-diameter collector-type wells, the infiltration rate on August 31, 1956, averaged 0.24 mgd per acre in the vicinity of the wells. A further study made by Dove in the summer of 1956 showed the infiltration rate in the same area to range from 0.13 to 0.14 mgd per acre for each foot of head difference between the surface of the river and the subjacent water table.

INFILTRATION RATES AT DAYTON

ROHRERS ISLAND WELL FIELD

The greater part of the Dayton municipal water supply comes from wells on and near Rohrers Island (pl. 4). These wells, most of which are screened in the upper sand and gravel aquifer (Norris and others, 1948, p. 53; Norris, 1959), yield an average of about 40 mgd; the peak pumpage has been as high as 90 mgd. The supply is maintained by artificially recharging the aquifer, in what is probably the outstanding example of proper ground-water management in this part of the United States.

Infiltration ditches and lagoons covering a 20-acre area, about one-tenth of the island, have been dredged and are flooded periodically, when the turbidity of the river is low, to recharge the underlying aquifer (figs. 8, 16). Flooding is accomplished (Norris and others, 1948, p. 53) by diverting water from the south channel of the Mad River through a large intake pipe near the head of the island. Flow through this diversion is maintained by a dam in the north (main) channel of the Mad River near the head of the island and by a dam in the south channel about one-third of a mile below the intake pipe (fig. 17). The purpose of these dams is to raise the water sufficiently to

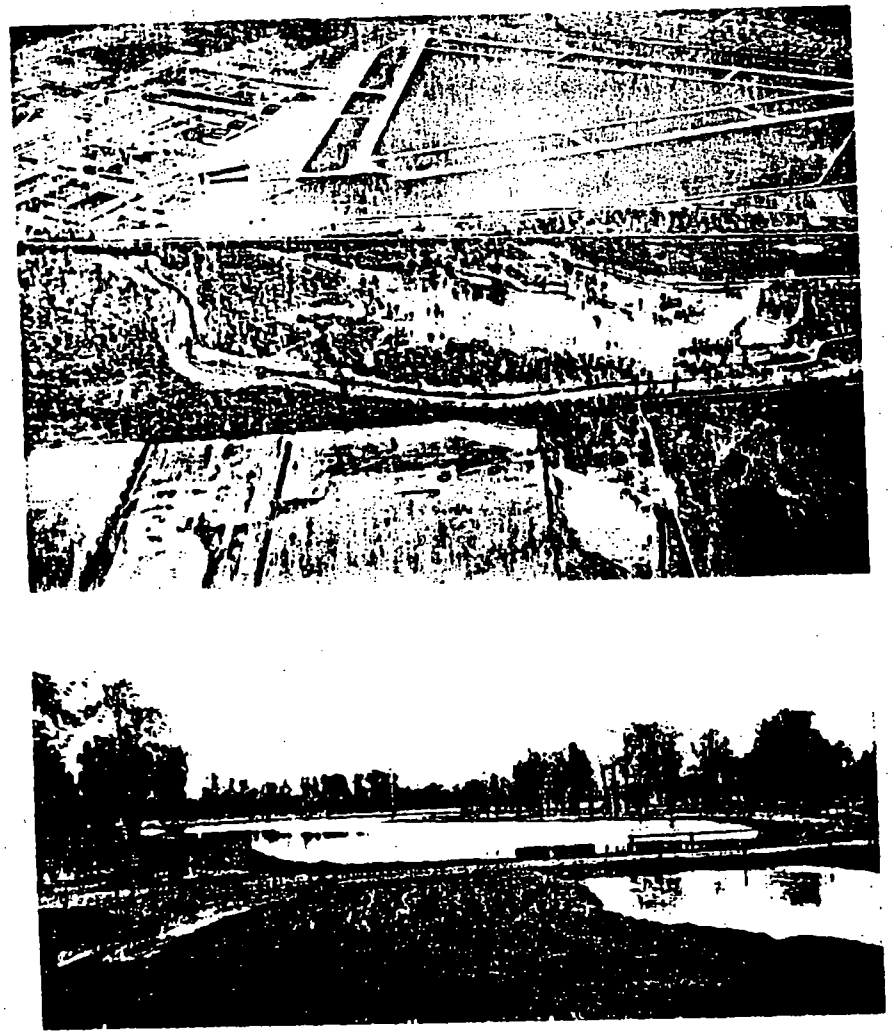

FIGURE 16.—Municipal well field on Rohrers Island.

cause flow into the infiltration areas. The lagoons and ditches are dredged each year to remove the bottom material and thus maintain a high rate of infiltration through the bottoms of the ponds.

According to Mr. Charles Stout, well-field supervisor, the intake is closed each January and dredging is begun in February. The muck and silt accumulation is dug out with a back hoe down to the clean sand and gravel (fig. 18), and by about May 1 the ponded areas are reflooded. Mr. Stout stated that after the intake is closed, the ponds take about a week to dry up. While the ponds are dry, water levels in the aquifer decline to 30–40 feet below the land surface. During the

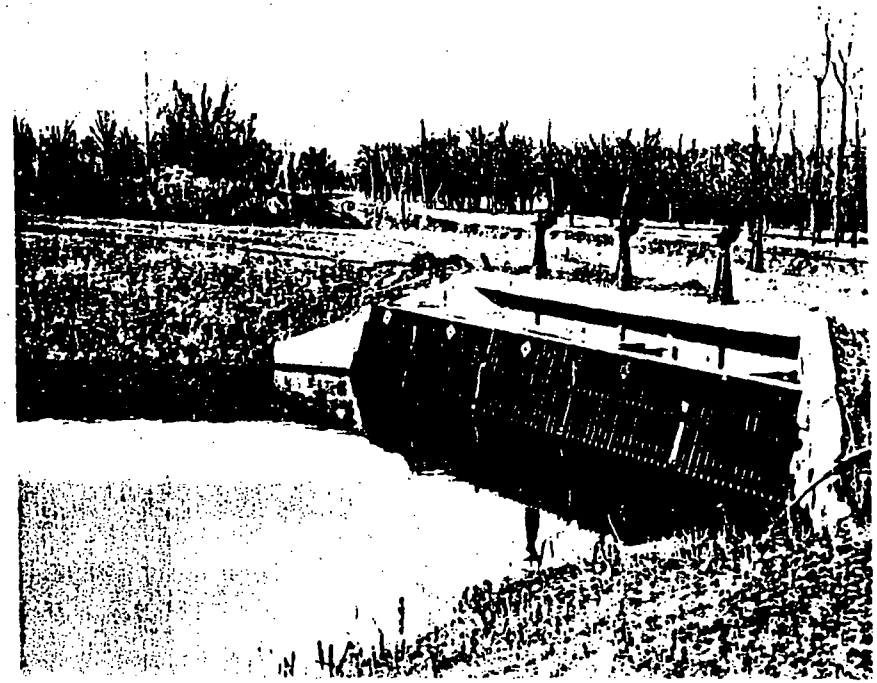

FIGURE 17.—Intake structure near head of Rohrers Island. Gate was closed at time photograph was made.

rest of the year, when the ponds are full, ground-water levels are 10–20 feet below the surface. Methods of maintaining and operating the recharge ponds have changed over the years as various experiments have been made, and they have evolved into the present system, the effectiveness of which is demonstrated by the stability of the water supply over the past several years.

The area subject to infiltration in the vicinity of Rohrers Island includes not only the 20 acres of ponds on the island, but also two ponds of about 7 acres each lying adjacent to Rohrers Island on the south bank of the Mad River, as well as the areas covered by the north and south channels of the river (fig. 16). The main channel of the Mad River, where it forms the north boundary of Rohrers Island, covers an area of about 15 acres at low and moderate stream stages, and the secondary channel of the Mad River, which forms the south boundary of the island, occupies an area of about 7 acres. Thus, the total area on and adjacent to Rohrers Island through which infiltration can occur is about 56 acres.

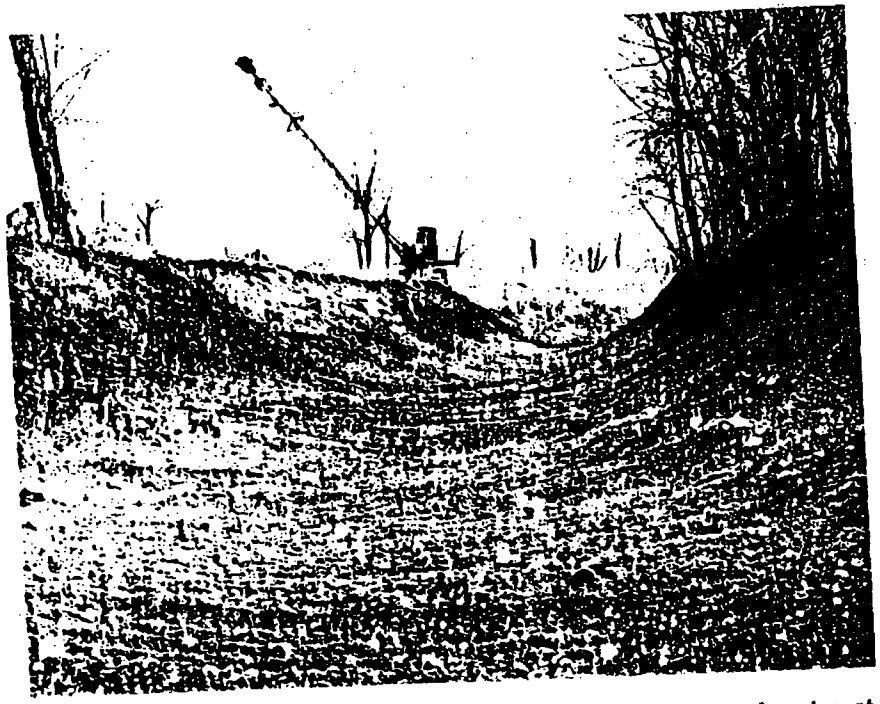

FIGURE 18.—Excavations made for artificial recharging of ground water at Rohrers Island. Upper photograph shows recharge channel soon after being drained. Mud and silt have accumulated on sides of channel. Lower photograph shows recharge channel after being cleaned and prepared for readmission of water.

Although a large area is subject to infiltration, most recharge to the underlying aquifer, at least during periods of low streamflow, takes place in the 20 acres that is artificially ponded and periodically dredged. Little dredging has been done in the remainder of the area, and relatively little infiltration is believed to occur there.

The U.S. Geological Survey made discharge measurements on and near Rohrers Island on August 2 and October 19, 1944, to determine the loss of the flow from the Mad River and the loss in ponded areas on the island. The measurements of August 2, 1944, were made at a time when the flow at the Huffman Dam–Mad River gage was approximately 166 cfs, which is equaled or exceeded about 95 percent of the time. A total of nine measurements were made by current meter at points in each channel of the Mad River and in the dredged areas on Rohrers Island. The total measured loss in streamflow between the upper and lower ends of Rohrers Island was approximately 30 mgd, of which about 21 mgd was lost in 13 acres of ponded area. Neglecting evaporation losses, this represents an infiltration rate of 1.6 mgd per acre. The total loss in streamflow of approximately 30 mgd was about 82 percent of the water pumped that day from the wells on Rohrers Island.

The discharge measurements made by the U.S. Geological Survey on October 19, 1944, in the vicinity of Rohrers Island are inconclusive, owing to a possibly erroneous measurement made in the Mad River below Rohrers Island. Other measurements on that day indicate a loss in the ponded areas of about 36 mgd, or an infiltration rate of about 2.5 mgd per acre. The flow at the Huffman Dam gage on October 19, 1944, was 152 cfs, or about 98 mgd. Thus, the loss in the ponded areas on that day amounted to more than one-third the total flow in the Mad River.

Discharge measurements were again made in the vicinity of Rohrers Island by the U.S. Geological Survey on October 4, 1960, as part of a low-flow study based on measurements made at several points on the Mad and Miami Rivers, between the Huffman Dam gage and the mouth of Holes Creek. At the time the measurements were made the discharge at the Huffman Dam gage was 182 cfs, about 16 cfs more than the discharge on August 2, 1944.

The measured loss in flow in the vicinity of Rohrers Island between station A, the Huffman Dam gage, and station B, about 400 feet below Harshman Road (pl. 4), was 31 mgd. Mr. Charles Stout estimated that when the U.S. Geological Survey made its measurements in 1960, about 30 mgd of water was entering the ponded areas on Rohrers Island, most of it flowing into six of the northernmost group of ponds on the island, which have a total area of about 15 acres. According to Mr. Stout, there was very little infiltration from the remainder of the

ponds on and near the island and from the Mad River because of the silted condition of these other areas. (The diversion into the ponds on Rohrers Island reduces velocity in the Mad River and increases siltation in the reach of the river adjacent to the island.) If it is conservatively estimated that 25 mgd was infiltrating through the beds of the six ponds, the infiltration rate was about 1.7 mgd per acre, which is nearly the same as the rate determined from the August 2, 1944, measurements.

Pumpage at Rohrers Island on October 4, 1960, was 28 mgd from the upper aquifer and 12 mgd from the lower aquifer. The measured loss in flow of 31 mgd between stations A and B represents nearly 80 percent of the water pumped on that day.

DISCHARGE MEASUREMENTS OF SEPTEMBER 7, 1951

On September 7, 1951, the U.S. Geological Survey made two discharge measurements on the Mad River, at the Huffman Dam gage and near its mouth, and two measurements on the Miami River, at the Main Street gage and near the Broadway Bridge in the southern part of Dayton. The discharge at the Huffman Dam gage was 235 cfs, about 30 percent greater than the flow on October 4, 1960. No data were obtained on effects of diversions between the measuring stations; however, the Mad River measurements indicate a loss of about 43 mgd between Huffman Dam and the mouth of the stream. The greater part of this loss probably occurred in the ponded areas on Rohrers Island.

DISCHARGE MEASUREMENTS OF OCTOBER 4, 1960

On October 4, 1960, engineers of the U.S. Geological Survey and the Miami Conservancy District measured the discharge at several points on the Miami and Mad Rivers to determine the amount of water entering the ground by seepage through the streambeds and to ascertain the areas in which the rate of infiltration was significant. On the day the measurements were made the flow of Miami River at Dayton was only 205 cfs, which normally is exceeded 98 percent of the time, and the flow at the Huffman Dam gage was 182 cfs. At such a low stage, measurements in the Miami River can ordinarily be made by men wading the stream.

Six measurements were made, and these were supplemented by discharge figures computed from gage readings at the Dayton gage and the Mad River gage at Huffman Dam. One measurement in the Miami River, about a mile above the mouth of Holes Creek, was made from a boat and was considered too inaccurate to use in the study. However, another measurement was made in the same place, reached by wading, on October 26, when the stream stage was the same as it had

been on October 4. The October 26 measurement is consistent with those of October 4 and is used in this analysis.

Conditions of stream stage and ground-water use were relatively constant for several days prior to the time of the measurements and remained so for several days thereafter. Light rains fell throughout Ohio on October 1 and 2, when a total of 0.40 inch was recorded at the Dayton Municipal Airport. This caused a rise of about 0.1 foot at the Dayton gage on the Miami River, which crested at midnight on October 2. Recession was gradual, and the stage was nearly constant by October 4.

To determine more accurately the gains or losses in discharge between successive measurement points, inflow from the city storm sewers and the major industrial plants and the effluent from the sewage treatment plant were recorded at or about the time the measurements were made. Discharges from the city storm sewers were computed on October 5; however, in the opinionof Mr. Elmer Gooch, Chief Engineer of the Bureau of Sewers, they were virtually the same as the flows of the previous day.

The points where the stream measurements were made are shown on plate 4, and the discharge data and rates of infiltration between successive stations are given in table 4. As expected, the greatest loss in flow, 31 mgd, occurred in the vicinity of Rohrers Island between stations A and B. Infiltration took place chiefly in the ponded areas on the island, as has already been described.

TABLE 4.—*Miscellaneous discharge measurements, October 4, 1960*

Measurement station	Approximate location	Discharge	Inflow between stations	Gain or loss between stations		Area of stream bed (acres)	Infiltration rate (mgd per acre)
		cfs			mgd		
A	Mad River at Huffman Dam gage	182					
B	Mad River at Harshman Rd.	134		−48	[1] −31	[2] 15	1.7
C	Mad River above Findlay St.	126		−8	−5.2	13	.40
D	Mad River near mouth	137	10	+1	+.6	19	
E	Miami River at Main St. gage	205	80	−12	−7.7	22	.33
F	Miami River below Broadway Street Bridge	233	44.3	−16.3	−10.5	156	.06
H	Miami River opposite Miami View Golf Course	306	[3] 74.3	−1.3	−.8	35	.02
I	Miami River 1 mile north of Holes Creek	[4] 293	7.8	−20.8	−13.4	48	.28

[1] It is estimated that all but 6 mgd entered the ground through 15 acres of pond area; hence, $\frac{25}{15}=1.7$.
[2] Represents only those ponds on Rohrers Island through which most infiltration occurred.
[3] Effluent from sewage-treatment plant.
[4] Measured Oct. 26, 1960.

Discharge measurements at stations B and C (pl. 4) show a loss in flow of about 5 mgd in the reach of the Mad River between Harshman Road and a point about 0.4 mile above Findlay Street. Ground-water

withdrawals in this part of the valley, chiefly from municipal wells C–7 and C–9, were estimated to be about 3.5 mgd on October 4. Recharge to these wells probably accounted for part of the loss in flow in this reach of the river; some of the loss may relate also to the filling of cones of depression around wells C–17 and C–18, from which about 4 mgd was being pumped up to a few hours before the measurements were made. Much of the loss in this reach was due also to pumping from the lower aquifer farther downstream, between stations C and D. Infiltration was facilitated by stream dredging then in progress in the vicinity of well C–17, about 2,000 feet below Harshman Road. The dredging had been going on intermittently all summer in this general area as part of a program of levee construction and channel straightening.

On the basis of the total area of the streambed between measurement points B and C, the infiltration rate was computed to be about 0.4 mgd per acre. However, infiltration was probably not uniform over the area, and the infiltration rate in the dredged areas no doubt greatly exceeded the rate calculated for this segment of the stream.

In the reach of the Mad River between measurement points C and D, from a point 0.5 mile below Eastwood Park nearly to the confluence with the Miami River, there was little change in flow. Pumping in this area of the valley amounts to about 3–5 mgd from the lower aquifer and to little or none from the upper aquifer. The piezometric surface of the lower aquifer is below river level in this area (pls. 7, 8), and some vertical leakage from the upper to the lower aquifer, and consequent loss of streamflow by infiltration to the upper aquifer, would be expected. However, hydrologic conditions in this part of the valley are altered by the presence of a local confining bed of till which occurs at shallow depth in the upper aquifer. The shallow till layer forms a local artesian aquifer which receives recharge from the unconfined part of the aquifer in the vicinity of Eastwood Park. A part of this recharge reaches the lower aquifer by downward leakage through the till-rich zone.

In the short reach of the Miami River between station D, near the mouth of the Mad River, and station E at the stream-gaging station about 1,000 feet below the Main Street Bridge, and including a 2,000-foot reach extending upstream from the mouth of the Mad River to station K, there was a loss of about 7.7 mgd based on the discharge measurements of October 4, 1960. The infiltration rate in this area was about 0.3 mgd per acre, a little less than that determined for the reach of the Mad River between stations B and C, below Rohrers Island.

The loss in flow between stations D and E results from pumpage of about 10 mgd in the central part of the city, which has lowered the piezometric surface of the lower aquifer as much as 20 feet below river level.

The October 4, 1960, discharge measurements show a loss of about 10.5 mgd between stations E and F, in the 3.5-mile reach of the river between the gaging station near the Main Street Bridge and a point below the Broadway Bridge, near the south limits of Dayton. Pumpage in this area is relatively heavy, currently averaging 25–30 mgd. As plate 8 shows, the piezometric surface of the lower aquifer is 20–35 feet below river level. Ground-water levels along this reach of the stream are the lowest in the Dayton area owing to a relatively low rate of infiltration, which on October 4, 1960, was only 0.06 mgd per acre. As a consequence of the low infiltration rate, more water was being removed from aquifer storage along this reach of the river on October 4, 1960, than along the rest of the channel.

The low infiltration rate between stations E and F is probably due to a greater accumulation of silt there than elsewhere, caused by the pooling of the river behind the low dam at the Tait Station of the Dayton Power & Light Co. In 1956 a board of consultants (Abel Wolman and others) made tests near Carillon Park, about 0.5 mile above the Tait Station Dam, and found that as much as 1 foot of fine-grained sediment generally covered the river bottom. At that time the water table was 3–12 feet below river level in the Carillon Park area.

On the basis of pumping-test data and the hydraulic gradient, the board of consultants estimated that on May 21, 1956, the Miami River was losing water in the test area near Carillon Park at the rate of 10 mgd per mile of channel. This estimate is much higher than that based on the measured loss in flow on October 4, 1960, of 10.5 mgd between stations E and F, which is equivalent to only 3 mgd per mile of channel. The discharge at the Dayton gage on October 4, 1960, was 205 cfs, and on May 21, 1956, it was 935 cfs. The higher discharge on May 21, 1956, would probably have resulted in a higher infiltration rate than occurred on October 4, 1960. However, the rate of 10 mgd per mile of channel, estimated near Carillon Park, cannot be applied to the entire 3.5-mile reach between stations E and F, and no comparison can be drawn between it and the infiltration rate determined on October 4, 1960.

Between stations F and H, in the 1.3-mile reach between a point near the south boundary of Dayton and a point opposite the Miami View Golf Course, south of the city sewage-treatment plant, there was little change in flow on October 4, 1960. Allowing for the diversion into the Miami River of the effluent from the sewage plant, there was

a measured loss in flow of only 0.8 mgd, a quantity too small to consider in view of the margin of error inherent in the discharge measurements.

There is very little pumpage in the reach between stations F and H; however, the cone of depression around the Tait Station wells to the north and that around the Frigidaire Division wells to the south merge in this area, and the piezometric surface of the lower aquifer is a few feet below river level. The hydraulic gradients are very low, however; this fact, plus the fact that ground-water recharge is received from the kame deposits that lie along the east edge of the valley, accounts for the small loss in streamflow on October 4, 1960.

In the reach of the Miami River between station H, near the Miami View Golf Course, and station I, 1 mile north of Holes Creek, the loss in streamflow was estimated to be about 13 mgd, on the basis of the discharge measurements of October 4 and 26, 1960. For the entire reach between stations H and I, the infiltration rate was about 0.3 mgd per acre. About 25 mgd is currently being pumped in the area adjacent to this reach of the stream, and the piezometric surface of the lower aquifer generally is a few feet below river level. Some water was being pumped from storage in the aquifer on October 4, 1960, and some of this was being replaced by flow from the kame deposits along the east edge of the valley. These permeable sand and gravel deposits, which extend south from Calvary Cemetery to Holes Creek, constitute a large natural reservoir which absorbs much precipitation and releases it slowly as ground-water discharge to the Miami River. (See geologic section *B–B'*, pl. 3.) Wells drilled in the valley between the river and the bordering kame deposits receive recharge from both sources.

Approximately 110–120 mgd was being pumped for municipal and industrial water supply in the Dayton area when the October 4, 1960, discharge measurements were made. These measurements show that about 50–55 percent of the water pumped from the ground was being replaced by induced stream infiltration. The remainder was being pumped from storage in the aquifer, except for a minor amount derived from inflow from the hills bordering the valleys. The measurements were made when the flow at the Dayton gage on the Miami River was 205 cfs, a discharge that is equaled or exceeded nearly 99 percent of the time (pl. 2). During the periods of such low flows the rate of infiltration from the rivers, except at Rohrers Island, is too low to keep pace with the quantity of water being pumped. Consequently, ground-water levels decline until infiltration from the streams becomes more effective in recharging the aquifers.

INFILTRATION AS RELATED TO STAGE, DISCHARGE, AND AREA

Comparison of the hydrographs of wells Mt–2, Mt–3, and Mt–6 to the mean discharge in the Miami River (pl. 2) shows that the annual fluctuations in ground-water levels follow closely the hydrograph of mean stream discharge. The highest ground-water levels usually lag behind the peak stream discharges by periods of a week or more; however, ground-water levels usually begin to rise from their seasonal lows in the early fall, when the streams still are at fairly low stages. The annual rise in ground-water levels in downtown Dayton begins at the end of the air-conditioning season, when pumpage is reduced.

Sustained discharges greater than about 2,000 cfs[2] at the Miami River (Main St.) gage produce most of the annual recharge to the ground-water reservoirs in central and southern Dayton. This is concluded from a comparison of the hydrographs of observation wells Mt–2, Mt–3, and Mt–6 to mean daily discharges in the Miami River (fig. 19) for 1956, a fairly typical year. It is not known whether the rate of infiltration is directly proportional to stream discharge and becomes sufficiently large when the discharge is about 2,000 cfs to exceed the present rate of withdrawal from the aquifers, or whether at some "critical" discharge a sudden disproportionate significant increase in the infiltration rate is produced. This may occur when the velocity reaches a point where scouring of the streambed begins; or it may relate to changes in the width of the channel, in that at higher discharge more of the channel is flooded than at lower discharge, allowing water to infiltrate in areas where the indurated channel deposits of muck and silt have not accumulated in significant amount.

A table follows that shows the relationship between discharge, stage, width, and velocity of stream at the Main Street gage (Miami River at Dayton).

Discharge (cfs)	Stage (ft)	Width of stream (ft)	Velocity (ft per sec)	
			Mean	Highest
125	[1] 0			
200	.18	292	0.50	1.08
300 [2]	.34	299	.74	1.30
2,000	1.96	357	1.75	2.57
10,000	5.88	451	4.08	4.64

[1] Gage-height datum is alt 720.0 ft.
[2] Discharge equaled or exceeded about 90 percent of the time.

[2] A discharge of 2,000 cfs at the Main St. gage is approximately equivalent to a discharge of 650 cfs at the Huffman Dam gage on the Mad River.

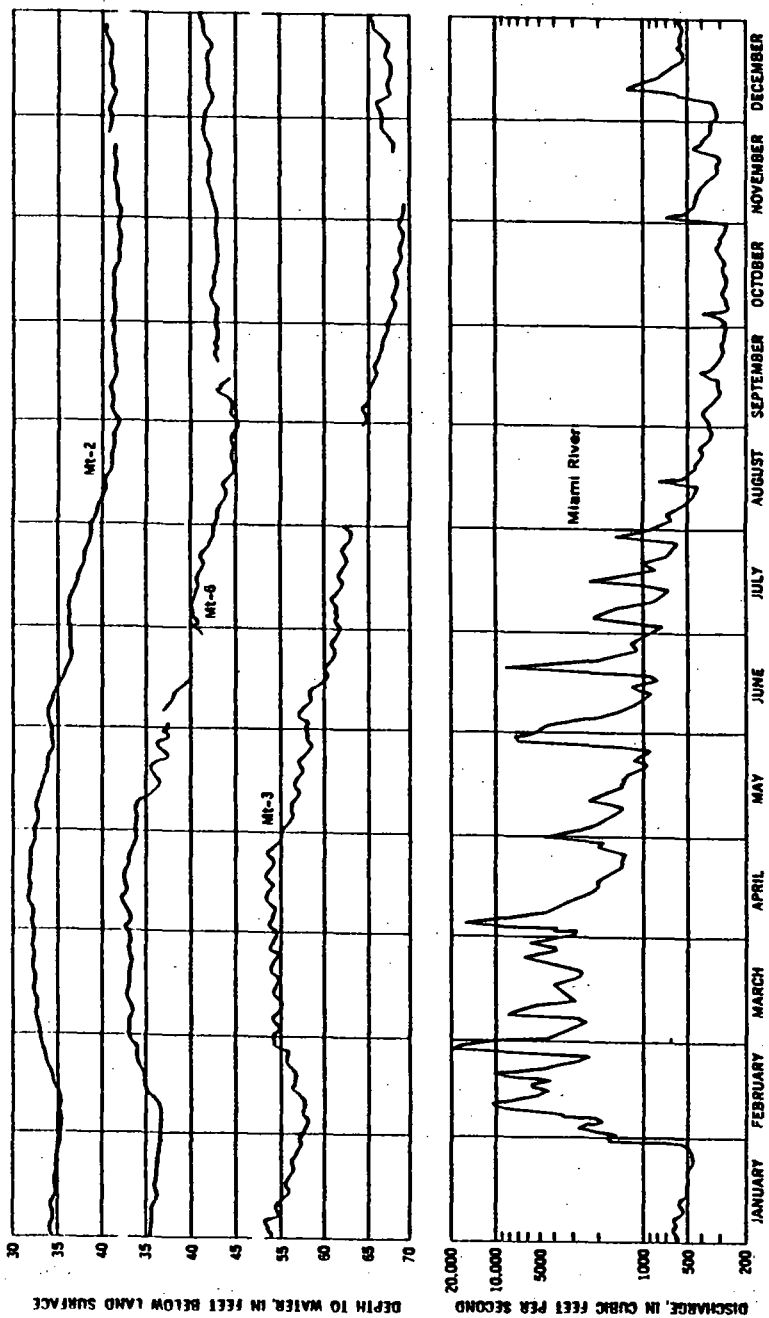

FIGURE 19.—Hydrographs of observation wells Mt-2, Mt-3, Mt-6 and of the Miami River at Dayton, 1956. Ground-water levels generally rise when discharge equals or exceeds about 2,000 cfs.

The relationship between width of the stream and specific discharge varies considerably between the Main Street gage and the low-head dam near the south limits of the city. The Miami River is more restricted below than above the dam, and width below the dam changes relatively little when discharge is 300–2,000 cfs.

In the vicinity of the Main Street gage the width of the stream changes little between stages of 6 and 9 feet. Below a stage of 6 feet, however, the infiltration rate may at times be significantly higher in the part of the channel lying between the "normal" water's edge and the waterline represented by a discharge of, say, 2,000 cfs. The intermittent exposure of this area, during which the ground is dried out, may temporarily increase its permeability.

The change in stage between discharges of 300 and 2,000 cfs is only about 1.6 feet at the Main Street gage, and the depth of water in the stream is not a significant factor in determining the amount of water infiltrated in downtown Dayton. Farther downstream, however, in the vicinity of Moraine City, the stage changes more with variations in discharge, and the head in the river has relatively greater influence in the recharging of the underlying aquifers.

At a discharge of about 30,000 cfs at the Main Street gage, levees are topped in the unimproved part of the channel, and infiltration can occur over a considerable area in the lowlands south of Dayton. A discharge of 30,000 cfs occurs, on the average, about once each 1½ years, according to records of the Miami Conservancy District, often enough for widespread flooding to be a major factor in recharging the ground-water reservoirs. Improvements will eventually be made which will restrict flows of this magnitude to the existing channel, limiting the areas that will be flooded and probably reducing ground-water recharge.

Infiltration rates are related also to the velocity of flow in the stream, in that at critical velocities the silt and indurated bottom seal may be scoured from the streambed, thereby increasing its permeability. Velocities at which a stream scours its bed vary greatly and depend upon the condition of the streambed, the sediment load in the stream, and the kind of sediment being transported. The effects of increased permeability of the streambed, caused by scouring, are partly offset by the higher turbidity of the water during floods, which reduces infiltration.

Engineering studies to determine the effects of the flow of water on bed materials have been directed toward the design of stable channels and permissible canal velocities, and little attention has been given to the relation of flow characteristics to infiltration rates. King (1939,

p. 284), commenting on the work of Fortier and Scobey (1926), stated that:

> there is no sharp line of demarcation between the velocities that can no longer maintain silt in movement and those that will scour a canal bed. It is believed that there is a broad belt of velocities between these two "critical" velocities within which silt already loosened or brought in through a headgate will remain in suspension while the bed will not be scoured. In general, old and well-seasoned canals will stand much higher velocities than new ones. This is true particularly if the canal bed or if the silt conveyed by the stream contains colloidal matter.

King (1939, p. 286) presented a table, also based on the work of Fortier and Scobey, listing permissible canal velocities after aging. Part of the table follows in modified form.

Original material excavated	Velocity (ft per sec)		
	Clear water, no detritus	Water transporting colloidal silt	Water transporting noncolloidal silt, sand, gravel, or rock fragments
Fine sand, noncolloidal	1.50	2.50	1.50
Fine gravel	2.50	5.00	3.75
Coarse gravel, noncolloidal	4.00	6.00	6.50

A more nearly complete table listing permissible velocities for use in the design of silt-stable canals was published in the U.S.S.R. in 1936 and presented in a report by Simons.[3] In modified form, it is as follows:

Material	*Diameter (mm)*	*Mean velocity (ft per sec)*	*Material*	*Diameter (mm)*	*Mean velocity (ft per sec)*
Silt	0.006	0.49	Pebbles:		
Sand:			Fine	15	3.94
Fine	.05	.68	Medium	25	4.59
Medium	.25	.98	Coarse	40	5.91
Coarse	1.00	1.80	Large	75	7.87
Gravel:			Do	100	8.86
Fine	2.50	2.13	Do	150	10.83
Medium	5.00	2.52	Do	200	12.80
Coarse	10.00	3.25			

These velocities, according to Simons, are modified by a correction factor which varies with depth as follows:

Depth ft	0.65	1.97	3.28	4.92	6.56	8.20	9.84
Correction factor	.80	.90	1.00	1.10	1.15	1.20	1.25

The foregoing discussion of permissible velocities in artificial channels cut in various materials is useful as a general guide in considering the effects of flow velocities in the natural stream channels at Dayton. Velocities vary considerably in the Miami and Mad Rivers, not only with discharge, but also with changes in width of the channels from

[3] Simons, D. B., 1957, Theory and design of stable channels in alluvial materials: Fort Collins, Colorado State Univ. Ph.D. thesis, p. 5–60.

place to place. Suffice it to say that in many places and at various times velocities in these streams are sufficiently high that streambeds are eroded. The effects of this erosion on the "bottom seal" have yet to be evaluated in terms of the relation between infiltration rates and specific flows in the streams.

GROUND WATER AVAILABLE FROM NATURAL STREAM INFILTRATION

In the reach extending upstream from Holes Creek to the Miami River well field of the city of Dayton, the Miami River at moderately low stages covers an area of approximately 400 acres. At comparable stages the Mad River, between its mouth and Huffman Dam, covers an area of approximately 75 acres, including 20 acres of ponds and lagoons on Rohrers Island.[4] Thus, during low to moderate stages a total of about 475 acres of streambed is covered by water. During higher discharges the streams cover somewhat more area; for the purpose of this discussion it is assumed that at discharges of about 2,000 cfs at the Main Street gage the total area covered by the streams is about 550 acres. Ground-water pumpage in this area totals approximately 110 mgd, of which an estimated 85 mgd is replenished by infiltration through the streambeds. Therefore, if infiltration occurs uniformly over the entire 550-acre area of streambed, the average infiltration rate will be approximately 0.15 mgd per acre, a value considerably below that observed in many places under natural conditions. It is understood, of course, that ground-water recharge does not occur uniformly over the area, but ranges from zero in small areas where the streams are gaining, to at least 1.7 mgd per acre in the ponded areas on Rohrers Island.

The highest rate of natural infiltration through the bed of the Miami River is in the reach extending from the mouth of the Mad River to the vicinity of the Broadway Street Bridge, near the south boundary of Dayton. Pumpage along this 4-mile reach is about 30 mgd, almost all of which, owing to the impermeable covering of buildings and city streets, must be replenished by infiltration through approximately 165 acres of streambed. Ground-water levels are below the streambed perennially in this area, and infiltration from the Miami River occurs all the time, though at varying rates. On an annual basis the infiltration rate averages about 0.18 mgd per acre. However, the average infiltration rate in most of this area was only 0.06 mgd per acre on October 4, 1960, during a period of low stream discharge. As explained previously, most recharge is associated with discharges at the Main

[4] The stream-covered areas were computed from aerial photographs taken Aug. 16 and 26, 1956, when the discharges at the Main St. gage were 450 and 375 cfs, respectively.

Street gage of about 2,000 cfs, or greater, which occur about 20 percent of the time.

If the infiltration rate is assumed to average 0.08 mgd per acre 80 percent of the time when the discharge is less than 2,000 cfs, it must average about 0.6 mgd per acre during the rest of the year to replenish the approximately 30 mgd being pumped. An infiltration of 0.6 mgd per acre is greater than that measured in any part of the natural stream channels on October 4, 1960, and it may be close to the maximum that occurs naturally in this part of the channel when most recharge occurs. This is consistent with results of dredging experiments made by the board of consultants, which showed that, locally at least, the "channel seal" was relatively impermeable in this area.

Because of the low average infiltration rate, ground-water development in this part of the Miami River valley, that is, in the central and southern parts of Dayton, has nearly reached its practical limit. Overdevelopment has occurred locally as ground-water levels have declined in the past 4 or 5 years in places where pumpage has not increased. The decline was halted only temporarily, in 1957, 1958, and early 1959, when discharge at the Main Street gage was above average. The year 1958 was unusual in that the dicharge in most of June, July, and August exceeded 2,000 cfs and, as a result, the seasonal decline in ground-water levels was much less than normal. With ground-water levels already abnormally high, the spring recharge of 1959, which was heralded by near-record-breaking floods, raised ground-water levels to highs that had not previously been reached since 1952. This recovery was short lived, however, and by the summer of 1960 ground-water levels in observation wells Mt-2 and Mt-6, in downtown Dayton, were at record lows. The water level in observation well Mt-3, in the southern part of Dayton near the Stewart Street Bridge, was near the low of record in 1960 and probably would have been at an alltime low had there not been a reduction in pumpage that year at nearby plants.

Pumpage has been reduced in places because of the lowering of ground-water levels; elsewhere, pumping levels are near the tops of the well screens in relatively deep wells, and shallower wells have been abandoned. These conditions have been noted at the National Cash Register Co. plant in south-central Dayton, at the Delco Products Division plant in central Dayton, and at the Third Street Station of the Dayton Power & Light Co., in the east-central part of town.

Pumpage can be increased locally in central and southern Dayton by the drilling of new wells in relatively undeveloped parts of the area. Increases obtained this way will be small, however, compared to the total quantity of water now being pumped in the area, and they cannot be depended upon to keep pace with the increase in water use.

Most land is already preempted, and water users are limited in their choice of drilling sites. Substantial increases in pumpage in this part of Dayton must await development of methods for increasing stream infiltration to the underlying aquifers.

Ground-water development can be increased in the Miami River valley in the northern part of Dayton, above the mouth of the Mad River, because pumpage there is only about 4 mgd and ground-water levels are relatively high. Much of this area is a residential section, however, and future pumpage is not likely to exceed 10–15 mgd, a quantity which can be readily obtained. The quantity of ground water available in this area will be reduced eventually by development of the new municipal well field in the Miami River valley, about a mile north of the city limits.

North of Dayton the aquifers were virtually untapped until the municipal water department began development of its new Miami River well field in the vicinity of Beardshear Road. Pumpage at the new well field was only about 8 mgd in the spring of 1961; however, water-department officials hope to develop ultimately a supply of 50 mgd from the well field by artificial recharging methods similar to those used at Rohrers Island.

Hydrologic conditions at the new well field are not nearly as favorable as they are at Rohrers Island for the development of a large ground-water supply. At the new well field the upper aquifer is comparatively thin and most of the wells will necessarily be screened in the lower aquifer, beneath the till-rich zone. Development of 50 mgd of water will be a practical undertaking only if the rate of leakage through the till-rich zone proves to be comparatively high.

About 10 percent of the time the flow of the Miami River at Taylorsvile, 7 miles above the new well field, is less than 60 mgd (Cross and Hedges, 1959, p. 139). After the well field is fully developed, pumpage at times of greatest demand, coincident with periods of low streamflow, will virtually dry up the stream in the area of the well field. At such times the quantity of ground water available in Dayton will be reduced, especially north of the mouth of the Mad River, into which area the cone of influence of the well field will probably spread. Farther south, in central and southern Dayton, ground-water levels may be lowered moderately in drought periods when, unfortunately, they are already critically low in some areas.

Ground-water development in the Mad River valley in the vicinity of Rohrers Island is near its practical limit. The municipal water department pumps more than 40 mgd on an average, from wells in the upper and lower aquifers. This amount is replenished chiefly by infiltration through lagoons and ditches on Rohrers Island. In the

summer, peak demand of more than 90 mgd frequently comes when the flow in the Mad River is so low that most of the water enters the ground in the area of the well field.

The large diversion at Rohrers Island must be considered in plans for additional development farther downstream; however, between Rohrers Island and the mouth of the Mad River conditions locally are favorable for additional large-scale development. In 1925, before the first well was drilled on Rohrers Island, the city pumped about 20 mgd from groups of wells in the Mad River valley below Rohrers Island.

An area of exceptionally good potential in the lower Mad River valley is that between Eastwood Park and Findlay Street, where the geologic evidence indicates a break in the till-rich zone and where, as a consequence, the sand and gravel deposits form a single relatively thick aquifer of high transmissibility. The city has already drilled wells C-42, C-43, C-44, C-45, and C-46 on or near the levee in this area and is presently pumping an average of about 8 mgd, with little lowering of ground-water levels. The possibilities for large-scale development might be further increased by the use of one or more abandoned gravel pits in this area to recharge the aquifer artificially.

The Miami River south of Dayton, between the Broadway Bridge and the mouth of Holes Creek, covers an area of approximately 110 acres at relatively low flow. If the stream were confined to this channel at all times, the quantity of water available naturally from induced infiltration could reasonably be estimated as 50–75 mgd annually. Presently, however, channel improvements are generally lacking in this reach, and flows of about 30,000 cfs, which occur on the average about once each 1½ years, result in the flooding of large areas of bottom land. These floodflows contribute substantially to the refilling of the ground-water reservoir, and in this area they enable larger withdrawals than will be possible in the future, when channel improvements are made and levees are heightened.

As a final note in this section, some mention should be made of potential for ground-water development in the Stillwater River valley in the northwestern part of Dayton. The Stillwater River is underlain by deposits of sand and gravel, but the deposits generally are thinner and of much less areal extent than those in the other principal valleys. Moreover, the Stillwater River flows mostly through a residential area in which large ground-water supplies probably will not be developed. Locally, however, there are sites along the river where ground-water supplies of perhaps as much as 1–2 mgd can be developed.

LEAKAGE THROUGH THE TILL-RICH ZONE

The rate at which water will move through the till-rich zone into the lower aquifer is a major factor determining the availability of ground water in some areas. In the vicinity of Rohrers Island the till-rich zone is relatively effective as a confining bed, and the piezometric surface of the lower aquifer averages about 30 feet lower than the water table as a result of the pumping of about 15 mgd from the lower aquifer (Norris, 1959, p. 14). The till-rich zone probably is equally effective as a confining bed in much of the downtown and northern parts of Dayton and more locally in areas south of Dayton, such as the vicinity of Moraine City. The till-rich zone is relatively ineffective as a confining bed in the Mad River valley in the Findlay Street–Eastwood Park area, where interbedded till deposits are generally thin or absent, and also in the vicinity of the Tait Station of the Dayton Power & Light Co., in South Dayton, where the till-rich zone comprises lenses and irregular masses of till.

In the Miami River valley the piezometric surface of the lower aquifer is about 10–30 feet below the water table in heavily pumped areas. It can be lowered an additional 20–30 feet in most places without dewatering the lower aquifer. If the water table is maintained at a relatively high level, providing a large potential head difference between water in the upper and lower aquifers, pumpage can increase substantially before the rate of leakage through the till-rich zone becomes a major limiting factor.

Figure 20 shows, for various leakage coefficients, the quantity of water that will leak through the till-rich zone under various head differences between the upper and lower aquifers in a segment of the valley 1 mile long where the valley-fill deposits are assumed to average 2.5 miles in width. In the Dayton area the value of the leakage coefficient has been determined only at one place, on Rohrers Island, where it ranges from 0.002 to 0.012 gpd per cu ft. If a median value of the leakage coefficient is selected, 0.007 gpd per cu ft for example, the graph shows that for a head difference of 30 feet between the upper and lower aquifers about 14 mgd will leak through the till-rich zone in a valley segment 1 mile long and 2.5 miles wide.

ARTIFICIAL RECHARGING METHODS

Aquifers have been artificially recharged through either injection wells or specially constructed pits or by land flooding, and people have asked whether artificial recharge would be feasible at Dayton. Although a detailed treatment of the subject is beyond the scope of this report, some of the principal factors to be considered in evaluating certain methods of artificial recharging are presented here. A brief

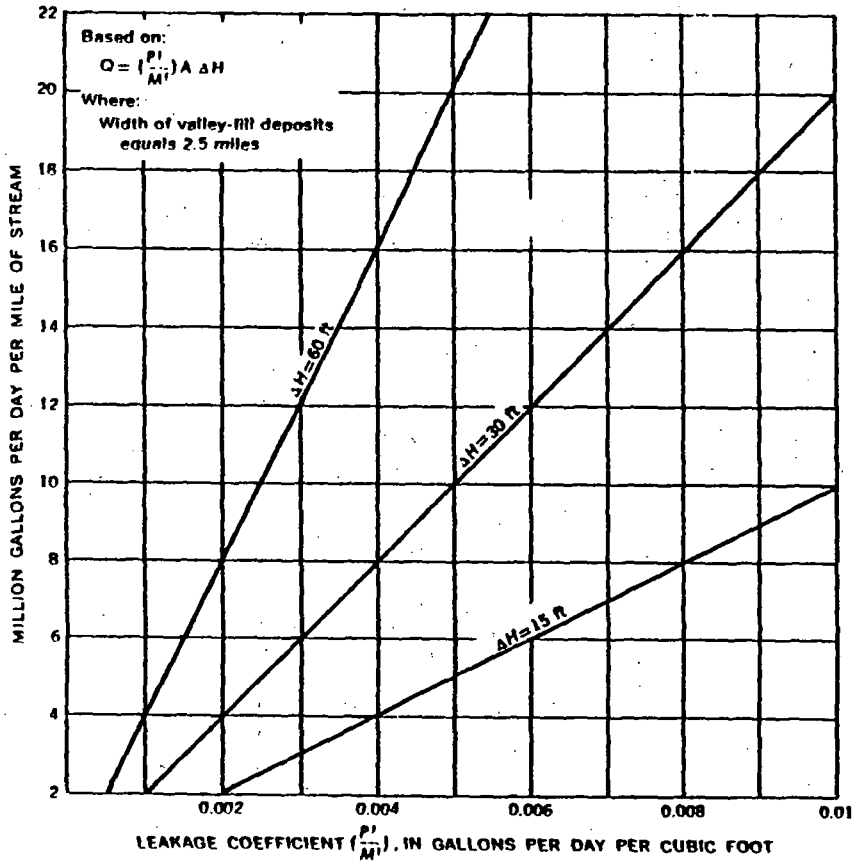

FIGURE 20.—Quantity of water that will leak through the till-rich zone at various values of the leakage coefficient and selected head differences in the aquifer.

description is given of dredging experiments in the Dayton area and of engineering studies on specially constructed recharge pits at Peoria, Ill.

EXPERIMENTS IN THE DAYTON AREA

Artificial recharging is not new to the Dayton area, as recharge ponds have been used with considerable success for several years by the Dayton Water Department at Rohrers Island. Also, a recharge pit about one-third of an acre in area is used each summer at the Frigidaire Division plant in Moraine City to dispose of 1–1.5 mgd of waste water. This pit is dredged about every 6 weeks while it is in use.

Recharge through wells is an attractive possibility, as water can be injected into an aquifer at rates comparable to rates of pumping

from the aquifer. Injection wells, like supply wells, require proper development for efficient operation. Also, injection wells must receive clear water or they will eventually become clogged. The chemical quality and temperature of the water used for recharging must be such that no adverse effects, such as precipitation of mineral compounds, result from mixing of this water with the water already in the aquifer. The temperature of the injected water may be critical also with respect to the use of the ground water for certain industrial purposes, and this may limit the time of year when recharge from surface-water sources can be carried on. Finally, the available head or pressure difference between the water being injected and the water in the aquifer must be considered, as this factor is major in determining the rate at which water can enter the aquifer.

In 1955 the Miami Conservancy District experimentally determined infiltration rates through the bed of a small recharge pit dug in a dry part of the Miami River channel. The pit, a quarter of an acre in area, was 500 feet downstream from the Main Street Bridge (pl. 4) and dug to a depth of 2 feet below river level. When the experiment was made the water table was several feet below the bottom of the pit.

As reported by a board of consultants (Abel Wolman and others, written commun., 1957), the infiltration rate was as high as 7 mgd per acre when unfiltered river water was first conveyed to the pit. The infiltration rate declined rather rapidly, however, and in one experiment it fell to approximately 0.65 mgd per acre at the end of 2 weeks. The decline was believed due to progressive silting of the pit bottom and to a reduction in the ground-water gradients in the vicinity of the pit caused by the building up of a ground-water mound beneath the pit.

This experiment attests to the very large increase that can be effected initially in the rate of streambed infiltration by artificial means, such as dredging, but it also points up the necessity of taking into account, in assessing the benefits of artificial recharging, the very rapid decline in efficiency of many common methods.

The Miami Conservancy District also made a recharge experiment in 1954 in south Dayton, on the right bank of the Miami River opposite Carillon Park, in an area where the water table was more than 10 feet below river level. The board of consultants (Abel Wolman and others, written commun., 1957) reported that:

> In this recharge test water was siphoned from the river over the top of the levee and into a large gravel pit nearby. The siphon action was started by means of a pump. Once established, the siphon was allowed to continue for a number of days. The gravel pit acted as a large recharge basin and allowed the siphoned river water to infiltrate into the ground-water system. No detailed data on water levels or infiltration rates were collected during this experiment. The main conclusion to be derived from the test was that operations of this type can successfully put large amounts of water into underground storage.

The board of consultants also experimented with artificial recharging methods in the spring of 1956 by dredging the channel of the Miami River in a small area near Carillon Park (pl. 4), where the water table was about 12 feet below normal river level. As stated by the board:

the chief purpose of this experiment was (1) to evaluate rates of river infiltration under natural conditions, and (2) to observe changes in these rates caused by artificially removing the upper few feet of river-bottom materials.

The test program involved the installation of numerous observation wells on both banks of the river and in the river channel itself. Measurements of water level in these wells were made periodically to determine changes in the profile of the water table across the stream channel with reference to changing conditions of river stage. When sufficient data had been obtained to permit an evaluation of natural rates of river infiltration, the river bottom was dredged to a shallow depth, and further observations made of the resulting effects on increased infiltration * * *.

During the installation of some of the observation wells in the river channel, frequent water-level measurements were made inside and outside the pipe to determine the exact position of the water table with reference to river level. In every instance, as soon as the well screen had penetrated more than a foot below the channel floor, the water standing in the pipe ran out into the highly permeable deposits at these shallow depths. The water table was not encountered until the well points had been driven to a depth of approximately 12 feet below river level * * *.

Except in a small area near the right bank, where several feet of silt had accumulated on the river bottom, the thickness of the channel seal at the probe sites was nowhere greater than about one foot. At most of the test sites, the standing water in the probe drained out after only about 8 to 10 inches of penetration into the channel bottom. The deposits below the channel seal were found to be highly permeable and carried water away as rapidly as it could be poured into the pipe * * *.

At the infiltration-test site, the water table was encountered below the channel floor at depths that varied from as little as three feet in wells in the deepest part of the channel to as much as 12 feet in wells along the river's edge * * *.

The most significant feature of the natural profile is the water-table ridge whose crest is almost directly below the deepest part of the river channel. This crest represents the highest elevation of the water table in the area and the flow of ground water must, therefore, be away from it * * *.

In May 1956, after several months of water-level and temperature observations, arrangements were made to remove the river-bottom seal in a strip 20 feet wide and 300 feet long, oriented parallel to the shoreline and located about 40 feet from the left bank * * *.

On May 21, a three-quarter-yard dragline, operating from the left bank, began cutting into the channel floor near well 13 [number not in accordance with system used in present report] and about 40 feet off-shore. The first attempts to remove material from the river bottom were unsuccessful and the dragline bucket contained practically no material when taken out of the water. This difficulty in breaking through the "crust" on the river bed had been anticipated by the dragline operators and by engineers and other construction workers familiar with the river * * *.

The cutting teeth on the dragline bucket were then inverted to provide a more satisfactory bite. After one or two cuts which brought up no material from the channel floor, the cutting teeth finally penetrated the deposits and the bucket was removed from the river partly filled with silt, sand, and gravel. The next few bites into the channel floor were made at about the same location and the bucket was brought up full or partly full each time. After making a total of five or six cuts, the operation was suspended temporarily to permit water-level measurements to be made in several of the nearby observation wells * * *.

The materials brought up from the first few cuts in the channel floor consisted chiefly of very coarse sand and gravel, with cobbles up to about six inches in diameter. Many of the pebbles and cobbles were stained dark black and the finer sand and gravel had a pronounced black appearance. After brief exposure to air and sunlight, the black color faded almost completely. The sediments brought up later from several feet below the crust were texturally similar, but were light gray in color instead of black.

Within a matter of minutes after the channel-bottom seal had been penetrated, water levels in nearby observation wells begins to rise as a result of increased river infiltration * * *.

* * * Water levels in wells very close to the dredged strip reached their highest levels on the last day of dredging operation, when infiltration rates were probably at a maximum. A slow decline of water levels in these wells began shortly thereafter * * *.

The relatively impermeable river-bottom seal or crust that occurs in places in the Miami River greatly retards the vertical seepage of water. Although the experimental dredging operation temporarily removed the seal in a small area, subsequent flood flows tended to quickly reseal the dredged cut with silt. Thus, it seems likely that dredging operations would have to be carried on almost continuously if any lasting increase over the natural rate of infiltration were to be attained * * *.

Increasing the rate of river infiltration by dredging in the losing stream areas would raise ground-water levels by only moderate amounts. The maximum rise of water levels would be no greater than the original difference between stream level and the underlying water table. In most places, this rise would be on the order of only a few feet, although rises of perhaps as much as 25 feet could take place at some sites. Pumping lifts in production wells near the river would be somewhat reduced and the yields would be increased slightly, but as discussed previously, it is thought that a considerable part of these benefits would be short-lived.

In view of the factors outlined above, dredging of the channel floor will accomplish little more than to raise ground-water levels locally near the river * * *.

In areas where concentrated pumping has extensively lowered ground-water levels, consideration should be given to recharging the underground reservoir by the basin method rather than by channel dredging, particularly in areas at considerable distances back from the Miami River.

EXPERIMENTS AT PEORIA, ILL.

In view of the board of consultants' suggestion relative to the possibility of recharging the aquifers through basins, information is presented on the results of basin experiments at Peoria, Ill. The Illinois State Water Survey Division conducted infiltration experiments over a period of several years, beginning in 1951, in two shallow recharge pits dug in glacial outwash deposits in this heavily pumped industrial area of the Illinois River valley. Other experiments also made use of

a recharge pit dug by the Bemis Bros. Bag Co. at Peoria. Results of this work were described by Suter and Harmeson (1960) in a bulletin of the Illinois State Water Survey.

Filter materials, consisting of several sizes of sand and of sand and gravel mixtures, were placed on the pit bottoms in the Peoria experiments, and river water of varying temperature and turbidity was channeled into the pits. The filter materials were cleaned or replaced several times in the course of the experiments to discover which material had the least tendency to become clogged by the sediment in the river water. The authors stated (1960, p. 31) that:

> In general, it has been observed that the types of silt materials in the river govern the effects on recharge to an extent equaling or exceeding the turbidity concentration. Strong winds create waves which scour the fine muds from the bottom of Peoria Lake. Turbidity created in this manner was presistent and rapidly clogged the filtering surface of the recharge pits. In many instances, higher concentrations of turbidity which were caused by excessive storm runoff were less persistent and had less effect on the recharge rate.

Suter and Harmeson (1960, p. 45) summed up the results of the Peoria recharge-pit experiments as follows:

> The problem of finding a method of recharge to meet the needs peculiar to Peoria has been solved. By means of pits, artificial recharge is conducted at high infiltration rates; operating costs are low in comparison to the cost of treating river water for direct use; practical methods of maintaining satisfactory infiltration rates have been developed; ground-water temperatures have been maintained within desirable limits; and a significant contribution has been made toward stopping the recession of local ground-water levels.
>
> Maximum infiltration rates of 175 feet per day[5] have been reached in the experimental Pit No. 2 constructed by the Water Survey, and rates higher than 200 feet per day have been achieved in the pit of Bemis Bros. Bag Company. Mean annual rates for three successive seasons of concurrent operation of the two Water Survey recharge pits were between 102.8 and 54.5 feet per day in Pit No. 2 and between 41.2 and 38.7 feet per day in Pit No. 1.
>
> Valuable information has been obtained relative to operating procedures and costs. The cost summaries show that the operating cost has been approximately two cents per thousand gallons recharged. This is substantially less than the limit of six cents per thousand gallons which had been estimated as the maximum to be attractive commercially. The unit cost of recharge was reduced during the years that both pits were operated for the reason that the quantity of water recharged was increased while the cost of supervision of operation remained almost constant. It appears that advantage lies with annual replacement of filter media because it enables higher recharge rates. Unit costs per thousand gallons recharged were almost identical whether the pit was cleaned annually or operated two or three years between cleanings.
>
> Experience has demonstrated the ability of pea gravel to serve as an effective filtration media [sic], while allowing a practical rate of infiltration over long periods of time. Bacterial analyses of samples taken since the pea gravel was first used have shown no deterioration in sanitary quality of the ground water. Repeated use of the pea gravel caused no significant reduction in the average daily recharge rate in Pit No. 1 and resulted in slight reductions in the rate of Pit No. 2. The pea gravel was replaced after three seasons of use because the concentration of silt was approaching the saturation limit of its void spaces.
>
> Temporary increases in recharge rate can be obtained by removing part of the accumulated silt with a suction cleaner. Although the benefits of such cleaning are immediately apparent, they are short-lived * * *.

[5] Author's note: The height of a column of water filtering through a unit of surface area in 24 hr; an infiltration rate of 1 ft is equal to about 0.32 mgd per acre.

The statements by the board of consultants on dredging experiments at Dayton and by Suter and Harmeson on the operation of recharge pits at Peoria, Ill., indicate that from an engineering standpoint, both methods of artificial recharge are probably feasible in the Dayton area. The problem remains, however, of determining how feasible these methods are in terms of cost and how to assess the benefits to individual users.

GROUND-WATER PUMPAGE IN THE DAYTON AREA

The Dayton area, where the average pumpage in 1958 was about 110 mgd, has the largest concentration of ground-water use in Ohio and one of the largest in the Midwest. The population and industrial production of the area are certain to increase during the next few decades, and water demands will increase concurrently. The present density and distribution of pumpage and the course of development of this pattern are fundamental to an evaluation of the ground-water potential of the area.

The hydraulic properties of the glacial-outwash deposits vary throughout the area, and some of the deposits can sustain a higher rate of pumping than others. Their development, however, has to some extent been haphazard and has not necessarily been greatest in the most favorable areas.

An inventory of ground-water pumpage in the Dayton area was made in 1954–55 by Mr. Robert E. Reemelin of the Water Conservation Subdistrict of the Miami Conservancy District. Supplemental data were collected by the authors in 1957–59, which brought the inventory up to date. Ninety-five industries that pump ground water and three public water-supply systems were surveyed with regard to average daily pumpage, peak pumpage, and the history of pumpage.

Figures given for the 3 public-supply systems in the area are accurate, as these systems meter their water and maintain pumpage records; however, only 4 of the 95 industries inventoried keep such records. Figures for the remaining 91 industries are estimates based on the number and capacity of wells and the number of hours per day each pump operates. These estimates range in accuracy from excellent to highly questionable. Most of the estimates of present water consumption are probably fairly accurate, whereas some of the histori-

cal data are more dubious. Very little of the information is recorded; it is usually kept only in the memory of a plant engineer or maintenance foreman, who may not remember exactly how much water his plant used 20 or 30 years ago. While lacking in detail, these figures do represent the order of magnitude of ground-water pumpage in years past.

Use of ground water in the Dayton area (table 5, fig. 21) has increased tenfold since 1900. Generally speaking, pumpage was at first concentrated in downtown Dayton and then spread gradually into the outlying areas, though not equally in all directions. To facilitate the discussion of pumpage distribution, the Dayton area has been divided into six districts (pl. 5), within the boundaries of which are the principal centers of pumping. Some of the larger districts have been subdivided because pumpage is concentrated in only a part of the district or at several separate centers. District boundaries wherever possible coincide with natural features, such as streams and the bedrock walls of the buried valleys, but in places they are arbitrary.

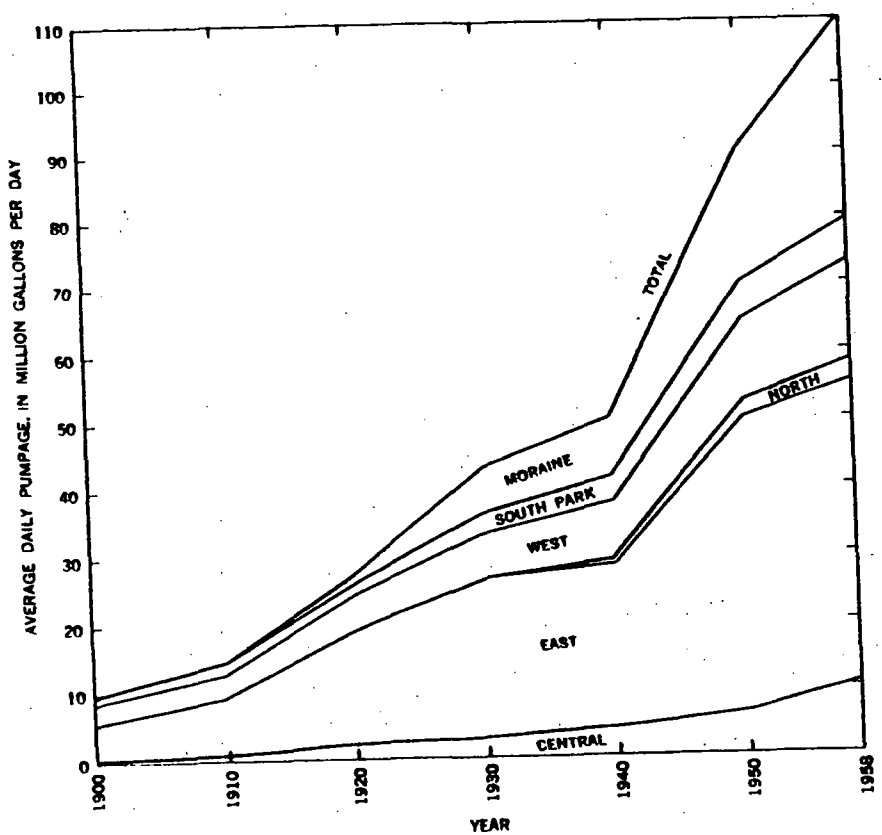

FIGURE 21.—Ground-water pumpage in the Dayton area by districts, 1900–58.

TABLE 5.—*History of ground-water pumpage in the Dayton area by districts, 1900–58*

Year	Central district		East district		North district		West district		South Park district		Moraine district		Total of all districts
	Ave daily pumpage (mgd)	Percent of total in Dayton area	Ave daily pumpage (mgd)	Percent of total in Dayton area	Ave daily pumpage (mgd)	Percent of total in Dayton area	Ave daily pumpage (mgd)	Percent of total in Dayton area	Ave daily pumpage (mgd)	Percent of total in Dayton area	Ave daily pumpage (mgd)	Percent of total in Dayton area	
1900	0.08	0.8	5.30	58.4	------		3.50	38.3	1.04	10.5	------	0	9.92
1910	.49	3.4	8.84	61.4	------	0	3.03	24.6	1.54	10.7	------	0	14.40
1920	2.12	7.8	16.78	61.7	0.08	.3	5.06	18.6	2.04	7.5	------	4.0	27.17
1930	2.77	6.5	22.72	53.7	.06	.2	6.28	14.7	3.17	7.4	1.09	15.4	42.61
1940	4.19	5.4	24.13	46.1	.39	1.2	8.84	17.2	4.03	8.0	4.56	17.1	52.15
1950	6.33	7.1	45.86	48.5	2.62	2.9	11.81	12.1	5.92	6.6	19.66	21.8	90.01
1958	10.21	9.3	44.72	41.4	3.06	2.8	12.88	12.5	6.78	6.1	28.83	27.0	110.47

Table 6 is a summary of ground-water pumpage in the Dayton area, showing for each district the average daily pumpage, area, and pumpage density in million gallons per day per square mile. Table 7 is a detailed record of pumpage by districts, showing pumpage in 1958, the number of wells, number of days per year in operation, and use of water by each industry inventoried.

TABLE 6.—*Summary of average daily ground-water pumpage, and area and density of pumpage in the Dayton area, Ohio, 1958*

District	Average daily pumpage (mgd)	Area (sq mi)	Pumpage density (mgd per sq mi)
Central	10.21	1.80	5.68
East	46.73	7.24	6.45
Eastern part	36.55	4.35	8.38
Western part	10.18	2.88	3.54
North	3.06	15.18	.20
Area of actual pumping	3.06	3.37	.91
West	13.86	7.37	1.88
Eastern part	13.86	5.01	2.77
South Park	6.78	1.17	5.80
Moraine	29.83	10.46	2.84
Western part	29.83	5.88	5.03
Total for Dayton area	110.47	43.23	2.56
Total for area actually sustaining pumpage	110.47	27.75	3.99

TABLE 7.—*Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1958*

Use of water: AC, air conditioning; B, boiler makeup; C, cooling or refrigeration; IRR, irrigation; P, processing; S, sanitary; W, washing.

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1958 (millions of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
Central district						
Delco Products Div., General Motors Corp.	7	365	1,170.0	3.200	4.500	P, AC, S
Frigidaire Div., General Motors Corp. (plant 1)	2	365	365.0	1.000	1.500	AC
Commercial Bldg.	2	365	219.0	.600	1.000	AC, S
Dayton Power & Light Co., Longworth St. Sta.	2	365	214.6	.590	1.000	B
Terminal Cold Storage Co.	2	365	209.1	.575	.600	C, S
Rike-Kumler Co.	3	330	166.0	.455	1.250	AC, S, B
Miami Valley Mill Producers Association	2	365	153.0	.420	1.000	C, W
Ice Cream Div., Borden Co.	1	365	112.4	.308	.500	C
Milk Div., Borden Co.	1	365	140.0	.385	.660	C
Dayton Power & Light Co., 3d St. Sta.	2	263	133.6	.365	.750	B
Elder & Johnston Co.	2	313	82.0	.225	.750	AC, S
Miami Hotel	1	365	69.0	.190	.200	AC, S
Sears Roebuck & Co.	1	[1] 150	69.3	.190	.600	AC

See footnote at end of table.

TABLE 7.—*Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1958*—Continued

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1958 (millions of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
Central district—Continued						
Huhman Bldg.	1	135	67.7	0.186	0.600	AC
Ohio Bell Telephone Co.	2	365	65.7	.180	.350	AC
Home Store	1	180	51.8	.142	.350	AC
Dayton Power & Light Co., 4th St. Sta.	1	365	44.0	.120	.120	C
King Kole Restaurant	1	365	42.6	.116	.350	C, W, S
Miller Bldg.	2	260	39.0	.103	.250	AC
Dayton Coca-Cola Bottling Co.	1	260	36.5	.100	.200	S, P, W
Gas & Electric Bldg.	1	260	27.0	.074	.150	AC
CIO (IUE) Local 801 Hall	1	[1] 120	20.5	.056	.250	AC
Model Laundry	1	260	18.9	.052	.075	W
Talbot Bldg.	1	[1] 132	19.0	.052	.200	AC
Donenfeld's, Inc.	1	268	18.1	.050	.075	AC
Metropolitan Clothing Co.	1	[1] 168	18.1	.050	.200	AC
Third National Bank	1	[1] 180	18.2	.048	.110	AC
McCrory's 5 & 10 cent Store	1	[1] 132	15.8	.043	.200	AC
Neal's Dairy	1	365	14.6	.040	.080	W, C
Gibbons Hotel	1	365	12.8	.035	.035	AC, B
Lowe Bldg.	1	[1] 132	11.1	.031	.110	AC
Loews Theater	1	140	10.5	.029	.180	AC
Columbia Theater	1	[1] 90	8.8	.024	.100	AC
Fraternal Order of Eagles	1	[1] 120	8.6	.024	.100	AC
Rossiter-Hurrett-Harman Co.	1	[1] 132	8.8	.024	.100	AC
Rialto Theater	1	[1] 92	4.2	.011	.050	AC
Westminster Church	1	[1] 32	3.2	.008	.150	AC
Otterbein Press	1	250	2.6	.007	.010	S, C
Gendert & Llenesch, Inc.	1	260	2.0	.006	.010	B, S
East district						
City of Dayton well fields	45	365	16,800.0	45.750	70.000	PS
Master Electric Co.	1	313	138.0	.380	.500	C, B, P
Focke Packing Co.	2	365	78.8	.215	.250	P
Hewitt Soap Co.	1	200	40.0	.110	.260	P
J. J. Boeckman Co.	1	356	39.4	.108	.110	C, W
Sheffield Corp.	1	132	38.0	.104	.300	C
White Clover Dairy	1	365	9.9	.027	.030	W, C
Farm Bureau Co-op Association	1	200	9.6	.026	.050	B, C
Dayton Packing Co.	1	365	2.0	.006	.006	C
B. C. Davis Co.	1	[1] 120	0.6	.002	.005	AC
North district						
Chrysler Airtemp Sales Co.	3	365	478.0	1.300	1.400	P, B, AC
Keystone Sand & Gravel Co.	1	196	131.9	.362	.750	W
G.H.F. Foundry Div., Dayton Malleable Iron Co.	2	310	124.0	.339	.750	P
Dayton Rust Proof Co.	2	300	112.5	.310	.375	P
Burdette Oxygen Co., Rita St.	1	260	88.7	.242	.432	C
Premier Rubber Co.	1	250	46.8	.128	.200	C, S
Stolle Corp.	1	260	31.4	.086	.150	C, W, S
East Dayton Tool & Die Co.	1	150	27.0	.074	.200	C
D. W. Mikesell Co.	1	260	20.8	.057	.125	W, S, AC
Salem Theatre	1	[1] 140	16.2	.045	.150	AC
McCook Bowling Co.	1	[1] 138	15.6	.043	.200	AC
Golden Age-Dayton Co.	1	260	13.1	.036	.075	W, P
Bluebird Baking Co.	1	360	10.8	.029	.050	AC
Burdette Oxygen Co., McCook Ave.	1	260	1.3	.004	.007	C
Price Bros. Co.	1	260	0.8	.002	.003	W, S

See footnote at end of table.

TABLE 7.—*Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1958*—Continued

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1958 (millions of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
West district						
Delco-Moraine Div., General Motors Corp.	4	365	1,458.0	4.000	5.000	P, B, C
Aetna Paper Co.	3	307	1,290.0	3.540	3.540	C
Dayton Tire & Rubber Co.	3	365	730.0	2.000	4.000	P
Himes Bros. Dairy	2	365	240.0	.660	.750	W
Sunshine Biscuits, Inc.	3	313	235.0	.650	1.000	C, P, B
City Products Corp.	2	365	210.0	.576	.750	C, P
Sucher Packing Co.	2	313	208.0	.557	.750	C, W, S
Dayton Steel Foundry Co.	1	300	150.0	.410	.500	P
Gem City Ice Cream Co.	2	365	147.6	.405	.600	C, B, W
Specialty Paper Co.	1	313	119.0	.377	.400	C,W,S
Dairy Div., Kroger Co.	1	365	64.0	.175	.259	W
Standard Register Co.	1	[1] 150	59.5	.162	.500	AC
Kuhns Bros. Foundry	1	365	38.0	.104	.150	C,AC
Monsanto Chemical Co.	2	[1] 120	30.0	.083	.300	AC
Lau Blower Co.	1	260	29.3	.080	.150	P,C,AC,W,S
Davies-Young Soap Co.	1	250	23.5	.064	.150	AC,P
Simonds-Worden-White Co.	1	365	14.5	.040	.050	C,P
Wolf Creek Soap Co.	2	260	4.7	.013	.025	C
National Foundry & Furnace Co.	1	313	3.1	.008	.010	P,S
South Park district						
National Cash Register Co.	9	365	2,370.0	6.500	7.500	B,C,P,AC,S
City of Oakwood	2	365	100.0	.275	.500	PS
Moraine district						
Frigidaire Div., General Motors Corp. (Moraine City plants)	20	365	7,300.0	20.000	30.000	C,W,P,AC
Montgomery County Sanitary Dept.	7	365	1,960.0	5.370	10.000	PS
Dayton Power & Light Co., Frank M. Tait Sta.	5	365	1,001.5	2.750	4.500	C
Air Reduction Sales Co.	1	365	236.5	.700	.700	C,W
M. G. Snyder & Sons, Inc.	3	365	146.0	.400	.750	PS,W
Dayton Power & Light Co., Service Bldg.	1	[1] 132	95.0	.260	.750	AC
National Cash Register Co. Golf Course	2	[1] 132	91.2	.250	1.000	IRR
Dayton Community Golf Course	1	[1] 132	18.2	.050	.250	IRR
City of Dayton, Miami View Golf Course	1	[1] 132	9.1	.025	.075	IRR
Moraine Box Co.	1	260	2.4	.007	.010	B,S,AC
South Dayton Motel	1	365	2.4	.007	.010	S
Crume Brick Co.	1	260	2.1	.006	.010	B,C,S
Dayton Brick Co.	1	260	1.0	.003	.005	W,C,S

[1] Pumping largely restricted to summer season.

CENTRAL DISTRICT

The Central district of the Dayton area is bounded on the north and west by the Miami and Mad Rivers; the rest of the boundary is arbitrary—a circle of 1-mile radius whose center is at the corner of Third and Main Streets.

It might be expected that the Central district would be the first to undergo significant ground-water development, but it hasn't. By 1900 the district was fairly well developed residentially and commercially, and little room remained for industry. The earliest industries were located in the West and South Park districts. The two large plants in the Central district, the Frigidaire and Delco Products Divisions of General Motors Corp., began operations long after 1900.

Pumpage has increased at a steady rate from 0.08 mgd in 1900 to 10.21 mgd in 1958. The Central district accounted for only 0.8 percent of the water pumped in the Dayton area in 1900, but this percentage had risen to 9.3 by 1958. Most of the percentage increase occurred between 1900 and 1920; from then to the present it has been in the range of 6–10 percent.

The pumpage density of 5.7 mgd per sq mi for the Central district is well above the average of 2.5 mgd per sq mi for the Dayton area as a whole. Forty establishments in the district withdraw ground water, but only two—the Delco Products and Frigidaire Divisions of General Motors Corp.—use 1 mgd or more. A large part of the water pumped in the Central district is used to air-condition office buildings; hence the daily pumpage during the summer far exceeds the average daily figure, which is based on the entire year.

The Central district, already saturated with commercial and residential establishments, is not likely to undergo extensive industrial development in the future. Any increase in pumpage here will likely be due to increased air conditioning of office buildings and will be small compared to increases that are likely to occur elsewhere.

EAST DISTRICT

The pumpage history of the East district can be virtually equated with the history of the Dayton municipal water system. Formerly, all the municipal wells were located here; this situation recently changed, when the Miami River well field, in the North district, began operation. The East district sustains very little pumpage other than from the municipal well fields.

Pumping of ground water by the municipal system began in 1869 from large-diameter dug wells at the corner of Dutoit and Beacon Streets, and 2 years later new wells were drilled at the corner of Keowee and Ottawa Streets. In 1887 a group of 8-inch wells was drilled along the Mad River just east of the main pumping station at Keowee Street. The number of wells increased with the city's population and water demands (Norris and others, 1948, p. 52-56). The "old main group," begun in 1887, expanded to 94 wells and by 1909 was supplemented by another group of 6 wells, the "aqueduct group." From 1914 to 1919, 28 wells were installed at Taits Hill and 11 at Eastwood Park. In 1926 development began of the present well field, centered at Rohrers Island. Drilling of additional and more efficient

wells there and along the banks of the Mad River has brought about gradual abandonment of the older wells from 1926 to the present. Municipal pumpage has spread from the area of the Keowee Street pumping station eastward along the banks of the Mad River, until now nearly the entire East district along the river is within the area of influence of the municipal wells.

Systematic records of municipal pumpage prior to 1910 are not available. In 1910 the municipal wells yielded an average of 8.53 mgd, or 59.3 percent of all water pumped in the Dayton area. Municipal pumpage, estimated at about 5 mgd in 1900, had increased to 45.75 mgd by 1958. The percentage of all water pumped in the Dayton area that is pumped by the municipal fields has decreased to about 40, whereas pumpage by privately owned industrial and commercial establishments has greatly increased.

Pumpage in the East district other than that from the municipal well fields has never totaled more than about 3 percent of the water pumped in the Dayton area.

The average of 45.8 mgd pumped by the Dayton municipal water system came from three centers (pl. 5). About 37.8 mgd came from 43 wells at and near Rohrers Island, about 5 mgd came from 5 wells along the south bank of the Mad River at Taits Hill, and about 3 mgd came from one well near the water-treatment plant, on the south bank of the Mad River east of Keowee Street. Pumpage from other establishments, mostly small industries, totals about 1 mgd, a relatively insignificant figure compared with the municipal pumpage.

Pumpage density for the East district is 6.45 mgd per sq mi, well above the average for the Dayton area. A better idea of pumpage distribution in the East district can be obtained by dividing the district in two along a line approximately normal to the Mad River at Taits Hill. The eastern part of the district, which includes all the municipal wells at Rohrers Island, has an area of 4.36 square miles, sustains an average daily pumpage of 36.55 mgd, and has a pumpage density of 8.38 mgd per sq mi. The western part has an area of 2.88 square miles, sustains an average daily pumpage of 10.18 mgd, and has a pumpage density of 3.54 mgd per sq mi. These figures clearly show that the eastern part of the district sustains far more pumpage than the western part. The eastern part has the highest pumpage density in the Dayton area, whereas the western part has a considerably lower density.

If any part of the Dayton area can be said to have reached its maximum feasible pumpage, it is either the eastern part of the East district or the South Park district. If pumpage in the first area were substantially increased, excessive drawdowns and a higher cost of lift would result. Officials of the city of Dayton have recognized that the well field in the vicinity of Rohrers Island is being pumped near its capacity, and they are therefore developing a well field adjacent to the Miami River north of Dayton to meet future demands.

NORTH DISTRICT

No pumping of ground water is known to have taken place in the North district prior to 1920; furthermore, pumpage did not exceed 1 mgd until the period from 1940 to 1950. By 1958, it had increased to 3.06 mgd, or nearly 3 percent of the total pumped in the Dayton area.

The North district is largest (15.18 sq mi) of the six divisions of the Dayton area. Only 3.38 square miles in the industrial part of North Dayton (pl. 5) sustains substantial ground-water pumpage. With an average pumpage of 3.06 mgd, this district has a pumpage density of 0.9 mgd per sq mi, the lowest computed for any part of the Dayton area.

In view of its particularly low pumpage density, the North district is one of the most promising parts of the Dayton area for future development of large ground-water supplies. The city of Dayton's Water Department purchased land north of Dayton, along the west bank of the Miami River, and is developing a new well field, which went into limited use in 1960. When the new well field is fully developed, the North district will undoubtedly be among the more heavily pumped parts of the Dayton area.

WEST DISTRICT

During the past 60 years the West district has accounted for a substantial part of Dayton's ground-water pumpage. Prior to 1930 most of this water was pumped by the Aetna Paper Co., whose average daily pumpage, 3.5 mgd, has remained virtually unchanged since 1900. Many companies, engaged in different industries, have since located in the West district and in 1958 the average pumpage had increased from the 3.5 mgd of the Aetna Paper Co. to 13.86 mgd. The West district's percentage of the water pumped in the Dayton area has declined, however, from 35.3 percent in 1900 to 12.5 percent in 1958. This does not mean to imply that the West district has correspondingly dropped in importance as a supplier of ground water. In the late 1920's, industrial expansion began there in earnest, and since then the district's percentage of the total has not declined appreciably (table 5, fig. 21); it even rose to 17.2 percent temporarily in 1940.

In 1958, 20 establishments accounted for the average daily pumpage of 13.86 mgd in the West district. Three of these—the Aetna Paper Co., the Dayton Tire & Rubber Co., and the Delco-Moraine Division of General Motors Corp.—each have an average daily pumpage in ex-

cess of 1 mgd. With the exception of these three large plants, pumpage is rather evenly distributed through the eastern part of the West district.

The eastern part of the West district, an area of 5.01 square miles (pl. 5), had a pumpage density of 2.77 mgd per sq mi in 1958, which is nearly the average for the Dayton area. The district as a whole had a pumpage density of 1.88 mgd per sq mi.

Pumpage in much of the West district is near its practical limit; however, close to the Miami River it could be increased without causing excessive drawdowns.

SOUTH PARK DISTRICT

The National Cash Register Co. has accounted for the bulk of ground-water pumpage in the South Park district since 1900. Its pumpage increased from about 1 mgd in 1900 to an average of 6.5 mgd in 1958. Beginning in 1927 the Oakwood municipal waterworks has withdrawn an average of 0.281 mgd, in addition to pumpage of The National Cash Register Co. This figure has remained constant despite the increase in Oakwood's population. The pumping capacity of the Oakwood waterworks is limited by its location near the edge of the buried valley, where the permeable sand and gravel deposits are relatively thin and are too far from the Miami River to receive recharge from infiltration. The additional water demands have been met by purchase of water from the city of Dayton and the Montgomery County Sanitary Department.

The percentage for the South Park district of all water pumped in the Dayton area dropped from 10.5 percent in 1900 to 6.1 percent in 1958; this decline reflects the relatively more rapid industrial expansion of other districts.

The National Cash Register Co. pumps its average of 6.5 mgd from nine wells distributed through the north half of the district. The bulk of its pumpage comes from three wells north of Stewart Street near the east bank of the Miami River. The Oakwood waterworks is located near the southeast border of the district.

The pumpage density in the South Park district is 5.80 mgd per sq mi, well above average for the Dayton area.

The South Park district is not likely to experience much increase in ground-water pumpage in the future. Drawdowns in the National Cash Register Co. wells are already so great that plant engineers feel it would not be prudent to pump more water. Many test wells have been drilled throughout the district with generally unfavorable results.

MORAINE DISTRICT

No significant pumpage of ground water in the Moraine district was recorded prior to 1915, when the plant now belonging to the Frigidaire Division of General Motors Corp. started production with an initial average daily pumpage of about 1 mgd. Late in the 1920's the Frank M. Tait Station of the Dayton Power & Light Co. began operation, and in 1930 it and the Frigidaire Division plant together pumped an average of 6.5 mgd. Since World War II, pumpage in the Moraine district has shown a spectacular increase—from 8.58 mgd in 1940 to 29.83 mgd in 1958.

In 1952 the Lamme Road well field of the Montgomery County Sanitary Department began pumping at an average rate of 2.4 mgd, which had increased to 5.37 mgd by 1958. A small but undetermined part of the total during the period 1956–58 was pumped from the well field at Dryden and Sellars Roads.

The Moraine district has shown the most rapid rise of all the districts with respect to percentage of water pumped in the Dayton area. Pumpage in this district increased from only 4 percent in 1920 to 27.0 percent in 1958.

Pumpage in the Moraine district is largely concentrated at the north and south ends of the western part (pl. 5). The three principal establishments which account for 95 percent of pumpage in the district are the Frank M. Tait Station of the Dayton Power & Light Co. at the north end, and the Frigidaire Division of General Motors Corp. and the Montgomery County Sanitary Department well fields at the south end.

An accurate representation of the pumpage density in the Moraine district is difficult to construct. The density for the entire district is 2.84 mgd per sq mi. Excluding the eastern part (pl. 5), which sustains no substantial pumpage, the rest of the district has a pumpage density of 5.03 mgd per sq mi. Even this figure is not completely representative, owing to the uneven pumpage distribution discussed above. Computing the pumpage density of arbitrary areas around these pumpage centers would be misleading, owing to the difficulty in defining boundaries for such areas. Suffice it to say that the pumpage density around the two principal centers of pumpage is considerably higher than the average for the district.

Pumpage in the Moraine district will probably continue to increase, though perhaps not at the phenomenal rate from 1940 to 1958. The eastern part of the district probably won't share in the expansion, as it is almost entirely residential. The rest of the Moraine district, however, has much land suitable for industrial growth. Even the present pumpage centers can stand some further development without

excessive drawdowns. The Moraine district is probably destined for more industrial growth than any other part of Dayton, and ground-water pumpage there can be expected to increase accordingly.

Possibly the greatest expansion of ground-water pumpage in the future will result from increase in output of the well fields of the Montgomery County Sanitary Department. This public-supply system, whose pumpage grew from nothing in 1951 to 5.37 mgd in 1958, seems destined for further expansion. The county is constantly extending its water mains to new areas; almost all new housing developments in Montgomery County south of Dayton will be served by the system. To meet these increased water demands, the county is developing a new well field south of Miami Shores (pl. 5). Conceivably this system could attain the magnitude of the Dayton municipal water system.

GROUND-WATER LEVELS IN THE DAYTON AREA

The need for systematic water-level records is seldom recognized until long after pumpage has become intensive. This is indeed true in the Dayton area, where the longest continuous water-level record, that of observation well Mt-2, dates from 1942; most of the others begin in 1945 or later. Thus ground-water levels cannot be accurately related to increasing pumpage except in the more recent years.

A well-rounded program of water-level record should relate water-level measurements to both time and area. The importance of the time element was recognized when, in 1942, the cooperative observation-well program was begun by the Ohio Engineering Experiment Station and the U.S. Geological Survey. In 1946 this program was expanded and made permanent (Kaser, 1956, p. 1). In more recent years a few of the larger industries and public water suppliers have recognized the need for systematic water-level records and have established their own observation wells.

Necessary though it is, the observation-well program does not fully meet the need for water-level information in a large and hydrologically complex area such as Dayton. Here enters the element of area. At best, the half dozen or so observation wells in the Dayton area provide a continuous record of the water level at only a half dozen or so locations. These few points are not sufficient to define the piezometric surface of an extensive aquifer and its many centers of pumpage (pl. 5), and the cost of drilling and maintaining a sufficient number of observation wells would be prohibitive.

The element of area in water-level records was considered during the present investigation. In the spring of 1955, Mr. R. E. Reemelin of the Water Conservation Subdistrict measured the water levels of

about 80 wells in the Dayton area. In 1958, personnel of the U.S. Geological Survey resumed measurement of these wells in the fall and spring of each year. Plates 7 and 8 show the configuration of the piezometric surface of the lower aquifer in April 1959, when water levels were relatively high, and in October 1960, when they were generally low.

WATER LEVELS PRIOR TO INTENSIVE PUMPING

Prior to pumping, the water level in the valley-fill deposits of the Dayton area probably ranged from 5 to 20 feet below the land surface. The Mad River valley in the Fairborn area, northeast of the Huffman Dam, is probably hydrologically similar to the Dayton area prior to the beginning of pumping. There the piezometric surface is about 10 feet below the land surface (Walton and Scudder, 1960, pl. 3).

Few water-level records prior to 1942 are available. A hydrograph of the Shaw Field well 103* of the National Cash Register Co., for the period 1933–40, is shown on pl. 6. The aquifer in the vicinity of this well was already being fairly heavily pumped during the period of record, so this record is not representative of conditions prior to such pumping.

Several wells, now abandoned, completed between 1917 and 1926 at the Moraine City plants of the Frigidaire Division of General Motors Corp., had static levels ranging from 4 to 12 feet below the land surface at the time of drilling. These levels indicate that the piezometric surface prior to the pumping was considerably higher than it is today. In recent years it has ranged from 20 to 40 feet below land surface in this vicinity. This decline is the expected result of continued pumping over a long period of time.

Well Mt-49 (pl. 6) is situated far enough away from heavy pumping not to be directly influenced thereby. Probably, however, its annual summer decline is accentuated by the pumping at Moraine and at West Carrollton. Its record approximates more nearly than any other observation-well record in the Dayton area conditions in a glacial-outwash aquifer not influenced by pumping. The brief record of Mt-53 (pl. 6) also is characteristic of an area not affected by pumping.

HYDROGRAPHS OF OBSERVATION WELLS

Piezometric surfaces continually change in response to natural and artificial recharge and discharge. In a humid temperate climate, such as prevails in Ohio, the recharge factor normally dominates from November through April, and the discharge factor usually dominates

*This well, now abandoned, was numbered according to a system different from that used in the present report.

from May through October. Of course, the norm is not always attained, as examination of the hydrographs (pl. 6) reveals. An abnormally dry year, such as 1954, causes the piezometric surface to drop far more than usual, whereas a year with above-normal precipitation, such as 1957, brings about a greater than normal rise. Over a period of several years, however, these deviations tend to average out. This annual recharge-discharge cycle is the dominant feature of most hydrographs of wells in the Dayton area.

Hydrographs are especially valuable in that they can indicate long-term overdraft from an aquifer. In a heavily pumped aquifer the natural decline during the summer is usually intensified by the superimposing of artificial discharge (pumpage) on the natural discharge. Moreover, peak pumpage, brought about by the use of water for air conditioning and irrigation, usually occurs during the summer, further intensifying the decline. If over a period of several years the water level of a well is lowered each summer more than can be made up by recharge the following winter, water is said to be "mined," and the result is a water deficit which cannot easily be made up.

Records of observation wells in areas of industrial or commercial pumping typically have daily and weekly cycles of fluctuation superimposed on the annual recharge-discharge cycle. Pumping is usually heaviest during the normal working hours on weekdays and is lightest on weekends; therefore, water levels in the observation wells will show a decline during the daytime followed by a recovery at night each weekday, and a greater recovery each weekend.

The hydrographs of 12 observation wells in the Dayton area are presented on plate 6. Of these records five are currently maintained by the Division of Water of the Ohio Department of Natural Resources in cooperation with the U.S. Geological Survey, three were formerly maintained by industries or public water suppliers, and one was formerly maintained by an industry. Only current records and others of several years' duration are presented herein. Complete lists of water-level records in the Dayton area are given by Kaser (1956, p. 91) and by Norris, Cross, and Goldthwait (1948, table 1).

Some features common to most of the Montgomery County hydrographs are here summarized to avoid repetition in the individual discussions of wells. Precipitation appears to run in cycles of feast and famine (pl. 2). During the period of current observation-well records, the years 1947–50 had precipitation well above normal, whereas 1953–56, and particularly 1953–54, had precipitation well below normal. The period 1957–59 was one of above-normal rainfall, and 1960 was deficient. These conditions are reflected in most of the observation-well records. Particularly evident are the small amount

of recharge in 1953 and 1954 and the immediate response of some wells near rivers to the heavy rainfall and resultant floods of 1957, 1958, and 1959.

OBSERVATION WELL Mt-1

Location.—In Rohrers Island well field of the city of Dayton, Mad River Township; sec. 18, T. 2, R. 7, lat 39°48′, long 84°06′, altitude 780 feet above mean sea level.

Description.—Unused drilled well of the city of Dayton; diameter 6 inches, depth 57 feet. Sand and gravel aquifer. Measuring point was top of 6-inch casing 4 feet above land-surface datum; observation by automatic recorder from March 1942 to November 1948.

Remarks.—This well shows water-level fluctuations in the upper aquifer (Norris, 1959, p. 3–4). The frequent abrupt fluctuations of the water level of this well are due to variations in the distribution of pumping and changes of head in the artificial-recharge pits at Rohrers Island. Despite the influence of nearby heavy pumping, the water table in the upper aquifer is maintained at a fairly high level. Owing to these artificial controls, this record is not at all representative of water levels in the Dayton area. It is the only record here where artificial factors dominate over the annual recharge-discharge cycle.

OBSERVATION WELL Mt-2

Location.—Steam-distribution plant (Fourth St. Sta.) of Dayton Power & Light Co., in downtown Dayton, sec. 4, T. 1, R. 7, lat 39°45′, long 84°11′, altitude 740 feet above mean sea level.

Description.—Unused drilled well of Dayton Power & Light Co.; diameter 8 inches, depth 52 feet. Sand and gravel aquifer. Measuring point at floor of shelter 5.68 feet above land-surface datum; observation by recording gage from May 1952 through December 1960.

Remarks.—This well is open either in the lower part of the upper aquifer or in the partially confining till-rich zone that separates the upper and lower aquifers. Figure 22 shows, for comparison, the recorded water levels for 1 week from well Mt-2 and from well 22, which is located in the same building but 143 feet deep and screened in the lower aquifer. The record of well 22 was made at a time when the pump was removed for repairs. The record of well Mt-2 indicates the same daily cycle caused by pumping, with recovery on the weekend, but the peaks and troughs are not so pronounced as those on the record of well 22 and are slightly delayed. Furthermore, the water level in Mt-2 is consistently about 1½ feet higher than that in well 22. Mt-2 shows the general water-table trend in its vicinity; well 22 shows the altitude of the piezometric surface of the lower aquifer.

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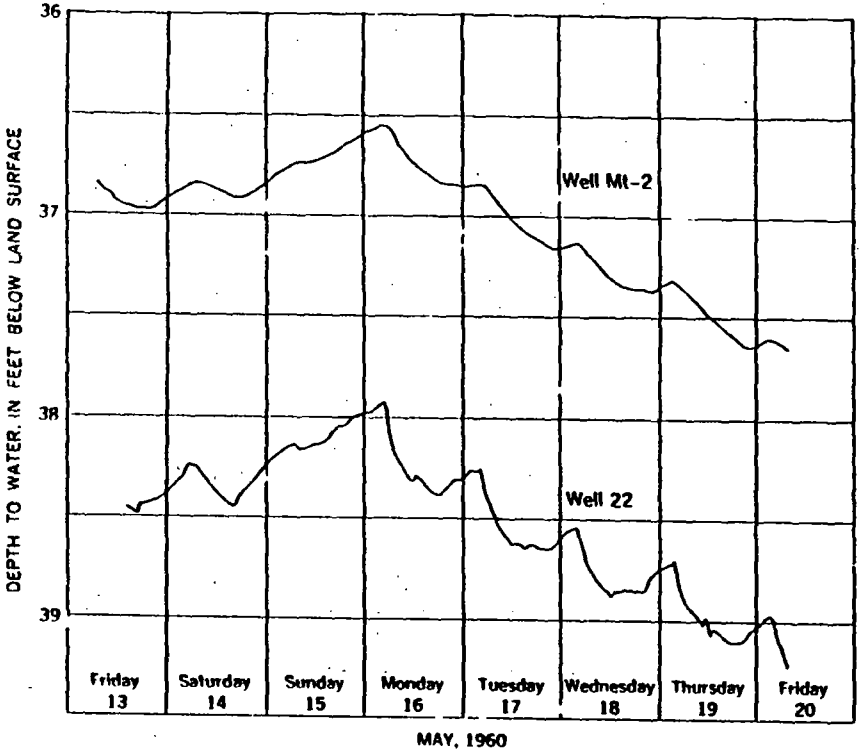

FIGURE 22.—Comparison of recorder charts from wells Mt-2 and 22 for the week beginning May 13, 1960.

The increasing declines each summer beginning in 1948 are due to increased pumping of ground water for air conditioning of nearby buildings. In years of normal or above-normal rainfall, winter recovery has been sufficient to offset the previous summer's decline.

OBSERVATION WELL Mt-3

Location.—In park area atop levee on east bank of Miami River at corner of Stewart Street and Patterson Boulevard, Dayton; sec. 2, T. 1, R. 7, lat 39°44′, long 84°12′, altitude 744 feet above mean sea level.

Description.—Drilled test well of the Ohio Department of Highways; diameter 6 inches, depth 80 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 1.2 feet above land-surface datum; observation by recording gage from November 1945 through December 1960.

Remarks.—The water level of this well fluctuates in response to the stage of the Miami River and to heavy industrial pumpage (avg 6.5 mgd) at the National Cash Register Co. plant nearby. This well was

originally drilled to a depth of 50 feet; it went dry from August through December 1962 and was then deepened to its present depth of 80 feet. The hydrographs of water-level fluctuations recorded before the well was deepened and of those recorded after it was deepened are generally similar, except that the projected general trend of the second hydrograph lies a few feet below that of the first. The displacement of the two parts of the hydrograph shows that originally the well was open in the upper aquifer, and that deepening the well carried it through the till-rich zone into the lower aquifer, where water levels are generally lower.

OBSERVATION WELL Mt-5

Location.—Kuhns Bros. Foundry, 1800 McCall Street, Dayton, sec. 5, T. 2 N., R. 6 E., lat 39°44′, long 84°12′, altitude 744.1 feet above mean sea level.

Description.—Unused drilled well; diameter 6 inches, depth 156 feet. Lower sand and gravel aquifer. Measuring point at floor of instrument shelter, 1.2 feet above land-surface datum; observation by recording gage from February 1946 to December 1952.

Remarks.—Slight pumpage nearby appears to have little effect on the annual cycle of this well, although it does affect the daily and weekly cycles.

OBSERVATION WELL Mt-6

Location.—Basement of Municipal Building, Third and Ludlow Streets, Dayton, sec. 4, T. 1, R. 7, lat 39°46′, long 84°12′, altitude 740 feet above mean sea level.

Description.—Unused drilled well of the city of Dayton; diameter 8 inches, depth 60 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 13.0 feet below land-surface datum; observation by periodic measurement from February 1946 to May 1947 and by recording gage from May 1947 through December 1960.

Remarks.—Long-term fluctuations are in response to the annual recharge-discharge cycle, with the summer discharge accentuated by nearby pumping for air conditioners. Although this well is of about the same depth as Mt-2, it is highly sensitive to nearby pumping because it is screened in gravel between two fairly widespread till sheets that here constitute the till-rich zone. The well is considered, somewhat arbitrarily, to be open in the upper aquifer.

OBSERVATION WELL Mt-49

Location.—Barnyard at northeast corner of Farmersville-West Carrollton Road and Baltimore & Ohio Railroad, in village of Whitfield, Jefferson Township, sec. 26, T. 3 N., R. 5 E., lat 39°40′, long 84°16′, altitude, 715 feet above mean sea level.

Description.—Test well drilled on property of Mr. E. F. Stenger; diameter 6 inches, depth 220 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 2.5 feet above land-surface datum; observation by recording gage from November 1947 through December 1960.

Remarks.—Mt-49 responds principally to the annual recharge-discharge cycle, and to changes of stage of the Miami River, about half a mile distant. Regional pumping upstream may accentuate the summer discharge, but this is difficult either to prove or to disprove. This well is outside the area of the present investigation but is a good index of ground-water levels in areas not directly affected by pumping.

OBSERVATION WELL Mt-51 (563)

Location.—South side of plant No. 2, Frigidaire Division, General Motors Corp., west side of Springboro Pike (South Broadway) just east of New York Central Railroad in Miami Township, sec. 16, T. 1, R. 6, lat 39°42′, long 84°13′, altitude 725 feet above mean sea level.

Description.—Unused drilled well of the General Motors Corp.; diameter 8 inches, depth 113 feet. Lower sand and gravel aquifer. Measuring point at top of instrument platform, 2.0 feet below land-surface datum. Observation by recording gage May 1953 to June 1960. Maintained by Ohio Division of Water in cooperation with U.S. Geological Survey from May 1953 to April 1955 and designated Mt-51; maintained independently by Frigidaire Division from May 1955 to June 1960 and designated 563.

Remarks.—This record is influenced by industrial pumpage of the Frigidaire Division plants, and to a lesser degree by pumpage at the Lamme Road and Dryden Road well fields of the Montgomery County Sanitary Department. Despite its proximity to one of the largest concentrations of pumpage in the Dayton area, no persistent downward trend has been noted in well 563. During the floods of 1957, 1958, and 1959, the effects of recharge from the Miami River, about a mile distant, were very rapid.

OBSERVATION WELL Mt-53

Location.—In Miami River well field of the city of Dayton, 1,250 feet southwest of third turn in Beardshear Road, 900 feet west of Miami River, Harrison Township, sec. 12, T. 2 N., R. 6 E., lat 39°48′, long 84°09′, altitude 749 feet above mean sea level.

Description.—Drilled well, to be put into production as well 1 of the city of Dayton; diameter 26 inches, depth 106 feet. Lower sand and gravel aquifer. Observation by recording gage from March 1957 to July 1959.

Remarks.—Mt-53 fluctuated largely in response to changes in stage of the nearby Miami River; there is no pumping within the area of influence of this well. The record of Mt-53 is probably representative of conditions in the valley-fill aquifers of the Dayton area near the major streams prior to heavy pumping.

OBSERVATION WELL M-9

Location.—In Lamme Road well field of Montgomery County Sanitary Department, Miami Township, sec. 10, T. 1, R. 6, lat 39°42′, long 84°13′, altitude 743.5 feet above mean sea level.

Description.—Drilled test well owned by Montgomery County Sanitary Department; diameter 6 inches, depth 135 feet. Sand and gravel aquifer. Observation by recording gage maintained by Montgomery County Sanitary Department from February 1954 to June 1960.

Remarks.—Well M-9 is surrounded by the pumping wells of the Lamme Road well field. The somewhat complicated hydrograph is due to alternation in pumping of several nearby wells at different distances from M-9. Although well M-9 is more than a mile from the Miami River and the wells of the Frigidaire Division lie between it and the river, M-9 responds to floods, though not so rapidly as does well 563.

OBSERVATION WELLS 530 AND 531

Location.—At Tait Station of the Dayton Power & Light Co., Carillon Boulevard and East River Road, Dayton, sec. 8, T. 1, R. 7, lat 39°43′, long 84°13′, altitudes 730 feet (530) and 727 feet (531) above mean sea level.

Description.—Two test wells of the Dayton Power & Light Co.; both 2 inches in diameter and 120 feet deep. Lower sand and gravel aquifer. Measuring point top of casing, at land surface; observation by weekly measurements by Dayton Power & Light Co. personnel from March 1946 to May 1960.

Remarks.—These two wells are effected by pumping at the Tait Station of the Dayton Power & Light Co. and by changes in stage of the Miami River, about 700 feet distant. The abrupt rise in water levels in response to the floods of 1957, 1958, and 1959 is evidence that the hydraulic separation of the upper and lower aquifers is not complete. (See also geologic section *D–D″*, pl. 3.)

PIEZOMETRIC-CONTOUR MAPS

Plates 7 and 8 are generalized contour maps of the piezometric surface of the lower aquifer, based on water-level measurements made in about 60 observation wells in the Dayton area in April 1959 and Octo-

ber 1960. These observation wells had been measured in April 1955 and twice annually in 1958, 1959, and 1960. The April 1959 and October 1960 contour maps were selected for inclusion in the report because they represent generally the highest and lowest water levels during this investigation.

In most places in the Dayton area the outwash deposits are separated into an upper and a lower aquifer by partially confining layers of clay-rich till. Nearly all the industrial supply and much of the municipal supply comes from the lower sand and gravel aquifer, at depths of 100–200 feet below the flood plain of the Miami and Mad Rivers. In areas where the lower aquifer is being heavily pumped, the piezometric surface of this aquifer is several feet lower than the water table of the upper aquifer. Where the lower aquifer is not being heavily pumped, little if any head differential exists.

The piezometric maps represent a compromise with the actual hydrologic conditions as previously described. A literal representation would require separate contour maps of the upper and lower aquifers for each time of measurement. Not enough observation wells tap the upper aquifer, however, to permit construction of such a map for this aquifer. Therefore, the maps accompanying this report are based largely on wells in the lower aquifer, supplemented by records from a few wells in the upper aquifer where no head differential or no separation is believed to exist. The maps are considered to be representative of the static water levels of most wells in the Dayton area. Streams are not treated as recharge boundaries owing to the almost complete isolation of the lower aquifer from the principal streams of the area. The bedrock walls of the Miami and Mad River valleys are arbitrarily selected as the limits of the contoured area.

The general configuration of both maps is the same. The piezometric surface of the lower aquifer in the part of the Dayton area affected by pumping ranges in depth from 20 to 50 feet below the land surface. In parts of the area not affected by pumping it is usually at a depth of less than 20 feet. Four major cones of depression are evident on both piezometric maps. One cone is at the Rohrers Island well field of the city of Dayton, in the eastern part of the East district. The second and largest cone in the Dayton area includes the Central and South Park districts, the eastern part of the West district, and the northernmost part of the Moraine district. It reaches its lowest point in the wellfield of the National Cash Register Co., in the South Park district. The third cone is at the Dayton Tire & Rubber Co. plant along Wolf Creek in the West district. The fourth cone, in the Moraine district, centers around the Montgomery Country Sanitary

Department well fields and the plants of the Frigidaire Division, General Motors Corp.

Water levels in October 1960 (pl. 8) were lower throughout the area than they were in April 1959 (pl. 7). The change was far from uniform, however. It was greatest in the four areas directly affected by heavy pumping and was least in the areas not so affected. In the four heavily pumped areas the difference in altitudes ranged from 7 to 26 feet and averaged about 15 feet. In the areas unaffected by pumping the range was 1–4 feet. The maximum lowering occurred at the Rohrers Island well field, where the piezometric surface declined more than 20 feet from April 1959 to October 1960. The minimum lowering of 1–4 feet occurred in north Dayton.

CHEMICAL QUALITY OF SURFACE AND GROUND WATERS

The utility of water is determined as much by its chemical quality as by its availability and quantity. Natural water from all sources contains varying quantities of dissolved solids; some of which may be objectionable or may even render the water unsatisfactory for certain uses. A knowledge of the concentrations of these constituents is therefore essential in any ground-water study.

Western Ohio is underlain mostly by carbonate-rich materials. The bedrock consists chiefly of limestone and dolomite, from which the surficial deposits were largely derived. Naturally occurring water tends to reflect its chemical environment, and both ground and surface waters in the Dayton area contain a relatively high proportion of calcium and bicarbonate.

In the present investigation, 44 samples of water from representative wells in the glacial-outwash aquifers of the Dayton area were collected and analyzed; table 8 summarizes the results of these analyses.

Table 9 records analyses of six miscellaneous surface-water samples from the Dayton area and environs. Lamar and Schroeder (1951) summarized the results of a regular surface-water-sampling program carried on during the period 1946–48 and reported on the quality of surface water in more detail than is feasible here.

CONSTITUENTS AND PROPERTIES OF NATURAL WATER

The ground-water samples were analyzed for the following: Silica, iron, manganese, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, specific conductance, pH, and color (table 8). The surface-water samples were analyzed for all the aforementioned constituents and properties except manganese (table 9). The source of these constituents, the

TABLE 8.—*Chemical analyses of ground-water samples from the Dayton area, Ohio*

[Results are in parts per million except as indicated]

Well	Owner	Depth (ft)	Date of collection of sample	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (see p. 125 for scale)
5	Milk Div., Borden Co.	80-90	11-20-57	60	12	0.11	0.07	90	34	20	3.5	335	78	30	0.4	4.3	459	365	90	720	7.5	4
14	Dayton Power & Light Co., 3rd St. Sta.	146	4-15-58	59	18	2.0	.12	116	43	30	2.7	426	114	48	.5	.8	587	467	118	962	7.4	4
22	Dayton Power & Light Co., 4th St. Sta.	143	4-15-58	58	14	.06	.00	92	34	11	1.6	358	72	20	.4	.9	434	370	76	711	7.4	3
28	Dayton Power & Light Co., Longworth St. Sta.	140	6-18-57	60	17	.00	.31	104	41	14	1.8	372	106	20	.3	5.3	511	428	123	770	7.2	2
31	Delco Products Div., General Motors Corp.	144	11- 7-57	58	16	.8	.24	95	38	19	1.9	380	81	24	.4	.3	476	393	82	753	7.4	4
76	Rike-Kumler Co.	130	6-18-57	62	14	.00	.00	82	30	12	1.8	305	65	18	.3	2.0	386	328	78	609	7.6	1
77	Sears Roebuck & Co.	148	6-18-57	61	12	.00	.14	80	29	14	2.4	296	71	20	.3	.7	386	319	76	598	7.7	3
112	Focke Packing Co.	33	4-15-58	56	13	.02	.00	131	40	29	2.8	442	121	48	.3	6.4	627	492	130	989	7.6	4
122	Master Electric Co.	56	6-18-58	60	14	.04	.01	122	44	16	2.2	445	112	32	.2	4.2	605	486	121	930	7.3	1
211	Chrysler Airtemp Sales Co.	32	6-18-58	61.5	12	.28	.03	98	57	22	3.0	368	100	28	.2	7.2	492	397	95	808	7.2	3
216	Dayton Rust Proof Co.	53	12-12-57	57	10	.04	.00	86	34	18	3.4	312	88	24	.2	30.0	439	355	99	728	7.8	2
217	do	141	12-12-57	55	15	1.9	.00	71	34	8.2	1.3	320	52	10	.5	.2	344	317	55	600	7.6	3
303	Aetna Paper Co.	133	6-18-57	55	15	.00	.32	80	32	11	1.5	317	58	18	.3	.6	380	331	71	603	7.3	1
311	Dayton Rubber Co.	198	6-18-57	59	17	1.8	.04	89	39	18	1.5	390	64	19	1.2	.1	450	353	63	714	7.5	3
359	Sunshine Biscuits, Inc.	108	11- 6-57	64	15	2.0	.50	131	46	28	2.1	470	142	33	.3	.4	654	516	131	980	7.3	3
407	National Cash Register Co.	147	4-16-58	60	18	.28	.14	128	46	26	3.4	468	125	38	.3	1.1	609	509	125	986	7.3	4
410	do	122.02	4-16-58	59	15	.03	.00	121	44	12	1.6	451	103	25	.3	2.3	568	483	114	893	7.2	4
418	do	149	4-16-58	58	16	.21	.03	108	40	21	2.3	416	93	29	.3	.3	500	429	88	843	7.3	3
509	City of Dayton, Miami View Golf Course.	122	4-10-57	56	14	1.5	.30	77	36	20	1.2	344	66	28	.6	.1	418	344	62	692	7.4	1
515	Crume Brick Co.	120	4-10-57	------	16	1.9	.00	83	35	7.3	1.0	380	33	11	.6	.1	377	351	40	640	7.3	4
516	H. G. Darroch	38	4-10-57	57	18	3.5	.08	84	40	8.2	1.3	448	21	1.2	1.3	.1	388	378	10	675	7.4	3
520	Dayton Power & Light Co., Moraine Substa.	58	6-18-58	60	14	.28	.13	111	36	28	2.2	442	72	22	.2	10.0	512	425	63	848	7.2	3
521	Dayton Power & Light Co., Frank M. Tait Sta.	65	6-18-58	------	8.8	.20	.16	77	29	13	2.0	287	74	19	.3	1.6	377	311	76	624	7.6	3
522	do	95	6-18-58	55	14	.52	.03	90	33	11	2.3	362	64	16	.3	2.1	410	360	64	692	7.4	4
523	do	70	6-18-58	59	10	.31	.02	98	35	39	4.0	268	165	60	.4	4.7	580	389	169	903	7.4	4
524	do	155	6-17-57	58	14	1.2	.10	90	36	18	1.8	326	85	34	.3	.1	452	373	106	705	7.6	3
541	Frigidaire Div., General Motors Corp.	111	12-18-57	58	15	.30	.00	92	36	12	1.8	380	66	16	.2	2.5	414	378	66	720	7.3	1
555	do	131	12-18-57	55	16	1.5	.02	79	34	18	1.8	348	53	20	.3	.00	386	337	52	666	7.4	1
558	do	123	4-23-58	------	16	2.0	.14	122	45	28	2.2	406	189	19	.1	4.8	651	490	157	952	7.7	3
595	M. G. Snyder & Son Co.	159	4-10-57	55	15	.02	.00	90	38	5.3	1.1	384	51	16	.3	4.5	411	381	66	694	7.2	1
598	Frank M. Tait	172	4- 9-57	57	13	.08	.00	88	33	8.8	1.7	369	39	16	.4	5.9	390	355	52	660	7.2	1
C-4	City of Dayton	--------	11-20-57	53	15	2.9	.14	104	40	5.3	1.0	405	87	10	.4	.2	487	424	92	745	7.3	4
C-15	do	85	11-20-57	64	10	.45	.02	90	35	12	2.3	345	85	17	.3	5.2	431	369	86	692	7.4	4
C-43	do	--------	11-20-57	63	9.8	.04	.02	87	32	10	2.1	290	93	16	.4	4.1	428	349	111	652	7.7	4
C-44	do	--------	4-23-59	50	9.5	.03	.00	83	29	9.1	1.6	298	71	16	.2	5.4	374	327	82	624	7.5	6
C-46	do	--------	4-23-59	53	10	.04	.00	102	36	15	4.5	344	97	20	.4	24.0	481	403	121	792	7.2	3
C-47	do	122	4-15-58	57.5	12	.03	.00	104	35	32	2.2	356	106	48	.3	5.1	533	404	112	870	7.3	4
T-1	City of Dayton, Miami River well field.	166	4-11-56	------	16	2.0	.11	74	35	5.3	1.2	340	37	6.5	.5	2.6	341	329	50	565	7.8	1
O-1	City of Oakwood	65	4-16-58	56	14	.02	.00	118	43	31	1.8	432	85	67	.2	2.8	607	472	118	976	7.4	4
M-2	Montgomery County Sanitary Dept.	200	4-16-58	54.5	14	.06	.02	91	34	5.1	1.1	382	49	10	.2	4.2	401	367	54	675	7.2	4
M-4	do	166	4-10-57	56	15	.01	.12	87	32	5.2	.9	350	48	10	.3	6.1	388	349	62	635	7.3	1
M-5	do	150	2-19-59	56	14	.02	.02	93	36	5.0	.9	384	48	13	.1	4.8	404	381	66	701	7.5	1
M-6	do	157	2-19-59	54	14	.02	.18	75	29	3.6	.7	298	53	12	.2	.7	345	307	62	574	7.5	1
M-10	do	247	4-16-58	54	16	.44	.00	60	29	5.2	.8	270	48	12	.3	.1	274	269	48	502	7.8	4

TABLE 9.—*Chemical analyses of surface-water samples from the Dayton area, Ohio*

[Results are in parts per million, except as indicated]

Source	Date of collection of sample	Mean discharge (cfs)[1]	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (see p. 135 for scale)
Miami River at Taylorsville	5-10-46	338	6.6	0.08	72	24	7.6	2.1	305	72	10	0.3	4.0	372	267	72	600	7.7	8
Do	6-13-46	70	1.6	.14	71	24	27	4.2	314	74	23	.4	4.0	388	317	95	686	7.5	5
Do	9-28-46	104	7.5	.05	72	24	6.9	1.7	314	74	14	.1	3.0	400	313	95	686	7.6	10
Do	1-6-60	1,340	4.8	.04	82	24	11		292	79	11	.2	1.7	317	271	92	543	7.6	5
Do	1-13-46	3,460	3.4	.04	82	23	29		305	141	21	.4	2.5	390	291	120	641	7.3	5
Miami River at Hamilton	4-19-46	486	4.0	.06	82	23	12		302	158	13	.4	2.8	517	276	113	819	7.3	5
Do	10-11-49	1,060	3.6	.06	80	23			305	158		.4	6.2	458	280	113	704	7.4	5
Do	6-26-47	[2]23	4.4	.08	88	30	5.2	1.4	[3]298	101	4.2	.3	6.2	400	355	118	668	7.9	0
Wolf Creek near Russells Point	5-14-46	610	7.2	.11	84	32	22	2.2	295	82	6.1	.1	16	397	284	83	490	7.7	5
Stillwater River at Englewood	5-15-46	14	1.2	.24	80	32	22	1.1	305	84	12	.2	2.2	388	282	81	535	7.6	5
Do	10-12-49	175	3.6	.04	84	32	22	2.2	310	79	8.0	.4	2.2	376	291	81	585	7.6	5
Do	5-14-46	542	7.6	.02	84	27	10	2.9	[4]312	75	9.8	.4	4.4	456	287	71	649	7.3	5
Mad River near Dayton	5-15-46	190	4.8	.04	84	27	1.8	1.8	[5]301	80	11	.2	4.2	476	287	100	728	7.6	5
Do	10-11-49	332	6.4	.11	87	24	12		350	79	10	.2	7.2	488	287	100	695	7.6	5
Do	9-28-49	224	7.8	.04	84	24	7.8	2.8	364	79	17	.2	7.5	493	287	84	675	7.9	5
Do	4-6-60	702	6.7		84	31		1.4	328	72	14	.3	11	481	287	84	648	7.4	6

[1] Water-discharge records for October 1949 are current-meter measurements or computed provisional discharge at time of sampling.
[2] Current-meter measurement at time of sampling.
[3] Includes equivalent of 8 parts of carbonate (CO_3).
[4] Includes equivalent of 6 parts of carbonate (CO_3).
[5] Includes equivalent of 17 parts of carbonate (CO_3).

factors accounting for the properties, and the significance of both with respect to the various uses of water are discussed briefly. Hem (1959) presented a fuller discussion in his study of the geochemistry of natural water.

SILICA (SiO_2)

Silicon is second to oxygen as the most abundant element in the earth's crust. It occurs in nature in the form of the silicate radical (SiO_4) or as silica (SiO_2). Silica has a low solubility, but all natural water contains small quantities of it. The silicia content of ground-water samples from the Dayton area ranges from 8.8 to 18 ppm (parts per million) and averages 14 ppm. It can cause the formation of a hard scale in boilers, particularly in high-pressure boilers.

IRON (Fe)

Iron is present in all rocks and consequently is a constituent of nearly all natural water. Iron concentration in the ground-water samples in the Dayton area ranges from 0.00 to 3.5 ppm and averages 0.66 ppm. A concentration of about 0.3 ppm or greater stains enamel, porcelain, and clothing. Iron concentration in excess of about 0.5 ppm gives water an unpleasant taste but causes no deleterious physiological effects.

The presence of so-called "iron bacteria" in wells and water-transmission lines creates a special problem. Iron bacteria are not true bacteria but are living organisms often found in natural water. Speller (1935, p. 187–188) reported that they depend upon iron for existence and thrive in slightly acid water containing 2 ppm or more iron. *Crenothrix* is probably the most common of the several iron bacteria known. Metallic and nonmetallic materials that carry water containing iron bacteria become coated by nodules of ferric hydroxide or by a slimy scum impregnated with ferric hydroxide. The water may become colored red, and its rate of flow may be affected by the activity of these organisms. They are responsible for one of the major water-treatment problems in the Dayton area but can be checked by certain methods. The Dayton Power & Light Co. chlorinates its water to kill the bacteria and adds a polyphosphate compound to keep the iron in solution.

MANGANESE (Mn)

The concentration of manganese in water is generally less than that of iron; however, the effects of the two constituents are similar. Of the 44 ground-water samples analyzed, 30 have a measurable concentration of manganese, ranging from 0.01 to 0.50 ppm and averaging 0.08 ppm. The manganese concentration of 18 samples equals or

exceeds the U.S. Public Health Service (1962) recommended limit of 0.05 ppm.

CALCIUM (Ca)

Calcium is one of the major constituents of natural water in a limestone terrane such as that in which the Dayton area is situated. Concentrations of calcium in the ground-water samples analyzed range from 60 to 131 ppm and average 95 ppm. Calcium and magnesium are the principal causes of water hardness; their effects are discussed under the heading "Hardness."

MAGNESIUM (Mg)

Dolomitic rock or unconsolidated materials derived therefrom are the principal source of magnesium. Concentrations of magnesium in the ground-water samples from the Dayton area range from 29 to 46 ppm and average 36 ppm. The effects of magnesium on ground water are discussed under "Hardness."

SODIUM (Na) AND POTASSIUM (K)

The alkali metals sodium and potassium are discussed together, as their source and effects are similar. Sodium is generally the more abundant of the two and is more easily dissolved from the source rock. Combined concentrations of the two metals in the ground-water samples analyzed range from 6 to 43 ppm and average 18 ppm. Although relatively low, these concentrations of the alkalies are sufficient to cause undesirable effects in some uses, such as in high-pressure boilers.

BICARBONATE (HCO_3)

Water which contains carbon dioxide (CO_2) dissolves the carbonates of calcium and magnesium from rock, forming the bicarbonate (HCO_3) ion. In a carbonate-rich terrane, bicarbonate is one of the major constituents of natural water. Concentrations in the ground-water samples analyzed range from 268 to 470 ppm and average 366 ppm. At high temperatures in boilers, the bicarbonate decomposes to yield carbon dioxide, which is corrosive.

SULFATE (SO_4)

Sulfate in natural water is largely dissolved from gypsum, a highly soluble mineral which occurs in the limestones and dolomites of western Ohio. Concentrations in the ground-water samples analyzed range from 21 to 189 ppm and average 80 ppm. Sulfate causes much of the noncarbonate hardness of water. Sulfate combines with calcium to form hard scale in boilers and in other heat-exchange equipment. The U.S. Public Health Service (1962) recommends that the sulfate content of drinking water not exceed 250 ppm.

CHLORIDE (Cl)

Chloride is a minor constituent of ground water in the glacial-outwash aquifers of the Dayton area. Concentrations in the ground-water samples analyzed range from 1.2 to 67 ppm and average 23 ppm. All the samples of ground water (table 8) and surface water (table 9) contain less chloride than the 250-ppm limit recommended by the U.S. Public Health Service (1962) for drinking water.

FLUORIDE (F)

Minute quantities of fluoride are found in most water from limestone terrane. In the analyses of ground water in the Dayton area, the fluoride concentration ranges from 0.1 to 1.3 ppm and averages 0.35 ppm. Protracted use of water having more than 1.5 ppm fluoride can cause mottling of teeth, especially in children (Dean and others, 1942). The U.S. Public Health Service (1962) recommends that the average fluoride concentration should not exceed 0.8–1.7 ppm; the figure depends on the annual average of maximum daily air temperatures.

NITRATE (NO_3)

Most of the nitrate occurring in ground water is derived from soil in which legumes are grown and on which animal excrement and nitrate fertilizers have been distributed. The concentrations reported in analyses of the ground-water samples from the Dayton area range from 0.0 to 30 ppm and average 4 ppm. All these analyses are well under the tentative limit of 45 ppm nitrate recommended by the U.S. Public Health Service (1962). The presence of nitrate in excess of this amount in drinking water has been definitely correlated with methemoglobinemia (cyanosis, or "blue baby" disease) in infants (Maxcy, 1950).

The three wells (216, 520, C-47) that yielded 10 ppm or more of nitrate are all located near streams and probably are receiving recharge by infiltration of stream water having a high nitrate content due to pollution. All other reported concentrations of nitrate are below 8 ppm.

DISSOLVED SOLIDS (RESIDUE AT 180°C)

The determination of dissolved solids is made in laboratories of the U.S. Geological Survey by evaporating a suitable volume of the sample to near dryness on a steam bath and then drying the residue in an oven for 1 hour at 180°C (Hem, 1959, p. 49–50; Rainwater and Thatcher, 1960, p. 220). Concentrations of dissolved solids in ground-water samples from the Dayton area range from 274 to 654 ppm and average 458 ppm. Water having more than 1,000 ppm of dissolved solids is generally considered to be unsatisfactory for most purposes.

The recommended upper limit of dissolved solids in drinking water is 500 ppm (U.S. Public Health Service, 1962). Some specialized industrial applications require a much lower concentration.

HARDNESS

For many years water's hardness has been regarded as its soap-consuming property. Soap-consuming water contains cations, chiefly calcium and magnesium, that form insoluble compounds with soap. This traditional concept is not entirely satisfactory, however, because a great many constituents other than those usually considered as contributing to hardness will react with soap. In analyses by the U.S. Geological Survey a standard procedure has been adopted (Hem, 1959, p. 146). Hardness is reported under two classifications: carbonate and noncarbonate. These are approximately equivalent to the traditional terms "temporary hardness" and "permanent hardness." Hardness that is attributable to calcium and magnesium is reported as an equivalent quantity of calcium carbonate ($CaCO_3$).

Carbonate hardness of the ground-water samples collected in the Dayton area ranges from 269 to 516 ppm and averages 386 ppm; noncarbonate hardness of the same samples ranges from 100 to 169 ppm and averages 86 ppm.

Ground water in the Dayton area is hard by almost any standard. Treatment is necessary for boiler use and is desirable for most other uses. The widespread use of detergents, however, has in many instances eliminated the need for softening water used for laundering. The lime-soda method of treatment is used by the Dayton water system to reduce the carbonate hardness to about 100 ppm. The other public water-supply systems in the area do not soften their water. Most small water-softening installations use the ion-exchange or zeolite method, whereby the calcium and magnesium ions are exchanged for sodium ions.

SPECIFIC CONDUCTANCE

The conductance of a solution (its ability to conduct an electrical current) generally is directly related to its dissolved-solids content. Conductance is the reciprocal of resistance and is measured in mhos, the reciprocal of ohms. As the conductance of all natural water is well below 1 mho, it is measured in micromhos (mhos$\times 10^6$). In water analyses by the U.S. Geological Survey the specific conductance is reported in micromhos at 25°C (Hem, 1959, p. 38).

Although specific conductance is not invariably related to the dissolved-solids content of water, it can be used to estimate such content. In the ground-water samples from the Dayton area, specific conductance ranges from 502 to 989 micromhos and averages 742 micromhos.

The specific conductance of water from glacial-outwash aquifers of the Dayton area generally is 1.5–2 times the dissolved-solids content.

pH

The pH value (the negative logarithm of the hydrogen-ion concentration) is a measure of the acidity or alkalinity of a solution. A pH of 7.0 denotes a neutral solution, less than 7.0 denotes an acid solution, and more than 7.0 denotes an alkaline solution. The pH of ground-water samples from the Dayton area ranges from 7.2 to 7.8 and is therefore on the alkaline side of the scale.

COLOR

Color is measured by a platinum-colbalt scale, on which one unit represents the color produced by 1 ppm of platinum. Most color in natural water is due to the presence of organic matter. In the ground-water samples from the Dayton area, color ranges from 1 to 6 color units and averages 3 color units. These values are insignificant for most uses of water and cannot be detected by the unaided eye.

TEMPERATURE

Temperatures of the ground-water samples from the Dayton area, when collected, ranged from 50° to 64°F and averaged 57.5°F. Temperatures of ground water in the Dayton area generally range from 52° to 56°F. The wider range of temperatures reported is due primarily to recharge by induced infiltration of warmer and colder surface water. Shallow wells that are pumped at a high rate and are near a stream yield water whose temperature usually fluctuates over a wide range seasonally, perhaps as much as from 45° to 75°F. Deep wells, and shallow wells not near a stream, generally yield water of more uniform temperature.

CHEMICAL QUALITY OF SURFACE WATER AND ITS RELATION TO GROUND WATER

The chemical quality of surface water is far more variable than that of ground water. There are two primary causes for this: (1) large seasonal fluctuation of discharge and attendant concentration or dilution of individual constituents and (2) the variability of contamination by effluent from industries and municipal sewage plants. The records of miscellaneous sampling of the Miami, Mad, and Stillwater Rivers and of Wolf Creek (table 9) illustrate the variation in concentrations.

In general, the surface water sampled in the Dayton area contains less dissolved solids than the ground water sampled. Nitrate is generally higher for the surface-water samples but well below the upper limit of 45 ppm. The values for color and pH likewise are higher

for the surface-water samples, and the temperature of the surface water shows a far wider range than that of the ground water.

The quality of surface water is of special interest in a ground-water investigation because in heavily pumped areas adjacent to a stream most recharge to the aquifer comes from induced infiltration from the stream.

The possibility always exists that polluted stream water may contaminate the aquifer. There is no evidence to date to suggest that any such contamination of the aquifer has taken place.

GRAPHIC PRESENTATION OF CHEMICAL-QUALITY DATA

Graphs are useful for presenting a concise summary of water-quality data, for they often clarify the less obvious relationships of the dissolved constituents in water. Several graphic methods of presenting these data have been devised, and their applications were summarized by Hem (1959, p. 164–186).

Two graphic methods were chosen to summarize the data of this investigation. The first (fig. 23) is a nomograph devised by Schoeller (1935) and adapted by R. C. Vorhis of the U.S. Geological Survey. As used here, the maximum, minimum, and average concentrations of the principal constituents of the 44 ground-water samples from the Dayton area are shown. Also plotted, for comparison, are the averages of daily sampling of the Miami and Mad Rivers in 1946 and 1947 (after Lamar and Schroeder, 1951). This diagram is especially useful for conversion of the various constituents from parts per million to equivalents per million.

Figure 24 is a trilinear diagram devised by Piper (1944) for showing the percentage composition of the principal chemical constituents of natural water. The diagram is an equilateral triangle divided into three fields. The lower left and lower right fields are smaller equilateral triangles, and the central field is diamond shaped. Piper's diagram indicates only the relative concentrations of the principal ions. It represents the cations calcium (Ca), magnesium (Mg), and sodium plus potassium (Na+K); and the anions chloride (Cl), carbonate plus bicarbonate (CO_3+HCO_3) and sulfate (SO_4). The percentage of each of the cations in equivalents per million is plotted at a point in the left triangular field according to conventional trilinear coordinates; the percentage of each of the three anions is plotted in the right triangular field. The two points for each analysis are projected parallel to the sides of the greater triangle, as shown in the small inset of figure 24, into the central diamond-shaped field. The point in

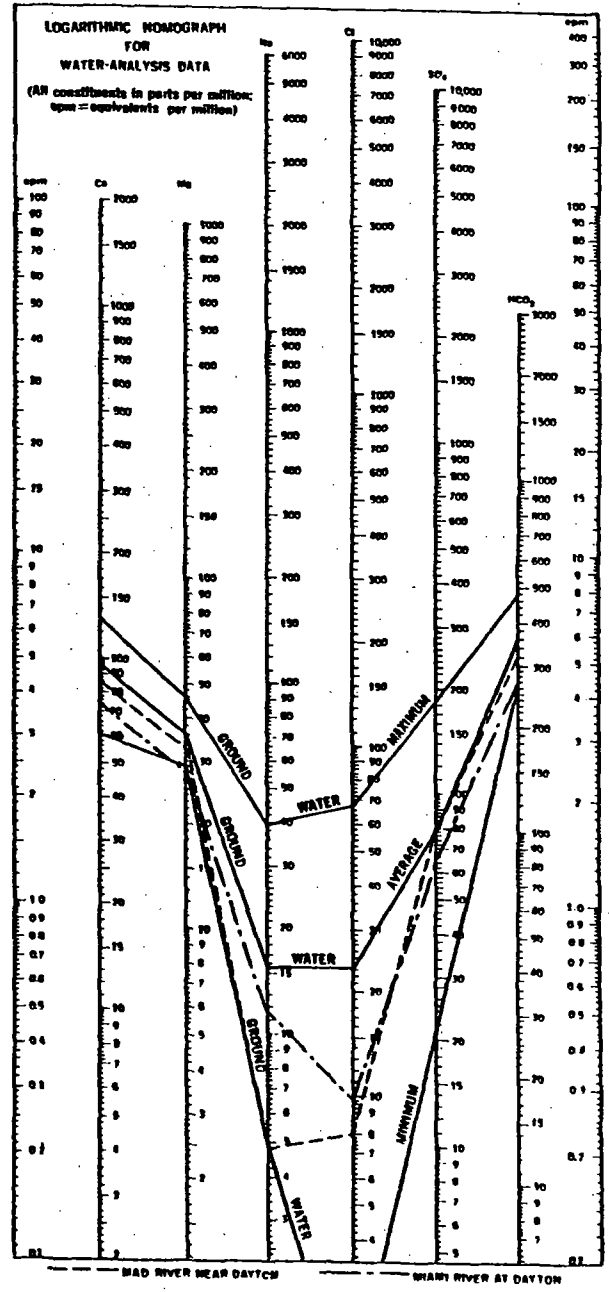

FIGURE 23.—Logarithmic nomograph showing range in concentration of the principal chemical constituents of ground- and surface-water samples from the Dayton area, Ohio.

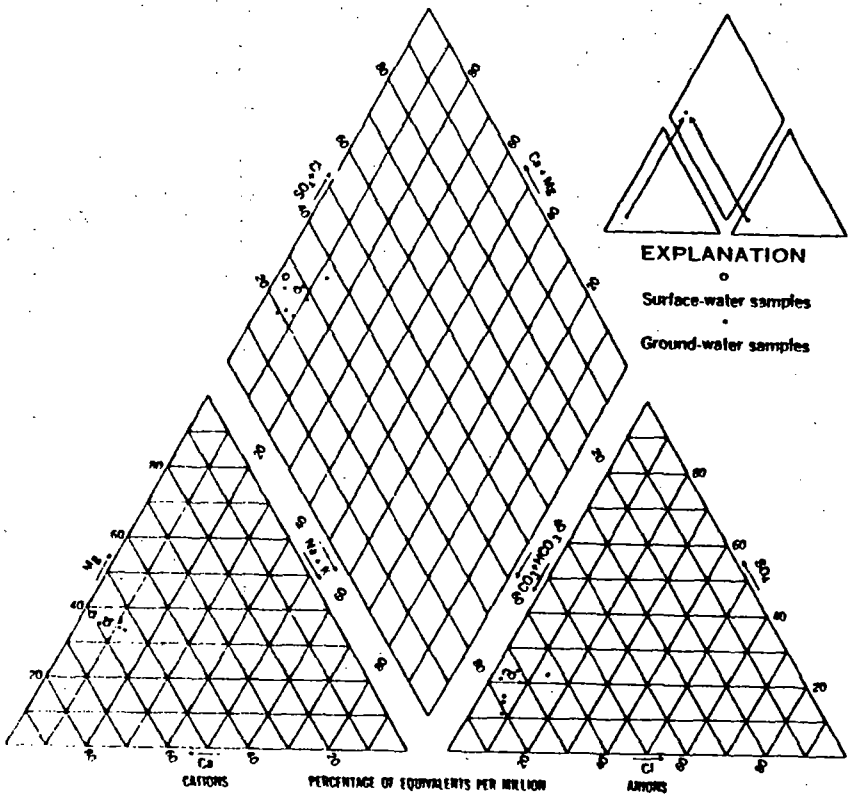

FIGURE 24.—Water-analysis diagram showing relative concentrations of the principal chemical constituents of surface- and ground-water samples from the Dayton area, Ohio. Surface-water samples from Miami River at Dayton and Mad River near Dayton; ground-water samples from wells 14, 311, 418, 598, C-4, C-15, and M-4.

the central field is an index of the chemical composition of the water with respect to the four pairs of ions indicated along the margins of the field.

The analyses of representative ground-water samples from the glacial-outwash aquifers of the Dayton area, plus the averages of analyses of the samples collected daily in 1946–47 from the Miami and Mad Rivers, are plotted in figure 24. It is readily apparent that all these analyses are represented in the same small segment of each of the three fields, indicating that all the waters analyzed are of strikingly similar composition, calcium (Ca) and bicarbonate (HCO_3) being by far the predominant ions. The relative compositions of the ground- and surface-water samples cannot be distinguished on the basis of these diagrams.

SUMMARY

On the basis of 44 samples analyzed, the ground water in all the valley-fill aquifers of the Dayton area is of remarkably similar chemical composition. Calcium and bicarbonate are the most prevalent constituents and cause an expectedly high hardness. All the samples analyzed are hard by most standards. Iron concentrations of 18 samples exceed the U.S. Public Health Service limit of 0.3 ppm for drinking water. Without treatment, such water would be disagreeable to the taste. Many samples contain enough iron to allow the growth of *Crenothrix* bacteria, resulting in a major treatment problem. All the samples analyzed are chemically satisfactory for drinking. The water requires treatment, however, for many industrial applications.

FUTURE GROUND-WATER NEEDS

Estimating future ground-water needs is at best a difficult undertaking, and the results are probably arrived at with more qualifications and more uncertainty than forecasts of most other human needs. Public officials and informed private observers alike anticipate a large increase in water use in the years ahead, resulting from several socioeconomic factors, all of which will affect the Dayton area in varying degree. First there is the natural growth in population. In recent years the rate of population growth has been relatively high, and it will probably continue at a high rate in the foreseeable future. Second, the per capita use of water for domestic purposes has increased even faster than has the population, as automatic washers, showers, and other water-using equipment and practices have become more widespread. The per capita rate of increase in domestic use probably will level off, however, as there appears to be a reasonable limit to the amount of water needed for washing, lawn sprinkling, and other home or personal requirements.

The third most important consideration affecting the use of water in the Dayton area is that of industrial water requirements. Generally, the rate of water use by industry has kept pace with or exceeded the increase in industrial output. However, water-saving methods have been instituted by some plants, and ways have been found to reduce the amount of water used in certain processes. Also, in some instances, water that formerly reached the plant effluent after being used only once is recirculated and used over again, perhaps many times. On the other hand, some plants, especially those making synthetic products and chemicals, now use raw materials of lower grade than formerly and require much more water than they did in the past (Piper, 1953, p. 5). There are no large chemical or synthetic plants

at Dayton, and probably no significant changes in water use relative to plant output have occurred in recent years.

Some plants, for example the Frigidaire Division plant at Moraine City, have begun returning water to the ground on a small scale and there is every likelihood that water-saving methods, reusing of water, and returning of water to the ground will be practiced increasingly by Dayton industries in future years. Despite these conservation measures, however, there is certain to be a large increase in the draft on the aquifers as population and industrial output continue to grow.

The increase in industrial use of water will be much greater than anticipated if large new plants are built at Dayton, or if new products whose manufacture requires additional use of water are developed. Much choice land is still available for industrial expansion. The pool of skilled labor, excellent transportation facilities, and a generally favorable climate for industry make it likely that many new plants will be built here in the next two or three decades. The cost of water may determine and ultimately limit the rate of any further industrial growth.

In his report on the nationwide water situation, Piper (1953, p. 1) wrote:

> In the half century ended with 1950, our National population about doubled but also our per capita withdrawals of water about doubled—roughly from 600 to 1,100 gallons per day. Thus, our total withdrawal increased about fourfold.
>
> * * * * * * *
>
> In inland areas, the unconsumed part of municipal and industrial withdrawals commonly is returned to streams or lakes and so may be reused downstream, perhaps several times. However, these returned waters generally are polluted by organic matter, acids and chemicals, oils, and other wastes—at some places they are grossly polluted. Also, their temperatures may be substantially higher than that of the original source of water. Thus, unless the flow of the receiving stream * * * is sufficiently large for effective dilution, only limited reuse may be possible.

Piper (1953, p. 6) estimated the Nation's 1975 water requirements by projecting water-use figures for 1950 approximately 25 years into the future. He wrote:

> This estimate indeed gives us pause. It foresees a doubled water requirement only 25 years hence; the rate of percentage increase would be the same as that we have experienced in the last half-century. It foresees an industrial water requirement two and a half or three times that of the present; the projection is not discordant with recent trends.
>
> * * * * * * *
>
> What is the end-point water requirement? A reasoned answer seems more remote with every year that passes.

Piper's estimate of a doubling in water use in the 25-year period 1950–75 applies to both surface water and ground water; however, it is not inconsistent with the increase in ground-water withdrawals in

the Dayton area in recent years. In 1950, ground-water pumpage in the Dayton area was about 50 mgd; in 1960, it was about 90 mgd. The tremendous growth of water use predicted by Piper appears to have begun somewhat before 1950 in the Dayton area.

Dr. Jerome P. Pichard of the Urban Land Institute, a private research organization, estimated (The Dayton Daily News, Nov. 18, 1959) that the population of the Dayton metropolitan area, which includes Montgomery and Greene Counties, will be 908,000 in 1980 and 1,343,000 in the year 2000. In 1960 the population of the area was 621,722. Dr. Pichard believes that by the year 2000, Dayton will be one of the major centers in the Great Lakes area, along with Columbus, Indianapolis, Akron, and Louisville.

Not all this million-plus population of the year 2000 will be served by the Dayton and the Montgomery County water systems, but a doubling of the present number of domestic customers served by these systems would seem not unlikely by that time.

Thus, if the per capita use of water for domestic needs continues to increase, at least moderately, in the next several years and if Piper's prediction that the increase in future industrial water requirements will be substantially greater than the increase in the use of water for other purposes is borne out, then estimates of the overall demand for ground water in the Dayton area are impressive indeed. By 1975, only about 15 years hence, ground-water demand will have risen from the 1958 figure of 110 mgd to at least 150 mgd. By the year 2000 no less than 210 mgd will be withdrawn from the valley-fill deposits in the Dayton area. These estimates are probably conservative and take into account the effects of water-conservation measures which probably will become widespread in the next several years. What the demand for water will be a few decades after 2000, say by the middle of the 21st century, cannot even be guessed with reasonable confidence. Of more immediate concern is whether Dayton's water needs in the next 40 years can be met at reasonable cost.

CONCLUSIONS

The Dayton area is richly endowed with ground-water resources. This is attested to by the fact that its pumpage of approximately 110 mgd in 1958 represented about one-fourth of the ground water used in Ohio. The thick and extensive sand and gravel aquifers in the valleys of the Miami and Mad Rivers are recharged by the streams which flow over them and yield ground water in quantities that are limited chiefly by the regimen of streamflow and the rate at which water can infiltrate through the streambeds.

Ground-water withdrawals can be materially increased in the Dayton area. An estimated 200 mgd can be obtained simply by continuing the present methods and geographical pattern of development, even though much of the increased pumpage would be from areas already yielding large supplies. The estimate would be higher, perhaps as much as 225 mgd, if most of the new wells that will be needed in the future could be drilled in presently undeveloped or only moderately developed areas. Such wells should be located close to the source streams and should tap the more permeable parts of the aquifers, preferably where there are no interbedded deposits of till to retard the downward movement of water to the well screens.

New wells will not all be drilled in favorable areas, however, as much land has been, or will be, preempted for uses other than water-supply development. Not all industrial plants are located where geologic and hydrologic factors are most favorable for well development. We can conclude, therefore, that ground-water resources will probably never be developed to the maximum extent possible.

Large though the presently undeveloped ground-water resources may seem, the total quantity of water available is brought into sober perspective by the steeply climbing rate of ground-water demand, which indicates a need for 150 mgd by 1975 and for as much as 210 mgd by the year 2000. This means that unless natural conditions are altered—that is, unless the rate of stream infiltration to the underlying aquifers is artificially increased—the Dayton area could experience a general shortage of ground water in less than 40 years. Widespread shortages are not inevitable, however, as economical methods will no doubt be found to increase the rate of replenishment to the principal aquifers. But such methods are not yet at hand, nor is there promise that they will be developed and applied soon enough to prevent the occurrence of local ground-water shortages.

Dayton's ground-water situation, which will dominate plans for additional water-supply development in the near future, is critical because much of the additional ground water needed in the next few years will of necessity be pumped in hydrologically poor areas, or in areas already extensively developed. The result will be an increasing incidence of acute local water shortages which may, unless a comprehensive plan is evolved, force adoption of piecemeal remedial methods and conservation measures that are likely to be both costly and relatively ineffective. Nowhere is this situation better illustrated than in the central and southern parts of Dayton, where ground-water development generally has reached its practical limits and locally has exceeded these limits.

In this area the Miami River traverses what can be called the industrial and commercial heartland of Dayton. From the confluence of the Mad and Miami Rivers near the Delco and Frigidaire Division plants, the Miami River winds southward through the downtown district with its scores of office buildings, hotels, and department stores, most of which pump large quantities of water for air conditioners; it flows past large industrial plants in the southern part of Dayton, including those of the Delco-Moraine Division and the vast complex of the National Cash Register Co.; thence it winds past the lagoons and beautifully landscaped terrain of National Cash Register's Old River Park, in the bend of a cutoff meander, past nearby Carillon Park with its tower of bells, to leave Dayton in a broad, sweeping meander on which is situated the large Tait Generating Station of the Dayton Power & Light Co.

Ground-water pumpage in this vital area is about 30 mgd, and it has been increasing from the time of earliest records. The hydrographs of observation wells Mt-2, Mt-3, and Mt-6 (pl. 2) show that ground-water levels have generally declined since about 1942, when the record began. The long-term decline has been moderate but persistent. In 1960, an unusually dry year, ground-water levels in wells Mt-2 and Mt-6 were the lowest of record, 2-5 feet lower than in the much publicized drought period of 1953-54.

Although of ominous future portent, the lowering of ground-water levels has not yet caused general concern. Moreover, given a long period of normal streamflow and no more than the expected rate of increase in water use, perhaps a decade or two will pass before low ground-water levels force a general reduction in pumpage. During years of abnormally high streamflow ground-water levels will recover somewhat, as they did in 1957, 1958, and early 1959.

However, as the use of ground water continues to grow in Dayton and the ground-water levels becomes progressively lower, each drought will produce increasingly severe demands on the reservoirs, hastening the time when acute water shortages or remedial measures become inevitable.

There is little doubt, therefore, that if the growth of Dayton in the next few decades is not to be retarded by rising water costs, ways must be found to use the ground-water reservoirs at their optimum perennial yield. Streamflow may have to be regulated and manipulated to take advantage of the increased rates of infiltration that are associated with relatively high flows. Methods of maintaining higher rates of stream infiltration will have to be developed. These may include dredging or harrowing of the bottom materials in some areas, or diversion of flow into specially prepared recharge ponds in other areas—as is done, for example, at Rohrers Island. Stream pollution, a matter that has not been explored in this investigation, will

become of greater concern with each passing year, as a progressively higher percentage of the streamflow is diverted into the underlying aquifers. Not only will pollution abatement be necessary to avoid contamination of wells closest to the source of such pollution, but also a reduction in the amount of chemical and organic wastes may be required to maintain high permeability of the channel bottom. There is evidence that the "bottom seal" that retards stream infiltration in parts of the Miami River channel is composed partly of organic wastes which act principally as a binding or cementing agent in forming a nearly impermeable deposit. Finally, conservation measures will have to be practiced on a large scale. These will include the reusing of water, the returning of water to the ground, and avoidance of local overdevelopment of aquifers.

All this implies that the cost of water in the Dayton area will inevitably go up. This is certainly true, but the cost need not rise to prohibitive levels if methods for the proper management of the ground-water resources are instituted now. With respect to the matter of cost, moreover, water generally will cost more in the future, and the Dayton area will merely be in competition with other areas where large supplies of water are available. Piper (1953, p. 6) wrote: "Thus far, availability of water has been a minor factor in the location of most industries, but [here he quotes Paley and others (1952, v. 5, p. 86)] * * * 'by 1975 water supply may be the most important factor affecting industrial location.' This seems to imply that industry will go to the water. But the distribution and marketing of industrial products is through a pattern of transportation routes and commercial centers long since crystallized."

Piper's observation gives pause to some statements that have been made to the effect that "Dayton has no water problem, as areas can be found within a few miles of present centers of pumping where the aquifers are virtually undeveloped." There are such areas, of course; moreover, some new industries will be attracted to these undeveloped areas, and wells will be drilled in other such areas and the water piped to where it is needed. That these things will have a major effect in mitigating or delaying water shortages in the Dayton area is not to be denied. However, Dayton and its immediate environs, with its well-established power, transportation, and communication facilities, will continue to hold more attraction for most industrial and commercial enterprises than relatively undeveloped areas many miles from the main hub of business activity. Dayton certainly is destined for more industry, and that industry will need water—water from the same sources and from wells in the same general areas from whence are supplied the present industrial and municipal requirements.

Special studies and the continuing collection of hydrologic data will insure proper water management and effective conservation measures. The studies should be directed specifically towards determining more about the mechanics of stream infiltration. Recharge rates should be accurately determined over a wide range of stream discharge, and the relationship between various rates of recharge and specific flows in the streams, sediment load, and other factors should be established. Areas most favorable for high rates of stream infiltration should be closely defined, and the effects on infiltration of any differences that might exist from place to place in the character of the sediments that make up the bottom of the channels should be determined. These facts are requisite to the design and proper management of structures that eventually may be deemed necessary to control and regulate streamflow for the purpose of increasing the rate of infiltration, or to determine the best places and methods for dredging or harrowing the streambed. They are likewise needed in the selection of areas for future ground-water development, and for the instituting of proper water-conservation measures. Special studies of the type needed would involve initially the installation of numerous observation wells in the upper aquifer, establishment of one or more additional gaging stations, and a program of water-quality and suspended-sediment study. Techniques and methods of interpretation will of necessity be evolved from the character of the data that are collected.

Additional geologic data also should be collected in the Dayton area if the best use is to be made of detailed knowledge that should become available on the mechanics of stream infiltration. Despite the large number of drillers' records of wells in the Dayton area, much still needs to be learned of the precise character of the aquifers and especially of the extent, continuity, and hydraulic properties of the till-rich zone. Additional electric logs and depth-to-bedrock data would be especially useful to the geologist.

Although generally not a limiting factor in the availability of ground water, the hydraulic properties of the till-rich zone are locally considered in setting pumping rates, and determination of the effectiveness of artificial recharging operations will depend on knowledge of these properties. For example, the till-rich zone controls the amount of water available from the lower aquifer at Rohrers Island, and it probably will be a determining factor in the selection of recharging methods to be used at the new municipal well field in the Miami River Valley north of Dayton. Therefore, future test drilling and pumping tests should be conducted in the Dayton area to ascertain the character of the till-rich zone wherever possible.

Proper management of Dayton's ground-water reservoirs must inevitably involve the cooperation and support of business and community leaders. This support must be based on an understanding of the basic hydrologic and geologic factors which are responsible for Dayton's ground-water resources, and the recognition that these resources can no longer be considered "inexhaustible." The success of water management can be assured only if business leaders, public officials, and the general public are kept adequately informed of the status of the ground-water supply by intelligent and unbiased investigations and research, including records of water levels in wells, changes in chemical quality of the ground water, trends in water use, and other pertinent data. Until severe water shortages are experienced, it may not be easy to acquaint people with the need to conserve and wisely use Dayton's ground-water resources; however, an informed public might postpone, or defer indefinitely, acute shortages and destructive competition on the part of water users, which would be damaging to the orderly growth of the Dayton area and to the prosperity of its citizens.

RECORDS OF WELLS IN THE DAYTON AREA

[For more well data, see pl. 9—"Graphic Logs of Wells in the Dayton Area"]

Well: See text for well-numbering system.
Character of aquifer material: Sand and gravel, except in well 604—till.
Geologic horizon of aquifer: Pleistocene.
Type of well: Drilled, except as shown under "Remarks."

Type of pump: C, centrifugal; J, jet; S, submersible; T, turbine.
Use: AC, air conditioning; D, domestic; Ind, industrial; Irr, irrigation; O, observation; PS, public supply; R, return; S, sanitary; T, test.

PRIVATELY OWNED WELLS

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level		Yield		Type of pump	Diameter of well (in.)	Use	Remarks
					Depth (ft)	Date	Rate (gpm)	Drawdown (ft)				
	Central district											
1	Biltmore Hotel	740	4-51	100			550		T	10	AC	Not currently used.
2	do	742	4-51	80	38.5	4-13-55			None	10	R	
3	Ice Cream Div., Borden Co.	740		120	44.42	6-13-55	600	27	T	12	Ind	
4	Milk Div., Borden Co.	739	2-42	110	35.74	5- 4-55	100		T	8	Ind	Do.
5	do	739		80-90					T	10	Ind	
6	CIO Local 801 Hall	740	4-49	160	28	4- -49	120	30	T	6	AC	
7	do	740	4-49	91	40.5	11-20-57	120	30	None	6	R	
8	Dayton Coca Cola Bottling Co.	740		173	40	4- -53	800	23	T	12	Ind	
9	Columbia Theater	745	4-49	85	57	4- -49	180	8	T	6	AC	
10	Commercial Bldg.	740	1937	130					T	8	AC	
11	do	740	1950	146					T	10	AC	
12	Crystal Laundry	741	1927	28	18.24	5- 5-55			T	8	Ind	Well not used since 1955.
13	Dayton Power and Light Co., 3rd St. Sta.	738	1936	152	36.90	2- 1-39			T	18	Ind	
14	do	738	7-45	146	40	3- 3-55	1,000		T	30	Ind	
15	do	738		130					T	8		
16	do	738		100						8		
17	do	738		70						8		
18	do	738		121						8		
19	do	738		155						8		
20	do	738		150						8		
21	do	738		137						8		
22	Dayton Power and Light Co., 4th St. Sta.	740	7-45	143	37.43	3- 3-55	85		T	8	Ind	
23	Dayton Power and Light Co., Longworth St. Sta.	738.2	5-53	140	41	3- 3-55	2,000	6	T	20	Ind	Gravel packed.
24	do	734.83	7-40	135	38.5	3- 3-55	1,500	2-3	T	16	Ind	
25	do	737.5	1-30	87	33	3- 3-55	875	31	None	18	Ind	Abandoned.
26	do	736	4-53	172	39						T	

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
	Central district—Continued											
27	Dayton Power and Light Co., Gas & Electric Bldg., 25 N. Main St.	740	1918	65	38.4	3- 4-55	170		T	8	Ind	
28	Delco Products Div., General Motors Corp.	740	3-14	125					T	8	Ind	
29	do	740	3-16	105					T	8	Ind	
30	do	740	1916	144					T	8	Ind	
31	do	740	7-34	144	35		440	6.75	T	10	Ind	
32	do	740	10-39	118	36	10- -39			T	12	Ind	
33	do	740	7-46	151	44	7- -46			T	14	Ind	
34	do	740	11-47	150	47	9-27-47		5	T	16	Ind	
35	do	740	9-47	200							T	
36	Donenfeld's Inc	740	4-38				125		T		SAC	
37	Elder & Johnston Co	740	1913	87	28.66	3- -53	300		T	8	AC	
38	do	745	4-41	186	38.11	4-15-55	700	13	T	12	AC	
39	Fidelity Bldg	740	1919	82	35.29	4-12-55			None	8		Abandoned
40	Fraternal Order of Eagles	740	1947	147			75		T	10	AC	
41	do	740	9-56	153	43	9- -56		20	T	8	AC	
42	Frigidaire Div., General Motors Corp.	740	10-50	193					T	12	AC	
43	do	740	10-50	181	21	2-19-51		20	T	12	AC	
44	do	740	7-55	175	38	7-10-55	1,200	10	T	16	Ind	Fire-protection wells.
45	Gibbons Hotel	740	1902	60					T	10	S	
46	do	740	1947	120					T	8	S	
47	Gondert & Lienesch, Inc	740	1928	70	40.89	5-12-55	150		T	6	Ind	
48	Home Store	740	5-50	140	25	5- -50	200	20	T	10	SAC	
49	Hulman Bldg	740	1932	125				9	T	16	AC	
50	King Cole Restaurant	740	9-53	152	33	6- 1-52	200		T	10	SAC	
51	do	740	1953	78					None	8	R	
52	Knott Bldg	740	1903						P		SAC	
53	Loew's Theater	740	1947	115			250		T	10	AC	
54	Loew Bldg	740	1937						T		AC	
55	McCrory's 5¢ & 10¢ Store	740	1937						T		AC	
56	Metropolitan Clothing Co	740	1940	80-90			150		T		AC	
57	Miami Hotel	740	1915	80			400		T	8	AC	
58	do	740	1915	80	38.16	4-28-55			T	8	AC	No longer used.
59	Miller Bldgs	740	1956	110			400		S	10	AC	
60	do	740	7-56	68			40		S	6	AC	
61	Miami Valley Milk Producers Association.	740	1923	126			90		T	6	Ind	
62	do	755	8-50	152	37	5- 5-55	350	5	T	10	Ind	
63	Model Laundry	740	1938	87			82		T	8	Ind	
64	Moraine Hotel	740	1920	125					C		S	Out of service.
65	Neal's Dairy	740		72	55.44	6-27-55				8	Ind	Abandoned.
66	do	740	8-54	177	60	7- -54	400	10	T	8	Ind	
67	Ohio Bell Telephone Co	740	5-41	80			125		T	8	AC	
68	do	740	2-57	111	34	2-20-57	450	15	T	10	AC	
69	do	740	3-58	115	39	3-15-58	900	45	T	10	AC	
70	Otterbein Press	740	1913	75	32.80	4-22-55	85		T	10	Ind	
71	Rialto Theater	740	1948	80-90			80		T	6	AC	
72	Rossiters-Jarrett-Harman Co	740	1948	165	42.34	4-21-55	100		T	8	AC	
73	do	740	1948	166					None	8	R	
74	Rike-Kumler Co	740	1911	55			300		T	8	SAC	
75	do	740	8-34	166	37.28	3-17-55	1,360		T	12	SAC	
76	do	740	4-50	130			1,600		T	12	SAC	
77	Sears Roebuck & Co	742	10-46	148	39	11-22-57	700	15	T	12	AC	
78	Stanley Greetings, Inc	740	1912	170	43.40	5- 3-55			T	10	Ind	
79	Talbot Bldg	740	1937						T		AC	
80	Terminal Cold Storage Co	740	1935	90	27.92	3-16-55	400		T	8	Ind	
81	do	740	1937	90	31.41	3-16-55	400		T	15	Ind	
82	Third National Bank	740	1934	160			400		T	12	AC	
83	Westminster Church	740		59	15	3- -50	175	10	T	8	AC	
	East district											
101	Acme Precision Products	750	1941		13.29	6-29-54	250		T	6	Ind	
102	Baltimore & Ohio RR	750	1924	90	15.21	3-28-55	290	9	T	18	S	
103	J. J. Boeckman Co	754	1946	105			55		T	6	Ind	
104	Van Dyne-Crotty, Inc	749	1940	65			85		T	5		No longer used.
105	B. G. Danis Co	749	7-48	37	25	7- -48	100	0	J	6	AC	
106	Dayton Packing Co	754	1930	92			6.66		J	6	Ind	Abandoned.
107	do	754	7-55	101	17	7- -55	20	50	S	6	Ind	
108	Duriron Co., Inc	750	1920	135	11.24	5-12-55			None	6		Do.
109	Farm Bureau Co-op Association chemical plant.	745	1905	110	10	1953	100		T	10	Ind	
110	do	745	1919	76	14				T	8	Ind	
111	Focke Packing Co	760	1928	50					None	8		Not used.
112	do	760	2-52	33					None	8		Abandoned.
113	do	760	3-53	56	25	3- -53	150		T	8	Ind	
114	do	760	3-55	60	36	11-22-57			T	8	Ind	
115	Globe Laundry	766	1914	80					None	8		Driven. Abandoned.
116	do	766	1914	130	15.50	7- 7-55			T	8	Ind	
117	Hewitt Soap Co	768	1931	87	19.44	5-10-55			None	6		Abandoned.
118	do	768	1931	63	20.88	5-10-55			None	5		Do.
119	do	768	1940	120	24.37				None	8		Do.
120	do	770	12-43	87			300	6.35	T	8	Ind	
121	Willis Martin	765	1-55	147	32	1- 8-55	15		J	8	D	
122	Master Electric Co	770	7-36	56	33	6- -35	500		T	10	Ind	

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
	East district—Continued											
123	Morart-Oxford Co.	760	12-56	36	13	12-20-56	10		J	6	Ind	Drilled to 85 ft, casing pulled back to 36 ft.
124	W. E. Scott	925	9-54	101	73	9-17-54	6	1	J	6	D	
125	Henry Sheets	770	10-54	78	24	10-24-54			J	6	D	
126	Sheffield Corp.	750	1941	73					T	8	Ind	
127	Wagner & Wagner, Inc.	815	10-56	82	40	4- 2-57	5		J	6	Ind	
128	White Clover Dairy	748	1935	65			65		T	6	Ind	
129	C. L. Wolfe	825	11-54	73	48	11- 8-54	20			6	D	
	North district											
201	Adam Ballman's Sons	770	2-52	60	18	2-23-52	40	1		6	S	
202	Air City Fuel Co.	750	12-52	40	18	12- 9-52	50	4	SW	6	Ind	
203	Baltimore & Ohio RR	757	4-53	49	30	4- -53	20	3	J	6	S	
204	do	754		50	16.84	3-28-55			J	6	S	
205	Bluebird Baking Co.	745	1946	179	15.8	12-12-57			T	12	Ind	Drilled to bedrock (270 ft); casing pulled back to 179 ft.
206	Burdette Oxygen Co.	738	1951	142	35	4- -51	200	10	T	10	Ind	
207	do	760	1953	110					None		Ind	Abandoned.
208	do	760	1953	220					T		Ind	
209	Richard Clippen	780	7-53	78	46		20	5	Hand	6	D	
210	Chrysler Airtemp Sales Corp.	750	1938	90	23	3-14-55	500	11	T	10	Ind	
211	do	752		52	18.54	3-14-55	500		T		Ind	
212	do	750	1947	137	16	1- 8-58	1,000		T	16	Ind	
213	Dayton Castings Co.	741	8-57	76	13	8-31-57			None	8	Ind	Neither well used as of 1958.
214	do	741	8-57	39	13	8-31-57			None	8	Ind	Return well.
215	Dayton Power & Light Co.	750	9-41	80	10.5	9- -41	30		T	6	S	
216	Dayton Rust Proof Co.	760	1900	53	33	1954	60		T	6	Ind	
217	do	760	6-47	141	26	1947	200		T	8	Ind	
218	East Dayton Tool & Die Co.	741	1938	46	38	5- -54	125		T	6	Ind	
219	Economy Linen & Towel Co.	736	1935	26							Ind	
220	GHR Foundry	740	11-44	70			230		T	12	Ind	
221	do	740	2-47	70			230		T	12	Ind	
222	do	740	1957						T	12	Ind	
223	Golden Age—Dayton Corp.	742	6-56	79	10	6- -56	500	20	T	12	Ind	
224	Grocers Co-op Dairy	752	1949	87	72	9- -48	500		T	8	Ind	Well no longer used.
225	James Keen	778	12-48	96	31	12- 6-48	20	0		5	D	
226	Keystone Sand & Gravel Co.	765	8-43	60	24.28	3-28-58			T	28	Ind	
227	Mad River Township School	780.24		145	44	4- 8-58			None	6	0	Drilled for use during construction.
228	do	780	7-56	122	47	7-31-56			T	8	S	
229	W. C. Martin	754		60					None	4	0	
230	McCook Bowling Co.	741	1941				80		T	8	AC	All water returned in return well.
231	D. W. Mikesell Co.	742	6-55	76	14	1-16-56	400	10	T	8	Ind	
232	Molen Dairy	760	1930	65			75		T	8	Ind	
233	Wm. H. Olson	770	4-54	81					J	6	D	
234	Charles Piffler	780	6-55	77	31	6-19-55	28	9	S	6	D	
235	Polish-American Democrat Club	750	6-54	62	8	6- 7-54	20	5	J	6	S	
236	Premier Rubber Co.	750	9-45	119	14	9- -45	1,000	19	T	10	Ind	
237	Price Bros.	745	11-56	79	12.7	11-17-56			J	6	Ind	
238	Mary Radvansky	770	12-56	60	33	12- 5-56	15	0	J	6	D	Stock.
239	Shell Oil Co.	760	4-49	63	50	4-23-49	300	10	J	8	Ind	
240	Sinclair Refining Co.	760	10-40	61	24	10- 4-48	100	10	J	6	Ind	
241	Ray Smart	758	9-54	89	34	9- 6-54	16.6	5	J	6	D	
242	Stelle Corp.	745	12-52	75	14.5	12- -52	100	0	T	8	Ind	
243	Ti Dee Products	760	5-57	106	21	5-17-57	20	5	SW	6	D	
244	Univis Lens Co.	742	1939	150					T		Ind	
245	L. A. Walprom	750		38						4	D	
246	Floyd Walker	750	10-54	57	16	10- 4-54	30	3		6	D	
247	Mrs. Heill	750	2-53	44	20					4	D	
248	Frank Miller	740	8-53	35	28	8-24-53	6.5	20		5	D	
249	Carl Hale	775	1-53	34	15	1-24-53	42			6	D	
250	Vergil Evans	775	7-48	41	29	7-27-48	30	1		6	D	
	West district											
301	Aetna Paper Co.	740	11-41	134					T	12	Ind	
302	do	740	3-45	148	46.5	1-15-58			T	12	Ind	
303	do	740	5-41	133	47	3-23-55			T	12	Ind	
304	do	740	1957	133	45	1-15-48			T	16	Ind	Fire protection only.
305	City Products Corp.	745	1928	96	36.5		200		T	10	Ind	
306	do	745	1928	96	20	1- -50	200		T	8	Ind	
307	Davies-Young Soap Co.	744	9-48	120			250		T	10	Ind	
308	Wolf Creek Soap Co.	760	1915	90			50			4	Ind	Piston.
309	do	761		35	18.80	6-14-54			None	2	S	Driven. Abandoned.
310	do	761		26	14.36				None	4	Ind	
311	Dayton Rubber Co.	753	1-44	198			1,000		T	16	Ind	
312	do	755	2-55	184	40	2- -55	1,000	25	T	16	Ind	
313	do	753	12-47	195	52	3-22-55	2,000	43	T	16	Ind	
314	Dayton Steel Foundry Co.	742	3-55	140	45	8- -55	1,000	20	T	12	Ind	
315	do	742	1-52	67	32	1- -52	430		T	18	Ind	
316	Faul's Motor Sales	730	1955		33.40	5-18-55			None			Not yet used.
317	Gem City Ice Cream Co.	742	5-42	137	33.60	4- 8-55	250		T	8	Ind	
318	do	742	3-45	135			350		T	10	Ind	

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
	West district—Continued											
319	Himes Bros. Dairy	755	1929	180	72.8	1-29-58			None	8		Not used.
320	do	755	2-46	160			350		T	10	Ind	
321	do	755	10-53	227	78	10- -53	1,000	20	T	12	Ind	
322	Dairy Div., Kroger Co	740	1945	82	46.30	7- 1-55	300	20	None	10	Ind	Abandoned.
323	do	741	1932	51	45.94	7- 1-55			None	12	Ind	Do.
324	do	741	3-46	136	45	3- -56			T	12	Ind	
325	Kuhns Bros. Foundry	752	1944	120	60.90	3-15-55	100		T	10	Ind	
326	Kurz Kasch, Inc	740	1936		41.27	3-14-58			T	10		Do.
327	Lau Blower Co	760	5-56	151	58	7- -56	500	80	T	12	Ind	
328	McCall Corp	758	1938	125	45	5- 6-55	500		T	12	Ind	Discontinued pumping in 1946.
329	do	755	10-51	195	52				None	6	T	
330	do	755	10-51	163	53				None	6	T	
331	do	755	11-51	169	53				None	6	T	
332	do	755	11-51	142	50				None	6	T	
333	do	755	11-51	155	54				None	6	T	
334	Monsanto Chemical Co	740	1944	126	38.44	1-21-58			None	10	R	
335	do	740	1942	128	31	1944	500	48.5	T	12	AC	
336	do	740	1942	120	40.27	6-21-55	300		T	12	AC	
337	do	740	1942	125					None	10	R	
338	Delco-Moraine Div., General Motors Corp.	742	7-48	203					T	14	Ind	
339	do	740	1950	200	46	1-14-58			T	14	Ind	
340	do	736	1953	191					T	20	Ind	Test well here 200 ft deep.
341	do		10-55	158	42	10-12-56			T	20	Ind	
342	do	736	4-53	208						8	T	
343	National Foundry & Furnace Co	737	1935	90	43.20	6-16-55			T		Ind	
344	do	737	1957		42.5	1-29-58			T		Ind	
345	Simonds-Worden-White	741	1935	43					T	8	Ind	Dug. Abandoned.
346	do	741	1950	93					T	8	Ind	
347	Specialty Paper Co	742	1938	148	57	1-23-58	300		T	12	Ind	
348	Standard Register Co	740	1937	129	48	1934	200		T	8	AC	
349	Sucher Packing Co	755	1920	132			425		T	12	Ind	
350	do	755	1920	140			250		T	12		Abandoned.
351	do	748	10-53	39					None	12		Capped, never used.
352	do	752	8-54	146	36.5	8- -54	225	70	T	12	Ind	
353	do	750	10-54	147					None	8		Never used.
354	do	750	6-55	208					T	10		Not yet used.
355	do	748	10-53	206					None	6	T	
356	do	745	3-54	208					None	6	T	
357	do	750	3-55						None	6	T	
358	Sunshine Biscuits, Inc	741		116	24.75	9-27-46	400	93	T	12	Ind	
359	do	741	4-46	108	24.75	9-27-46	715	83	T	12	Ind	
360	do	741	4-46	116	41		896	11	T	12	Ind	
361	do	741		75	31.75	9-27-46			T	12	Ind	
362	do	741		76	46.12	11- 6-57			None	12	O	
	South Park district											
401	Heidelberg Cafe		6-48	75	48	6- -48			J	6	S	
402	Miami Maid Bakery	740		110	38	1-16-58			None	6		Abandoned.
403	National Cash Register Co	742	6-44	144	34.68	9- -50	1,200	66	T	16	Ind	
404	do	760	1943								T	
405	do	760	12-43	140							T	
406	do	740	9-41								T	
407	do	748	3-42	147	51.24	9- -50	200	41	T	16	Ind	
408	do	736.27	4-39	132	45.27	9- -50	1,100	50	T	12	Ind	
409	do	715.75	12-38	96	25.25	9- -50	800	15	T	36	Ind	
410	do	733.5	12-38	122	43.52	9- -50	800	48	T	12	Ind	
411	do	746	7-37		65	7- -37					T	
412	do	748	6-37	57			250	5	T	18	Ind	Not used. Capped.
413	do	730.68	4-37	53	37.98	3- -54	450	7	T		Ind	
414	do	756	12-29	76			700	8	T	18	Ind	
415	do	757	6-37	92	74	8-15-37				6	T	
416	do	744	1911	101							T	
417	do	749	3-49	181						6	T	
418	do	746	3-51	149	48.8		1,800		T	18	Ind	
419	do	753	4-56	141	56.8	4- -56	100			10	T	
420	do	733.13	7-48	167	45.13	9- -50	1,900	33	T	18	Ind	
421	Univ. of Dayton		1900	16	12.8	7- 5-55			None	10	S	Dug. No longer used.
	Moraine district											
501	Air Reduction Sales Co	730	1943	120	40.65	3-18-55	450		T	12	Ind	
502	Gene W. Baker	712	10-54	92	19	10-10-54	33	2	J	6	D	
503	Webster Baker	728	1955	80	40	1- -55			J	6	D	
504	Eugene Betz	835	12-54	220	158	12-20-54	20	10	J	6	D	
505	Calvary Cemetery	790	1916	130	105	3-26-57				4	Lr	Dug to 70 ft, remainder drilled. Piston.
506	Carillon Cafeteria	840	1955	210	155	1955			S	6	S	

727-016 O—66——11

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
	Moraine district—Continued											
507	Carillon Cafeteria	840		164	163				S	6	S	
508	Central Ready Mix Co	725	6-55	68	28	6-13-55	20	7	J	6	Ind	
509	City of Dayton, Miami View Golf Course	722	4-53	122	16		200	17	T	8	Irr	
510	do	722		52	32	3-28-57			None	6		Not used.
511	A. B. Compton	832	10-53	180	147	10-31-53	10		S	6	D	
512	Forest Cooper	710	1935	38	24	4- 2-57			J	2	D	Driven.
513	Myron-Cornish Co	745	2-53	78	34.5	2-14-53	10	5	J	6	D	
514	James Countryman	712	7-54	85	25	7- 1-54	20	0	J	6	D	
515	Crume Brick Co	760	2-54	120	55	2- 5-54	30	5	T	6	Ind	
516	H. G. Darroch	730	1949	38	Flows	2-28-57			None	6	D	Stock.
517	do	730		35	Flows	2-28-57			None	38	D	Dug and driven. Stock.
518	Dayton Power & Light Co., Service Bldg	745	5-55	70	35	5-27-55	20	50	S	6	S	Drilled for use during construction.
519	do	745	7-56	138	30	7-20-56	1,000	10	T	14	AC	
520	Dayton Power & Light Co., Moraine Substa	720	4-51	59	27	4-21-51	50	20	J	6	S	
521	Dayton Power & Light Co., Frank M. Tait Sta	725	9-36	65			700	13	T	18	Ind	
522	do	740		95	28	3-27-51	1,000	15	T	26	Ind	
523	do	733.5		70	24.5	3-17-48	600	10	T	26	Ind	
524	do	735		155	23	3- 5-56	3,000	10	T	20	Ind	
525	do	740		117	28	8- 8-49	1,000	12	T	26	Ind	
526	do	735	11-28	65	20		800	5	None	18		Abandoned.
527	do	735	9-39	95	32		2,200	17.6	None	16		Do.
528	do	745	9-41	117	30		1,200	32.5	None	18		Do.
529	do	735	9-43	118	43		1,500	47.5	T	18		
530	do	730		194	33.8	11- 8-55			None	2	O	120 ft of 2-in. pipe in rotary test hole.
531	do	727		209	30.3	11- 3-55			None	2	O	Do.
532	Everett Evans	720	10-55	74	36	10-14-55	15	0	J	6	D	
533	O. A. Everetts	720	8-54	49	17	8- 7-54	20	0	J	6	D	Stock.
534	Film Associates	730	7-56	110	35	7-16-56	50	2	S	6	S	
535	Frigidaire Div., General Motors Corp.	728.5	1937	120	26	1-18-37	1,000		T	12	Ind	
536	do	730.3	1942	122	24.8	5-20-49	800		T	16	Ind	Not used.
537	do	729	1-45	112	27	1945	1,200		T	16		Abandoned.
538	do	728.4	7-46	122	23	7-19-46	1,200	7	T	20	Ind	
539	do	728.7	5-46	118	37.8		1,000	29	T	20	Ind	
540	do	733.8	6-46	118	26	6-13-46	1,500	7.25	T	20	Ind	
541	do	731.5	11-49	111	27	11-12-49	1,200	10	T	20	Ind	
542	do	735	10-50	108	31	10-27-50	1,200	5	T	20	Ind	
543	do	729.79	1-24	113	47.75	8-17-54	460		T	8	Ind	
544	do	729.67	4-54	115	47	9- 9-54	960		T	14	Ind	Do.
545	do	729.95	12-47	120	40	12- -47	1,000		T	18	Ind	
546	do	739.77	4-51	174	40	5-22-52	1,785	10.5	T	20	Ind	
547	do	740.06	9-51	122	34	9- 6-51	1,200	8	T	20	Ind	
548	do	734.62	4-51	114	30	4-17-51	1,760	10	T	20	Ind	
549	do	734.62	1951	130							T	
550	do	741.27	3-52	135	36	3-16-52	1,200	12	T	20	Ind	
551	do	737.4	9-53		43	8-19-53	1,830	13	T	20	Ind	
552	do	737.4	6-53	145	43	6-12-53				8	T	
553	do	729.79	7-53	125	37.93	12-18-57	1,200	8	T	20	Ind	
554	do	729.8	6-53	130	35	6-12-53					T	
555	do	729.37	6-55	131	33	8-12-55	1,600	19	T	20	Ind	
556	do	729.37	8-55	135	43	8-17-55	1,200	10	T	16	Ind	
557	do	729.37	7-55	205							T	
558	do	735	12-55	123	45	12-22-55	1,200	10	T	16	Ind	
559	do	735	12-55	190							T	
560	do	729.79	10-55	115	36	10-10-55	1,000	10	T	16	Ind	
561	do	727.79	10-55	189							T	
562	do	732.21	12-55	97	45.75	12- -54	200		None	20	R	
563	do	724.86		115					None	8	O	Observation well.
564	Clay P. Garrison	750	1954	80	60	3-27-57			S	4	D	
565	Gem Machine Co	735	1-52	32	25	1- 1-52	8.3	0	J	6	Ind	
566	James Grey	735	10-56	60	20	10-15-56	3	50	J	10	D	
567	Gulf Refining Co	825	8-48	134	117	8-26-48	20	0		5	S	Abandoned.
568	Theodore Gutwein	755	1953	44	Flows	Fall-55			None	4	D	
569	Albert Hensley	740		42	32.43	6-29-55			Hand	5	D	
570	Richard Hochnalt	725	9-54	76	35	9-10-54	15	2	J	6	D	
571	G. Lyle Holden	715	1954	85	31	3-20-57			J	6	D	
572	Dallas Howell	710	12-55	44			30		J	6	D	
573	Jackson Sand & Gravel Co	745		65	41.75	4-10-56			J	6	Ind	
574	George Johnson	720	8-54	46	28	8-16-54			J	6	D	
575	Miss Kling	865	5-56	247	177	5-28-56	10	20	S	6	D	
576	Kocolene Service Sta	750	11-55	90	60	11-18-55	6		J	6	S	
577	Morris Matusoff	730	11-54	95	42				J	6	S	
578	Mrs. Edward McGinnis	815	1951	160	107	1951	75	0	S	6	D	
579	Miami Shores School	720	12-56	100	32	12-19-56	125	0	T	10	S	
580	Moraine Box Co	744	1927	60					T	6	Ind	
581	Moraine Country Club	818	1937	135	128.5	2-20-57			T	8	Irr	
582	National Cash Register Co. Golf Course.	763.57	1952	74	58	4-22-53	32		None	10		Do.
583	do	757	1952	74	41.5	Spring-52	400	1.4	None	10		Do.
584	do	726.75	8-54	111	28	8-25-54	340		T	10	Irr	
585	do	726.82	9-54	110	30	9-20-54	340		T	10	Irr	
586	Red Horse Tourist Court	730	8-53	100	35-40	8-21-53			J	6	S	
587	Bradley Rice	715	8-54	88	35		8		J	5	D	
588	Delbert Roberts	720	1-54	44	18	1-18-54			J	6	D	

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
	Moraine district—Continued											
589	A. E. Shively	860	7-54	264	185	7-20-54	20	10	S	6	D	
590	Siebenthaler Co.	738		51	21	3- -37			T	6	Irr	
591	do	725	3-55	94	31	3-26-55	800	4	T	10	Irr	
592	Harold H. Singer	725	2-56	54	29	2-11-56	17		J	6	D	
593	M. G. Snyder & Son Co.	820	1948	125					None	6	Ind	Not used.
594	do	810	1947	150					T	8	Ind	
595	do	815	1954	159	114	1954	870	13	T	12	Ind	
596	South Dayton Motel	760	1954	72	60	1954			T	8	S	
597	Southern Hills Pit, Inc.	710	11-54	91	22.5	11- 3-54	1,500		T	16	Ind	
598	Frank M. Tait	842		172	157	4- 9-57			T	10	Irr	
599	do	842		209	154	4- 9-57			S	8	Irr	Domestic.
600	Paul Waitkus	735		65	42	2-19-57			J	6	D	
601	W. R. Wood	725	8-54	66	28	8- 9-54	24	0	J	6	D	
602	John Roach	720	8-54	53	30	8-12-54			J	6	D	
603	Frank Smith	720	5-54	42	32	5- 4-54			J	6	D	
604	Russel Casson	825	1956	84	50	1956			J	6	D	
605	Dayton Brick Co.	750	1942	69	37.99	3-13-58			S	6	Ind	
606	Dayton Community Golf Course	840		170					T	8	PS	Irrigation.
607	Dayton Power & Light Co., Frank M. Tait Sta.	735		209					None	8	T	
608	Unknown	730			28	4-11-58			None	24	Ind	Abandoned.
	PUBIC-SUPPLY WELLS											
C-1	City of Dayton	763	4-49	152	59	1- -53	2,000	11	T	26	PS	
C-2	do	762	12-49	149	55	1- -53	2,000	14	T	26	PS	
C-3	do	772	6-49	137	55	1- -53	2,000	12	T	26	PS	
C-4	do	768	4-51	148	44	1- -53	2,000	26	T	26	PS	
C-5	do	773	4-51	135	15		2,000	32	T	26	PS	
C-6	do	774	5-51	136	50	1953	2,000	27	T	26	PS	
C-10	do	768	1926	75			1,760	24	T	38	PS	40-ft screen.
C-11	do	773	1926	77					T	38	PS	35-ft screen.
C-12	do	772		54			1,600	12	T	26	PS	
C-13	do	770	1930				1,160	4	T		PS	20-ft screen.
C-14	do	770	1931	74			2,860	6.5	T	26	PS	40-ft screen.
C-15	do	770	1931	85			2,950	17	T	30	PS	30-ft screen.
C-16	do	774	1931	65			2,219	17	T	26	PS	Do.
C-18	do	775		61	21				T	38	PS	
C-19	do	772	1939	79					T	36	PS	15-ft screen.
C-20	do	773	1939	78			3,500	16	T	30	PS	25-ft screen.
C-21	do	773	1941	68			1,729	12	T	26	PS	16-ft screen.
C-22	do	775	1941	73			1,526	21	T	26	PS	15-ft screen.
C-23	do	775	1941	83			1,637	41.5	T	26	PS	22-ft screen.
C-24	do	775	1941	64			838	24	T	26	PS	11-ft screen.
C-25	do	772	1941	70			2,010	27	T	26	PS	16-ft screen.
C-26	do	775	1941	75			1,568	10	T	26	PS	22-ft screen.
C-27	do	775	1941	69			1,253		T	26	PS	16-ft screen.
C-28	do	775	1941	76			1,779	24.5	T	26	PS	Do.
C-29	do	773	1941	90			4,556	24	T	26	PS	27-ft screen.
C-30	do	770	1941	98			4,341	25	T	26	PS	32-ft screen.
C-31	do	770	1941	73			2,239	10.5	T	26	PS	16-ft screen.
C-32	do	777	1942	165	40	3-18-58	2,159	32.5	T	17.5	PS	33-ft screen.
C-33	do	775	1942	157			2,565	24	T	17.5	PS	29-ft screen.
C-34	do	772	1942	161			2,565	19	T	17.5	PS	25-ft screen.
C-35	do	775	1942	154			2,239	34.5	T	17.5	PS	29-ft screen.
C-36	do	772	1949	58	28	1949	1,421	17	T	26	PS	
C-37	do	775		66	15	1949	2,564	20	T	26	PS	
C-38	do	775	1949	62	11	1949	2,118	19	T	26	PS	
C-39	do	775	1949	67	15	1949	2,010	32	T	26	PS	
C-40	do	774	1949	65	14	1949	2,632	15	T	26	PS	
C-41	do	778	1949	75	14	1949	2,000	14	T	26	PS	
C-42	do	762	2-54	55	14	8-16-54	2,100		T	26	PS	
C-43	do	765	2-54	98	14.6	8-23-54	2,100		T	26	PS	
C-44	do	750	10-54	72	26	10-23-56	2,000	24	T	26	PS	
C-45	do	750	11-54	76	25	10-25-56	2,100	27	T	26	PS	
C-46	do	750	12-54	96	22	4-25-57	2,100		T	26	PS	
C-47	do	750		122	21.4	12-10-51	2,450	20	T	26	PS	
T-184	do	762	5-49	146	48.05	3-19-58			None	6	T	
T-186	do	765	7-49	144					None	6	T	
T-187	do	772	8-49	104					None	6	T	
T-188	do	774	8-49	144					None	6	T	
T-189	do	773	9-49	145					None	6	T	
T-190	do	772	10-49	120					None	6	T	
T-192	do	765	1-50	137					None	6	T	
T-193	do	765	2-50	122					None	6	T	
T-195	do	767	5-50	150					None	6	T	
T-196	do	768		154					None	6	T	
T-198	do	771	4-51	138					None	6	T	
T-200	do	771	5-51	145					None	6	T	
T-202	do	772	5-51	237	15.00				None	6	T	

PUBLIC-SUPPLY WELLS—Continued

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level: Depth (ft)	Water level: Date	Yield: Rate (gpm)	Yield: Drawdown (ft)	Type of pump	Diameter of well (in.)	Use	Remarks
T-1	City of Dayton, Miami River well field	745	12-55	166					None		F	Observation well MT-53.
T-2	do	749	12-55	128	11.5	3-28-57	2,233	9	None	26	F	
T-3	do	750	1-56	135					None		F	
T-4	do	740	1-56	131					None		F	
T-5	do	750	1-56	136					None		F	
T-6	do	748	6-57	150					None		F	
T-7	do	738	6-57	140					None	6	F	
T-8	do	750	6-57	128					None		F	
T-9	do	750	7-57	136					None		F	
T-10	do	750	7-57	136					None		F	
T-11	do	750	7-57	143					None		F	
T-12	do	743	8-57	140					None		F	
T-13	do	742	10-57	110					None		F	
T-14	do	742	10-57	170	12.5	10-16-57			None		F	
T-15	do	742	11-57	175					None		F	
T-16	do	750	12-57	156					None		F	
T-17	do	745	1-58	123	17	9-19-57			None		F	
T-18	do	738	1-58	170					None		F	
T-19	do	754	1-58	149					None		F	
T-20	do	749	1-58	130					None		F	
T-21	do	745	8-58	130					None		F	
T-22	do	745	8-58	110					None		F	
T-23	do	745	8-58	170					None		F	
T-24	do	746	10-58	170					None		F	
M-1	Montgomery County Sanitary Dept.	744	1948	125	37				None	20	PS	Lamme Rd.
M-2	do	749.44	5-50	200	47	5-1-50	1,000	17		16	PS	Do.
M-3	do	745	5-50	157	40	6-1-50	1,000	11		16	PS	Do.
M-4	do	745	2-53	166	33	2-19-53	1,700	24		16	PS	Do.
M-5	do	735	2-53	150	33	2-17-53	1,700	43		16	PS	Do.
M-6	do	749	3-54	157	38					16	PS	Do.
M-7	do	740	3-54	200						16	PS	Do.
M-8	do	740	3-54	200						16	PS	Do.
M-9	do	743.55	3-54	133	51	7-9-54	40	.5		6	O	Do.
M-10	do	720	7-54	247	29					8	PS	Drydan Rd.
M-11	do	720								8	PS	Do.
M-12	do	784.33		65	Flows		250	11		8	PS	Do.
O-1	City of Oakwood	780.49		70	Flows		250	11			PS	Do.
O-2	do											

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Sometimes wells are developed by introducing compressed air into the water through a long hose or pipe. This agitates and lifts the water until, laden with sand and other particles washed through the well screen, it overflows from the casing.

The most common method of developing wells in the Dayton area is by surging. In this method a tightly fitting surge block affixed to the drilling tool is worked up and down in the well like a ramrod in a gun. This forces water back and forth through the well screen at comparatively high velocity and brings the finer material into the well where it can be removed by bailing. Thorough development may require 1–2 days or even longer and is usually worth the expense on the basis of pumping costs alone. The difference in drawdown between wells that are properly developed and wells that aren't is commonly as much as 10 feet. For a pumping rate of 1,500 gpm, the cost of operating an improperly developed well may be as much as $1 per day more than for operating a properly developed well. After a few years the additional pumping cost could equal the original cost of the well. Moreover, added maintenance problems usually are associated with inadequate well development.

Some wells decline in efficiency after a few years and may require redevelopment at intervals. Several conditions may cause this decline. The most common is an incrustation of the well screen caused by either the deposition of limy materials in the screen openings and in the sand and gravel adjacent to the screen or by the growth of iron- or sulfate-forming bacteria in a slimy deposit, which clogs the well screen or the gravel around the well.

Iron-forming bacteria of the genus *Crenothrix* may grow in water containing iron in excess of about 0.2 parts per million. Methods of control include disinfection and regular treatment of the well and pumping equipment with hydrochloric acid or other chlorine compounds. Where contamination extends into the aquifer, some distance away from the well face, it is difficult to control and may eventually threaten an entire well field. Contamination of an aquifer over a large area is not known to occur anywhere in the Dayton area, though the problem locally is acute and should be carefully watched so that widespread control measures can be taken quickly if necessary.

Serious problems of well maintenance caused by iron-forming bacteria have occurred at the National Cash Register Co. plant and at the plants of the Delco-Moraine and Frigidaire Divisions of General Motors Corp. At the National Cash Register Co. plant a well drilled in 1950 was treated with acid in 1954 and again in 1958 in efforts to restore its efficiency, which had been appreciably reduced by the growth of iron-forming bacteria. At the Delco-Moraine Division

plant, a well (No. 338) drilled in 1948 to a depth of about 125 feet soon declined in yield and was deepened in 1950 to 200 feet. Since 1950 the well has twice been clogged by bacterial growth and both times was treated with acid. It has now been abandoned. No doubt the yield of many other wells in the Dayton area has been adversely affected by iron-forming bacteria. The problem warrants a more systematic study than was possible during this investigation.

CONTROLLED PUMPING TESTS

The method most commonly used to determine the storage and transmission properties of an aquifer is based on the nonequilibrium formula, which was introduced by Theis (1935). In this method the effects of pumping a well at a known constant rate are measured at several observation wells that tap the same aquifer. Graphs of drawdown versus distance from the pumped well, or of drawdown versus time since pumping started, are used to solve equations that express the relation between the coefficients of transmissibility and of storage of an aquifer and the lowering of water levels in the vicinity of a pumped well (Brown, 1953).

By methods based on the theory of images (Ferris, 1948), boundary effects are evaluated whereby the position, with respect to a pumped well, of a source of recharge (such as an infiltrating stream) or of an impermeable barrier (such as bedrock valley walls) can be determined. Effects of leakage through a semiconfining layer, such as a bed of glacial till, may be determined by methods described by Hantush (1955). Examples of pumping-test analysis were presented by Walton (1953, 1960) and by Norris (1959).

Control of pumping tests is made difficult in the Dayton area by interference from other wells and by the scarcity of observation wells. Technical difficulties hamper maintainance of constant pumping rates and precise measurement of ground-water levels in observation wells. Close control of a pumping test for periods longer than a few hours usually is not possible in the Dayton area. This difficulty, plus the heterogeneity of the aquifer, complicates interpretation of the test results.

One of the most difficult problems of interpretation is that of determining whether recharge to a well comes directly from an infiltrating stream or from vertical leakage through a till bed. The effects on ground-water levels observed during typical pumping tests are much the same for either source of recharge. Seldom are there enough properly spaced observation wells to indicate unequivocally the source of recharge; consequently, a great deal of judgment based upon a knowledge of the geology is involved

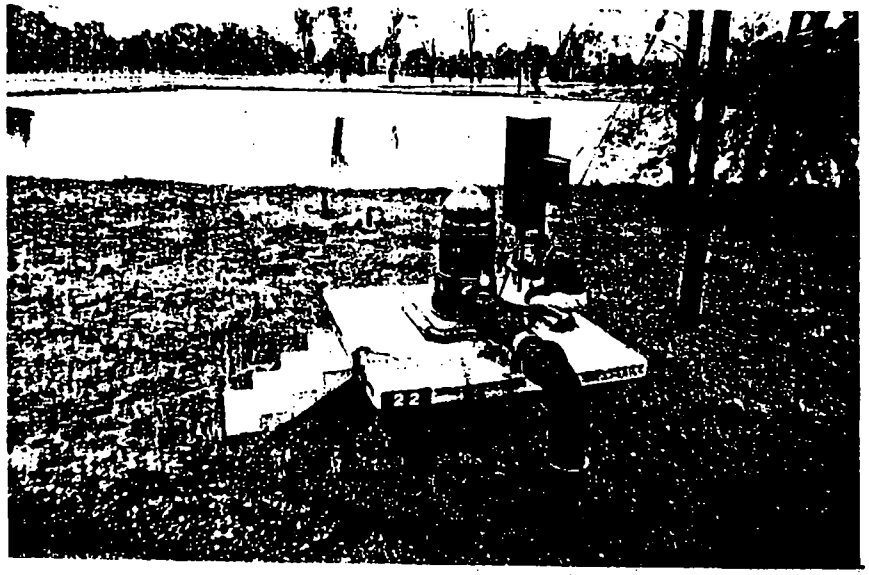

FIGURE 13.—High-capacity turbine pump installed on municipal well at Rohrers Island. Recharge pond in background. Photograph courtesy of the Dayton Daily News.

was to exclude from the well everything but the water. Consequently, the slots or openings in the screens were made small enough to keep out sand and other fine particles. This concept has changed, however; modern well screens are designed so that the openings are large enough to pass 40–60 percent of the aquifer materials. The size of the screen openings used in a typical production well is usually determined from a sieve analysis of sand and gravel samples collected in drilling the test hole. During development the finer grained material is washed through the screen and is removed from the well by pumping or bailing. This forms what is termed a natural "gravel pack" around the well screen and usually results in a much more efficient well than that obtained by earlier construction methods.

Artificial gravel packs also are used in some wells. These are constructing by first putting down a large-diameter casing, into which is inserted a casing of smaller diameter having a screen at its lower end. The annular space between the large-diameter casing and the well screen is filled with gravel of predetermined size and the outer casing then is withdrawn, exposing the gravel packing.

A few well screens in the Dayton area are of cemented gravel construction, in which graded gravel is mixed with cement and cast into a porous thick-walled screen reinforced by wire mesh and longitudinal

iron rods. The size of the gravel used in these screens is determined by analysis of samples of sand and gravel from the aquifer.

A few industrial wells in the Dayton area are not screened at all, except through perforations in the well casing. Most of these wells were drilled during World War II, when metal screens were scarce. Some, though not all, are of low efficiency or short life. A well driller informed the authors that he was replacing several wells, 12 years old, in which perforated casing was used in place of screens.

The yield of a well is roughly proportional to the length of the well screen, as the more fully a well penetrates an aquifer the smaller are the losses due to "partial penetration," which occur even in a perfectly homogeneous aquifer. (See Peterson and others, 1953.) In the sand and gravel aquifers at Dayton, horizontal layering of the deposits causes the permeability transverse to the bedding to be much less than the permeability parallel to the bedding. In some areas thin layers of clay or till interbedded with an otherwise homogeneous-appearing sand and gravel aquifer may further reduce the permeability in the vertical direction. Those factors greatly increase losses in wells that only partly penetrate the aquifers. The obvious solution to this problem is to use a long screen, which can "tie together" the more permeable parts of the aquifer. Moreover, the longer the well screen, the greater is the total area of the screen openings and the smaller is the head loss as the water flows through the screen into the well.

The screen lengths of about 60 wells in the Dayton area were plotted against their specific capacities. Wells whose screens were up to 10 feet in length had specific capacities up to 40 gpm per ft.; wells whose screens were 10–20 feet in length had specific capacities up to 160 gpm per ft.; and wells whose screens were 20–30 feet in length had specific capacities up to 320 gpm per ft. These are maximum or near-maximum capacities for the respective screen lengths. Some wells studied, whose screens were 20–30 feet long, had lower specific capacities than wells having 10-foot screens.

After a well is drilled and the screen is installed, the well is developed to permit water to flow more freely through the sand and gravel in the immediate vicinity of the well screen and thus to enter the well with minimum head loss. Development consists of removing part of the finer grained material from the aquifer; this causes rearrangement of the sand and gravel particles adjacent to the well screen. Removal of the finer particles from the sand and gravel envelope surrounding the screen reduces the chance that the well will "sand up" or "pump sand" when the pump is installed. The foregoing terms are commonly applied to the fouling of the pump or distribution lines by fine sand pumped up with the water.

Analysis Report

Lancaster Laboratories

EPA Region 5 Records Ctr.
349915

ANALYTICAL RESULTS

Prepared for:

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933
248-576-5741

Prepared by:

Lancaster Laboratories
2425 New Holland Pike
Lancaster, PA 17605-2425

SAMPLE GROUP

The sample group for this submittal is 852417. Samples arrived at the laboratory on Saturday, May 17, 2003. The PO# for this group is N99C403749-B.

Client Description	Lancaster Labs Number
MIP-60-45 Grab Water Sample	4046913
MIP-60-45-Filtered Grab Water Sample	4046914
MIP-66-55 Grab Water Sample	4046915
MIP-66-55-Filtered Grab Water Sample	4046916

1 COPY TO	Earth Tech	Attn: Ms. Lisa Smith
1 COPY TO	Earth Tech	Attn: Mr. Justin Kelley

Questions? Contact your Client Services Representative
Katherine A Klinefelter at (717) 656-2300.

Respectfully Submitted,

Christine M. Dulaney
Sr. Chemist

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meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4046913

Collected:05/15/2003 10:15 by DD

Account Number: 10160

Submitted: 05/17/2003 10:30
Reported: 05/30/2003 at 11:16
Discard: 07/30/2003
MIP-60-45 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

60-45 SDG#: DCL85-01

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	39.3		0.0453	mg/l	1
01758	Manganese	7439-96-5	1.40		0.00051	mg/l	1
09584	Ferric Iron	n.a.	32.8		0.20	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.		0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	409.		0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	922.		2.5	mg/l as CaCO3	5
00219	Nitrite Nitrogen	14797-65-0	0.019	J	0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	1.1		0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.		1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.						
00273	Total Organic Carbon	n.a.	2.2		0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	80.6		15.0	mg/l	10
04001	Chemical Oxygen Demand	n.a.	63.1		9.0	mg/l	1
08344	Ferrous Iron	n.a.	6.5		0.20	mg/l	25
07105	Volatile Headspace Hydrocarbon						
07107	Ethane	74-84-0	3.8	J	1.0	ug/l	1
07108	Ethene	74-85-1	1.6	J	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	05/21/2003 09:52	Joanne M Gates	1
01758	Manganese	SW-846 6010B	1	05/21/2003 09:52	Joanne M Gates	1
09584	Ferric Iron	SW-846 6010B Modified	1	05/21/2003 13:30	Max E Snavely	1
00201	Alkalinity to pH 8.3	EPA 310.1	1	05/27/2003 18:44	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	05/27/2003 18:44	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	05/27/2003 11:00	Susan A Engle	5
00219	Nitrite Nitrogen	EPA 353.2	1	05/17/2003 11:56	Michelle A Bolton	1
00220	Nitrate Nitrogen	EPA 353.2	1	05/25/2003 10:59	Michelle A Bolton	1
00229	Sulfite	EPA 377.1	1	05/28/2003 08:00	Yolunder Y Bunch	1
00273	Total Organic Carbon	EPA 415.1	1	05/23/2003 18:08	Timothy M Petree	1

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DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

60-45 SDG#: DCL85-01

01125	Sulfate (turbidimetric)	EPA 375.4	1	05/28/2003 08:35	Susan A Engle	10
04001	Chemical Oxygen Demand	EPA 410.4	1	05/29/2003 05:20	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	05/18/2003 05:30	Daniel S Smith	25
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	05/20/2003 14:11	Lisa A Johnson	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	05/20/2003 10:15	Christine Conlin	1

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4046914

Collected:05/15/2003 10:15 by DD

Account Number: 10160

Submitted: 05/17/2003 10:30
Reported: 05/30/2003 at 11:16
Discard: 07/30/2003
MIP-60-45-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03020
Dayton Thermal/Dayton, OH

6045F SDG#: DCL85-02

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	2.33	0.0453	mg/l	1

This sample was field filtered for dissolved metals.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	05/21/2003 09:57	Joanne M Gates	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	05/20/2003 10:15	Christine Conlin	1

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Lancaster, PA 17605-2425
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2425 New Holland Pike • Lancaster, PA 17601

Explanation of Symbols and Abbreviations

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N.D.	none detected	**BMQL**	Below Minimum Quantitation Level
TNTC	Too Numerous To Count	**MPN**	Most Probable Number
IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

Dry weight basis Results printed under this heading have been adjusted for moisture content. This increases the analyte weight concentration to approximate the value present in a similar sample without moisture. All other results are reported on an as-received basis.

U.S. EPA CLP Data Qualifiers:

Organic Qualifiers

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B	Analyte was also detected in the blank
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D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
P	Concentration difference between primary and confirmation columns >25%
U	Compound was not detected
X,Y,Z	Defined in case narrative

Inorganic Qualifiers

B	Value is <CRDL, but ≥IDL
E	Estimated due to interference
M	Duplicate injection precision not met
N	Spike sample not within control limits
S	Method of standard additions (MSA) used for calculation
U	Compound was not detected
W	Post digestion spike out of control limits
*****	Duplicate analysis not within control limits
+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4046915

Collected:05/15/2003 13:40 by DD

Account Number: 10160

Submitted: 05/17/2003 10:30
Reported: 05/30/2003 at 11:16
Discard: 07/30/2003
MIP-66-55 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

66-55 SDG#: DCL85-03

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	146.		0.0453	mg/l	1
01758	Manganese	7439-96-5	4.41		0.00051	mg/l	1
09584	Ferric Iron	n.a.	112.		0.80	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.		0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	353.		0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	2,470.		12.3	mg/l as CaCO3	25
00219	Nitrite Nitrogen	14797-65-0	N.D.		0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	N.D.		0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.		1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.						
00273	Total Organic Carbon	n.a.	2.8		0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	N.D.		75.0	mg/l	50
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.						
04001	Chemical Oxygen Demand	n.a.	17.4	J	9.0	mg/l	1
08344	Ferrous Iron	n.a.	33.7		0.80	mg/l	100
07105	Volatile Headspace Hydrocarbon						
07107	Ethane	74-84-0	7.2		1.0	ug/l	1
07108	Ethene	74-85-1	2.2	J	1.0	ug/l	1

The sample received for the COD analysis was subsampled from an unpreserved container.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	05/21/2003 10:10	Joanne M Gates	1
01758	Manganese	SW-846 6010B	1	05/21/2003 10:10	Joanne M Gates	1
09584	Ferric Iron	SW-846 6010B Modified	1	05/21/2003 13:25	Max E Snavely	1
00201	Alkalinity to pH 8.3	EPA 310.1	1	05/27/2003 22:16	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	05/27/2003 22:16	Elaine F Stoltzfus	1

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meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

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ppb parts per billion

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Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4046915

Collected:05/15/2003 13:40 by DD

Account Number: 10160

Submitted: 05/17/2003 10:30
Reported: 05/30/2003 at 11:16
Discard: 07/30/2003
MIP-66-55 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

66-55 SDG#: DCL85-03

00216	Total Hardness	EPA 130.2 (modified)	1	05/27/2003 11:00	Susan A Engle	25
00219	Nitrite Nitrogen	EPA 353.2	1	05/17/2003 11:57	Michelle A Bolton	1
00220	Nitrate Nitrogen	EPA 353.2	1	05/25/2003 11:55	Michelle A Bolton	1
00229	Sulfite	EPA 377.1	1	05/28/2003 08:00	Yolunder Y Bunch	1
00273	Total Organic Carbon	EPA 415.1	1	05/23/2003 18:16	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	05/28/2003 08:35	Susan A Engle	50
04001	Chemical Oxygen Demand	EPA 410.4	1	05/29/2003 05:20	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	05/18/2003 05:30	Daniel S Smith	100
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	05/20/2003 14:21	Lisa A Johnson	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	05/20/2003 10:15	Christine Conlin	1

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meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4046916

Collected:05/15/2003 13:40 by DD

Account Number: 10160

Submitted: 05/17/2003 10:30
Reported: 05/30/2003 at 11:16
Discard: 07/30/2003
MIP-66-55-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03020
Dayton Thermal/Dayton, OH

6655F SDG#: DCL85-04*

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	2.59		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	13.1	J	9.0	mg/l	1

This sample was field filtered for dissolved metals & COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	05/21/2003 10:14	Joanne M Gates	1
04001	Chemical Oxygen Demand	EPA 410.4	1	05/29/2003 05:20	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	05/20/2003 10:15	Christine Conlin	1

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ppb parts per billion

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 05/30/03 at 11:16 AM

Group Number: 852417

Laboratory Compliance Quality Control

Analysis Name	Blank Result	Blank MDL	Report Units	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Batch number: 03128022901A	Sample number(s): 4046913,4046915							
Sulfite	N.D.	1.2	mg/l	80		68-103		
Batch number: 03137105103A	Sample number(s): 4046913,4046915							
Nitrite Nitrogen	N.D.	0.015	mg/l	105		90-110		
Batch number: 03138834401A	Sample number(s): 4046913,4046915							
Ferrous Iron	N.D.	0.0080	mg/l	97		92-105		
Batch number: 031390005A	Sample number(s): 4046913,4046915							
Ethane	N.D.	1.0	ug/l	110		80-120		
Ethene	N.D.	1.0	ug/l	110		80-120		
Batch number: 031401848007	Sample number(s): 4046913-4046916							
Iron	N.D.	0.0453	mg/l	102		91-114		
Manganese	N.D.	0.00051	mg/l	105		93-110		
Batch number: 03143011112B	Sample number(s): 4046913,4046915							
Total Organic Carbon	N.D.	0.50	mg/l	100		89-115		
Batch number: 03145106101B	Sample number(s): 4046913							
Nitrate Nitrogen	N.D.	0.040	mg/l	100		90-110		
Batch number: 03145106102B	Sample number(s): 4046915							
Nitrate Nitrogen	N.D.	0.040	mg/l	101		90-110		
Batch number: 03147020201A	Sample number(s): 4046913							
Alkalinity to pH 4.5				100		98-103		
Batch number: 03147020202A	Sample number(s): 4046915							
Alkalinity to pH 4.5				100		98-103		
Batch number: 03147021601A	Sample number(s): 4046913,4046915							
Total Hardness	N.D.	0.49	mg/l as Ca	104		98-107		
Batch number: 03148112501A	Sample number(s): 4046913,4046915							
Sulfate (turbidimetric)	N.D.	1.5	mg/l	97		90-110		
Batch number: 03149400101A	Sample number(s): 4046913,4046915-4046916							
Chemical Oxygen Demand				100		95-107		

Sample Matrix Quality Control

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03128022901A	Sample number(s): 4046913,4046915								
Sulfite	52	39	29-104	29*	20	N.D.	N.D.	67* (1)	20
Batch number: 03137105103A	Sample number(s): 4046913,4046915								
Nitrite Nitrogen	103		90-110			N.D.	N.D.	25* (1)	20

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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Lancaster, PA 17605-2425
717 656 2300 Fax: 717 656 2681

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umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
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meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 05/30/03 at 11:16 AM

Group Number: 852417

Sample Matrix Quality Control

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03138834401A	Sample number(s): 4046913,4046915								
Ferrous Iron	94	89	76-119	3	5	26.9	27.1	1 (1)	20
Batch number: 031390005A	Sample number(s): 4046913,4046915								
Ethane	110	107	74-121	3	20				
Ethene	123	121	73-133	1	20				
Batch number: 031401848007	Sample number(s): 4046913-4046916								
Iron	(2)	(2)	75-125	3	20	21.7	22.2	2	20
Manganese	106	105	85-111	1	20	0.930	0.945	2	20
Batch number: 03143011112B	Sample number(s): 4046913,4046915								
Total Organic Carbon	110		63-136			3.3	3.3	0 (1)	3
Batch number: 03145106101B	Sample number(s): 4046913								
Nitrate Nitrogen	106		90-110			0.12	0.12	2 (1)	2
Batch number: 03145106102B	Sample number(s): 4046915								
Nitrate Nitrogen	107		90-110			0.098 J	0.099 J	1 (1)	2
Batch number: 03147020201A	Sample number(s): 4046913								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	99	100	64-130	1	2	78.4	77.0	2	4
Batch number: 03147020202A	Sample number(s): 4046915								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	100	100	64-130	0	2	166.	167.	0	4
Batch number: 03147021601A	Sample number(s): 4046913,4046915								
Total Hardness	104	104	93-115	0	2	70.0	72.0	3	4
Batch number: 03148112501A	Sample number(s): 4046913,4046915								
Sulfate (turbidimetric)	100	99	69-124	1	4	18.8	18.2	3 (1)	4
Batch number: 03149400101A	Sample number(s): 4046913,4046915-4046916								
Chemical Oxygen Demand	97	97	90-110	0	2	8,630.	8,500.	2	4

Surrogate Quality Control

Analysis Name: Volatile Headspace Hydrocarbon
Batch number: 031390005A

	Propene
4046913	95
4046915	90
Blank	111
LCS	105
MS	89
MSD	88

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Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 05/30/03 at 11:16 AM

Group Number: 852417

Surrogate Quality Control

Limits: 74-120

*- Outside of specification
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Analysis Report

Lancaster Laboratories

EPA Region 5 Records Ctr.
349916

ANALYTICAL RESULTS

Prepared for:

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933
248-576-5741

Prepared by:

Lancaster Laboratories
2425 New Holland Pike
Lancaster, PA 17605-2425

SAMPLE GROUP

The sample group for this submittal is 856270. Samples arrived at the laboratory on Wednesday, June 18, 2003. The PO# for this group is N99C403749-B.

Client Description	Lancaster Labs Number
MIP-26-35 Grab Water Sample	4066724
MIP-26-35-Filtered Grab Water Sample	4066725
MIP-46-25 Grab Water Sample	4066726
MIP-46-25-Filtered Grab Water Sample	4066727
Trip_Blank Water Sample	4066728

1 COPY TO	Earth Tech	Attn: Ms. Lisa Smith
1 COPY TO	Earth Tech	Attn: Mr. Justin Kelley

Questions? Contact your Client Services Representative
Katherine A Klinefelter at (717) 656-2300.

Respectfully Submitted,

Jenifer E. Hess
Group Leader

MEMBER ACIL
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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4066724

Collected:06/17/2003 18:10 by DD

Account Number: 10160

Submitted: 06/18/2003 09:50
Reported: 06/30/2003 at 09:26
Discard: 08/30/2003
MIP-26-35 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

-2635 SDG#: DCN02-01

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	59.2	0.0453	mg/l	1
01758	Manganese	7439-96-5	2.18	0.00051	mg/l	1
09584	Ferric Iron	n.a.	54.	0.16	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.	0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	1,180.	0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	1,440.	4.9	mg/l as CaCO3	10
00219	Nitrite Nitrogen	14797-65-0	N.D.	0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	N.D.	0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.	1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.					
00273	Total Organic Carbon	n.a.	2.6	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	N.D.	30.0	mg/l	20
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.					
01553	Chemical Oxygen Demand	n.a.	75.4	3.5	mg/l	2
08344	Ferrous Iron	n.a.	5.3	0.16	mg/l	20
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	3.3 J	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 05:46	Donna R Sackett	1
01758	Manganese	SW-846 6010B	1	06/27/2003 05:46	Donna R Sackett	1
09584	Ferric Iron	SW-846 6010B Modified	1	06/27/2003 14:38	Nina C Haller	1

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Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4066724

Collected:06/17/2003 18:10 by DD

Account Number: 10160

Submitted: 06/18/2003 09:50
Reported: 06/30/2003 at 09:26
Discard: 08/30/2003
MIP-26-35 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

-2635 SDG#: DCN02-01

00201	Alkalinity to pH 8.3	EPA 310.1	1	06/19/2003 21:15	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	06/19/2003 21:15	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	06/26/2003 10:32	Susan A Engle	10
00219	Nitrite Nitrogen	EPA 353.2	1	06/19/2003 08:23	Timothy M Petree	1
00220	Nitrate Nitrogen	EPA 353.2	1	06/22/2003 15:10	Michelle A Bolton	1
00229	Sulfite	EPA 377.1	1	06/20/2003 07:45	Michele L Graham	1
00273	Total Organic Carbon	EPA 415.1	1	06/19/2003 22:25	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	06/25/2003 11:00	Susan A Engle	20
01553	Chemical Oxygen Demand	EPA 410.2	1	06/24/2003 06:15	Susan A Engle	2
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/18/2003 22:45	Daniel S Smith	20
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/25/2003 16:55	Lisa A Johnson	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

Explanation of Symbols and Abbreviations

The following defines common symbols and abbreviations used in reporting technical data:

N.D.	none detected	**BMQL**	Below Minimum Quantitation Level
TNTC	Too Numerous To Count	**MPN**	Most Probable Number
IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

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ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

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Organic Qualifiers

A	TIC is a possible aldol-condensation product
B	Analyte was also detected in the blank
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D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
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P	Concentration difference between primary and confirmation columns >25%
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X,Y,Z	Defined in case narrative

Inorganic Qualifiers

B	Value is <CRDL, but ≥IDL
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+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4066725

Collected:06/17/2003 18:10 by DD

Account Number: 10160

Submitted: 06/18/2003 09:50
Reported: 06/30/2003 at 09:26
Discard: 08/30/2003
MIP-26-35-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

F2635 SDG#: DCN02-02

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	1.13		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	17.2	J	8.2	mg/l	1

This sample was field filtered for dissolved metals and COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 05:51	Donna R Sackett	1
04001	Chemical Oxygen Demand	EPA 410.4	1	06/20/2003 07:53	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4066726

Collected:06/17/2003 18:55 by DD

Account Number: 10160

Submitted: 06/18/2003 09:50
Reported: 06/30/2003 at 09:27
Discard: 08/30/2003
MIP-46-25 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

-4625 SDG#: DCN02-03

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	290.	0.0453	mg/l	1
01758	Manganese	7439-96-5	7.07	0.00051	mg/l	1
09584	Ferric Iron	n.a.	290.	0.080	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.	0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	404.	0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	3,120.	24.5	mg/l as CaCO3	50
00219	Nitrite Nitrogen	14797-65-0	0.12	0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	6.3	0.080	mg/l	2
00229	Sulfite	14265-45-3	N.D.	1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.					
00273	Total Organic Carbon	n.a.	1.5 J	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	N.D.	15.0	mg/l	10
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.					
01553	Chemical Oxygen Demand	n.a.	471.	8.7	mg/l	5
08344	Ferrous Iron	n.a.	2.8	0.080	mg/l	10
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	7.7	1.0	ug/l	1
07108	Ethene	74-85-1	1.6 J	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 05:56	Donna R Sackett	1
01758	Manganese	SW-846 6010B	1	06/27/2003 05:56	Donna R Sackett	1
09584	Ferric Iron	SW-846 6010B Modified	1	06/27/2003 14:40	Nina C Haller	1
00201	Alkalinity to pH 8.3	EPA 310.1	1	06/19/2003 21:15	Elaine F Stoltzfus	1

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Account Number: 10160

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Discard: 08/30/2003
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DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

-4625 SDG#: DCN02-03

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01553	Chemical Oxygen Demand	EPA 410.2	1	06/24/2003 06:15	Susan A Engle	5
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/18/2003 22:45	Daniel S Smith	10
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/25/2003 17:06	Lisa A Johnson	1
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Collected:06/17/2003 18:55 by DD

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Reported: 06/30/2003 at 09:27
Discard: 08/30/2003
MIP-46-25-Filtered Grab Water Sample

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

F4625 SDG#: DCN02-04

Account Number: 10160

DaimlerChrysler Corporation
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Livonia MI 48153-7933

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+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4066728

Collected: n.a.

Submitted: 06/18/2003 09:50
Reported: 06/30/2003 at 09:27
Discard: 08/30/2003
Trip_Blank Water Sample

Account Number: 10160

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

DTTB- SDG#: DCN02-05TB*

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	N.D.	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/25/2003 17:17	Lisa A Johnson	1

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ml	milliliter(s)	**l**	liter(s)
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ppb parts per billion

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 06/30/03 at 09:27 AM

Group Number: 856270

Laboratory Compliance Quality Control

Analysis Name	Blank Result	Blank MDL	Report Units	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Batch number: 03169834401A	Sample number(s): 4066724,4066726							
Ferrous Iron	N.D.	0.0080	mg/l	96		92-105		
Batch number: 03170011114B	Sample number(s): 4066724,4066726							
Total Organic Carbon	N.D.	0.50	mg/l	99		89-115		
Batch number: 03170020202A	Sample number(s): 4066724,4066726							
Alkalinity to pH 4.5				101		98-103		
Batch number: 03170105101A	Sample number(s): 4066724,4066726							
Nitrite Nitrogen	N.D.	0.015	mg/l	97		90-110		
Batch number: 03171022901A	Sample number(s): 4066724,4066726							
Sulfite	N.D.	1.2	mg/l	85		68-103		
Batch number: 03171400101A	Sample number(s): 4066725,4066727							
Chemical Oxygen Demand				100		95-107		
Batch number: 03173106101A	Sample number(s): 4066724							
Nitrate Nitrogen	N.D.	0.040	mg/l	104		90-110		
Batch number: 03173106101B	Sample number(s): 4066726							
Nitrate Nitrogen	N.D.	0.040	mg/l	104		90-110		
Batch number: 031731848006	Sample number(s): 4066724-4066727							
Iron	N.D.	0.0453	mg/l	104		91-114		
Manganese	N.D.	0.00051	mg/l	102		93-110		
Batch number: 03175155301A	Sample number(s): 4066724,4066726							
Chemical Oxygen Demand				92		84-108		
Batch number: 031760005A	Sample number(s): 4066724,4066726,4066728							
Ethane	N.D.	1.0	ug/l	93		80-120		
Ethene	N.D.	1.0	ug/l	95		80-120		
Batch number: 03176112501A	Sample number(s): 4066724,4066726							
Sulfate (turbidimetric)	N.D.	1.5	mg/l	97		90-110		
Batch number: 03177021601A	Sample number(s): 4066724,4066726							
Total Hardness	N.D.	0.49	mg/l as Ca	104		98-107		

Sample Matrix Quality Control

*- Outside of specification
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(2) The background result was more than four times the spike added.

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g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

J *estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).*

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ppb parts per billion

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P	Concentration difference between primary and confirmation columns >25%
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Inorganic Qualifiers

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation Group Number: 856270
Reported: 06/30/03 at 09:27 AM

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03169834401A	Sample number(s): 4066724,4066726								
Ferrous Iron	103	97	76-119	3	5	5.3	5.3	1	20
Batch number: 03170011114B	Sample number(s): 4066724,4066726								
Total Organic Carbon	113		63-136			2.0	1.3 J	46* (1)	3
Batch number: 03170020202A	Sample number(s): 4066724,4066726								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	100	100	64-130	0	2	81.5	81.1	1	4
Batch number: 03170105101A	Sample number(s): 4066724,4066726								
Nitrite Nitrogen	101		90-110			N.D.	N.D.	0 (1)	20
Batch number: 03171022901A	Sample number(s): 4066724,4066726								
Sulfite	51	46	29-104	10	20	N.D.	N.D.	200* (1)	20
Batch number: 03171400101A	Sample number(s): 4066725,4066727								
Chemical Oxygen Demand	95	93	90-110	1	2	1,240.	1,230.	1	4
Batch number: 03173106101A	Sample number(s): 4066724								
Nitrate Nitrogen	112*		90-110			N.D.	N.D.	0 (1)	2
Batch number: 03173106101B	Sample number(s): 4066726								
Nitrate Nitrogen	106		90-110			N.D.	N.D.	116* (1)	2
Batch number: 031731848006	Sample number(s): 4066724-4066727								
Iron	77	75	75-125	1	20	2.20	1.95	12	20
Manganese	95	94	85-111	0	20	0.520	0.488	6	20
Batch number: 03175155301A	Sample number(s): 4066724,4066726								
Chemical Oxygen Demand	99	103	61-118	3	6	65.7	65.0	1	7
Batch number: 031760005A	Sample number(s): 4066724,4066726,4066728								
Ethane	93	93	74-121	0	20				
Ethene	95	97	73-133	2	20				
Batch number: 03176112501A	Sample number(s): 4066724,4066726								
Sulfate (turbidimetric)	101	99	69-124	2	4	45.5	46.1	1 (1)	4
Batch number: 03177021601A	Sample number(s): 4066724,4066726								
Total Hardness	102	98	93-115	1	2	116.	115.	2	4

Surrogate Quality Control

Analysis Name: Volatile Headspace Hydrocarbon

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 06/30/03 at 09:27 AM

Group Number: 856270

Surrogate Quality Control

Batch number: 031760005A

	Propene
4066724	94
4066726	102
4066728	98
Blank	102
LCS	104
MS	102
MSD	105
Limits:	74-120

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Analysis Report

Lancaster Laboratories

EPA Region 5 Records Ctr.
349917

ANALYTICAL RESULTS

Prepared for:

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933
248-576-5741

Prepared by:

Lancaster Laboratories
2425 New Holland Pike
Lancaster, PA 17605-2425

SAMPLE GROUP

The sample group for this submittal is 854690. Samples arrived at the laboratory on Friday, June 06, 2003. The PO# for this group is N99C403749-B.

Client Description	Lancaster Labs Number
MIP-34-40 Grab Water Sample	4057688
MIP-34-40-Filtered Grab Water Sample	4057689
MIP-40-35 Grab Water Sample	4057690
MIP-40-35-Filtered Grab Water Sample	4057691
Trip_Blank Water Sample	4057692

1 COPY TO	Earth Tech	Attn: Ms. Lisa Smith
1 COPY TO	Earth Tech	Attn: Mr. Justin Kelley

Questions? Contact your Client Services Representative
Katherine A Klinefelter at (717) 656-2300.

Respectfully Submitted,

Melissa A McSermott
Senior Chemist

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

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Organic Qualifiers

A	TIC is a possible aldol-condensation product
B	Analyte was also detected in the blank
C	Pesticide result confirmed by GC/MS
D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
P	Concentration difference between primary and confirmation columns >25%
U	Compound was not detected
X,Y,Z	Defined in case narrative

Inorganic Qualifiers

B	Value is <CRDL, but ≥IDL
E	Estimated due to interference
M	Duplicate injection precision not met
N	Spike sample not within control limits
S	Method of standard additions (MSA) used for calculation
U	Compound was not detected
W	Post digestion spike out of control limits
*****	Duplicate analysis not within control limits
+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057688

Collected:06/05/2003 13:45 by DD

Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/23/2003 at 09:35
Discard: 08/23/2003
MIP-34-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OH40- SDG#: DCL96-01

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	80.7		0.0453	mg/l	1
01758	Manganese	7439-96-5	3.08		0.00051	mg/l	1
09584	Ferric Iron	n.a.	78.		0.16	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.		0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	395.		0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	1,410.		4.9	mg/l as CaCO3	10
00219	Nitrite Nitrogen	14797-65-0	N.D.		0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	0.55		0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.		2.4	mg/l	2
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring. Due to interferences from the sample matrix, the reporting limit for the Sulfite determination was increased.						
00273	Total Organic Carbon	n.a.	1.6	J	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	N.D.		30.0	mg/l	20
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.						
01553	Chemical Oxygen Demand	n.a.	57.4		1.7	mg/l	1
08344	Ferrous Iron	n.a.	2.7		0.16	mg/l	20
07105	Volatile Headspace Hydrocarbon						
07107	Ethane	74-84-0	4.0	J	1.0	ug/l	1
07108	Ethene	74-85-1	1.0	J	1.0	ug/l	1

Laboratory Chronicle

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PO Box 12425
Lancaster, PA 17605-2425
717-656-2300 Fax: 717-656-2681

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

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N.D.	none detected	**BMQL**	Below Minimum Quantitation Level
TNTC	Too Numerous To Count	**MPN**	Most Probable Number
IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

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Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057688

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Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/23/2003 at 09:35
Discard: 08/23/2003
MIP-34-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OH40- SDG#: DCL96-01

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/10/2003 14:12	Joanne M Gates	1
01758	Manganese	SW-846 6010B	1	06/10/2003 14:12	Joanne M Gates	1
09584	Ferric Iron	calculation	1	06/11/2003 11:55	Erika J Rabuck	1
00201	Alkalinity to pH 8.3	EPA 310.1	1	06/10/2003 22:36	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	06/10/2003 22:36	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	06/06/2003 15:35	Susan A Engle	10
00219	Nitrite Nitrogen	EPA 353.2	1	06/06/2003 20:59	Michelle A Bolton	1
00220	Nitrate Nitrogen	EPA 353.2	1	06/11/2003 19:18	Venia B McFadden	1
00229	Sulfite	EPA 377.1	1	06/09/2003 11:30	Michele L Graham	2
00273	Total Organic Carbon	EPA 415.1	1	06/09/2003 13:35	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	06/10/2003 09:45	Susan A Engle	20
01553	Chemical Oxygen Demand	EPA 410.2	1	06/12/2003 06:15	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/06/2003 19:30	Daniel S Smith	20
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/13/2003 16:44	Tracy A Cole	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/09/2003 09:22	Denise K Conners	1

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PO Box 12425
Lancaster, PA 17605-2425
717-656-2300 Fax: 717-656-2681

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

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umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

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Inorganic Qualifiers

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057689

Collected:06/05/2003 13:45 by DD

Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/19/2003 at 16:56
Discard: 08/19/2003
MIP-34-40-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OHF40 SDG#: DCL96-02

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	1.45		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	19.6	J	9.0	mg/l	1

This sample was field filtered for dissolved metals and COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/10/2003 14:17	Joanne M Gates	1
04001	Chemical Oxygen Demand	EPA 410.4	1	06/10/2003 08:02	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/09/2003 09:22	Denise K Conners	1

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Lancaster, PA 17605-2425
717-656-2300 Fax: 717-656-2681

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2425 New Holland Pike • Lancaster, PA 17601

Explanation of Symbols and Abbreviations

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TNTC	Too Numerous To Count	**MPN**	Most Probable Number
IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

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Organic Qualifiers

A	TIC is a possible aldol-condensation product
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D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
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X,Y,Z	Defined in case narrative

Inorganic Qualifiers

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M	Duplicate injection precision not met
N	Spike sample not within control limits
S	Method of standard additions (MSA) used for calculation
U	Compound was not detected
W	Post digestion spike out of control limits
*****	Duplicate analysis not within control limits
+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057690

Collected:06/05/2003 18:30 by DD

Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/23/2003 at 09:35
Discard: 08/23/2003
MIP-40-35 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OH35- SDG#: DCL96-03

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	124.	0.0453	mg/l	1
01758	Manganese	7439-96-5	4.68	0.00051	mg/l	1
09584	Ferric Iron	n.a.	120.	0.16	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.	0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	512.	0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	2,000.	4.9	mg/l as CaCO3	10
00219	Nitrite Nitrogen	14797-65-0	N.D.	0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	3.8	0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.	1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.					
00273	Total Organic Carbon	n.a.	2.3	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	N.D.	75.0	mg/l	50
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.					
01553	Chemical Oxygen Demand	n.a.	88.9	1.7	mg/l	1
08344	Ferrous Iron	n.a.	8.6	0.16	mg/l	20
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	5.6	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor

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Lancaster Laboratories

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Collected:06/05/2003 18:30 by DD

Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/23/2003 at 09:35
Discard: 08/23/2003
MIP-40-35 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OH35- SDG#: DCL96-03

01754	Iron	SW-846 6010B	1	06/10/2003 14:22	Joanne M Gates	1
01758	Manganese	SW-846 6010B	1	06/10/2003 14:22	Joanne M Gates	1
09584	Ferric Iron	calculation	1	06/11/2003 12:01	Erika J Rabuck	1
00201	Alkalinity to pH 8.3	EPA 310.1	3	06/11/2003 20:20	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	3	06/11/2003 20:20	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	06/06/2003 15:35	Susan A Engle	10
00219	Nitrite Nitrogen	EPA 353.2	1	06/06/2003 21:00	Michelle A Bolton	1
00220	Nitrate Nitrogen	EPA 353.2	1	06/11/2003 19:20	Venia B McFadden	1
00229	Sulfite	EPA 377.1	1	06/09/2003 11:30	Michele L Graham	1
00273	Total Organic Carbon	EPA 415.1	1	06/09/2003 13:43	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	06/18/2003 10:40	Susan A Engle	50
01553	Chemical Oxygen Demand	EPA 410.2	1	06/12/2003 06:15	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/06/2003 19:30	Daniel S Smith	20
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/13/2003 12:31	Tracy A Cole	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/09/2003 09:22	Denise K Conners	1

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2425 New Holland Pike • Lancaster, PA 17601

Explanation of Symbols and Abbreviations

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N.D.	none detected	**BMQL**	Below Minimum Quantitation Level
TNTC	Too Numerous To Count	**MPN**	Most Probable Number
IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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ppb parts per billion

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X,Y,Z	Defined in case narrative

Inorganic Qualifiers

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057691

Collected:06/05/2003 18:30 by DD

Account Number: 10160

Submitted: 06/06/2003 09:25
Reported: 06/19/2003 at 16:56
Discard: 08/19/2003
MIP-40-35-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

OH35F SDG#: DCL96-04

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	0.250		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	17.2	J	9.0	mg/l	1

This sample was field filtered for dissolved metals and COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/10/2003 14:26	Joanne M Gates	1
04001	Chemical Oxygen Demand	EPA 410.4	1	06/10/2003 08:02	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/09/2003 09:22	Denise K Conners	1

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4057692

Collected: n.a.

Submitted: 06/06/2003 09:25
Reported: 06/19/2003 at 16:56
Discard: 08/19/2003
Trip_Blank Water Sample

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

TBHHS SDG#: DCL96-05TB*

Account Number: 10160

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	N.D.	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/13/2003 12:42	Tracy A Cole	1

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 06/19/03 at 04:57 PM

Group Number: 854690

Laboratory Compliance Quality Control

Analysis Name	Blank Result	Blank MDL	Report Units	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Batch number: 03157021602A	Sample number(s): 4057688,4057690							
Total Hardness	N.D.	0.49	mg/l as Ca	103		98-107		
Batch number: 03157105101A	Sample number(s): 4057688,4057690							
Nitrite Nitrogen	N.D.	0.015	mg/l	103		90-110		
Batch number: 03157834401A	Sample number(s): 4057688,4057690							
Ferrous Iron	N.D.	0.0080	mg/l	97		92-105		
Batch number: 03160011112A	Sample number(s): 4057688,4057690							
Total Organic Carbon	N.D.	0.50	mg/l	96		89-115		
Batch number: 03160022901A	Sample number(s): 4057688,4057690							
Sulfite	N.D.	1.2	mg/l	74		68-103		
Batch number: 031601848001	Sample number(s): 4057688-4057691							
Iron	N.D.	0.0453	mg/l	105		91-114		
Manganese	N.D.	0.00051	mg/l	101		93-110		
Batch number: 03161020202A	Sample number(s): 4057688							
Alkalinity to pH 4.5				100		98-103		
Batch number: 03161112501A	Sample number(s): 4057688							
Sulfate (turbidimetric)	N.D.	1.5	mg/l	96		90-110		
Batch number: 03161400101A	Sample number(s): 4057689,4057691							
Chemical Oxygen Demand				101		95-107		
Batch number: 03162020202A	Sample number(s): 4057690							
Alkalinity to pH 4.5				101		98-103		
Batch number: 03162106102B	Sample number(s): 4057688,4057690							
Nitrate Nitrogen	N.D.	0.040	mg/l	104		90-110		
Batch number: 031630022A	Sample number(s): 4057688,4057690,4057692							
Ethane	N.D.	1.0	ug/l	108		80-120		
Ethene	N.D.	1.0	ug/l	108		80-120		
Batch number: 03163155301A	Sample number(s): 4057688,4057690							
Chemical Oxygen Demand				95		85-106		
Batch number: 03169112501A	Sample number(s): 4057690							
Sulfate (turbidimetric)	N.D.	1.5	mg/l	96		90-110		

Sample Matrix Quality Control

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03157021602A	Sample number(s): 4057688,4057690								
Total Hardness	97	97	93-115	0	2	25.7	24.2	6*	4

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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Quality Control Summary

Client Name: DaimlerChrysler Corporation Group Number: 854690
Reported: 06/19/03 at 04:57 PM

Sample Matrix Quality Control

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03157105101A	Sample number(s): 4057688,4057690								
Nitrite Nitrogen	97		90-110			0.45	0.46	2	20
Batch number: 03157834401A	Sample number(s): 4057688,4057690								
Ferrous Iron	99	97	76-119	1	5	1.7	1.7	2	20
Batch number: 03160011112A	Sample number(s): 4057688,4057690								
Total Organic Carbon	95		63-136			3.1	3.0	5* (1)	3
Batch number: 03160022901A	Sample number(s): 4057688,4057690								
Sulfite	54	49	29-104	10	20	N.D.	N.D.	0 (1)	20
Batch number: 031601848001	Sample number(s): 4057688-4057691								
Iron	117	116	75-125	0	20	1.29	1.32	2	20
Manganese	103	103	85-111	0	20	0.0871	0.0876	1	20
Batch number: 03161020202A	Sample number(s): 4057688								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	87	87	64-130	0	2	58.8	59.9	2	4
Batch number: 03161112501A	Sample number(s): 4057688								
Sulfate (turbidimetric)	103	103	69-124	0	4	33.4	36.6	9* (1)	4
Batch number: 03161400101A	Sample number(s): 4057689,4057691								
Chemical Oxygen Demand	96	95	90-110	1	2	7,710.	7,860.	2	4
Batch number: 03162020202A	Sample number(s): 4057690								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	100	101	64-130	1	2	72.5	73.8	2	4
Batch number: 03162106102B	Sample number(s): 4057688,4057690								
Nitrate Nitrogen	106		90-110			N.D.	N.D.	0 (1)	2
Batch number: 031630022A	Sample number(s): 4057688,4057690,4057692								
Ethane	98	85	74-121	13	20				
Ethene	102	89	73-133	14	20				
Batch number: 03163155301A	Sample number(s): 4057688,4057690								
Chemical Oxygen Demand	89	91	61-118	1	6	84.4	84.4	0	7
Batch number: 03169112501A	Sample number(s): 4057690								
Sulfate (turbidimetric)	96	98	69-124	1	4	51.9	50.9	2	4

Surrogate Quality Control

Analysis Name: Volatile Headspace Hydrocarbon
Batch number: 031630022A
Propene

4057688	88

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

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X,Y,Z	Defined in case narrative

Inorganic Qualifiers

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 06/19/03 at 04:57 PM

Group Number: 854690

Surrogate Quality Control

4057690	81
4057692	85
Blank	88
LCS	93
MS	83
MSD	75
Limits:	74-120

*- Outside of specification.
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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2425 New Holland Pike • Lancaster, PA 17601

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meq	milliequivalents	**lb.**	pound(s)
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Analysis Report

Lancaster Laboratories

EPA Region 5 Records Ctr.
349918

ANALYTICAL RESULTS

Prepared for:

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933
248-576-5741

Prepared by:

Lancaster Laboratories
2425 New Holland Pike
Lancaster, PA 17605-2425

SAMPLE GROUP

The sample group for this submittal is 856459. Samples arrived at the laboratory on Thursday, June 19, 2003. The PO# for this group is N99C403749-B.

Client Description	Lancaster Labs Number
MIP-31-40 Grab Water Sample	4067747
MIP-31-40-Filtered Grab Water Sample	4067748
MIP-18-40 Grab Water Sample	4067749
MIP-18-40-Filtered Grab Water Sample	4067750
Trip_Blank Grab Water Sample	4067751

1 COPY TO	Earth Tech	Attn: Ms. Lisa Smith
1 COPY TO	Earth Tech	Attn: Mr. Justin Kelley

Questions? Contact your Client Services Representative
Katherine A Klinefelter at (717) 656-2300.

Respectfully Submitted,

Max E. Snavely
Sr. Chemist

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067747

Collected:06/18/2003 10:40 by DD

Account Number: 10160

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-31-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

31-40 SDG#: DCN03-01

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	82.7		0.0453	mg/l	1
01758	Manganese	7439-96-5	1.60		0.00051	mg/l	1
09584	Ferric Iron	n.a.	62.		0.80	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.		0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	382.		0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	2,510.		24.5	mg/l as CaCO3	50
00219	Nitrite Nitrogen	14797-65-0	N.D.		0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	N.D.		0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.		1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.						
00273	Total Organic Carbon	n.a.	1.7	J	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	35.4	J	15.0	mg/l	10
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.						
01553	Chemical Oxygen Demand	n.a.	86.2		1.7	mg/l	1
08344	Ferrous Iron	n.a.	20.9		0.80	mg/l	100
07105	Volatile Headspace Hydrocarbon						
07107	Ethane	74-84-0	6.2		1.0	ug/l	1
07108	Ethene	74-85-1	1.1	J	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 06:06	Donna R Sackett	1
01758	Manganese	SW-846 6010B	1	06/27/2003 06:06	Donna R Sackett	1
09584	Ferric Iron	SW-846 6010B Modified	1	06/27/2003 14:43	Nina C Haller	1

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Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067747

Collected:06/18/2003 10:40 by DD

Account Number: 10160

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-31-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

31-40 SDG#: DCN03-01

00201	Alkalinity to pH 8.3	EPA 310.1	1	06/22/2003 18:17	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	06/22/2003 18:17	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	06/26/2003 12:35	Susan A Engle	50
00219	Nitrite Nitrogen	EPA 353.2	1	06/20/2003 10:05	Timothy M Petree	1
00220	Nitrate Nitrogen	EPA 353.2	1	06/25/2003 14:51	Frank A Cozzi	1
00229	Sulfite	EPA 377.1	1	06/20/2003 07:45	Michele L Graham	1
00273	Total Organic Carbon	EPA 415.1	1	06/20/2003 02:35	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	06/25/2003 11:00	Susan A Engle	10
01553	Chemical Oxygen Demand	EPA 410.2	1	06/24/2003 06:15	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/19/2003 19:40	Daniel S Smith	100
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/25/2003 17:28	Lisa A Johnson	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067748

Collected:06/18/2003 10:40 by DD

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-31-40-Filtered Grab Water Sample

Account Number: 10160

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

3141D SDG#: DCN03-02

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	5.22		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	22.1	J	8.2	mg/l	1

This sample was field filtered for dissolved metals and COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 06:11	Donna R Sackett	1
04001	Chemical Oxygen Demand	EPA 410.4	1	06/20/2003 07:53	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

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ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

> greater than

J estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).

ppm parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg), or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter of gas per liter of gas.

ppb parts per billion

Dry weight basis Results printed under this heading have been adjusted for moisture content. This increases the analyte weight concentration to approximate the value present in a similar sample without moisture. All other results are reported on an as-received basis.

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Organic Qualifiers

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B	Analyte was also detected in the blank
C	Pesticide result confirmed by GC/MS
D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
P	Concentration difference between primary and confirmation columns >25%
U	Compound was not detected
X,Y,Z	Defined in case narrative

Inorganic Qualifiers

B	Value is <CRDL, but ≥IDL
E	Estimated due to interference
M	Duplicate injection precision not met
N	Spike sample not within control limits
S	Method of standard additions (MSA) used for calculation
U	Compound was not detected
W	Post digestion spike out of control limits
*****	Duplicate analysis not within control limits
+	Correlation coefficient for MSA <0.995

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067749

Collected:06/18/2003 13:15 by DD

Account Number: 10160

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-18-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

18-40 SDG#: DCN03-03

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	84.9	0.0453	mg/l	1
01758	Manganese	7439-96-5	7.26	0.00051	mg/l	1
09584	Ferric Iron	n.a.	81.	0.080	mg/l	1
00201	Alkalinity to pH 8.3	n.a.	N.D.	0.41	mg/l as CaCO3	1
00202	Alkalinity to pH 4.5	n.a.	357.	0.41	mg/l as CaCO3	1
00216	Total Hardness	471-34-3	1,960.	12.3	mg/l as CaCO3	25
00219	Nitrite Nitrogen	14797-65-0	N.D.	0.015	mg/l	1
00220	Nitrate Nitrogen	14797-55-8	0.24	0.040	mg/l	1
00229	Sulfite	14265-45-3	N.D.	1.2	mg/l	1
	The 40 CFR Part 136 requires that analysis for sulfite be performed immediately (within 15 minutes) upon sample collection. Although this analysis is performed promptly upon receipt at the laboratory, the results may not be acceptable for NPDES compliance monitoring.					
00273	Total Organic Carbon	n.a.	1.6 J	0.50	mg/l	1
01125	Sulfate (turbidimetric)	14808-79-8	47.6 J	30.0	mg/l	20
	Due to interferences from the sample matrix, the reporting limit for the sulfate determination was increased.					
01553	Chemical Oxygen Demand	n.a.	31.0	1.7	mg/l	1
08344	Ferrous Iron	n.a.	3.8	0.080	mg/l	10
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	3.1 J	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 06:26	Donna R Sackett	1
01758	Manganese	SW-846 6010B	1	06/27/2003 06:26	Donna R Sackett	1
09584	Ferric Iron	SW-846 6010B Modified	1	06/27/2003 14:45	Nina C Haller	1

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PO Box 12425
Lancaster, PA 17605-2425
717-656-2300 Fax: 717-656-2681

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

Explanation of Symbols and Abbreviations

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umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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ppb parts per billion

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Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067749

Collected:06/18/2003 13:15 by DD

Account Number: 10160

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-18-40 Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

18-40 SDG#: DCN03-03

00201	Alkalinity to pH 8.3	EPA 310.1	1	06/22/2003 18:17	Elaine F Stoltzfus	1
00202	Alkalinity to pH 4.5	EPA 310.1	1	06/22/2003 18:17	Elaine F Stoltzfus	1
00216	Total Hardness	EPA 130.2 (modified)	1	06/26/2003 12:35	Susan A Engle	25
00219	Nitrite Nitrogen	EPA 353.2	1	06/20/2003 10:06	Timothy M Petree	1
00220	Nitrate Nitrogen	EPA 353.2	1	06/25/2003 14:53	Frank A Cozzi	1
00229	Sulfite	EPA 377.1	1	06/20/2003 07:45	Michele L Graham	1
00273	Total Organic Carbon	EPA 415.1	1	06/20/2003 02:44	Timothy M Petree	1
01125	Sulfate (turbidimetric)	EPA 375.4	1	06/25/2003 11:00	Susan A Engle	20
01553	Chemical Oxygen Demand	EPA 410.2	1	06/24/2003 06:15	Susan A Engle	1
08344	Ferrous Iron	SM 18, 3500-Fe D (modified)	1	06/19/2003 19:40	Daniel S Smith	10
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/25/2003 17:39	Lisa A Johnson	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

Lancaster Laboratories
2425 New Holland Pike • Lancaster, PA 17601

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C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
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ppb parts per billion

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067750

Collected:06/18/2003 13:15 by DD

Account Number: 10160

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
MIP-18-40-Filtered Grab Water Sample

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

1840D SDG#: DCN03-04

CAT No.	Analysis Name	CAS Number	As Received Result		As Received Method Detection Limit	Units	Dilution Factor
01754	Iron	7439-89-6	0.610		0.0453	mg/l	1
04001	Chemical Oxygen Demand	n.a.	17.2	J	8.2	mg/l	1

This sample was field filtered for dissolved metals and COD.

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
01754	Iron	SW-846 6010B	1	06/27/2003 06:30	Donna R Sackett	1
04001	Chemical Oxygen Demand	EPA 410.4	1	06/20/2003 07:53	Susan A Engle	1
01848	WW SW846 ICP Digest (tot rec)	SW-846 3005A	1	06/22/2003 09:10	Julie A Slaughenhoupt	1

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Lancaster, PA 17605-2425
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umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
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ppb parts per billion

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Analysis Report

Lancaster Laboratories

Lancaster Laboratories Sample No. WW 4067751

Collected: n.a.

Submitted: 06/19/2003 09:10
Reported: 06/30/2003 at 13:49
Discard: 08/30/2003
Trip_Blank Grab Water Sample

Account Number: 10160

DaimlerChrysler Corporation
PO Box 537933

Livonia MI 48153-7933

Site Code: SC001 RFA# ET03030
Dayton Thermal/Dayton, OH

030TB SDG#: DCN03-05TB*

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Method Detection Limit	Units	Dilution Factor
07105	Volatile Headspace Hydrocarbon					
07107	Ethane	74-84-0	N.D.	1.0	ug/l	1
07108	Ethene	74-85-1	N.D.	1.0	ug/l	1

Laboratory Chronicle

CAT No.	Analysis Name	Method	Trial#	Analysis Date and Time	Analyst	Dilution Factor
07105	Volatile Headspace Hydrocarbon	SW-846 8015B, modified	1	06/26/2003 11:31	Lisa A Johnson	1

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Lancaster Laboratories

Quality Control Summary

Client Name: DaimlerChrysler Corporation
Reported: 06/30/03 at 01:49 PM

Group Number: 856459

Laboratory Compliance Quality Control

Analysis Name	Blank Result	Blank MDL	Report Units	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Batch number: 03170011115B	Sample number(s): 4067747,4067749							
Total Organic Carbon	N.D.	0.50	mg/l	101		89-115		
Batch number: 03170834401A	Sample number(s): 4067747,4067749							
Ferrous Iron	N.D.	0.0080	mg/l	100		92-105		
Batch number: 03171022901A	Sample number(s): 4067747,4067749							
Sulfite	N.D.	1.2	mg/l	85		68-103		
Batch number: 03171105101A	Sample number(s): 4067747							
Nitrite Nitrogen	N.D.	0.015	mg/l	101		90-110		
Batch number: 03171105101B	Sample number(s): 4067749							
Nitrite Nitrogen	N.D.	0.015	mg/l	101		90-110		
Batch number: 03171400101A	Sample number(s): 4067748,4067750							
Chemical Oxygen Demand				100		95-107		
Batch number: 03173020201A	Sample number(s): 4067747,4067749							
Alkalinity to pH 4.5				100		98-103		
Batch number: 031731848006	Sample number(s): 4067747-4067750							
Iron	N.D.	0.0453	mg/l	104		91-114		
Manganese	N.D.	0.00051	mg/l	102		93-110		
Batch number: 03175155301A	Sample number(s): 4067747,4067749							
Chemical Oxygen Demand				92		84-108		
Batch number: 031760005A	Sample number(s): 4067747,4067749,4067751							
Ethane	N.D.	1.0	ug/l	93		80-120		
Ethene	N.D.	1.0	ug/l	95		80-120		
Batch number: 03176106101A	Sample number(s): 4067747,4067749							
Nitrate Nitrogen	N.D.	0.040	mg/l	101		90-110		
Batch number: 03176112501A	Sample number(s): 4067747,4067749							
Sulfate (turbidimetric)	N.D.	1.5	mg/l	97		90-110		
Batch number: 03177021602A	Sample number(s): 4067747,4067749							
Total Hardness	N.D.	0.49	mg/l as Ca	105		98-107		

Sample Matrix Quality Control

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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IU	International Units	**CP Units**	cobalt-chloroplatinate units
umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

< less than - The number following the sign is the limit of quantitation, the smallest amount of analyte which can be reliably determined using this specific test.

> greater than

J *estimated value – The result falls within the Method Detection Limit (MDL) and Limit of Quantitation (LOQ).*

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ppb parts per billion

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D	Compound quantitated on a diluted sample
E	Concentration exceeds the calibration range of the instrument
N	Presumptive evidence of a compound (TICs only)
P	Concentration difference between primary and confirmation columns >25%
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X,Y,Z	Defined in case narrative

Inorganic Qualifiers

B	Value is <CRDL, but ≥IDL
E	Estimated due to interference
M	Duplicate injection precision not met
N	Spike sample not within control limits
S	Method of standard additions (MSA) used for calculation
U	Compound was not detected
W	Post digestion spike out of control limits
*****	Duplicate analysis not within control limits
+	Correlation coefficient for MSA <0.995

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Quality Control Summary

Client Name: DaimlerChrysler Corporation Group Number: 856459
Reported: 06/30/03 at 01:49 PM

Analysis Name	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD MAX	BKG Conc	DUP Conc	DUP RPD	Dup RPD Max
Batch number: 03170011115B	Sample number(s): 4067747,4067749								
Total Organic Carbon	80		63-136			2.5	2.6	5* (1)	3
Batch number: 03170834401A	Sample number(s): 4067747,4067749								
Ferrous Iron	97	94	76-119	3	5	20.9	20.8	0	20
Batch number: 03171022901A	Sample number(s): 4067747,4067749								
Sulfite	51	46	29-104	10	20	N.D.	N.D.	200* (1)	20
Batch number: 03171105101A	Sample number(s): 4067747								
Nitrite Nitrogen	98		90-110			N.D.	N.D.	0 (1)	20
Batch number: 03171105101B	Sample number(s): 4067749								
Nitrite Nitrogen	99		90-110			N.D.	N.D.	200* (1)	20
Batch number: 03171400101A	Sample number(s): 4067748,4067750								
Chemical Oxygen Demand	95	93	90-110	1	2	1,240.	1,230.	1	4
Batch number: 03173020201A	Sample number(s): 4067747,4067749								
Alkalinity to pH 8.3						N.D.	N.D.	0 (1)	4
Alkalinity to pH 4.5	100	96	64-130	2	2	156.	158.	1	4
Batch number: 031731848006	Sample number(s): 4067747-4067750								
Iron	77	75	75-125	1	20	2.20	1.95	12	20
Manganese	95	94	85-111	0	20	0.520	0.488	6	20
Batch number: 03175155301A	Sample number(s): 4067747,4067749								
Chemical Oxygen Demand	99	103	61-118	3	6	65.7	65.0	1	7
Batch number: 031760005A	Sample number(s): 4067747,4067749,4067751								
Ethane	93	93	74-121	0	20				
Ethene	95	97	73-133	2	20				
Batch number: 03176106101A	Sample number(s): 4067747,4067749								
Nitrate Nitrogen	85*		90-110			14.6	15.4	5*	2
Batch number: 03176112501A	Sample number(s): 4067747,4067749								
Sulfate (turbidimetric)	101	99	69-124	2	4	45.5	46.1	1 (1)	4
Batch number: 03177021602A	Sample number(s): 4067747,4067749								
Total Hardness	102	98	93-115	1	2	2,820.	2,780.	1	4

Surrogate Quality Control

Analysis Name: Volatile Headspace Hydrocarbon

*- Outside of specification
(1) The result for one or both determinations was less than five times the LOQ.
(2) The background result was more than four times the spike added.

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umhos/cm	micromhos/cm	**NTU**	nephelometric turbidity units
C	degrees Celsius	**F**	degrees Fahrenheit
meq	milliequivalents	**lb.**	pound(s)
g	gram(s)	**kg**	kilogram(s)
ug	microgram(s)	**mg**	milligram(s)
ml	milliliter(s)	**l**	liter(s)
m3	cubic meter(s)	**ul**	microliter(s)

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> greater than

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Quality Control Summary

Client Name: DaimlerChrysler Corporation
Group Number: 856459
Reported: 06/30/03 at 01:49 PM

Surrogate Quality Control

Batch number: 031760005A

	Propene
4067747	96
4067749	88
4067751	101
Blank	102
LCS	104
MS	102
MSD	105
Limits:	74-120

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Section 2
HYDROGEOLOGY

DESCRIPTION

The glacial deposits that supply water to the City of Dayton are the outwash (or valley train) sand and gravel left by ice of two Wisconsinan substages. During these substages, glacial sediments were deposited within the Great Miami River bedrock valley.

The form of this bedrock valley was initially defined during the Teays Stage, before glaciation, and was modified (deepened by erosion occurring) during the Deep Stage, an interglacial period. The bedrock underlying the valleys and along the valley walls is shale and thin interbeds of limestone of Ordovician age, referred to as the Richmond Group (Norris and Spieker, 1966).

The boundaries of the Valley-Fill aquifer are defined by the shape of the bedrock-overburden contact (see Figure 2-1). The difference in permeability between the bedrock and the outwash limits lateral movement of the groundwater within the valley fill deposits. Groundwater flow within the Valley-Fill aquifer is approximately parallel to the bedrock valley walls.

AQUIFER COMPOSITION AND PHYSICAL PROPERTIES

The glacial valley fill deposits are not homogeneous in nature. The lithology varies over extremely short distances and with depth (see Figure 2-2). Tills and till-rich zones are interbedded within the sand and gravel outwash. Near the Miami Well Field, the till-rich zones do not appear to be continuous. However, localized vertical groundwater flow within the consolidated deposits may be slowed or impeded by the presence of these till-rich zones.

Transmissivities (or transmissibilities) of the Valley-Fill aquifer in the Dayton area are on the order of 100,000 to 250,000 gpd/ft (13,400 to 33,400 ft^2/d). Transmissivity is defined as the saturated thickness of the aquifer times the hydraulic conductivity (or permeability). Transmissivities over 200,000 gpd/ft (26,700 ft^2/d) have been recorded in the Miami Well Field (City of Dayton data, 1969).

The upper portion of the aquifer is unconfined while the lower portion of the aquifer is locally semiconfined. The storativity of the aquifer is defined as the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. The storativities of unconfined aquifers are much higher than the storativities of

confined aquifers. The higher values of unconfined aquifers reflect the fact that releases from storage in unconfined aquifers represent an actual dewatering of the soil pores whereas releases from storage in confined aquifers represent only the secondary effects of water expansion and aquifer compaction caused by changes in the fluid pressure (Freeze and Cherry, 1979). The thickness of the upper sand and gravel varies from 30 to 80 feet. The storativity of this portion of the aquifer has been estimated at 0.04 to 0.2. The lower portion of the aquifer (30 to 80 feet) has a storativity estimated from pump test data to be 0.0001 to 0.0006. Hydraulic conductivity values for the upper and lower portion of the aquifer have been estimated at 270 and 90 ft/day, respectively. (The hydraulic conductivity is defined as the volume rate of flow through the porous medium under a unit hydraulic gradient.)

Prior to development of the Miami Well Field, the hydraulic gradients in the area were approximately 0.003 ft/ft. Assuming an effective porosity of 0.30 and an average hydraulic conductivity of 150 ft/d, the average interstitial velocity of the groundwater flowing through the region was 1.5 ft/d. Assuming different hydraulic conductivity values for the upper and lower portions of the aquifer (270 and 90 ft/day) results in average interstitial groundwater velocities on the order of 3 and 1 ft/day, respectively.

To simulate the behavior of the aquifer, two groundwater flow models were developed. The regional model was used to model the Valley-Fill aquifer north of the southern end of the City of Dayton to the regions approximately 3½ miles upstream near the major dams located on the Great Miami River and its tributaries. The well field model was used to simulate flow in the region near the Miami North and South Well Fields. (Refer to Appendix A for a discussion of the development, calibration, and verification of the regional groundwater flow model and the development and calibration of the Miami Well Field groundwater flow model.)

After development of the Miami Well Field, a cone of depression has formed around the center of pumpage. According to model simulations, the influence of pumpage extends to the bedrock valley walls. Hydraulic gradients near the center of pumpage may be as high as 0.025 ft/ft. Groundwater interstitial velocities associated with these high gradients are 12.5 ft/d. Because the effect of pumpage diminishes with increased distance from the well field, hydraulic gradients north of the well field gradually decrease to approximately 0.003 ft/ft. Groundwater velocities accelerate as the water approaches the center of pumpage.

AQUIFER INFLOWS

There are five types of inflows supplying water to the Valley-Fill aquifer at the Miami Well Field:

- Inflow from the aquifer north of the well field,
- Precipitation recharge,
- Natural river bed recharge,
- Artificial lagoon bed recharge,
- Inflow (surface runoff and groundwater inflow) from adjacent uplands.

Inflows and aquifer boundaries are illustrated in Figure 2-3.

Inflow from the aquifer north of the well field contributes approximately 0.5 mgd of water to the well field. Inflow of water from the adjacent uplands is minimal (less than 0.1 mgd/mile of valley wall) compared to the other forms of natural inflow.

Approximately one-third of the precipitation that falls directly on the valley fill deposits infiltrates the groundwater. This flow varies seasonally but averages approximately 12 inches per year per unit surface area (Norris and Spieker, 1966). This amounts to approximately 1.7 mgd in the Miami Well Field area (CH2M HILL, 1982).

Natural recharge in the form of river bed leakage from the Great Miami River is estimated at 0.15 mgd/acre of river bed, amounting to approximately 7.5 mgd over the 2.6 mile well field river reach. Artificial recharge from recharge lagoon beds can generate 1.4 mgd/acre, according to the estimates made at the Mad River Well Field. Historic artificial recharge rates (mgd) for the Miami Well Field have not been accurately estimated.

Historically, the recharge lagoons at the Miami Well Field have failed to recharge water at these rates. As a result, water levels in the well field have declined with increased pumpage (CH2M HILL, 1982). Prior to development of the well field (1965), the groundwater levels were above 750 feet above mean sea level (msl). In the summer and fall of 1984, water levels were as low as 701 feet above msl.

Recent (September 1985) modifications in the design of these recharge lagoons have contributed to significant increases in well field groundwater levels. Between September 1985 and mid-January 1986, groundwater levels have risen 18 feet.

Continued commitment to the proper management of the existing artificial recharge system should result in an inflow of approximately 1.4 mgd/acre. The rate in terms of mgd is dependent on the area of the lagoons, in good hydraulic connection with the water table.

Appendix A

DAYTON REGIONAL AND MIAMI WELL FIELD GROUNDWATER MODELS

INTRODUCTION

The Dayton regional groundwater model was developed to help establish the boundaries and hydrogeologic conditions for use in a numerical model of the Miami River well field. The regional model was used to simulate pumping of the well field and to estimate the extent of the regional Valley-Fill aquifer affected by the pumping. The affected portion of the aquifer was examined in greater detail by a numerical model of the well field area with the hydraulic heads at the model boundaries set to a constant value taken from the results of the regional simulations. In addition to generating boundary conditions for the well field model, calibration of the regional model was used to estimate hydrogeologic parameters of the aquifer system.

The Miami Well Field Groundwater Model was developed to facilitate the study of groundwater development options and environmental protection in the Miami Well Field vicinity. Development options included installing new production wells and recharge basins, both in the present area of development (at the Miami South Well Field) and to the north (at the Miami North Well Field). Environmental protection studies included generating hydraulic gradients suitable for determination of travel times between potential source areas, monitoring wells, and production wells. Capture zones for the various development options were generated with an interest in which production wells would be effected by possible release of contaminants at various potential source areas. Also, drawdown cones were developed to determine if the required amount of groundwater withdrawal could feasibly be supplied by the proposed development option.

The model activities involved five major tasks:

- Collection of available data
- Determination of initial modeling parameters
- Calibration and verification of the regional model
- Conversion to the well field model
- Study of environmental protection and development options

The initial collection of data was accomplished by reviewing reports of previous hydrogeologic investigations of the area by Norris and Spieker (1966); the Ten-Year Master Plan for

the Dayton Water System by Black, Crow, and Eidsness (1970); the Ten-Year Master Plan Update by CH2M HILL (1984); and project files and notes provided by Paul Plummer of the Miami Conservancy District.

Modeling studies of the Valley-Fill aquifer at Dayton were undertaken by Fidler (1975) and later by Rebholz-Ukayli (1977). Fidler modeled the region as a single, continuous, isotropic, two-dimensional aquifer which was represented as semiconfined in the Rhorers Island area and unconfined elsewhere. Rebholz-Ukayli revised and updated Fidler's model by adjusting some of the hydrologic parameters used in the model and by including more recent pumpage records. The additional pumpage data included withdrawal from the Miami Well Field.

DEVELOPMENT OF CH2M HILL REGIONAL MODEL

COMPUTER CODE

The modular three-dimensional finite difference computer code developed by McDonald and Harbaugh (1984) was used to simulate groundwater flow in the Valley-Fill aquifer. The Strongly Implicit Procedure (SIP) was used to solve the finite difference equations for specific boundary conditions and discharge stresses.

REGIONAL MODEL AREA AND GRID SYSTEM

The Regional Model included the area from the Taylorsville Dam extending east to Huffman Dam. The northern boundary was placed at the Taylorsville Dam and the southern boundary was located at the groundwater divide south of downtown Dayton (Figure A-1). A rectangular finite difference grid consisting of 40 columns and 50 rows, similar to that of Fidler (1975) and Rebholz-Ukayli (1977), was used to model the area. The dimensions of each square grid-block was 1,000 ft. by 1,000 ft. The grid was oriented roughly 45 degrees from north-south as were the grids of Fidler (1975) and Rebholz-Ukayli (1977).

The Miami Model consists of approximately one fourth the area of the Regional Model. Designed to have the southern edges of the model at groundwater divides, the Miami Model encompassed columns 7-26 and rows 9-33 of the Regional Model. Node spacing is at 500 ft.

INPUT DATA

AQUIFER THICKNESS

The thickness of the glacial-outwash deposit ranges from 150 to 250 ft. (Norris and Spieker, 1966). This deposit consists of sand and gravel interbedded with discontinuous layers

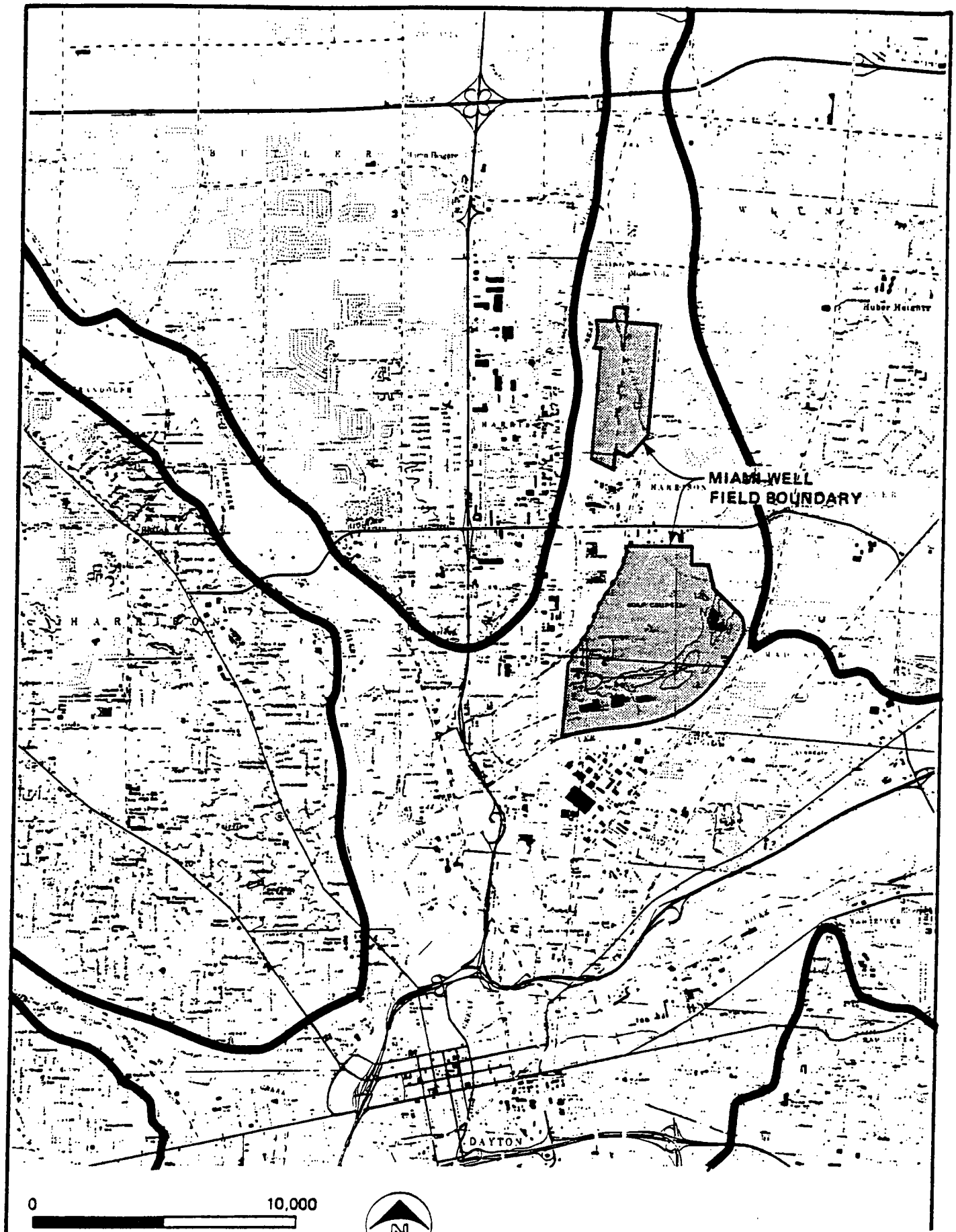
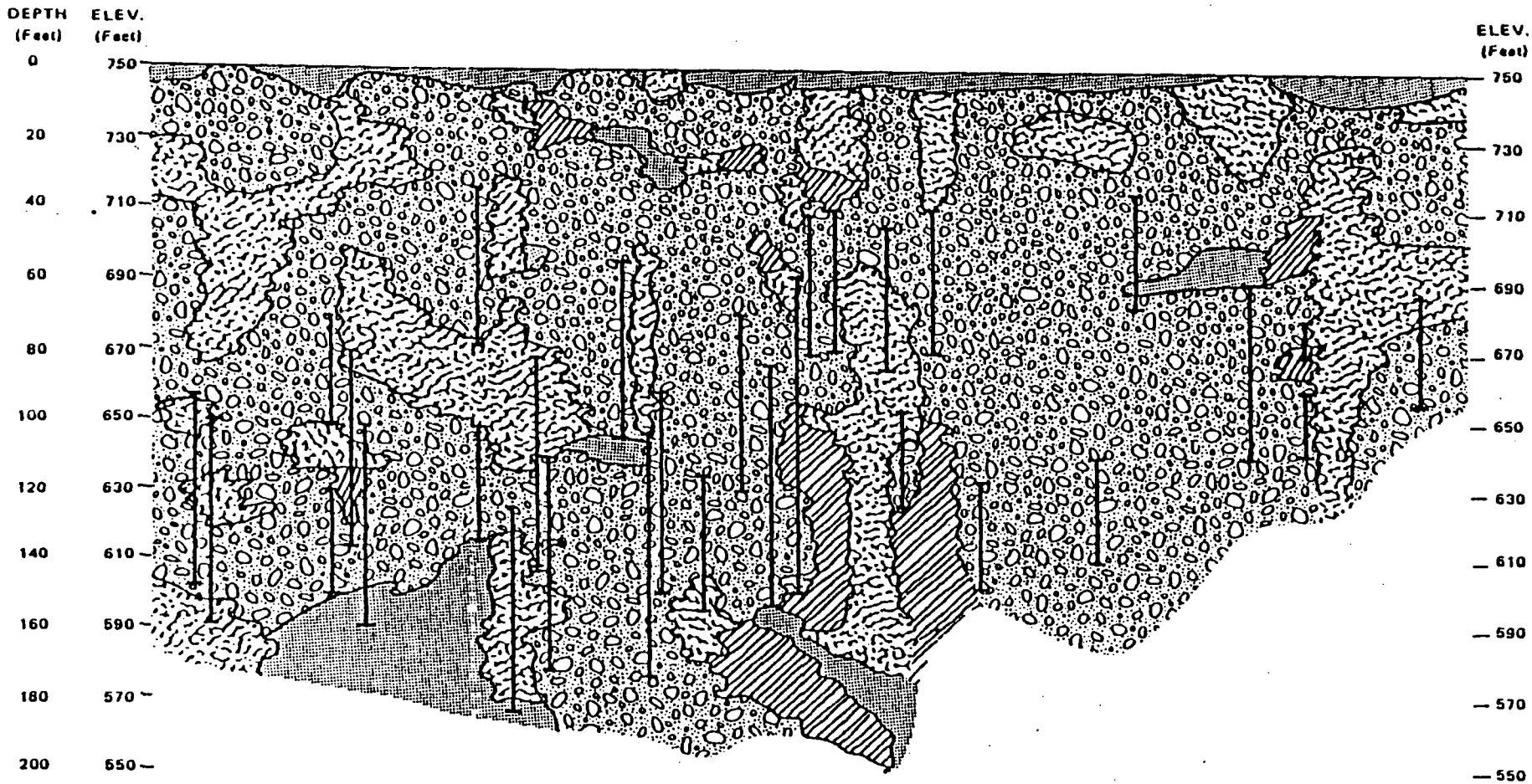


FIGURE 2-1
APPROXIMATE BEDROCK-VALLEY-FILL CONTACT

CH2M HILL



LEGEND

Sand, Gravel, Cobbles, Boulders

As Above, with Some Clay

As Above, with More Clay

Clay, Hardpan, Cemented Horizons

Screened Interval of Well

Horizontal Scale, ½" = 400'

Vertical Exaggeration, 20x

SOURCE: MIAMI WELL FIELD PRODUCTION WELL LOGS

FIGURE 2-2
COMPOSITE GEOLOGIC SECTION, SHOWING VARIABLE COMPOSITION OF VALLEY-FILL AQUIFER

CH2M HILL

and lenses of till which imperfectly separates the sand and gravel deposit into upper and lower aquifers. The upper sand and gravel aquifer is reported to have a thickness of 30 to 80 feet and to behave as an unconfined system. The lower aquifer is reported to behave as a semi-confined aquifer and may have a thickness of 30 to 80 ft. In areas where no till exists the glacial-outwash aquifer behaves as a single unconfined system (Norris and Spieker, 1966).

The Valley-Fill aquifer was modeled as upper unconfined and lower semi-confined permeable aquifers separated by a relatively impermeable layer with no storage, representative of the till-rich zones described by Norris and Spieker (1966). The upper aquifer was assumed to have a saturated thickness of 50 ft.

The thickness of the till-rich zone was estimated from available well logs. To conform to the conceptual model of two sand and gravel aquifers separated by a relatively impermeable layer, the thickness of the till-rich zone was taken as the cumulative thickness of all layers of silt, clay or till identified on the well logs. Contours of thickness of the till-rich zone (Figure A-2) were inferred from the cumulative thicknesses at each well location. Thicknesses of the till-rich zone at the model nodal points were extrapolated from the contours.

The bedrock was assumed to form an impermeable boundary below the lower aquifer, as was assumed for the models of Fidler (1975) and Rebholz-Ukayli (1977). The elevation of the top of bedrock was digitized from the bedrock surface contours presented in the report by Rebholz-Ukayli (Figure A-3).

The thickness of the lower aquifer at each nodal point was calculated by subtracting the top of rock elevation from the initial water level elevation (estimates of initial water level elevations will be discussed in a later section), and then by subtracting from this thickness the 50 ft. saturated thickness of the upper aquifer and the thickness of the till-rich zone. Contours of the calculated thickness of the lower aquifer are shown on Figure A-4.

HYDRAULIC CONDUCTIVITY

Each of the three layers in the models were assumed to be homogeneous and isotropic with respect to hydraulic conductivity. While both the upper and lower aquifers were represented in the models by isotropic layers, the overall representation of the Valley-Fill aquifer in the models is anisotropic due to the presence of the impermeable layer between the aquifers. A degree of anisotropy also resulted

from the use of different hydraulic conductivities for the upper and lower aquifers.

Reported values for the hydraulic conductivity of the sand and gravel aquifer in the Dayton region ranges between 1.55×10^{-3} to 4.64×10^{-3} ft/s (4.7×10^{-2} to 1.4×10^{-1} cm/sec). The upper aquifer is thought to have somewhat greater conductivity than the lower aquifer (Norris, 1959). The hydraulic conductivity of the till-rich zone has been reported to be 1.55×10^{-8} to 7.8×10^{-7} ft/s (4.7×10^{-7} to 2.4×10^{-5} cm/sec) (Norris and Spieker, 1966).

The final hydraulic conductivity values used in the models were 3×10^{-3} ft/s (9.1×10^{-2} cm/sec) for the upper aquifer, 4.4×10^{-7} ft/s (3.4×10^{-6} cm/sec) for the till layer, and 1×10^{-3} ft/s (3×10^{-2} cm/sec) for the lower aquifer. Those final values were chosen as a result of the process of model calibration (discussed in a later section).

At the locations within the modeled area where the till-rich zone did not occur between the upper and lower aquifers (that is, zero thickness of the till-rich zone), the leakance through the impermeable layer was adjusted so as to allow hydraulic connection of the upper and lower permeable layers. At these locations, the thickness of the impermeable layer was such that the leakance through the layer was approximately the same as the hydraulic conductivity of the upper permeable layer.

AQUIFER STORAGE

Values of aquifer storage were taken from the previous hydrogeologic investigations and modeling studies. The storage coefficient of the glacial-outwash aquifer is reported to range from 0.0003 to 0.003 ft/ft (Norris, 1959 and CH2M HILL Southeast, 1984). A value of 0.2 ft/ft was assigned to the upper aquifer, 0.0 ft/ft to the till layer, and 0.0001 ft/ft to the lower aquifer in the Regional Model and 0.0006 ft/ft in the Miami Model. Because of the extended aeration of pumping, neither model was sensitive to the storage coefficient.

AQUIFER RECHARGE

The sources of recharge to the upper aquifer incorporated into the model included uniformly distributed recharge from precipitation, infiltration from recharge basins and lakes, constant head model boundaries, and leakage from the rivers. The sources of recharge to the lower aquifer included leakage from the upper aquifer and Miami Well Field recharge basins and constant head model boundaries.

Areal recharge from precipitation is the depth of water over the entire model area which enters the upper aquifer as infiltration, expressed as a constant rate over a given period of time. The areal recharge of 7.5 in/yr ($2x10^{-8}$ ft/sec) taken from Fidler (1975) was used in the regional model.

In the model, recharge from rivers is dependent on the leakage factors of the riverbed and the differences between the river stage and the hydraulic head in the upper aquifer. Leakage factors were computed by multiplying the leakance of the riverbed by the percent of the model grid-block area covered by the river. Riverbed leakance has been reported to be in the range of $2.1x10^{-6}$ to $8.9x10^{-5}$ ft/sec ft (Ten-Year Master Plan). A leakance of $5.3x10^{-5}$ ft/sec ft was used in the models, and the percent of model grid block covered by the rivers were visually estimated from overlying the model grid on USGS topographic maps. River stages were estimated from USGS topographic maps, and for the Rhorers Island area, from ortho-topographic photographs of the Mad River Well Field (Woolpert Consultants, 1977).

Recharge from lakes and recharge basins was simulated in the same way as recharge from rivers. Each node designated as a lake or a recharge basin was assigned a value for stage or water level elevation, and for leakance. The stages of the lakes and recharge basins were taken off of USGS topographic maps or ortho-topographic photographs of the Mad River well field. Leakance values for the lakes, Mad River, recharge basins, and Miami River recharge basins were $5.0x10^{-7}$, $5.0x10^{-5}$, and $2.0x10^{-5}$ ft/sec-ft respective. The leakance value for lakes was chosen to be lower than that for rivers since lake bottom siltation is not periodically scoured as is river bottom siltation. The recharge basins are periodically dredged and therefore they were assigned a leakance value greater than that for the rivers.

In the models, recharge from rivers, lakes, and recharge basins could occur only to the upper aquifer. The only exception is in the Miami recharge basins where the construction of the basins allows for recharge to the lower aquifer. To simulate the possible bottom depth of rivers, lakes, and recharge basins, maximum hydraulic head differences between the surface water and groundwater levels were specified. If, during the model simulations, the head differences exceeded the maximum values, the surface water body essentially became "perched" above the water table.

For the Great Miami River and the Mad River, the maximum head difference was set at 10 ft. For the Stillwater River and Wolf Creek, the maximum head difference was set at 5 ft. It was assumed that the river stages remained constant during the simulations. The maximum head difference allowed for recharge basins was 10 ft. Since the depths of lakes in the

model are unknown, the maximum allowable head difference was set at 100 ft., thereby allowing for a saturated hydraulic connection between the lakes and the 50 ft. thick upper aquifer.

GROUNDWATER DISCHARGE

The groundwater models included groundwater discharge to pumping wells, to constant head boundaries, and to rivers. Leakage to the rivers was only allowed to occur from the upper aquifer.

Pumpage for municipal and industrial use accounts for the majority of the aquifer discharge in the modeled region. Fidler (1975) used estimates of pumpage and water use inventories compiled by Norris and Spieker (1966) for 10-year intervals from 1900 to 1950, and by the Miami Conservancy District for 1954 to 1955. Rebholz-Ukayli (1977) added pumpage data collected by the U.S. Geological Survey and the Miami Conservancy District in 1972 and 1975.

Pumpage of groundwater was separated into eight pumping periods. Pumping periods and rates are summarized in Table A-1. The locations of model nodes from which pumping was simulated are shown in Figures A-5a and A-5b. The location and rate of pumpage for pre-1941 to 1972 (excluding the upper aquifer at Rhorers Island) were taken from Rebholz-Ukayli (1977). The discharge rates for wells in the upper aquifer at Rhorers Island were calculated by subtracting lower-aquifer pumping rates used in the Rebholz-Ukayli model from total pumpage from Rhorers Island. The difference was equally distributed among active upper aquifer wells at Rhorers Island.

To derive the pumpage for 1973 to 1984, it was assumed that pumpage for areas other than Miami River and Rhorers Island municipal well fields remained the same as in 1972; it was assumed that this pumpage occurred from the lower aquifer, except where it was less than 20 ft thick. Pumpage for this period from the municipal well fields was derived from records obtained from the Miami Conservancy District and the City of Dayton. It was assumed that pumpage from the Miami River well field occurred from the lower aquifer only. At the Mad River well field, it was assumed that the ratio of pumpage from the upper and lower aquifers was the same as in 1972. Pumpage from individual wells in the lower aquifers at the municipal well fields were proportioned on the basis of individual well pumping rates provided by the Miami Conservancy District and documented by Rebholz-Ukayli (1977).

BOUNDARY AND INITIAL CONDITIONS

Table A-1
PUMPING PERIODS AND RATES

Time Period	Total (mgd)	Miami River Well Field (mgd)	Mad River Well Field Upper (mgd)	Mad River Well Field Lower (mgd)	Other Wells (mgd)
Before 1941	37.1	1.2	14.8	1.0	20.1
1941 - 1946	56.2	2.0	18.0	11.0	25.2
1947 - 1950	70.1	2.9	26.0	11.0	30.2
1951 - 1954	78.6	2.8	28.9	13.0	33.9
1955 - 1960	83.9	2.8	29.2	15.0	36.9
1961 - 1972	102.9	9.1	38.8	19.2	35.8
1973 - 1984	96.0	20.3	26.4	14.3	35.0
1985 - 1986	118.4	42.7	26.4	14.3	35.0

GLI579/10

Constant hydraulic head boundaries incorporated into the Regional Model are shown on Figure A-5a and A-5b. The southwest boundary was defined as a no-flow boundary. This boundary was located approximately at a groundwater divide located in downtown Dayton between two areas of significant pumping. The bedrock walls of the valley were designated as no-flow boundaries. The boundaries of the Miami Model were designated as constant head.

Initial groundwater level elevations were derived from river stages indicated on USGS topographic maps. It was assumed that river stages were representative of elevations of both the water table and the potentiometric surface in the lower aquifer. The river stage elevations were contoured and the initial groundwater levels in both the upper and lower aquifers were extrapolated from the contours. Hydraulic heads at the constant head boundaries were also extrapolated from the river stage contours. It was assumed that at any point within the model area, the initial groundwater elevations were the same in both the upper and lower aquifers. The initial groundwater elevations used in the model are shown in Figure A-5a and A-5b.

MODEL CALIBRATION AND VERIFICATION

The initial model simulations incorporated values of the input data which were obtained from the previous hydrogeologic investigations and modeling studies. Values of hydraulic conductivity of the upper and lower aquifers, of leakance through the till-rich zone, and of leakance through the bottoms of rivers, lakes, and recharge basins were adjusted during the process of model calibration. The initial and adjusted values of the model input data are summarized in Table A-2.

The regional model was calibrated against water levels in the lower aquifer measured by Norris and Spieker in 1959 to 1960 (1966). Contours generated by the regional model using 1959-1960 well pumping rates were compared to the Norris and Spieker data. The regional model was verified by comparing computer generated contours to water level measurements in June 1972 by Rebholz-Ukayli (1977). The contours generated by the regional model and water level measurements are shown in Figure A-6 for the model calibration comparisons, and in Figure A-7 for the model verification comparisons.

Further verification of the Mad River area along with calibration of the Miami area was made possible by the collection of water levels in January 1986. During the calibration of the Miami area, it was determined that 2.0×10^{-5} provided a better value for leakance for the Miami River recharge basins than those determined for the Mad River recharge

Table A-2

INITIAL AND FINAL VALUES FOR MODEL INPUT DATA

Parameter	Initial Value	Final Value
Hydraulic Conductivity (ft/sec)		
Upper Aquifer	0.00116*	0.003
Lower Aquifer	0.00116*	0.001
Till	0.55×10^{-7}**	4.4×10^{-7}
Storativity (ft/ft)		
Upper Aquifer	0.2*	0.2
Lower Aquifer	0.0001*	0.0001
Till	0	0
Recharge by Precipitation (ft/sec)	2.0×10^{-8}	2×10^{-8}
Leakance (ft/sec-ft)		
River	2.0×10^{-7}***	5.3×10^{-5}
Lake	2.0×10^{-8}***	5.0×10^{-7}
Lagoons: Mad	2.0×10^{-6}***	5.0×10^{-5}
Miami		2.0×10^{-5}

* Taken from Fidler

** Average value of values used by Rebholz-Ukayli

*** Assumed

GLT579/11

basins. Results of the simulation of the January 1986 modeling results are presented in Figure A-8.

Further documentation of the Miami Well Field model is presented in Appendix A of the Development Plan.

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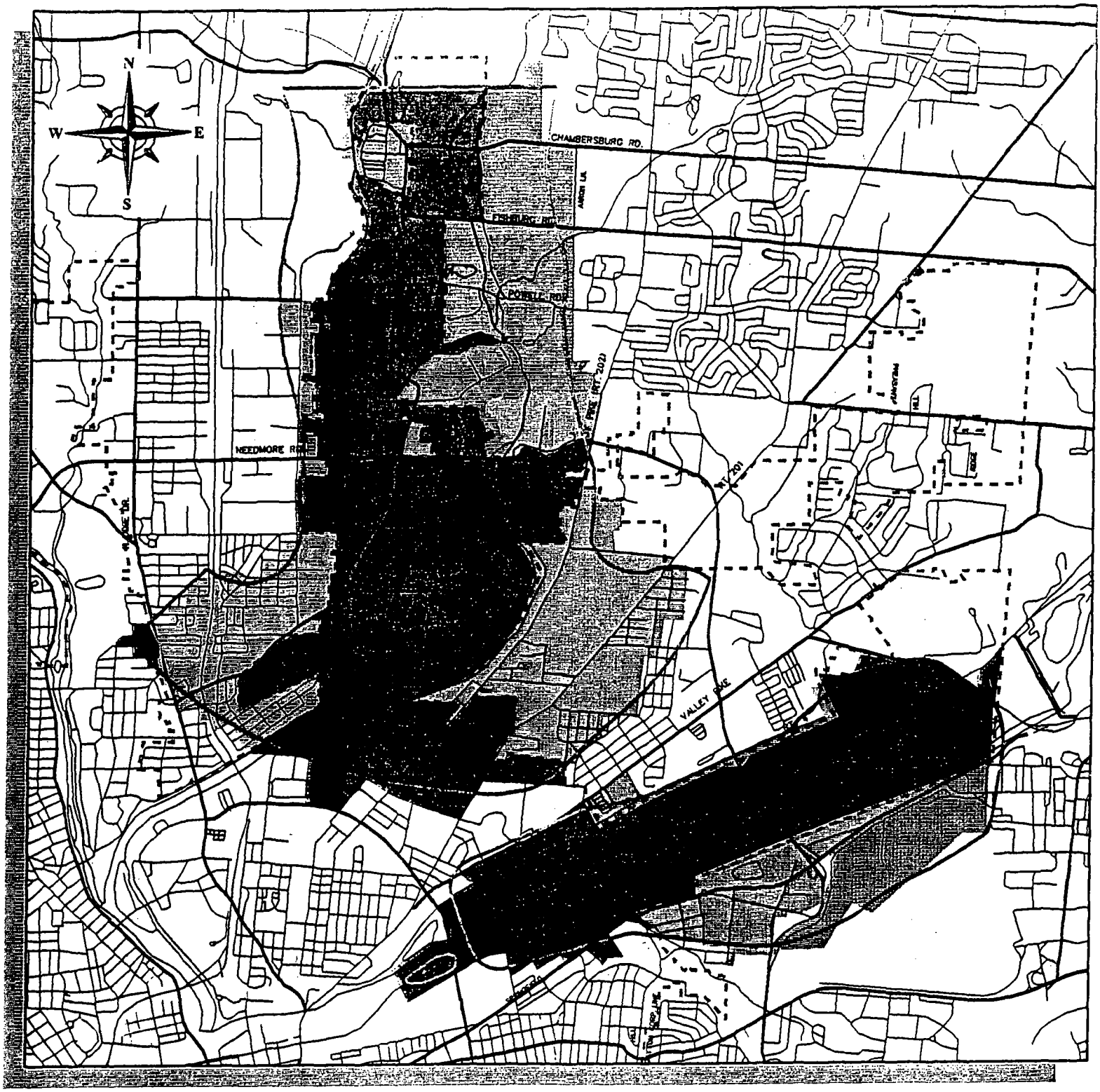
GLT579/38



DESIGNATED WELL FIELD PROTECTION AREA

- DAYTON
- VANDALIA
- WRIGHT PATTERSON AFB
- HARRISON TWP.
- HUBER HEIGHTS
- RIVERSIDE

CAPTURE AREA BOUNDARY

TECHNICAL MEMORANDUM

TO: Bill Zilli/City of Dayton
Dusty Hall/City of Dayton
George Crosby/City of Dayton
Abe Martin/City of Dayton
Bruce Henkel/City of Dayton
Martha Schwendeman/City of Dayton
Dave Mason/City of Dayton
Drew Diefendorf/CH2M HILL

FROM: Pixie Newman/CH2M HILL
Toni Pezzetti/CH2M HILL

DATE: December 8, 1988

RE: Miami South Well Field Source Investigation Results and Recommendations

PROJECT: GLO21573.G0.13

INTRODUCTION

Low levels of volatile organic compounds (VOCs) have been detected in the City of Dayton's Miami South Well Field (referred to herein as Miami South), as has groundwater contamination both upgradient and south of the well field. In response to these findings, the City of Dayton retained CH2M HILL to conduct an evaluation of current water quality conditions, local hydrogeologic conditions, and monitoring well coverage south of the well field. These activities, including recommendations regarding future investigations, constitute the Miami South Source Investigation (MSSI). This memorandum summarizes the study results, methodologies used, and recommendations made to the City of Dayton.

BACKGROUND

The MSSI study area contains disposal, industrial, and residential areas. It is bounded to the west by I-75 and Wagoner Ford Road, to the north by the Miami Water Treatment Plant, to the east by the eastern edge of Valley Crest Landfill, and to the south by the southern edge of Brandt Pike Tank Farm (referred to herein as the tank farm) (Figure 1). Four areas historically used for dumping are Wagoner Ford Landfill, located due west of Miami South, and the Valley Crest, Brandt Park (Hotopp) and Cripps Landfills, all located south and southwest of Miami South. The tank farm is a petroleum bulk storage facility located to the south of the well field. Industrial areas generally cover the western half of the study area. Residential areas are mainly in the eastern portion of the study area, with smaller clusters of private homes scattered throughout the study area (Figure 2).

Two monitoring wells that are part of the City's groundwater monitoring well network are on the south side of the Great Miami River (MW-28S) and immediately to the north of the tank farm and near the northwest corner of Valley Crest Landfill (MW-27S). VOC contamination has been detected in both wells. Trichloroethylene (TCE), 1,2-dichloroethyene (DCE), trichloroethane (TCA), and 1,1-dichloroethane (DCA) have been detected in MW-27S, and low levels of tetrachloroethylene (PCE) have been detected in MW-28S (see Appendix A). Free petroleum has been observed, as reported on installation reports submitted to the Ohio Department of Natural Resources, in tank farm monitoring wells located approximately 1/2 mile south of the well field. Benzenes, aliphatics, and other contaminants associated with petroleum products have also been found in the groundwater at the tank farm (see Appendix A). In 1986, 383 tons of PCE-contaminated materials (including soils and waste oil) were removed from the Van Dyne Crotty facility site northeast of the tank farm (OEPA, 1987). In 1988, PCE-contaminated groundwater (see Appendix A) was found at a tank farm monitoring well immediately adjacent to the Van Dyne Crotty property.

METHODOLOGY

Information was collected from the following sources:

- City of Dayton - water level data, city well logs, and organic and inorganic water quality data
- Ohio Department of Natural Resources - private well logs
- Miami Conservancy District (MCD) - water level data and some private well logs
- Ohio Environmental Protection Agency (OEPA) - VOC water quality data

Identified well logs were located on the study area base map. After determining the June/July 1988 potentiometric surface within the study area (Figure 3), four geologic cross sections were constructed (Figure 4). Water quality data was summarized and plotted on the base map.

RESULTS

GEOLOGY

The general lithology of the Miami Valley Aquifer consists of sands and gravels with interspersed tills. The cross sections (Figure 4) illustrate the generally discontinuous nature of the tills in the study area, although some thicker tills appear to be more laterally continuous (see Figure 4b). In general, tills appear to be thin and less horizontally extensive in the well field and in the eastern part of the study area. The thick till interval illustrated in cross section B-B' can be traced from the Great Miami River to the southern end of the cross section. Because of the shallow depth of the monitoring wells at the tank

farm, the presence of this till beneath the northern portion of the farm has not been confirmed.

Few geologic logs from the southwest (industrial) portion of the study area were available at the public agencies from which information for this study was obtained. Additional wells may exist in this area, but information regarding them is not on file at the agencies.

HYDROGEOLOGY

Based on the available geologic data the Great Miami Buried Aquifer probably behaves as one hydrostratigraphic unit within and east of the well field. The till layer causes the aquifer to act as two units south of the well field.

Available water level information is limited to what has been collected by the City of Dayton for its monitoring and observation well network and by MCD at selected residential and industrial wells in the area. Although data for areas outside the well field are sparse, a potentiometric surface map was prepared using June/July 1988 water level data (Figure 2). The cone of depression in the well field is similar to that illustrated in historic water level maps. Gradients toward the cone of depression (measured off the June/July potentiometric surface map) were found to be 0.005 ft/ft along A-A', 0.008 ft/ft along B-B', and 0.009 ft/ft along C-C'.

Based on field test results (Battelle Columbus Division, 1987) and modelling data (CH2M HILL, 1986) the hydraulic conductivity for the aquifer in the study area is 60 to 260 ft/day. Assuming that the average effective porosity is 0.25 (based on the known specific yield of 0.20 [Norris and Spieker, 1966]), resulting groundwater flow velocities would be on the order of 1.9 to 8.6 ft/day toward the well field. At these rates, groundwater and nonreactive contaminants flowing by advection from the northern edge of the tank farm would travel to City well P-9 in approximately a 1 to 3 year period.

WATER QUALITY

The general distribution of known VOC contamination within the groundwater (Figure 5 and Appendix A) indicates that up to seven distinct contaminant plumes may be migrating into the well field. (Note: water quality data from February 4, 1983 were not used in contructing Figure 5 because presence of most contaminants indicated by these results has not been confirmed in subsequent sampling events.) Plumes B through G were identified during this investigation. The VOCs detected, VOC concentrations, and other characteristics of Plumes B through G are summarized in Table 1. Plume A is being investigated separately and is not discussed in detail in this memorandum.

Sparse water quality data exist for most areas outside Miami South. Coverage of water quality data outside the well field is provided only by occasional testing of private wells, MW-27S and