In cooperation with the
U.S. Environmental Protection Agency

Evaluation of Ground-Water/Surface-Water Relations, Chapman Creek, West-Central Ohio, by Means of Multiple Methods

Water-Resources Investigations Report 01–4202

U.S. Department of the Interior
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By Denise H. Dumouchelle

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U.S. Department of the Interior
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Columbus, Ohio
2001

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
acre	0.4047	square hectometer
	Volume	
gallon (gal)	3.785	liter
	Flow Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature is given in degrees Celsius (^oC), which can be converted to degrees Fahrenheit by use of the following equation:

$$^oF = 1.8\,(^oC) + 32$$

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 1929) - a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Evaluation of ground-water/surface-water relations, Chapman Creek, west-central Ohio, by means of multiple methods

By Denise H. Dumouchelle

Abstract

Chapman Creek, a tributary to the Mad River, passes within about 500 feet of a landfill near Tremont City, in Clark County, west-central Ohio. In autumn 2000, the ground-water/surface-water relation was investigated by use of piezometers, seepage meters, temperature monitors, and a gain-loss study. Four piezometers were installed in the streambed along about a 1-mile reach, inclusive of the landfill. Four seepage-meter tests were done at locations near two of the piezometers. Four temperature-monitoring stations were established along a reach of about 700 feet near the landfill. A fifth temperature station was located near a piezometer about 3,000 feet downstream from the landfill. A streamflow gain-loss study was done over a 3-mile reach that included the reaches studied with the other methods. The data from the piezometers, seepage meters, and temperature monitors indicated an apparent change from losing to gaining and back again several times over fairly short distances. The gain-loss data indicated that the creek was consistently a gaining stream over the 3-mile reach. Investigation of streambed conditions and local geology revealed that the streambed consists of sand and gravel overlying a fine-grained till layer. The stream water readily moves in and out of the coarse streambed such that the piezometers, seepage meters, and temperature monitors measured the local flow in the streambed; therefore, these data did not reflect the true relation between the creek and ground water. On the other hand, the gain-loss study, less affected by the movement of water in the streambed, showed that Chapman Creek probably is a gaining stream throughout the 3-mile reach.

Introduction

Chapman Creek, a tributary to the Mad River, drains a rural area of about 24 mi^2 in west-central Ohio (fig. 1). About 1.8 mi upstream from the Mad River is the Tremont City landfill, a 58-acre site. The southern boundary of the landfill is within about 500 ft of Chapman Creek. Local residents have expressed concern regarding the potential effects of ground-water flow from the landfill on the quality of water in the creek (U.S. Environmental Protection Agency, 2000). Initial investigations based on stream levels and water-level data from landfill monitoring wells indicated that Chapman Creek changed from a losing to a gaining stream at about the midpoint of the reach adjacent to the landfill (Eagon and Associates, 1992). To obtain a better understanding of the ground-water/surface-water relations of Chapman Creek, the U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency, did a study in autumn 2000.

Purpose and scope

The purpose of this report is to present data on and describe the ground-water/surface-water relations along a reach of Chapman Creek. Findings are based on a multipart study in autumn 2000 during which four piezometers, two seepage meters, and five stream/streambed-temperature monitors were installed in the creek and a streamflow gain-loss study was done.

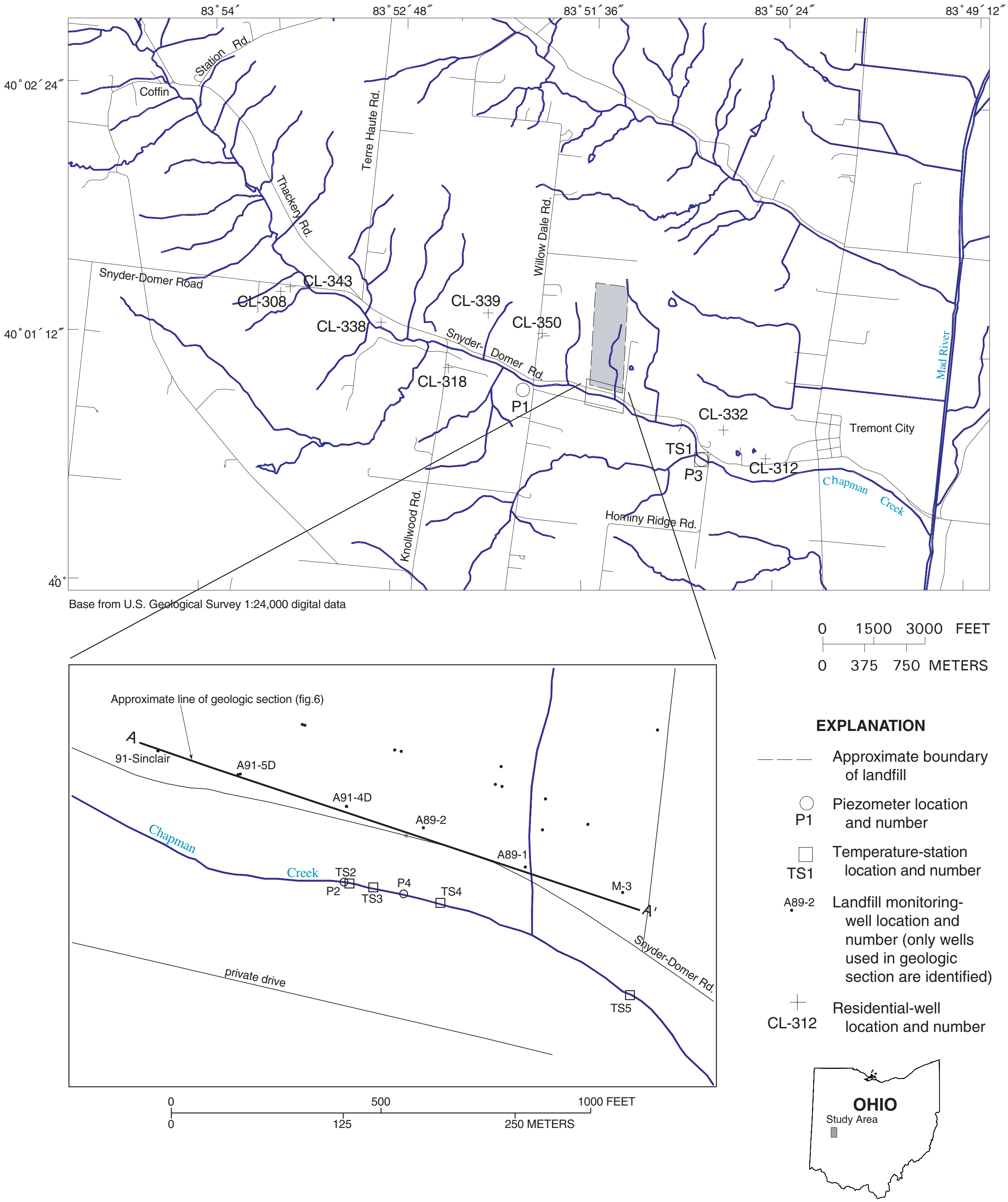

Figure 1. Location of study area in west-central Ohio.

Description of the study area

The study area is in Clark County, Ohio, about 1 mi west of Tremont City (fig. 1). The topography is characterized by nearly level till plains with minor relief due to erosion and glacial features. Buried bedrock valleys, filled with glacial sediments, are present in the area. The bedrock underlying the glacial sediments consists of limestone and dolomite of Silurian age. The glacial sediments consist of fine-grained tills and minor sand-and-gravel deposits. The glacial deposits and the carbonates are used for water supplies in the area (Norris and others, 1952). The reach of Chapman Creek from Coffin Station Road to Hominy Ridge Road was investigated, with emphasis on the reach near the landfill (fig. 1). In the study area, Chapman Creek generally is less than 2 ft deep and has a coarse streambed ranging from fine sand to large cobbles and boulders. In many places the creek is incised about 10 to 15 ft below the adjacent land.

Methods

The interaction of surface and ground water can be investigated by means of various methods. Four methods were used in this study: streambed piezometer, seepage meter, instream temperature monitor, and streamflow measurement (gain-loss study). Each method provides different data on the hydraulic relation between the stream and the ground water. Piezometers measure the vertical gradient through the streambed. Seepage meters can indicate vertical flow directions. Temperature monitors can indicate areas of inflow or outflow from the stream. Streamflow gain-loss studies can measure gains from or losses to the ground-water system.

Streambed-piezometer method

The vertical hydraulic gradient between the stream and ground water, an indication of flow directions, can be determined by comparing the water level in a streambed piezometer with the water level of the stream. Four piezometers were installed in the streambed of Chapman Creek (fig. 1). Each piezometer consisted of a 1.25-in.-diameter pipe with either a 12 in.- or 18-in.-long wire-wrapped stainless steel screen with a drive point at the bottom. Although the screens were relatively long (12–18 in.) the tops of these screens were set 2.5 to 3 ft below the streambed, a depth that should be adequate to provide data on vertical gradients.

The piezometers were installed by pounding the pipe into the streambed. Three piezometers (P1–P3) were installed in early September 2000, and the fourth (P4) was installed about a month later. P1 was set just upstream from the Willow Dale Road bridge, P2 and P4 were across from the landfill, and P3 was just upstream from the Hominy Ridge Road bridge (fig. 1). The top of the screens of P1 and P3 were set about 3 ft below the streambed; P2 and P4 were about 2.5 ft below the streambed. P1, P2, and P3 were roughly in the center of the stream, whereas P4 was adjacent to the bank. Water levels were measured with an electric or chalked-steel tape and are considered accurate to $\pm$ 0.02 ft. The piezometers were measured about once a week until early November.

Seepage-meter method

Seepage meters (Lee, 1977) can be used to determine streambed permeability and flow directions. A seepage meter measures flux between ground water and surface water by isolating an area of streambed and measuring the change in water volume over time. Each meter was constructed from the end section of a 55-gal drum. A rubber stopper was fitted into the bunghole of the drum, and the stopper was connected with flexible tubing to a sealed plastic bag. A temporary piezometer was installed next to the seepage meter to measure the difference in head between the stream and the water table. Trapped air was allowed to escape as the open end of the drum was driven into the streambed.

Streambed conditions are an important consideration in the installation. Sand, silt, and/or soft clay with little or no gravel provide the best seal and are the easiest materials to drive the meter into, whereas gravel and cobbles provide a poor seal by interfering with the penetration of the meter. After installation, a collection bag with a known volume of water was connected to the meter. Later, the amount of water in the bag was measured. A decrease in volume indicated that the stream was losing water; an increase indicated that ground water was flowing to the stream. On October 12, four seepage-meter tests were done at two locations. The first location was about 10 ft downstream from P2 and the second, about 50 ft upstream from P3 (fig. 1).

Temperature-monitor method

Continuous, simultaneous temperature measurements of stream water and water in the streambed can indicate the gain of ground water or the loss of surface water. A contrast between the stability of ground-water temperature and daily variability of stream-water temperatures can result in an indication of ground-water inflow to a stream. In a strongly gaining stream, the temperature of water in the streambed will be controlled largely by advection from the ground water and would be expected to be relatively constant for days. In a strongly losing stream, the temperature of water in the streambed will mimic the stream-water temperature, and the average temperature will be close to the average stream-water temperature. If there is no flow between the stream and ground water, the temperature of the water in the streambed will vary during the day like the stream water, but the average temperature will be between the stream-water temperature and that expected from subsurface geothermal gradient (Silliman and Booth, 1993).

Five temperature stations (TS1–TS5) were established in Chapman Creek between piezometer stations P2 and P3 (fig. 1). All were installed on October 20, 2000; four were removed in early November, and the fifth in early December. Each station consisted of a steel fencepost driven into the streambed and two temperature data loggers, each encased in a waterproof container. The data loggers used are rated from -20^{o} to 70^{o} C with a resolution of $\pm$ 0.4^{o}C and are accurate to $\pm$ 0.7^{o}C. At each station, one logger was secured to the fencepost so that the case was resting on or just above the streambed (fig. 2). The second logger was buried 6 to 8 in. into the streambed, secured to the fencepost by a length of cable. Streambed sediments ranged from sand to gravel and cobbles. Temperature was recorded hourly.

Gain-loss study

On October 25, 2000, a streamflow gain-loss study was done on Chapman Creek from Coffin Station Road to Hominy Ridge Road, a reach of about 3 mi (fig. 1). The study was done during a period of low flow—155 ft^3/s on the nearby Mad River, which is about 73 percent of the flow-duration curve for the Mad River (Straub, 2001)—to minimize surface flows from runoff or precipitation. The study consisted of four streamflow measurements along Chapman Creek and six measurements on tributaries; all other tributaries were dry. Prior to the study, a reference point for measuring stream stage was established and the measurement sites were chosen to ensure that the channel was stable. Streamflow measurements were made according to the methods outlined by Rantz and others (1982), either the conventional current-meter (wading) method or the volumetric method. The gain or loss of water over the reach was determined by subtracting the difference between two mainstem measurements and then subtracting the tributary

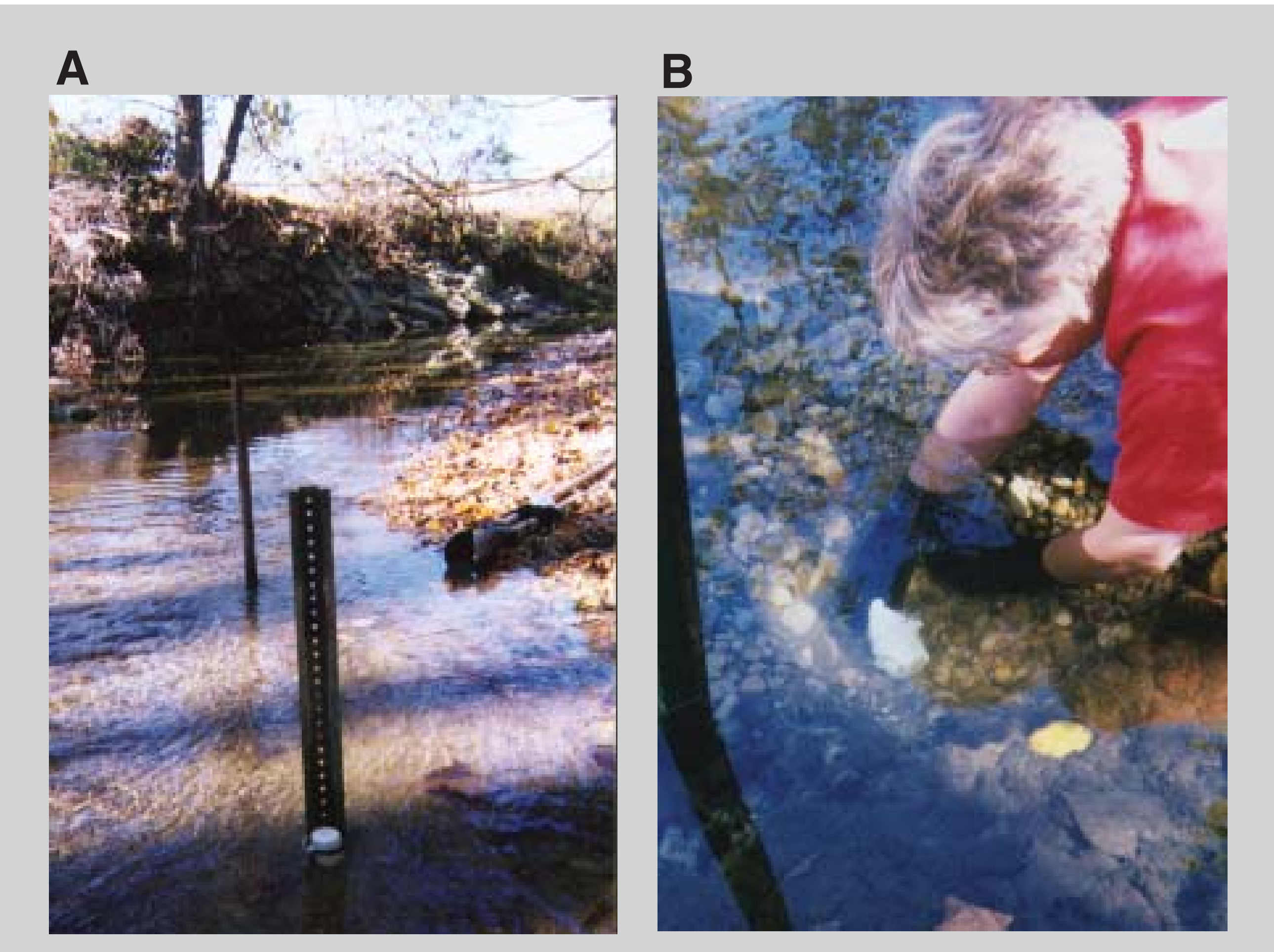

Figure 2. Temperature-monitoring equipment in Chapman Creek, west-central Ohio. Note the piezometer in the background (upstream) of A and the coarse streambed in B.

inputs. If the result was negative, the reach was losing; if positive, the reach was gaining.

Ground-water/surface-water relations

Results from the individual methods

Streambed piezometers. Data from the piezometers are listed in table 1. Although the differences in water levels measured in the piezometers and the creek were quite small, P2 and P3 consistently showed lower water levels than the stream, indicating streamflow loss. Measurements at P1 also indicate streamflow loss; however, given the accuracy of the measurements, the differences in some of water levels are small enough (0.03 ft) to cast doubt on whether the stream is really losing water. In three out of four measurements at P4, water levels in the piezometer were higher than the stream, indicating ground-water flow into the stream; the fourth measurement indicated a loss of streamflow.

The data from P1–P3 consistently indicated streamflow loss; however, the data from P4 indicates that gradients between the stream and ground water might be changing for at least a short reach in the vicinity of the landfill. A change from a losing to a gaining stream in this area is consistent with the earlier study (Eagon and Associates, 1992).

Seepage meters. Results of the seepage-meter tests are listed in table 2. The streambed at the P2 site consists of

Table 1. Piezometer data for Chapman Creek, west-central Ohio

[P1, piezometer; ft, feet; bmp, below measuring point; ---, no data; negative differences in water levels indicates flow into the aquifer, postitive differences indicates flow into the stream]

	P1			P2			P3			P4		
Date 2000	Piezometer water level (ft, bmp)	Stream level (ft, bmp)	Water-level difference	Piezometer water level (ft, bmp)	Stream level (ft, bmp)	Water-level difference	Piezometer water level (ft, bmp)	Stream level (ft, bmp)	Water-level difference	Piezometer water level (ft, bmp)	Stream level (ft, bmp)	Water-level difference
09-08	2.32	2.24	-0.08	---	----	---	2.35	2.27	-0.08	---	---	---
09-13	---	---	---	3.13	3.11	-0.02	2.33	2.23	-.1	---	---	---
09-27	2.27	2.20	-.07	3.14	3.09	-.05	2.32	2.24	-.08	---	---	---
10-4	2.28	2.23	-.05	3.15	3.11	-.04	2.34	2.24	-.1	---	---	---
10-12	2.31	2.28	-.03	3.10	3.03	-.07	2.27	2.19	-.08	1.93	2.05	0.12
10-20	2.30	2.27	-.03	3.08	3.02	-.06	2.27	2.17	-.1	1.96	2.08	.12
10-25	2.31	2.28	-.03	3.08	3.00	-.08	2.29	2.22	-.07	1.96	1.90	-.06
11-2	2.31	2.26	-.05	3.05	3.02	-.03	2.31	2.22	-.09	1.92	2.08	.16

Table 2. Seepage-meter data for Chapman Creek, west-central Ohio

[P2, piezometer; mL, milliliters; min, minutes]

Test location	Initial volume (mL)	Ending volume (mL)	Change in volume (mL)	Time (min)	Difference in temporary piezometer-stream levels (feet)
Near P2	200	121	-79	98	-0.04
Near P2	200	124	-76	102	-.04
Near P3	200	334	134	110	-.11
Near P3	200	406	206	90	-.02

fine sand with numerous cobbles. The cobbles made installation of the meter difficult and may have prevented a good seal. Because of difficulties installing the seepage meter, the two tests were done without removing and resetting the meter. A temporary piezometer was installed near the meter, the top of the piezometer screen being set to a depth of about 1 ft into the streambed. Both tests ran longer than 1.5 hours, and in both tests the seepage meter lost water (table 2), indicating a losing stream. Water levels in the temporary piezometer and P2 also indicated a losing stream (tables 1 and 2).

The streambed at the site upstream from P3 consists of fine to coarse sand. A temporary piezometer was installed near the meter to a depth of about 1 ft into the streambed. Two tests were done; between tests the meter and temporary piezometer were removed and reset at an adjacent location about 10 ft apart. In both tests, the seepage meter gained water, indicating a gaining stream, but the temporary piezometer and P3 (downstream) indicated a losing stream. Although the stream could alter from gaining to losing in the distance from the test sites to P3 (about 50 ft), the temporary piezometer was set within 5 ft of the meter, and a change in stream conditions between that piezometer and the meter is improbable, particularly given that both were moved between tests. On the basis of the sandy streambed and consistent gain in volume in both tests, it appears unlikely that the seepage meter was improperly set; however, the time after installation may have been too short for the water level in the temporary piezometer to stabilize.

Stream-water and streambed-temperature monitors. Channel conditions at the temperature stations and the average temperatures recorded are listed in table 3. The coarse streambed at stations TS3 and TS4 necessitated the addition of sand to help bury the streambed temperature monitor. At all stations, the streambed temperature mimicked the stream-water temperature. The changes in streambed temperatures were offset slightly from the stream-water temperatures, although the offset is barely noticeable at station 1, where the period of data collection was the longest (fig. 3). No substantial difference is apparent between the average streambed and stream-water temperatures or between stations; lower averages at station 1 are caused by the additional month of data. The similarity of the streambed and stream-water temperatures may indicate a strongly losing stream (Silliman and Booth, 1993).

Streamflow. Results of streamflow measurements at four locations on Chapman Creek from Coffin Station Road to Hominy Ridge Road and on six tributaries are listed in table 4. No flow was observed at 15 additional tributaries or culverts. After subtracting tributary inputs, the difference in flow between the main-stem measurements is positive, indicating that the stream is gaining ground water.

Interpretation of the results

The four methods used in this study measure conditions at different scales; the piezometers, seepage meters and temperature monitors measure conditions immediately around the equipment, at a scale of feet, whereas a gain-loss study measures regional conditions at a scale of miles. The data from the first three methods indicate that Chapman Creek may alternate between losing and gaining; however, there also are conflicting results from within and among these three methods. Water-level measurements in three of the

Table 3. Conditions and average temperatures of temperature monitors in Chapman Creek, west-central Ohio

[in., inches; °C, degrees Celsius]

Station	Dates of collection (2000)	Tree cover	Streambed composition	Stream depth[1] (in.)	Average temperature[2] (°C)	
					Streambed	Stream water
1	Oct. 20–Dec. 5	Mostly shaded	Sand	6	8.0	7.9
2	Oct. 20–Nov. 2	Unshaded	Fine sand, cobbles	24	12.9	12.5
3	Oct. 20–Nov. 2	Unshaded	Cobbles, some gravel	6	13.2	13.1
4	Oct. 20–Nov. 2	Partially shaded	Cobbles, gravel	9	12.9	12.8
5	Oct. 20–Nov. 2	Shaded	Sand	9	13.1	12.9

[1] Depth is approximate, based on conditions of October 20, 2000.
[2] Average temperature listed is the average for the entire period of record.

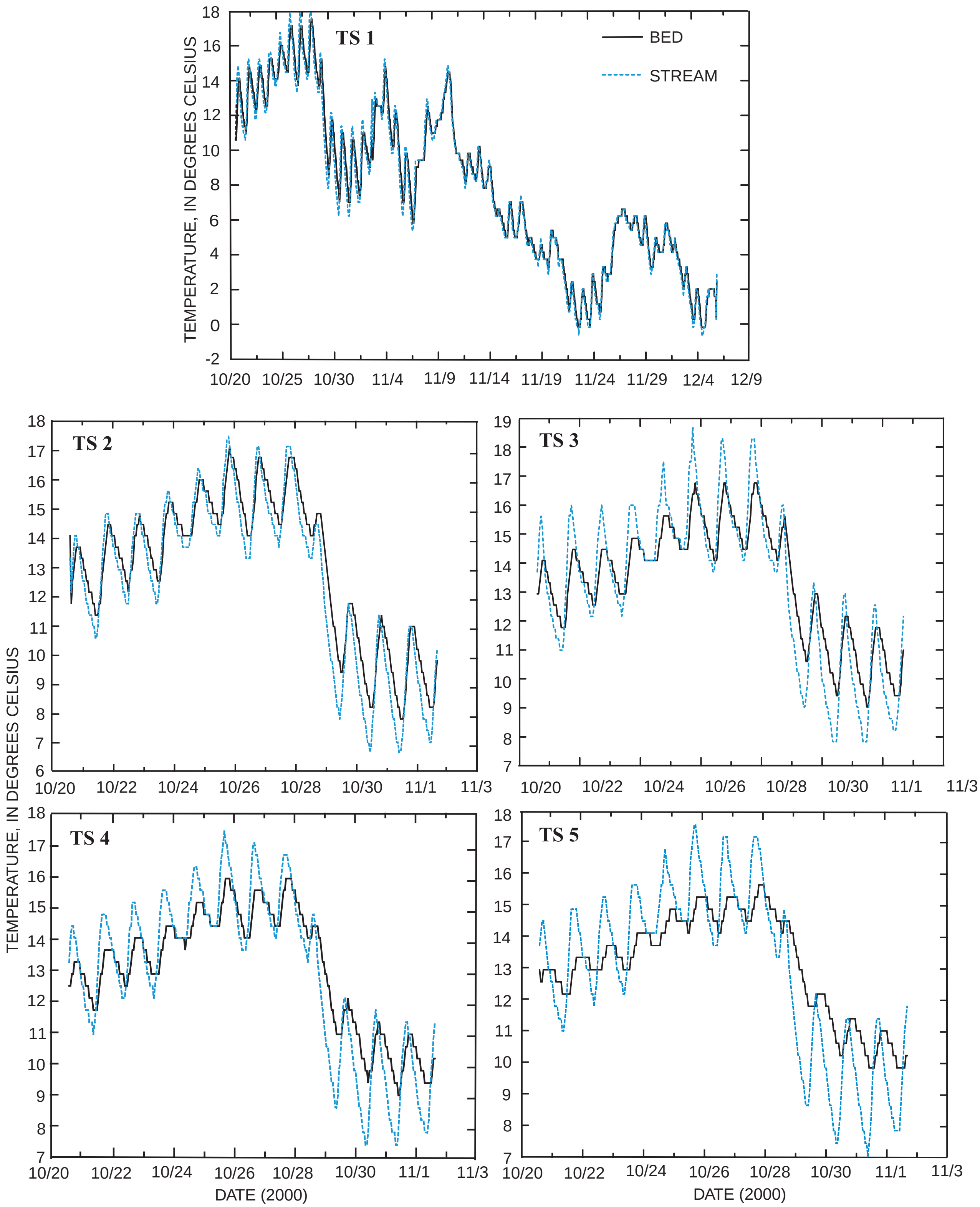

Figure 3. Plots of stream-water and streambed-temperature data, Chapman Creek, west-central Ohio. (Location of temperature stations (TS) shown in fig. 1.)

four piezometers indicated a losing stream, but the fourth (P4) showed a gaining stream near the landfill. The seepage meters indicate both losing and gaining reaches. Temperature data indicate a losing stream over the reach, which included piezometer P4 where water-level data indicated a gaining stream. Finally, the streamflow gain-loss study—the fourth method—indicated a steady gain of ground water for the entire reach.

Taking the data from the three local-scale methods together, one might judge that the creek generally is gaining but that it changes to losing around P1, P2, and P3 and then changes to gaining and back to losing between TS3 and TS4 (fig. 1) and from losing to gaining to losing between T4 and P3. Although a creek may alternate from losing to gaining, the frequency and short distances between reversals implied by the data from Chapman Creek seem excessive. Further examination of the streambed characteristics reveals a possible explanation for the conflicting data.

Various lines of evidence indicate that beneath 2–4 ft of coarse streambed materials is a layer of fine-grained till. While trying to install a piezometer just downstream from Willow Dale Road (downstream from P1, fig. 1), USGS personnel hit a very hard layer about 2 ft below the streambed. Installing the piezometer into this layer was nearly impossible. After 2 hours of pounding, the piezometer was about 1.5 ft into the hard layer and it could not be removed—the piezometer broke off at the screen. A similar hard layer was found between 3.5 and 4 ft at P3, and the piezometer was pulled back when the layer was encountered. In addition, when walking along the streambed, USGS personnel noted many scour holes, and the floor of these holes consisted of a hard, gray, fine-grained sediment (fig. 4). Near TS5 was a cutbank that was relatively clear of vegetation. The bank consisted of fine-grained layer with an interbedded cobble layer (fig. 5). The darker sediment color beneath the cobbles was caused by moisture; leaf litter had been removed to expose the bank. The fine-grained sediment continued to the bottom of the bank and appeared to be continuous under the stream to a scour hole just beneath opposite bank. A geologic section between the landfill and the creek shows that fine-grained sediments generally are present at the approximate elevation of the streambed or only 5 to 10 ft beneath sand and gravel (fig. 6). Finally, drillers have identified clay on residential well logs in the area at or near the elevation of the streambed (fig. 1; table 5)

Table 4. Streamflow data for gain-loss study on Chapman Creek, west-central Ohio, October 25, 2000

[trib., tributary; W, wading (current meter) streamflow measurement; V, volumetric streamflow measurement; F, fair (+/-8 percent); G, good (+/-5 percent); E, excellent, (+/-2 percent); ft^3/s, cubic feet per second; ----, not applicable]

Site name	Method	Quality rating	Streamflow (ft^3/s)	Change in main-stem flow (ft^3/s)
Chapman Creek at Coffin Station Road	W	F	0.89	----
Unnamed trib. at northwest intersection of Terre Haute, Thackery, and Snyder-Domer Roads	V	G	.008	----
Unnamed trib., right bank, between Coffin Station and Terre Haute Roads	V	F	.007	----
Chapman Creek at Snyder-Domer Road	W	F	1.55	0.65
Unnamed trib., left bank, upstream from Knollwood Road	V	G	.012	----
Unnamed trib., right bank, downstream from Knollwood Road	V	E	.004	----
Unnamed trib., left bank, upstream from Willow Dale Road	V	E	.005	----
Chapman Creek at Willow Dale Road	W	F	2.05	.48
Unnamed trib., left bank, upstream from Hominy Ridge Road	V	F	.007	----
Chapman Creek at Hominy Ridge Road	W	G-F	2.46	.40

Near Willow Dale Road Bridge, hole is about 5 feet in length.

Near TS5.

Scour hole downstream from P4 (upstream from TS4), about 5.5 feet wide.

Figure 4.

Scour holes in Chapman Creek, west-central Ohio. (White lines indicate approximate edges of

Figure 5. Till and gravel layer (near TS5) along bank of Chapman Creek, west-central Ohio. The large boulder on the right of the photo is approximately 2 feet across.

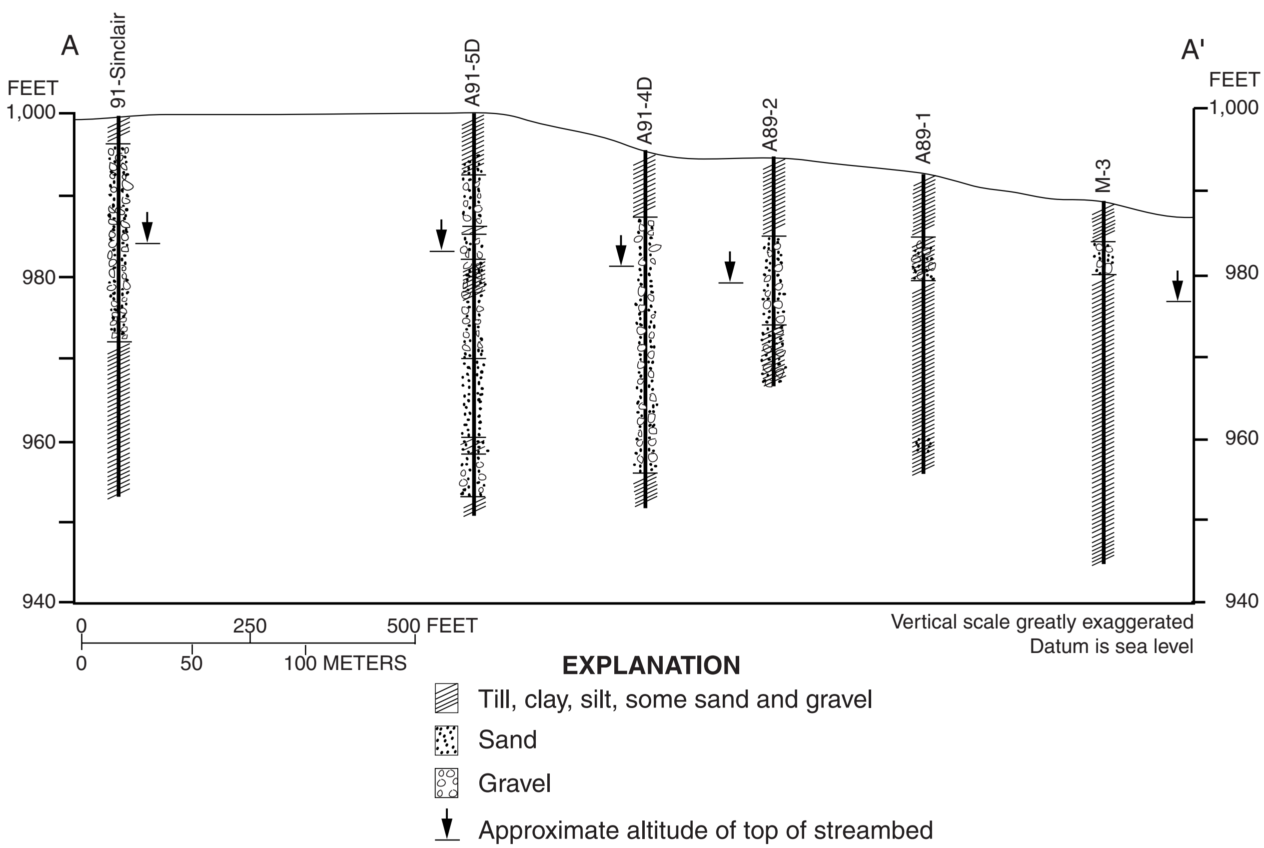

Figure 6. Geologic section A–A', west-central Ohio. (Line of section shown in fig. 1).

Table 5. Relation between clay layers recorded in residential wells and those noted in Chapman Creek, west-cental Ohio.

[Well locations shown on fig. 1; altitudes are in feet above sea level]

Well number	Approximate altitude of clay	Approximate altitude of streambed
CL-308	1,043 - 1,023	1,037
CL-343	1,040 - 1,022	1,037
CL-338	1,030 - 1,005	1,018
CL-318	1,036 - 958	995
CL-339	1,056 - 983	995
CL-350	999 - 964	993
CL-332	997 - 991[a]	960
CL-312	959 - 951[b]	953

[a] At an altitude of 960 feet, well log shows gravel.
[b] At an altitude of 951 feet, well log shows sand and gravel.

Thus, it appears that the streambed consists of as much as 3 to 5 ft of coarse sediments resting on fine-grained sediments. Locally, water flow in these coarse sediments probably is dominated by stream hydraulics, with stream water moving in and out of the coarse sediments depending on permeability and location in streamflow (fig. 7). This interchange between a gravel bed and stream has been discussed in other studies (Vaux, 1968; White, 1993). The piezometers, seepage meters, and temperature monitors were all within a coarse streambed layer and measured only the local conditions near the equipment.

In Chapman Creek, the piezometer, seepage-meter, and temperature data do not necessarily reflect the true relation between the creek and the ground water. By contrast, the gain-loss study reflects regional conditions, unaffected by flow between the stream and gravel bed. When all data are considered together, with observations of streambed conditions and geology, Chapman Creek appears to be a gaining stream throughout the reaches studied.

The value of using multiple methods to assess relations between a stream and ground-water inputs is apparent from the results of this study. Piezometers and seepage meters are relatively easy to install and use, which makes them ideal for small projects. Temperature monitors also are easy to install and use, and they have the added advantage of providing continuous data. Use of all three types of methods, however, may provide misleading data (as shown at Chapman Creek). In this case, the larger scale of a gain-loss study provided more regional data unaffected by localized variations in stream conditions. Gain-loss studies may not be applicable to all situations; these studies may not provide useful data if the differences in streamflow measurements are smaller than the measurement errors, a common situation on streams with high flows. The investigation of Chapman Creek has shown that the best approach to understanding ground-water/surface-water relations is to use various methods combined with consideration to the streambed conditions and the local geology.

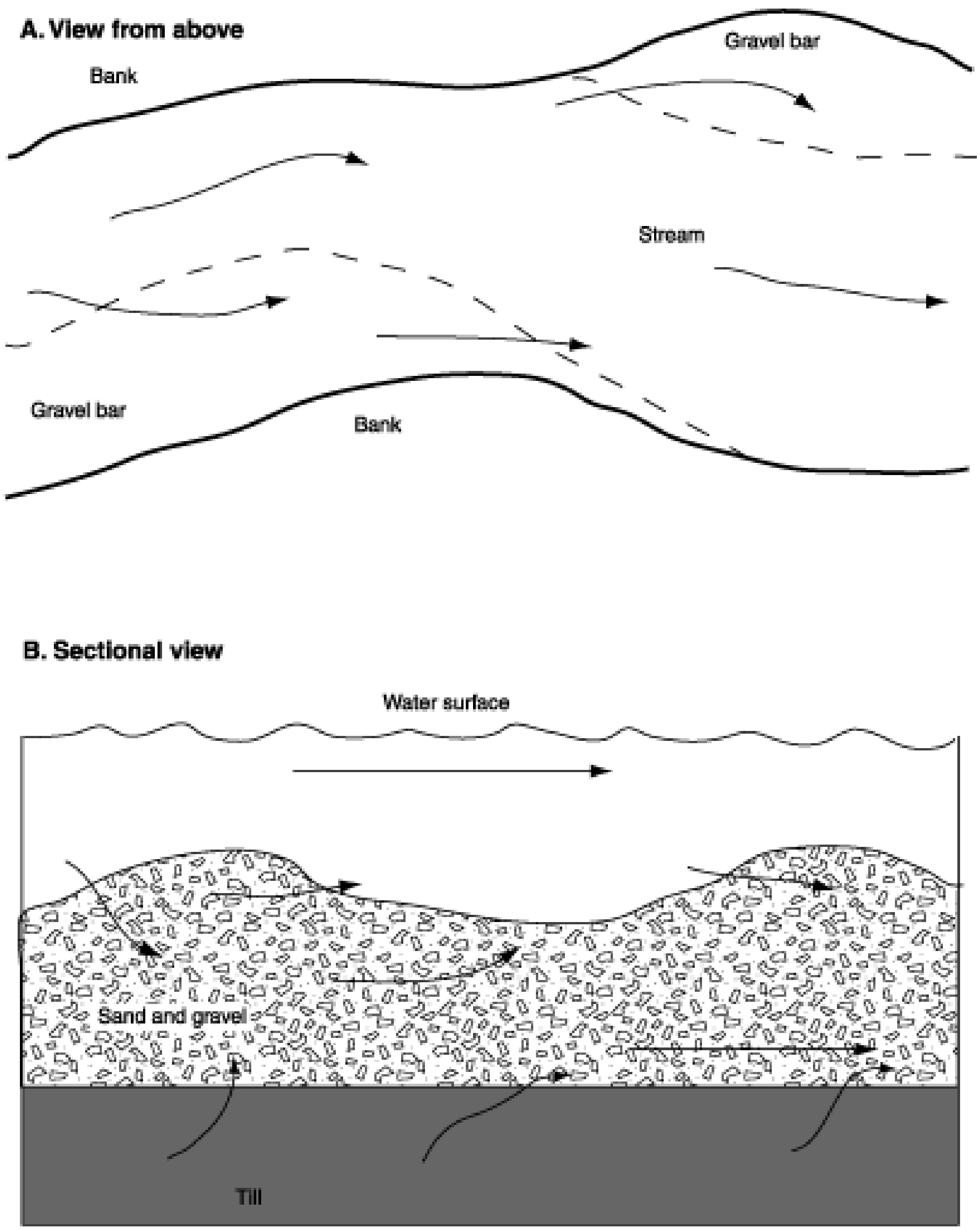

Figure 7. Schematic of flow in Chapman Creek, west-central Ohio. (Arrows indicate direction of flow: Diagrams not to scale.)

Summary and conclusions

Chapman Creek, a tributary to the Mad River, passes within about 500 ft of the Tremont City landfill in west-central Ohio. Earlier investigations indicated that the creek changed from losing to a gaining stream at about the midpoint of the reach adjacent to the landfill. The USGS did a study, in cooperation with the USEPA, in October 2000 using piezometers, seepage meters, temperature monitors, and a streamflow gain-loss study to further investigate the relation of the creek and the ground water.

At the time of the initial site visit, the sand-and-gravel streambed of the creek seemed ideal for the use of piezometers, seepage meters, and temperature monitors. Data from four piezometers, four seepage-meter tests, and five temperature monitors were collected. The data from these three methods appeared to indicate that the creek changed from losing to gaining and back again several times and over fairly short distances (tens of feet). The gain-loss data, however, indicated that the creek was consistently a gaining stream over a 3-mi reach.

Further investigation of the streambed and local geology revealed the that the sand-and-gravel streambed overlies a fine-grained till layer. Stream water readily moves in and out of the coarse streambed; thus, the piezometers, seepage meters, and temperature monitors were measuring the local flow in the coarse streambed. The data from these methods do not reflect the true relation between the creek and ground water. On the other hand, the gain-loss study measures more regional conditions over a distance of miles and is less affected by flow in the streambed. Final analysis of all the data shows that Chapman Creek probably is a gaining stream throughout the 3-mi reach studied.

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