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Text, Figures, and Tables to Accompany Water-Resources Investigations Report 98-4196

Recharge-Area Delineation and Hydrology, McCraken Springs, Fort Knox Military Reservation, Meade County, Kentucky

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USGS
science for a changing world

Louisville, Kentucky
1998

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	448.831	gallon per minute
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon per day (gal/d)	3.785	liter per day
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 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.

Altitude, as used in this report, refers to distance above or below sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

INTRODUCTION

McCraken Springs, consisting of three perennial springs—Main, Bat Cave, and Rocky Springs—and several intermittent springs, are used as a source of public water by the Fort Knox Military Reservation in Meade County, Ky. The water supply provided by McCraken Springs is potentially vulnerable to natural and induced stresses on the karst aquifer and to degradation by contaminants introduced by stormwater entering sinkholes and a large sinking stream in the Springs' recharge area.

The U.S. Department of the Army is preparing a spring-basin protection plan for McCraken Springs, in accordance with State water-supply regulations and as specified under U.S. Environmental Protection Agency Guidelines for the Wellhead Protection Program (U.S. Environmental Protection Agency, 1991). In order to provide the information needed to prepare the plan, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, conducted a hydrogeologic study of the McCraken Springs in 1997-98. This report presents the results of that investigation. Ground-water-tracer tests and the results of potentiometric-surface mapping were used to identify ground-water basins drained by major perennial springs and to delineate the approximate boundaries of the recharge area for McCraken Springs. Additional hydrologic data were collected to determine the discharge and recharge characteristics of the Springs.

Karst aquifers and springs are widely recognized as being more sensitive to degradation to point- and nonpoint-source contamination than most granular and fractured-rock aquifers (Field, 1990). Delineation of the geographic area contributing recharge to a water-supply spring is a principal step in identifying potential sources of ground-water contamination and developing a strategy to ensure the availability and protect the sustainability of the water supply. Conventional methods of aquifer testing and numerical modeling are not sufficient to determine the flow boundaries of ground-water basins in conduit-dominated karst aquifers. Previous studies published by Quinlan and Ewers (1989); Mull and others (1990); Bayless and others (1994); and Schindel and others (1995) demonstrate the utility of ground-water-tracer tests, used in combination with potentiometric-surface mapping, to identify flow directions in karst aquifers, and to delineate karst ground-water-basin boundaries.

Hydrogeologic Setting

McCraken Springs lies within the northern Mississippian Plateau physiographic region, a karstic-limestone belt extending from southern Indiana, into central and western Kentucky, and much of central Tennessee. Map coverage of the study area (pl. 1) includes all or part of the Rock Haven, Flaherty, Big Spring, and Guston 7.5-minute topographic quadrangles. The development of karst in this part of Meade County, Kentucky, is strongly affected by the geomorphic and hydrologic history of the Ohio River Valley (George, 1976). The physiography of the area is that of maturely developed karst and is distinctive for its large karst springs, extensive sinkhole plains, and almost complete lack of surface drainage. Most of the hydrology of the area is controlled by subsurface-conduit drainage developed by dissolution of limestone bedrock. Surface runoff is typically captured by sinkholes and short, ephemeral sinking streams, and drains vertically through fractures and solution conduits connected to horizontal trunk conduits that discharge to one or more karst springs. Two types of karst springs identified in this report are (1) perennial springs that drain major ground-water basins and flow even during dry-weather periods, and (2) intermittent springs that flow only after storm events or during wet-weather periods. The intermittent springs, also termed overflow springs (Quinlan and Ray, 1995), are "activated" when rising ground-water levels result in the diversion of subsurface flow to usually inactive conduits.

Surficial bedrock units mapped in the study area include both carbonate and clastic rocks of Middle-to-Late Mississippian age (Swadley, 1963; Peterson, 1964; Palmer, 1978; Withington and Sable, 1969). The carbonates include (from oldest to youngest) the Salem, St. Louis, Ste. Genevieve, Paoli, and Beaver Bend Limestones. Karst features are poorly developed in the Paoli and Beaver Bend Limestones, which crop out in thin belts in isolated hills, and are moderately developed in the dolomitic and silty limestones of the Ste. Genevieve Limestone.

A perched-aquifer zone and intermittent-spring horizon is formed by the Lost River Chert, a leaky confining bed in the lower Ste. Genevieve Limestone, near the contact with the upper St. Louis Limestone.

Karst features and conduit drainage are best developed in the St. Louis Limestone, the principal limestone aquifer. A significant perennial-spring horizon is developed near the stratigraphic contact between the St. Louis Limestone and the underlying Salem Limestone. The presence of evaporites in the lower part of the St. Louis Limestone is thought to enhance conduit development there, whereas the underlying silty, dolomitic Salem Limestone may form a regional confining unit that limits the depth of active ground-water circulation (George, 1976). Most large karst springs in the area, including McCraken Springs, Head-of-Doe-Run Spring, Hargan Spring, and Big Spring are located at or near the St. Louis-Salem Limestone stratigraphic contact. The St. Louis Limestone aquifer is recharged by infiltration of precipitation through soil and regolith, by surface runoff entering sinkholes and sinking streams, and by leakage from the aquifer zone perched above the Lost River Chert.

The non-carbonate rocks in the study area are fluvial sandstones of the Sample Sandstone and Mooretown Formations. The Sample Sandstone crops out on dissected plateaus and isolated ridges in the southwest and south-central parts of the study area, where it overlies the Ste. Genevieve Limestone and acts as a leaky confining unit. As a cap rock, the Sample Sandstone inhibits erosion and karstification of the underlying limestone. The Mooretown Formation, a channel-fill sandstone, forms a linear, northeast-trending ridge known locally as the Sand Ridge. Deposited in a former stream channel incised in the lower Ste. Genevieve Limestone and upper St. Louis Limestone, the Mooretown Formation has been exposed and topographically inverted by differential erosion (Swadley, 1963). The sandstones of the Mooretown Formation are deeply weathered and slumped and do not seem to be effective confining beds. Instead, the Mooretown Formation probably provides recharge directly to the karstified limestones beneath.

Bedrock strata in the study area exhibit relatively complex structural deformation, characterized by a series of anticlinal and synclinal folds. The regional direction of geologic dip is to the northwest; however, dip direction varies locally with the tightness of the folds. In the northern part of the area, the dip of strata typically ranges from 15 to 40 ft/mi; in the southern part, the dip of strata typically ranges from 40 to 50 ft/mi. The axes of many of the anticlinal and synclinal folds parallel the trends of east- and northeast-striking fault zones mapped in the Flaherty topographic quadrangle by Swadley (1963). In addition, the limestone bedrock exhibits many well-developed joints and bedding-plane fractures. Three prominent joint sets—striking N68°W, N06°E, and N54°E—are visible in outcrops of the St. Louis Limestone exposed in the McCraken Springs valley.

Interpretation of the Potentiometric-Surface Map

Synoptic water-level measurements were made during base-flow conditions in September–October 1997 in private water wells completed exclusively in the St. Louis Limestone. Using the locations of the wells and water-level measurements as control points, a contoured potentiometric-surface map was prepared (pl. 1). The potentiometric-surface map represents the distribution of hydrostatic heads and ground-water flow gradients in the St. Louis Limestone aquifer. The altitudes of hydrostatic heads measured in wells completed in the aquifer range from about 725-ft above sea level to the south, to less than 600-ft above sea level to the north and east. Ground water flows from areas of higher hydrostatic heads to areas of lower hydrostatic heads.

The overall configuration of the potentiometric surface in the study area is similar to that shown on a 1:250,000-scale potentiometric map published by Plebuch and others (1985). The potentiometric surface reflects both regional flow of ground water to the north toward the Ohio River and local flow of ground water to major springs along Otter Creek to the east and the edge of the sinkhole plain to the west. The dominant feature of the map is a central potentiometric ridge that approximately bisects the study area from north to south. The position and shape of this feature seems to be topographically and stratigraphically influenced and closely coincides with the contact between the Ste. Genevieve–St. Louis Limestone. Closely spaced potentiometric contours, which flank the potentiometric ridge, reflect the presence of relatively steep, vertical-flow gradients in the less karstified Ste. Genevieve Limestone. Thus, the potentiometric ridge also indicates the area where the St. Louis Limestone obtains recharge by leakage from the aquifer zone perched on the Lost River Chert.

In addition to the potentiometric ridge, local inflections in the potentiometric surface form a radial pattern of trough-like depressions. In the absence of a gaining surface stream, such potentiometric troughs are interpreted as representing areas where ground water is collected by major, horizontal trunk conduits drained by perennial springs; in other words, karst ground-water basins. Significant potentiometric troughs are visible upgradient of the locations of Head-of-Doe-Run Spring, McCraken Springs, Hargan Spring, and Big Spring. Most of these potentiometric troughs coincide with the axes of mapped synclinal or anticlinal folds, indicating that the development of conduit-drainage networks in the major ground-water basins in the area has been influenced by local structural deformation.

Ground-Water-Tracer Tests

No previously published ground-water-tracer test data are available for McCraken Springs or for most other springs in the study area. Springs to be monitored as tracer-recovery sites and sinkholes or sinking streams to be used as tracer-injection sites were identified in a field reconnaissance during the fall of 1997. Qualitative ground-water-tracer tests were done during January-June 1998 to identify ground-water-flow routes and to confirm the locations of inferred ground-water-basin boundaries. In each ground-water-tracer test, a fluorescent dye was injected into the karst aquifer using natural or induced runoff entering open sinkholes or sinking streams. Most dye injections were made during or shortly after storm events, when ground-water levels were relatively high.

Resurgent dyes were recovered on passive charcoal detectors that were generally collected and exchanged at 2- to 5-day intervals. Ambient fluorescence was evaluated at every dye-monitoring site prior to each dye injection. Positive or negative determination of tracer-dye recovery was made using a scanning spectrofluorophotometer in the manner described by Duley (1986). Positive recovery of tracer dye was determined by analytical results indicating the presence of a specific tracer dye on charcoal at concentrations at least 10 times greater than ambient fluorescence, as measured against dye-concentration standards.

Nine ground-water-tracer tests were successfully conducted during the investigation (table 1). Two dye injections (ground-water-tracer tests #8 and #9) did not result in successful recovery of the tracer dye; however, each injection was subsequently repeated with successful results (ground-water-tracer tests #10 and #11). Results obtained from two additional ground-water-tracer tests done by private consultants are also reported in table 1 (ground-water-tracer tests #12 and #13). The interpreted flow route of each recovered tracer dye through the karst aquifer is illustrated as a curvilinear flowpath (pl. 1). Traced flow routes follow local changes in the slope of the potentiometric surface to karst springs along Otter Creek and at the margins of the sinkhole plain to the west. The collective results of the ground-water-tracer tests confirm the radial pattern of ground-water flow away from the central potentiometric ridge. Traced flow routes also help identify the presence of five major ground-water basins drained by the following perennial springs: Blue Spring, Head-of-Doe-Run Spring, Big Spring, Hargan Spring, and McCraken Springs. A flow route traced by a private consultant (ground-water-tracer test #12) identifies a sixth major ground-water basin, drained by Head-of-Rough Spring, near the southern boundary of the study area.

Table 1. Summary of ground-water-tracer tests, McCraken Springs study area, Ft. Knox, Kentucky

[lb, pound; ---, not applicable]

Tracer test	Dye-injection date	Quantity/type dye used	Dye-recovery site(s)	Date of first dye recovery	Straight-line distance, in miles
Ground-water-tracer-tests conducted by U.S. Geological Survey					
1	03/20/98	5 lbs Uranine	Head-of-Doe Run	03/25/98	3.7
2	03/27/98	1.75 lbs Rhodamine WT	McCraken Springs: Main Spring Bat Cave Spring Rocky Spring	03/31/98	2.5
3	03/27/98	4 lbs Uranine	McCraken Springs: Main Spring Bat Cave Spring	04/07/98	7
4	04/08/98	8 lbs Tinopal CBS-X	Head-of-Doe Run	04/14/98	7.5
5	03/25/98	1.5 lbs Rhodamine WT	Big Springs karst windows	04/01/98	1.9
6	04/08/98	.4 lbs Rhodamine WT	Hargan Spring	04/10/98	1
7	05/15/98	3.5 lbs Eosine OJ	Head-of-Doe Run McCraken Springs: Main Spring Bat Cave Spring	05/21/98 06/02/98	7.8 5
8	05/22/98	5 lbs Tinopal CBS-X	No tracer dye recovered	---	---
9	06/05/98	1 lb Rhodamine WT	No tracer dye recovered	---	---
10	06/25/98	1.5 lbs Uranine	Blue Spring	06/29/98	2.4
11	06/30/98	1.5 lbs Rhodamine WT	Head-of-Doe Run	07/08/98	5.8
Ground-water-tracer-tests conducted by private consultants					
[1]12	11/19/97	2.5 lbs Pyrannine Green #8	Otter Creek Boils Bluehole at Dry Fork Branch	11/20/97 11/20/97	.74 .66
[2]13	02/13/98	3 lbs DNC Red 28	Head-of-Rough	02/15/98	5

[1]Dennis Connair, Dames and Moore, oral commun., 1998.
[2]William T. Clauson, Crawford and Associates, oral commun., 1998.

Dye flowpaths plotted for ground-water-tracer tests #3, #4, #7, and #11 cross beneath Bee Knob Hills and Sand Ridge, indicating that these major topographic divides are not effective ground-water divides and are underdrained by major conduits. In two cases where this occurs, ground-water-tracer test #3 to McCraken Spring, and ground-water-tracer test #11 to Head-of-Doe Run Spring, the traced flow routes are interpreted to be influenced by the presence of a linear structural feature, such as an unmapped fault or major joint.

The tracer dyes were transported rapidly in almost all ground-water-tracer tests. Most dye injections resulted in the positive recovery of dye within 3 to 5 days. Estimated ground-water velocities, at a minimum, range from 0.5 to 1.5 mi per day through the conduit-dominated parts of the karst aquifer (under the hydrologic conditions represented during the ground-water-tracer tests). Results of the ground-water-tracer tests illustrate two characteristics of ground-water basins in the area: (1) convergent ground-water flow in the upper (headwater) and middle parts of the basins and (2) divergent ground-water flow at the discharge zones of the basins. Convergent ground-water flow is illustrated by an intersection between traced flow routes to McCraken Springs and Head-of-Doe-Run Spring. The intersection between flow routes represents the conjectured confluence of major ground-water conduits in the downstream direction. Divergent (or distributary) ground-water flow is indicated by bifurcation of a traced flow route. Divergent flow typifies the Head-of-Doe-Run Spring Basin, where ground water is distributed to perennial and overflow spring outlets during high-flow conditions, and McCraken Springs, where enhanced dissolution of limestone has resulted in the development of multiple perennial and overflow spring outlets.

McCraken Springs Ground-Water Basins

Ground-water-tracer tests #2, #3, and #7 indicate that the recharge area of McCraken Springs consists of two distinct ground-water basins (pl. 1). The largest basin (shaded orange), extending south from McCraken Springs, is approximately 13.8 mi^2 in area and contributes recharge to the Main Spring and Bat Cave Springs only. The southern basin does not contribute to the Rocky Spring because the trunk conduit of the Rocky Spring is perched by a cherty limestone bed at a higher altitude than the conduits drained by the other two perennial springs. The geographic area within the lower part of the southern basin is dominated by sinkhole drainage; however, the upper part of the basin is dominated by the catchment area of a large sinking stream located approximately 2 mi south of Flaherty, Ky. (1 mi south of the Sand Ridge). The linear proportions of the southern basin indicate that it may be strongly affected by a northeast-trending structural element, such as an unmapped fault or major joint. The sinking stream in the upper part of the basin seems to be near the end of a mapped, northeast-trending fault (Swadley, 1963). Ground-water-tracer tests indicate that ground-water basins drained by Head-of-Doe-Run Spring, Big Spring, Head-of-Rough Spring, Hargan Spring, and Otter Creek Boils, bound the southern McCraken Springs Basin.

The second ground-water basin (shaded yellow) is approximately 5.6 mi^2 in area and is drained principally by the Rocky Spring and Bat Cave Spring. The results of ground-water-tracer test #2 indicate that this northern basin also contributes recharge to the Main Spring. The area within the northern basin itself is dominated by sinkhole drainage; no sinking stream is present. A prominent alignment of sinkholes near the center of the basin probably traces the route of a former surface stream that is now underdrained by conduits. A synclinal fold dipping to the west may have affected the development of the conduit-drainage network in the northern basin; however, the direction of ground-water flow through the northern basin is to the east, contrary to the direction of local geologic dip. Ground-water-tracer tests indicate that ground-water basins drained by Head-of-Doe-Run Spring and Blue Spring bound the northern McCraken Springs Basin. The area immediately north of the northern McCraken Springs Basin is probably drained by Training Area 10 Springs, although no ground-water-tracer test data were obtained during this investigation to test the assumption.

Spring Discharge Characteristics

Periodic discharge measurements were made during April 1997–April 1998 at the Main, Bat Cave, and Rocky Springs (table 2). The total discharge measured from the three perennial springs ranges from 2.5 to 85.5 ft^3/sec. The Main Spring accounts for approximately 66 percent of the total spring discharge under most hydrologic conditions. A continuous-discharge hydrograph for the period October 1997–April 1998, illustrates the flashy, seasonal fluctuations in the discharge of the Main Spring (fig. 1). The maximum mean daily discharge from the Main Spring, recorded on the hydrograph in January 1998, is 137 ft^3/sec. During flood events, however, the discharge from the Main Spring is estimated to increase by a factor of at least three, as indicated by an instantaneous peak discharge of 426 ft^3/sec (not shown on the hydrograph), measured after a storm event in late December 1997.

Base-flow discharge is particularly important in evaluating the sustainability of the flow of McCraken Springs as a source of public water supply for Fort Knox. Base-flow conditions are reflected in discharge measurements collected during August 13–December 19, 1997. Mean base-flow discharge is 2.5 ft^3/sec from the Main Spring, 1.2 ft^3/sec from the Bat Cave and Rocky Springs combined, and 3.8 ft^3/sec from all three perennial springs. At base flow, the Main Spring accounts for approximately 69 percent of the total combined spring discharge.

Table 2. Summary of discharge measurements for McCraken Springs, April 1997—April 1998

[Measurements from 08/13/97 to 12/19/97 considered to be at base-flow conditions]

Date	Combined discharge (all springs), in cubic feet per second	Main Spring only, in cubic feet per second	Bat Cave and Rocky Spring outlets, in cubic feet per second	Discharge of Main Spring, as percentage of combined discharge
04/08/97	35.7	22.9	12.8	64
07/29/97	7.2	4.6	2.6	64
08/13/97	5.7	3.7	2.0	65
08/29/97	4.6	3.5	1.1	76
09/12/97	6.4	3.6	2.8	56
10/06/97	3.4	2.1	1.3	62
10/22/97	2.5	1.9	.6	76
11/06/97	2.6	2.0	.6	77
12/05/97	3.5	2.4	1.1	69
12/19/97	3.3	2.2	1.1	67
01/09/98	85.5	47.3	38.2	55
01/29/98	8.8	5.8	3.0	66
02/25/98	18.9	12.2	6.7	65
04/24/98	30.2	20.5	9.7	68
Mean (all values)	15.6	9.6	6.0	66
Mean (base flow)	3.8	2.5	1.2	69

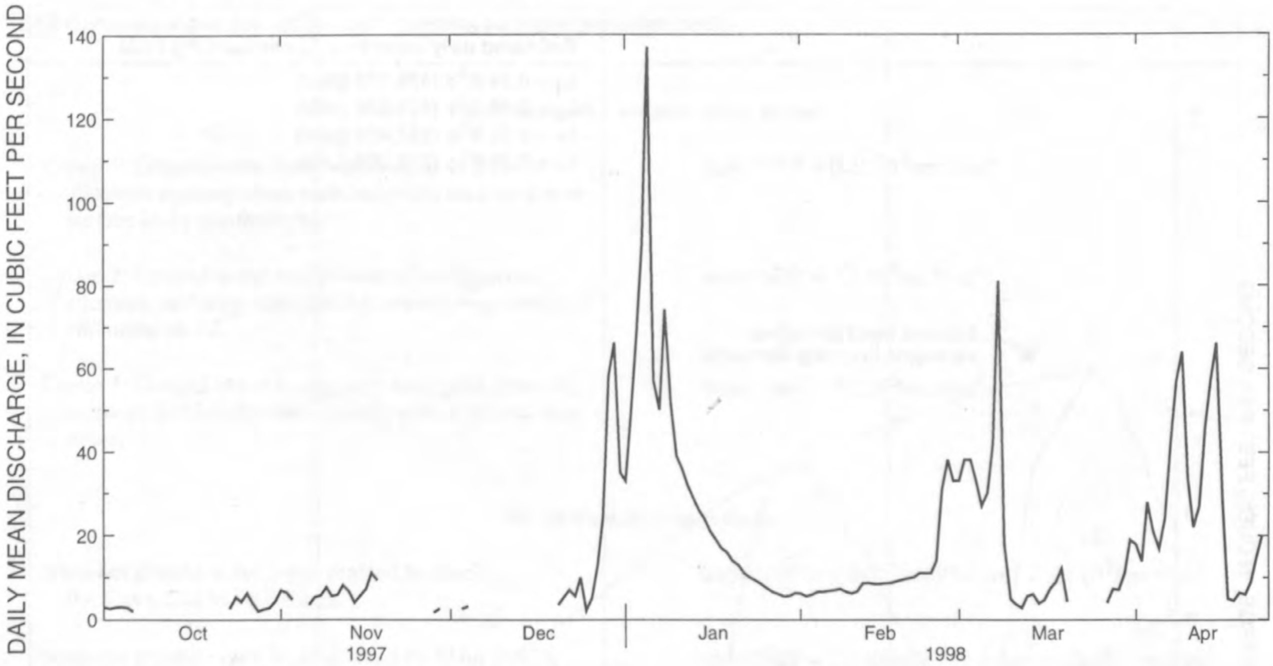

Figure 1. Daily mean discharge measured at Main Spring, October 1, 1997–April 24, 1998. (Gaps in hydrograph indicate periods during which discharge was affected by pumping-induced stress from an unidentified source of withdrawal.)

Discharge measured by the continuous recorder at the Main Spring dropped below 2 ft^3/sec several times during October–December 1997, and once in March 1998 (fig. 1). During these periods of low flow, daily fluctuations in stage (discharge) were observed that indicate the presence an unidentified source of withdrawal (pumpage) from the McCraken Springs Basin. A typical hydrograph sequence, illustrating the effects of the unidentified withdrawal, is shown in figure 2. During the 4-day period (October 7-10, 1997) shown on the hydrograph, the estimated loss of water from the Main Spring caused by the unidentified withdrawal ranged from 232,258 to 478,075 gal/d.

Normalized Base Flow

The normalized base flow (NBF), or base-flow discharge per unit recharge area, is a useful indicator of the anticipated size of karst ground-water basins located in similar geologic and physiographic settings (Quinlan and Ray, 1995). Mean NBF values for ground-water basins in the Mammoth Cave area of central Kentucky, grouped by the percentage of allogenic water (recharge to the karst ground-water basin obtained from surface drainage or from non-karstified rock) are provided in table 3. Mean NBF values calculated for each of the McCraken Springs Basins, and for the total recharge area delineated for McCraken Springs, compare favorably with mean NBF for Group 1 and 2 ground-water basins in the Mammoth Cave area (table 3). The mean NBF calculated for the southern McCraken Springs Basin compares most favorably with the mean NBF of Group 2 springs and probably reflects the large contribution of allogenic water from the sinking stream catchment in the upper part of the basin. Overall, these calculations provide supporting evidence that the boundaries delineated for the McCraken Springs Basins and total recharge area indicate geographic areas of the anticipated proper size, given the mean base-flow discharge measured for the perennial springs.

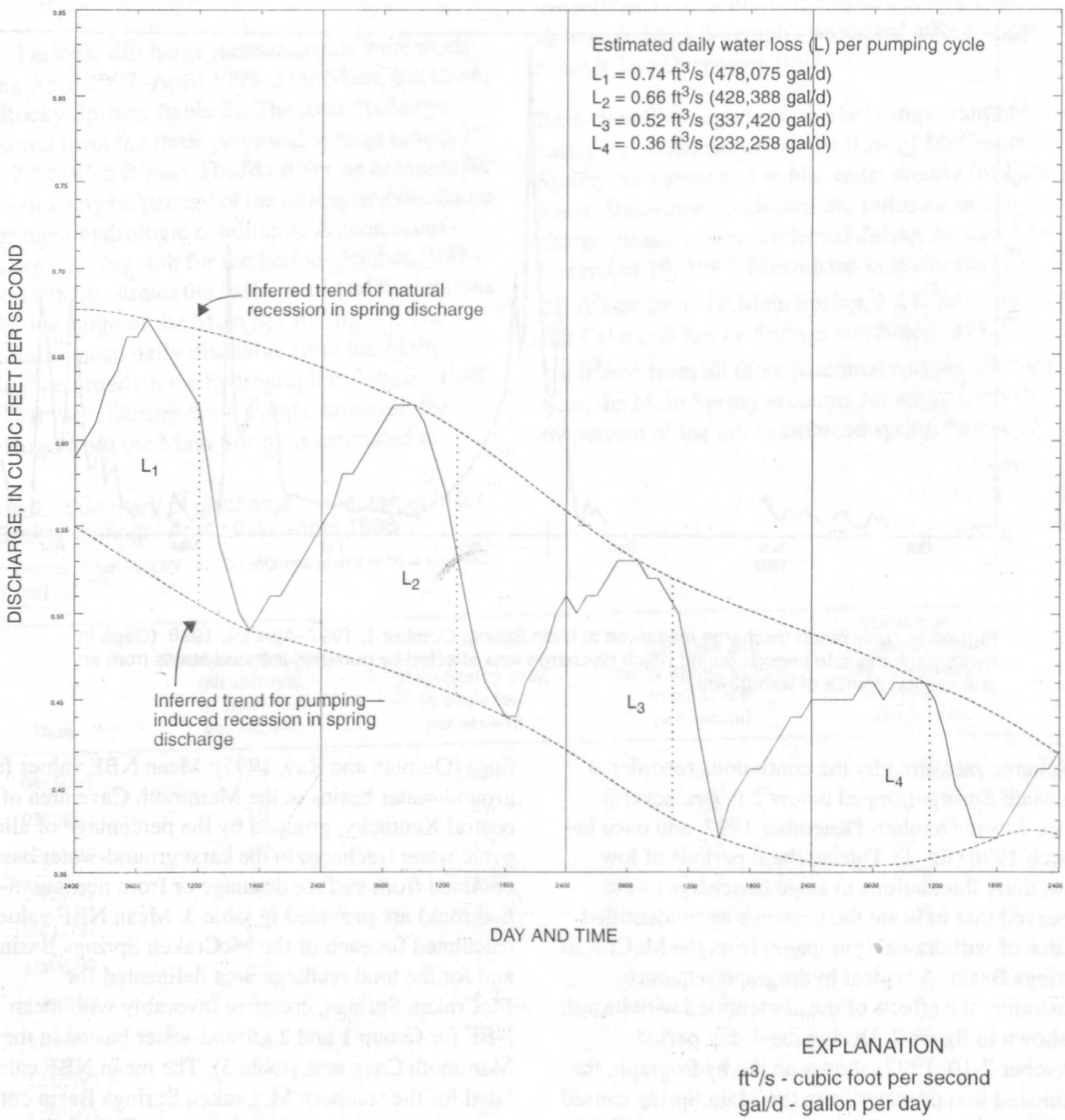

Figure 2. Effects of pumping-induced stress on discharge at the Main Spring, and estimated daily water loss per pumping cycle, October 7-10, 1997.

Table 3. Mean normalized base-flow values for Mammoth Cave area springs and McCraken Springs

[NBF, normalized base flow; $(ft^3/sec)/mi^2$, cubic feet per second per square mile]

For Mammoth Cave area spring basins[1]	
Group 1: Ground-water basins with up to 25 percent allogenic recharge from non-carbonate rock, or a near-surface leaky confining bed.	mean NBF = 0.21 $(ft^3/sec)/mi^2$
Group 2: Ground-water basins with up to 30 percent allogenic recharge from sinking streams originating on carbonate rocks.	mean NBF = .17 $(ft^3/sec)/mi^2$
Group 3: Ground-water basins with negligible allogenic recharge and locally thick, areally extensive sediment cover.	mean NBF = .85 $(ft^3/sec)/mi^2$
For McCraken Springs Basins	
Northern ground-water basin drained by Rocky, Bat Cave, and Main Springs.	mean NBF = 1.2 $(ft^3/sec)/5.6\ mi^2$ = .21 $(ft^3/sec)/mi^2$
Southern ground-water basin drained by Main and Bat Cave Springs.	mean NBF = 2.5 $(ft^3/sec)/13.8\ mi^2$ = .18 $(ft^3/sec)/mi^2$
Total recharge area delineated for McCraken Springs.	mean NBF = 3.8 $(ft^3/sec)/19.4\ mi^2$ = .19 $(ft/sec)/mi^2$

[1]Quinlan and Ray, 1995.

Spring Recharge Characteristics

Recharge events produce significant changes in the hydraulic head and chemistry of ground water in conduit-dominated karst aquifers. Analysis of the time of arrival of changes in discharge, conductivity, and temperature is a useful way to evaluate the recharge, storage, and transfer mechanisms in the ground-water basin of a spring (Meiman and others, 1989; Idstein and Ewers, 1992).

A multi-parameter water-quality monitor, a data logger, and a rain gage were installed at the Main Spring in August 1997 and used to obtain continuous records of stage, specific conductance, pH, temperature, dissolved oxygen, and turbidity, measured at 15-minute intervals. Trends in stage-related discharge and conductivity reveal that the McCraken Springs Basin does not contain significant conduit storage and receives a large pulse of allogenic water immediately after storm events. This is illustrated by a sharp decrease in the conductivity of water discharging from the Main Spring within 1 to 2 days of significant rainfall during December 20-23, 1997, and January 4-6, 1998 (fig. 3). The sharp decrease in conductivity is generally mirrored by similar trends in temperature and pH of the discharged water (not shown). After passage of the allogenic water pulse, the conductivity of water discharging at the Main Spring rises sharply for several days, indicating the flushing and arrival of ground-water stores from the slow-flow part of the ground-water basin.

The increase in discharge at the Main Spring following storm events is complex and dependent on antecedent hydrologic conditions. During low-flow conditions, an increase in the discharge of the Main Spring lags several hours after a storm event. During high-flow conditions, discharge increases almost immediately after rainfall as a pressure-wave response is transmitted through water-filled conduits. Multiple discharge peaks visible on the stage-discharge hydrograph (fig. 3) reflect, in part, the difference in time of arrival of stormwater pulses from the northern and southern ground-water basins.

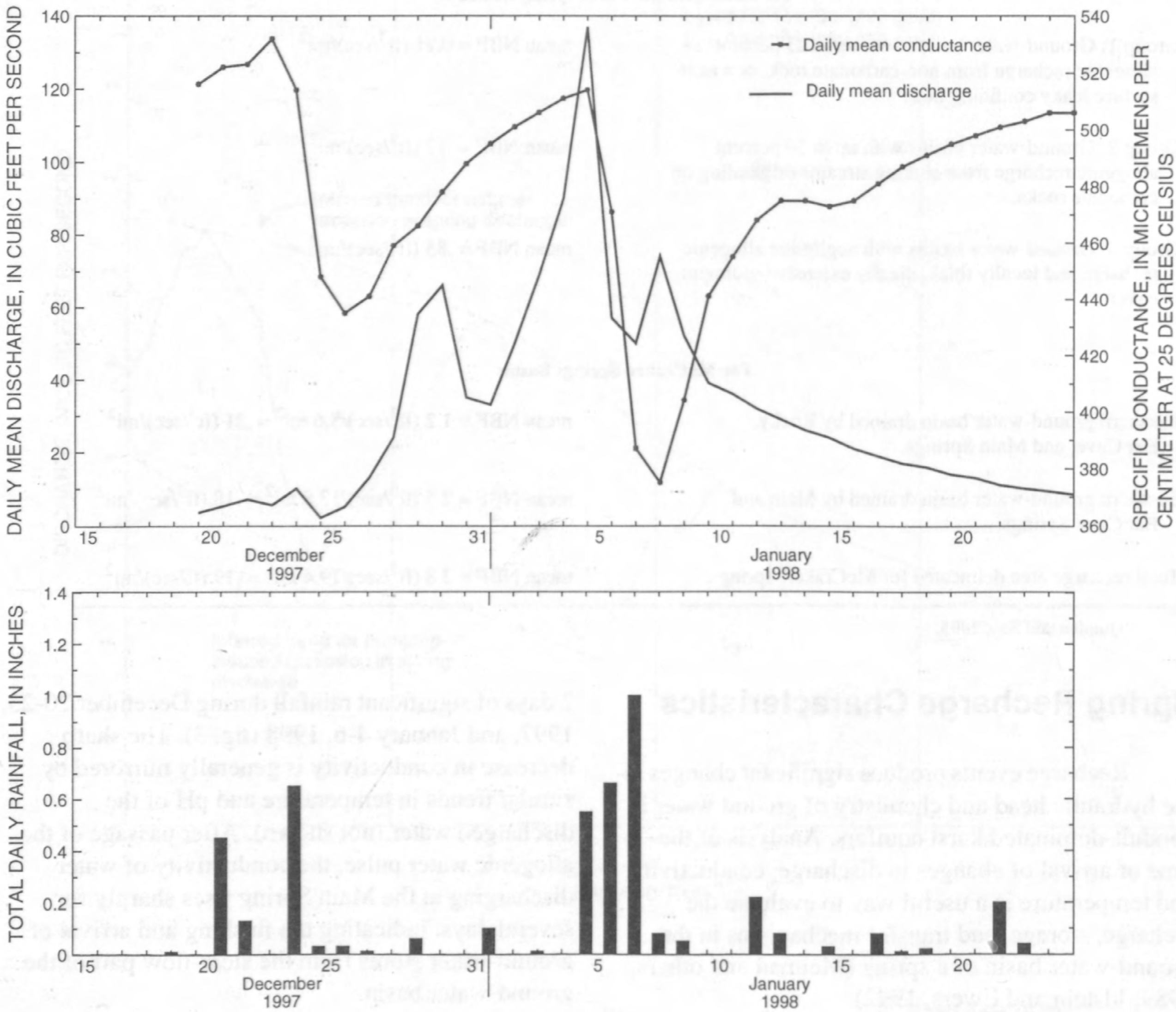

Figure 3. Relation between discharge and specific conductance at Main Spring, December 15, 1997–January 25, 1998, with rainfall histogram.

The surge of allogenic water through the McCraken Springs Basin originates mostly as stormwater drained by the sinking stream in the southern ground-water basin and demonstrates the potential vulnerability of McCraken Springs to any contaminants in surface-water runoff. Sinkholes with open swallets (subsurface drains) located in residential and agricultural areas, troop training areas, and near highways are other points of recharge vulnerable to the entry of potential ground-water contaminants. Ground-water contaminants entering the conduit-dominated part of the McCraken Springs Basin could be expected to resurge at the springs within 1 to 5 days, depending on distance of the point of entry from the springs and the hydrologic (flow) conditions. Although important to the subject, an in-depth discussion of the vulnerability, protection, and management of karst aquifers and water-supply springs is beyond the scope of this report. The reader is directed to reports published by Mull and others (1988); Field (1990); Quinlan and others (1992); and Schindel and others (1995), for information about these topics.

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