Maryland Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Jeffrey P. Halka, Acting Director

OPEN-FILE REPORT NO. 2008-02-18

PHASE 2 STUDY OF THE AREA CONTRIBUTING GROUNDWATER TO THE SPRING SUPPLYING THE A.M. POWELL STATE FISH HATCHERY, WASHINGTON COUNTY, MARYLAND

by

Mark T. Duigon

Prepared in cooperation with the
Maryland Department of Natural Resources
Fisheries Service

2009

CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the inch-pound units published in this report to International System (SI) units.

Multiply	By	To obtain
inch (in.)	2.54 (exact)	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	3785	cubic meters per day (m^3/d)

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PHASE 2 STUDY OF THE AREA CONTRIBUTING GROUNDWATER TO THE SPRING SUPPLYING THE A.M. POWELL STATE FISH HATCHERY, WASHINGTON COUNTY, MARYLAND

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ABSTRACT

Geologic inference and dye tracing of groundwater flow were used to investigate the boundary of the area contributing groundwater to the flow of the spring supplying the Albert M. Powell State Fish Hatchery in Washington County, Maryland. The contributing area extends about 5 miles northeast from the hatchery spring, broadening to the west from about 1 mile in width at the southwestern end to about 2.5 miles at the northeastern end, and has an area of approximately 8.2 square miles. It is bounded on the east by the Beaver Creek Fault, an old, mylonitized thrust fault presumed to be a barrier to groundwater flow. The Eakles Mills Fault on the west is a younger, high-angle fault along which the rock reacted in a brittle fashion, thereby likely becoming a linear zone of enhanced permeability. The Eakles Mills Fault may act as a linear sink draining toward the southwest, intercepting any groundwater flow coming from the west. During periods of high groundwater levels, some of the water draining along the Eakles Mills Fault may be diverted by a cross fault located on the hatchery property to Beaver Creek and, during periods of highest groundwater levels, to the hatchery spring.

Dye injected into Beaver Creek approximately 1.2 miles north-northeast of the hatchery spring was detected at the spring about one day after injection, confirming the hypothesis that a portion of springflow consists of water that has leaked through the streambed of Beaver Creek (at least under similar flow conditions when the stream is losing water along this reach). Dye injected into a sinkhole located about 2.8 miles north-northeast of the spring took about two and a half days to arrive. Dyes injected into a well located about 400 feet northwest of the spring and into a sinkhole located about 2.9 miles north of the spring were not detected at the spring. The latter sinkhole was located to the west of the Eakles Mills Fault.

Physical properties and major-ion concentrations measured in the hatchery spring water were typical of groundwater from the Elbrook Formation in Washington County—very hard with total-dissolved solids concentration just over 300 milligrams per liter. Nitrate concentration in two samples taken from the spring were 5.36 and 6.08 milligrams per liter (as N), suggesting there may be some nutrient input from the basin (which is in largely agricultural and residential use). Fifteen of 28 trace elements for which the samples were analyzed were detected. All of the pesticides and wastewater compounds for which the samples collected in 2008 were analyzed were below detection limits except for CIAT (also known as deethylatrazine, a degradation product of the herbicide atrazine) and tetrachloroethylene (a solvent, degreaser, and dewormer), and those concentrations were close to detection limits.

INTRODUCTION

The A.M. Powell State Fish Hatchery, located about 5 miles (mi) southeast of Hagerstown, Maryland (fig. 1), rears many of the trout released into Maryland waters for sport fishing. Two episodes of turbidity of the water discharging from the spring that supplies the hatchery in November, 2004, resulted in significant mortality of young fish and prompted the Maryland Department of Natural Resources to investigate the area contributing groundwater to the spring that supplies the hatchery. As an initial phase of study (referred to in this report as “phase 1”), relevant hydrogeologic data were compiled, a conceptual model of the hydrologic system was described, and a preliminary delineation of the area contributing groundwater to the spring was made (Duigon, 2007).

PURPOSE AND SCOPE

This report describes additional work determining the area contributing groundwater to the main spring that supplies the A.M. Powell State Fish Hatchery and presents some additional groundwater-quality data that may be used for comparison with data collected in the future. I have revised the delineation of the contributing-area boundary based upon the results of five groundwater traces conducted during this second phase of study, and on the results of five traces conducted by Maryland Department of the Environment (MDE) in past years, plus reinterpretation of the geology of the vicinity since the phase 1 report (Duigon, 2007).

ACKNOWLEDGMENTS

Funding for this project was provided by Maryland Fisheries Service and Maryland Geological Survey (MGS), both agencies of the Maryland Department of Natural Resources. The owners of the Beaver Creek Quarry (initially H.B. Mellott Estate, Inc., transferred in August 2007 to LaFarge Mid-Atlantic LLC) provided springflow, well-location, water-level, and other information. Malcolm Field, U.S. Environmental Protection Agency, provided guidance, instrumentation, and dyes for conducting groundwater tracing. Molly Edsall, Maryland Department of the Environment, provided access to a scanning spectro-flurophotometer for dye analysis and information supplied by the operators for surface-mining permits. David K. Brezinski, MGS, discussed his observations of karst features and geology in the study area. David Bolton, MGS, collected water-quality samples from the hatchery spring.

HYDROLOGY AND GROUNDWATER TRACING

Annual mean flows of hatchery spring WA Bj 4 ranged from 651 to 968 cubic feet per second (ft^3/s) over water years 1987 through 1997 (James and others, 1999, p. 271). About 92 percent of the springflow in 1988 was derived from recharge that percolated diffusely through soil and unenlarged rock fractures (Duigon, 2001, p. 31) before reaching the aquifer. This slowly draining water provides springflow during the dry periods of the year. About 2 percent of the recharge in 1988 arrived at the spring quickly after storms, evidently reaching the aquifer through sinkholes, swallets or other points of connection between the surface and the aquifer. Duigon (2007, p. 28) estimated the area contributing groundwater to the hatchery spring to be 7 to 10 square miles (mi^2).

REVISION IN GEOLOGIC INTERPRETATION SINCE PHASE 1 STUDY

The geology of the study area has been undergoing reinterpretation since the compilation of the geology of the Hagerstown

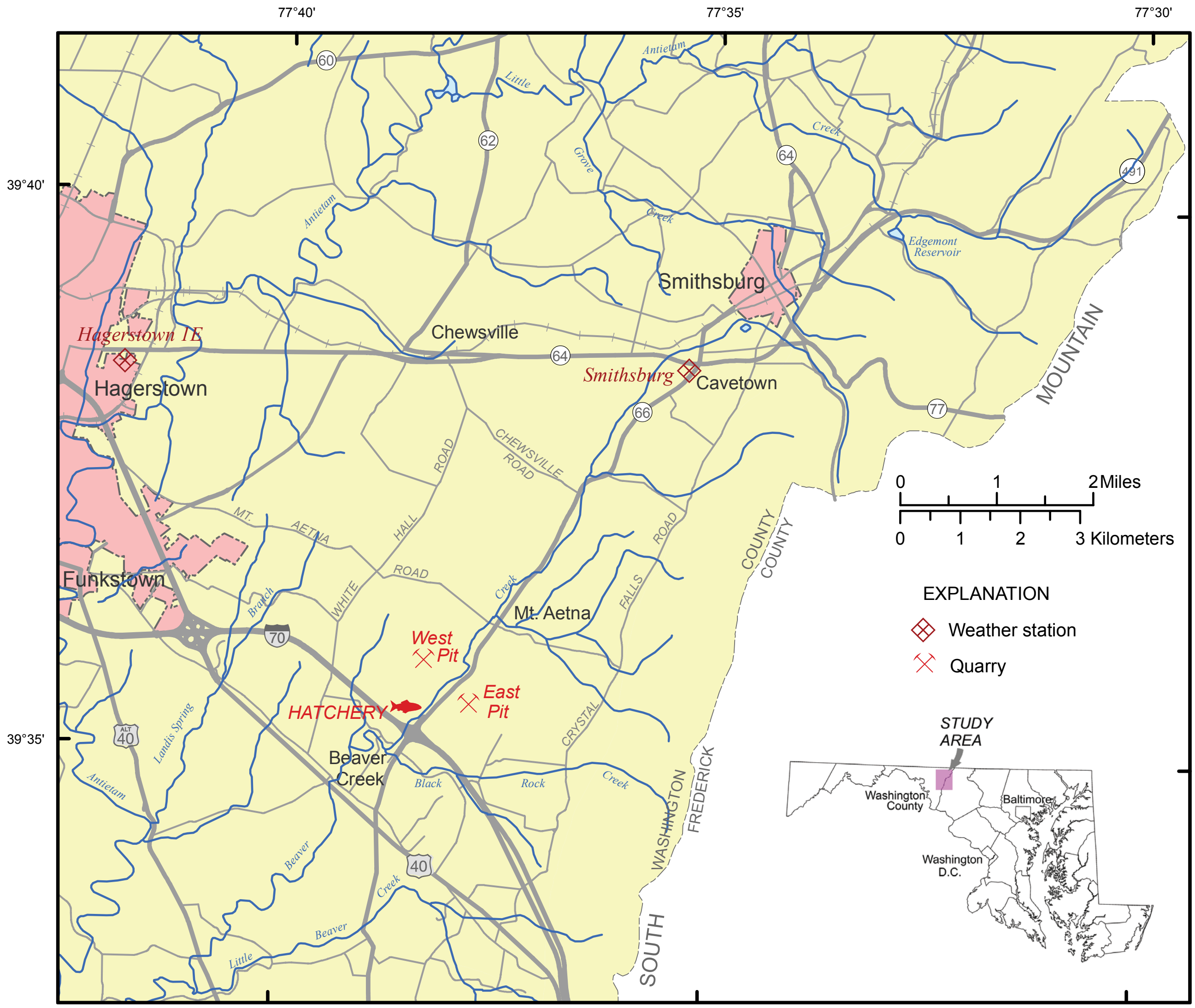

Figure 1. Location of the Albert M. Powell State Fish Hatchery.

Valley (Duigon, 2001), a portion of which is included in the report on the initial phase of study of the hatchery spring (Duigon, 2007). Two revisions by D.K. Brezinski of the Maryland Geological Survey (written commun., 2007, 2008) affect interpretation of the hydrology of the study area. First, the Eakles Mills Fault is extended from south of I-70 about one-half mile southwest of the hatchery all the way into Pennsylvania where it coincides with a fault mapped in the adjacent quadrangle to the north by Root (1968). Second, a dog-leg in the trace of the Beaver Creek Fault at the intersection of I-70 and Md. Route 66 is reinterpreted as a cross fault extending through the hatchery property and terminating at the Eakles Mills Fault (figs. 2 and 3). The stratigraphic descriptions remain the same as described in the phase 1 report and are repeated in table 1 for convenience. Geologic units assigned to inventoried wells will have to be updated when geologic map revisions are complete.

Part of the trace of the extended Eakles Mills Fault coincides with the segment of the previously mapped Beaver Creek Fault. This revision is significant because of the very different nature of the two faults. Although the Beaver Creek Fault plane is concealed in the study area, it is known to be one of several ductile shear zones along South Mountain—a subhorizontal, mylonitic thrust fault (Campbell and others, 1992) that formed during the Alleghany orogeny of the late Paleozoic. This type of fault presents a zone of reduced permeability, owing to shear flow and recrystallization under high pressure. In contrast, the Eakles Mills Fault is a younger, high-angle fault (Brezinski, 1992, p. 52). The wall rocks reacted in a brittle fashion and fracturing can be observed where the fault plane is exposed (D. Brezinski, oral commun., 2007) and the fault may facilitate groundwater flow.

A cross fault is inferred extending from the Eakles Mills Fault, through the hatchery property, and displacing the Beaver Creek Fault (fig. 4). This fault could play an important role in groundwater flow on the west side of the lower end of the flow system discharging at the main hatchery spring. Its exact location and properties are unknown, nor is it known how its effect on groundwater flow may vary from low to high water levels.

GROUNDWATER LEVEL FLUCTUATIONS

Water levels measured in well WA Bj 222 (quarry's number FH-1) provide some context for observed hydrologic behavior (fig. 5). This well is located approximately 400 feet (ft) northwest of hatchery spring WA Bj 4. The lowest water levels occurred during 2002, a period of drought that began in May, 2001 and persisted into fall-winter, 2002 (Maryland State Climatologist, no date).

A transducer and datalogger were deployed in well WA Bj 222 in March 2007 but had to be removed in June. A second transducer-datalogger was installed in July 2008, one capable of logging temperature and specific conductance as well as water level. The record from the second instrument includes two noteworthy features (fig. 6). It begins about half a day after a 2-inch (in.) rainfall on July 23, 2008, too late to determine the time at which the water level began to respond, or the magnitude of the response, but it shows that the water level in the well reached a maximum about two and a half days after the rain before beginning to decline. The record from the earlier transducer shows a response beginning on the same day of a similar-size rainfall in April 2007 and reaching a maximum about one day later.

The water-level record for late July 2008 also shows a small diurnal fluctuation (fig. 7). This fluctuation deviates only about 0.08 to 0.018 ft from the general downward trend, but is present daily and likely is due to evapo-transpiration. During this period, water level was about 7 ft below land surface, corn in the adjacent field was high, and there are trees near the well. Diurnal fluctuations may be present in the record from the earlier transducer, particularly for June 2007, but they are less clear. Hourly logging of water levels may provide information useful for estimating water

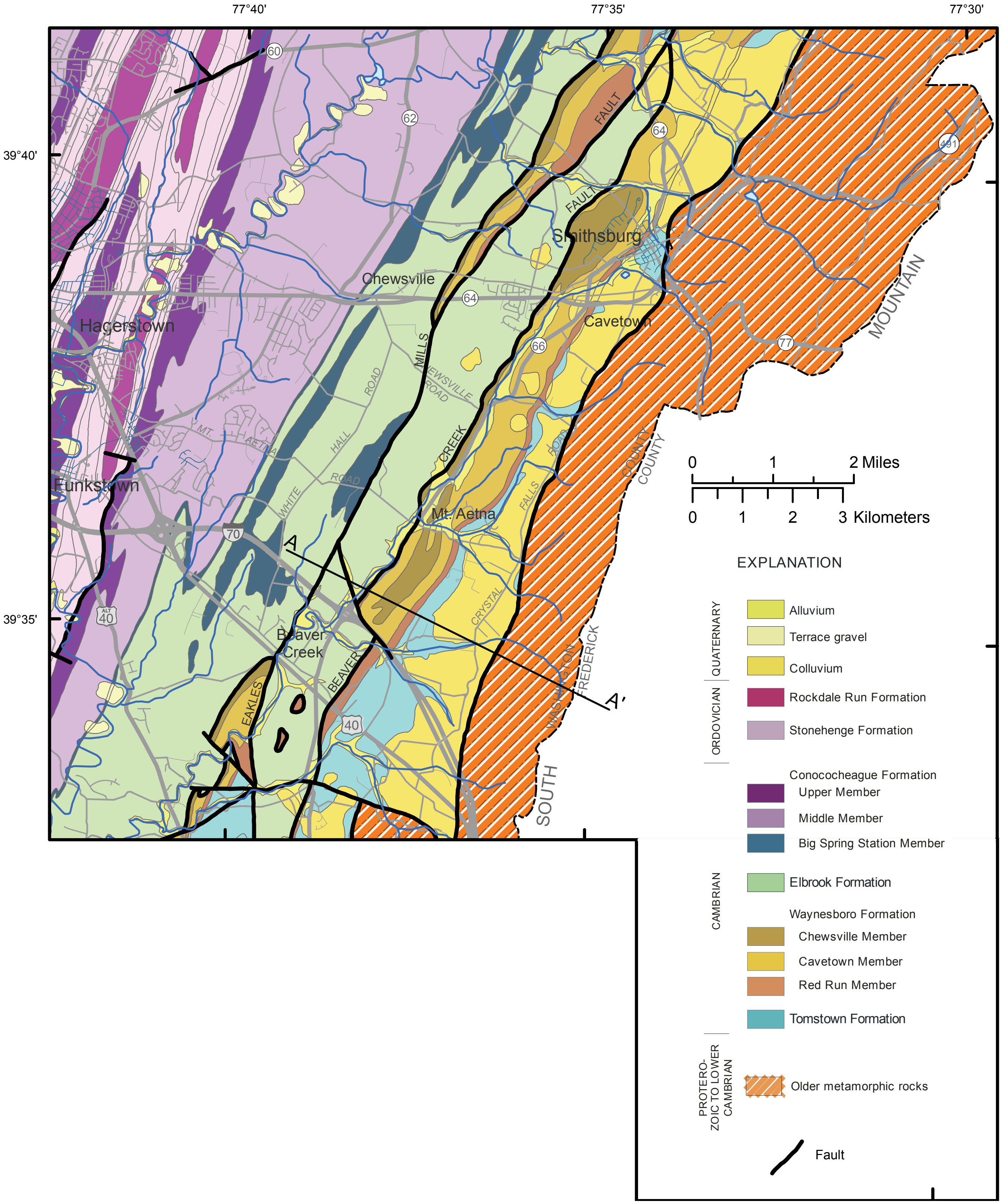

Figure 2. **Geology of the study area and vicinity. Modified from Duigon (2007) according to reinterpretation by Brezinski (written communication). Section A—A´ is shown in figure 3.**

Table 1. Stratigraphic column of the study area

[Descriptions from Brezinski, 1992 and 1993; Bell, 1993; and Fauth, 1981; Fm., formation; ft, feet; in., inches]

System	Formation		Description
QUATERNARY	Alluvium		Poorly sorted, unconsolidated, tan to dark-gray mud, silt, sand, and pebbles. Thickness generally 3-10 ft, up to 30 ft.
	Colluvium		Unconsolidated sand, cobbles, and boulders. Material consisting mostly of angular boulders that overlie or are downslope from quartzite outcrops is of undetermined thickness; further west, on the footslope, materials consisting of clay, sand and rounded pebbles and cobbles ranges from less than 3 to more than 300 ft thick.
ORDOVICIAN	Rockdale Run Fm.		Limestone and dolomite, biohermal and ribbony; abundant chert in many places. Thickness up to 2,500 ft.
	Stonehenge Fm.		Limestones comprising four facies, including shaly ribbony carbonate interbedded with flat-pebble limestone conglomerate and laminated limestone; and massive algal biohermal limestone. Thickness 1,000-1,400 ft.
UPPER CAMBRIAN	Conococheague Fm.	Upper Member	Ribbony, flaggy-weathering sets of alternating, thin, planar beds of limestone and dolomite, 0.5 to 3 ft beds of blue and pink marble, and thin-bedded, flat-pebble limestone and conglomerate. Thickness 650 to 750 ft.
		Middle Member	Cyclic and noncyclic limestone and interbedded dolomite. Includes massive, algal, and stromatolitic limestone and ribbony carbonate, flat-pebble limestone conglomerate, cross-bedded oolitic lime grainstone beds with deep mudcracks, and light-gray laminated dolomite. Thickness 1,500-2,000 ft.
		Big Spring Station Member	Sets of thin, dolomitic siltstone and massive dolomite containing lenses, stringers, or discontinuous beds of well-sorted quartz sand up to 8 in. thick. These sets are intercalated with cyclically-arranged limestones and include massive algal and stromatolitic limestones, ribbony carbonate-rock units up to 3 ft thick, and beds of flat-pebble limestone conglomerate. Thickness 150-250 ft.
MIDDLE CAMBRIAN	Elbrook Fm.		Interbedded, medium-gray, thinly-bedded limestone, white, mylonitic marble, tan, laminated dolomite, and thin, calcareous shale to shaly dolomite. Thickness 2,000-2,500 ft.
LOWER CAMBRIAN	Waynesboro Fm.	Chewsville Member	Interbedded, maroon shale, mudstone and argillaceous sandstone, light-gray sandstone, and tan, sandy dolomitic limestone and dolomite. Thickness 100-150 ft.
		Cavetown Member	Interbedded, medium- to dark-gray, bioturbated, dolomitic limestone and laminated limestone, with a few thin siliciclastic intervals near the middle. Thickness 500-600 ft.
		Red Run Member	Interbedded, light-olive-gray shale, light-gray, fine-grained sandstone, and medium- to dark-gray, sandy dolomitic limestone. Thickness 100-125 ft.
	Tomstown Fm. (undifferentiated)		Dark gray to light gray dolomite and limestone, bioturbated near top and bottom; lowest part sheared with white, mylonitic marble. Total thickness is somewhat more than 1,000 ft.
PROTEROZOIC TO LOWER CAMBRIAN	Older metamorphic rocks		Metamorphosed clastic rocks, consisting of phyllite, quartzite and metagraywacke, and metaconglomerate (Chilhowee Group). Total thickness approximately 3,000 to over 4,000 ft. These rocks overlie metamorphosed igneous rocks, chiefly metabasalt and metarhyolite (Catoctin Formation).

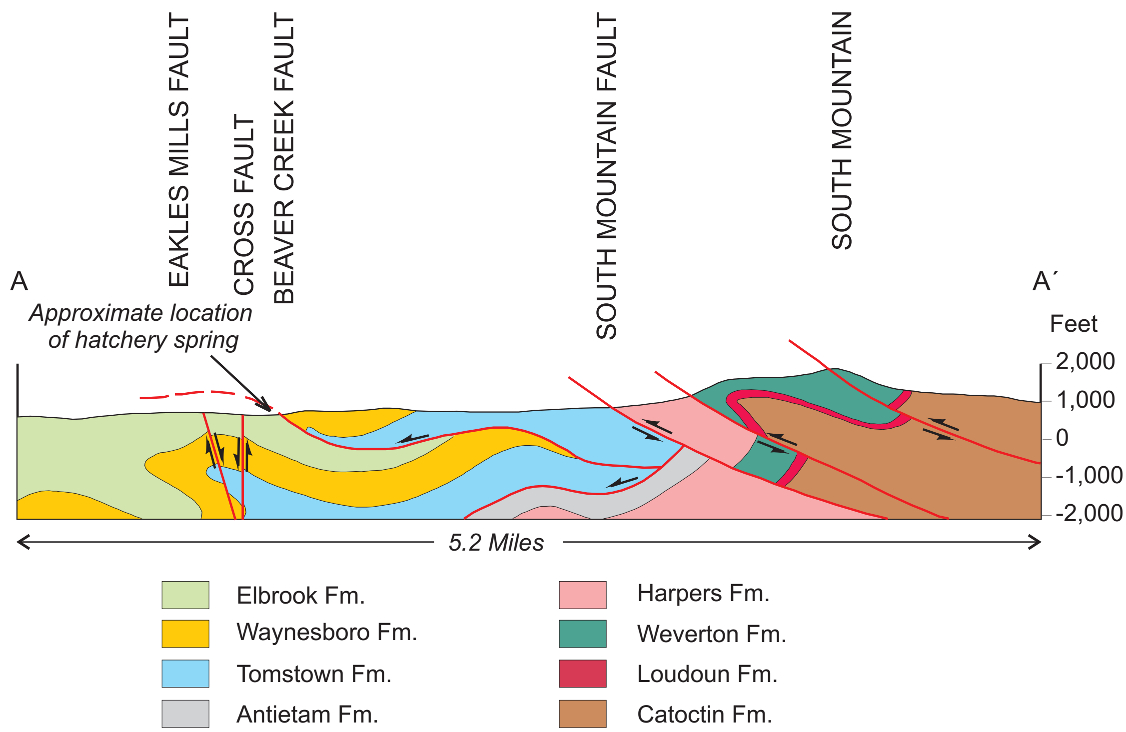

Figure 3. Geologic section across the study area. Location of the section is shown in figure 2. Units stratigraphically lower than the Tomstown Formation are shown as "older metamorphic rocks" on figure 2. Modified from Brezinski (1992).

balance and estimating parameters used in modeling spring flow.

DYE TRACING

MGS conducted groundwater tracing in 2007–08 to help delineate the area contributing groundwater to the hatchery spring, WA Bj 4. Maryland Department of the Environment (MDE) conducted traces in previous years to investigate groundwater sources of this spring and other springs serving as sources for public-water supply. Locations of dye-injection sites for the MGS and relevant MDE traces are shown in figure 8, as well as dye-sampling sites for the MGS traces.

Maryland Department of the Environment Traces

Maryland Department of the Environment Trace at Hauver Spring.

In 1992, MDE investigated the contribution of streamflow to spring WA Ak 3 (Hauver Spring), located about 2 mi north of Smithsburg, which was being used as a source for the municipal water supply (Maryland Department of the Environment, 1992). Dye was released into Little Antietam Creek at the point labeled MDE0 in figure 8 and was detected in spring discharge. The creek lost about 3.71 ft^3/s along a 1.3-mi reach upstream from the spring, nearly equal to the discharge of the spring (3.48 ft^3/s).

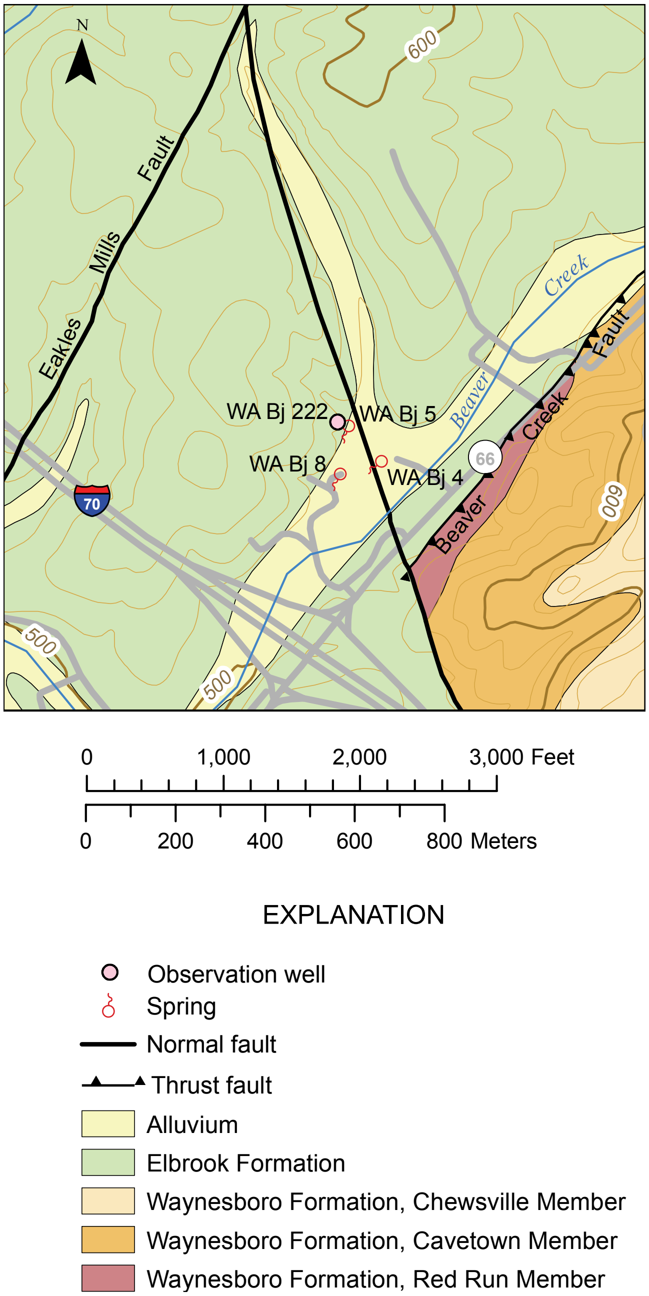

Figure 4. Faults in the immediate vicinity of the A.M. Powell State Fish Hatchery. The three hatchery springs and observation well WA Bj 222 are also shown.

Brezinski (D.K. Brezinski, oral commun., 2008) observed the stream disappear into a swallet at a later date. As can be seen in figure 8, spring WA Ak 3 is located very close to the trace of the Beaver Creek Fault. I hypothesize that water in Little Antietam Creek seeped through the stream bed into the Tomstown Formation (passing through an unknown thickness of alluvium and colluvium), and, upon reaching the Beaver Creek Fault, its flow was impeded causing the water to issue at land surface as spring WA Ak 3. If this hypothesis is correct, this situation provides evidence that the Beaver Creek Fault is a barrier to groundwater flow.

Maryland Department of the Environment Traces, 2002

MDE conducted two simultaneous traces in 2002 (M.K. Gary [later M.K. Edsall], written commun., 2002). One of the 2002 injection sites (labeled MDE1 on fig. 8) was within the area hypothesized (Duigon, 2007, p. 25) to be contributing groundwater flow to the hatchery spring; dye from this injection was detected in the spring (and at other sites). The second 2002 injection (labeled MDE2 on fig. 8) was into a swallet about 0.9 mi southeast of the hatchery spring. The swallet is on a tributary to Black Rock Creek. This dye was recovered from several sites along Black Rock Creek, south and southeast of the area drained by the hatchery spring.

Maryland Department of the Environment Traces, 2004–05

The purpose of the traces conducted by MDE in 2004-05 was to investigate the possibility that turbidity at the spring in November 2004 was caused by construction of one of several wells completed at about the time that the turbidity was noticed. Dye from the first injection (at site MDE3, shown on fig. 8) was not detected in the hatchery spring, but was detected in Beaver Creek downstream from the hatchery. Flow from the injection may have been directed generally along strike to the south-southwest, emerging along the Beaver Creek tributary (if the tributary were flowing at the time), moving along the cross fault towards

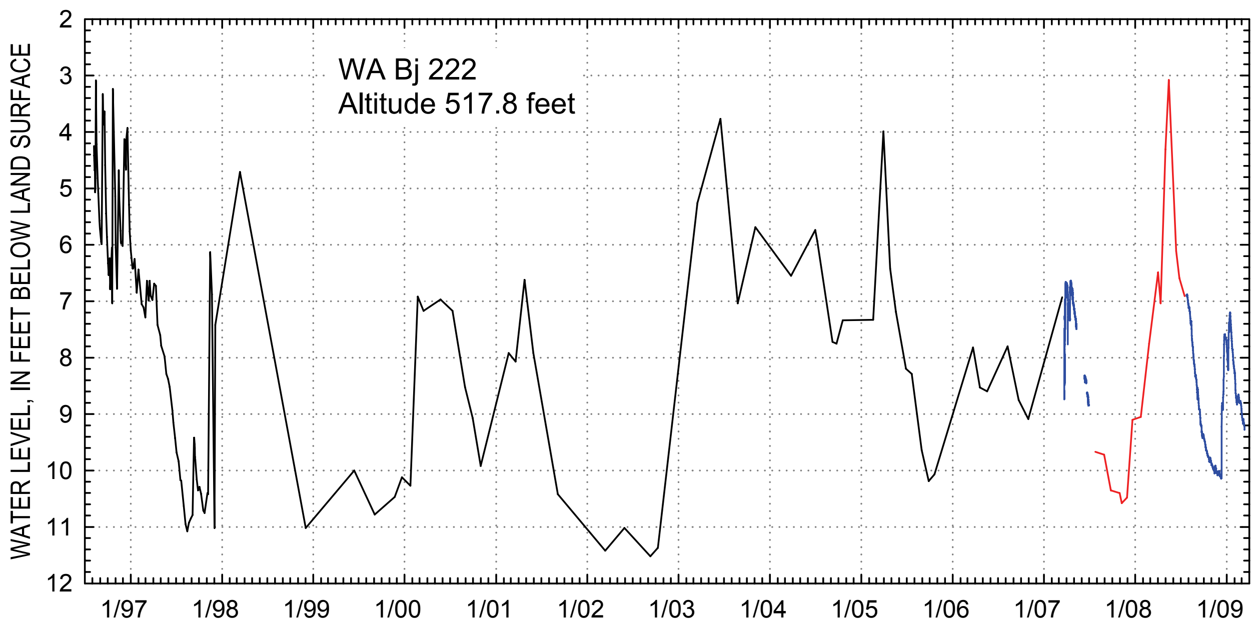

Figure 5. Hydrograph of well WA Bj 222 for the period August 1996 through March 2009. Water levels from August 1996–March 2007 (black line) measured by H.B. Mellott Estate personnel. Blue lines (March–June 2007 and July 2007–March 2009) are water levels recorded by transducers installed in the well. Water levels from July 2007–July 2008 were measured by the author (red line).

Beaver Creek, or reaching the Eakles Mills Fault, which Beaver Creek touches at a few points north of U.S. Route 40. Groundwater levels were moderate to high at the time of this trace. If this interpretation is correct, it places this flow region outside of the hatchery spring's contributing area.

The second 2004 injection (at site MDE4, shown on fig. 8) was into a monitoring well east of the hatchery spring, uphill from a well considered another possible source of the turbidity. Dye was recovered from the hatchery spring and from Beaver Creek downstream from the hatchery, but not from any other location. Strata dip steeply to the southeast at the injection site, which is located at the nose of a ridge, along the flank of a northeastwardly plunging syncline. The lower part of the well intersects a cavernous zone. The three-dimensional extent of the cavernous zone is unknown; it may or may not be related to cavernous zones reported in well WA Bj 261 (quarry's well number N-11), located about 560 ft southwest along the strike. About 800–900 ft to the east, the main passages of Mt. Aetna Cave trend to the southwest (Davies, 1950, fig. 13). Groundwater flow likely is directed by geologic structure to the southwest, but there may be occasional fractures allowing flow toward Beaver Creek to the west.

I hypothesize that the dye-bearing groundwater, rather than being transported from the injection well and emerging at the hatchery spring, discharged (in part) at the base of the alluvium beneath Beaver Creek and (in part) along Black Rock Creek, plus whatever was intercepted by the East Pit of the quarry. Streamflow data are not available for the period; however, Beaver Creek is known to lose flow between Mt. Aetna and the hatchery, at least during some periods (Duigon, 2001), as discussed in the section describing MGS trace 1, below. Dye-bearing water may have flowed downvalley at or near the alluvium-bedrock

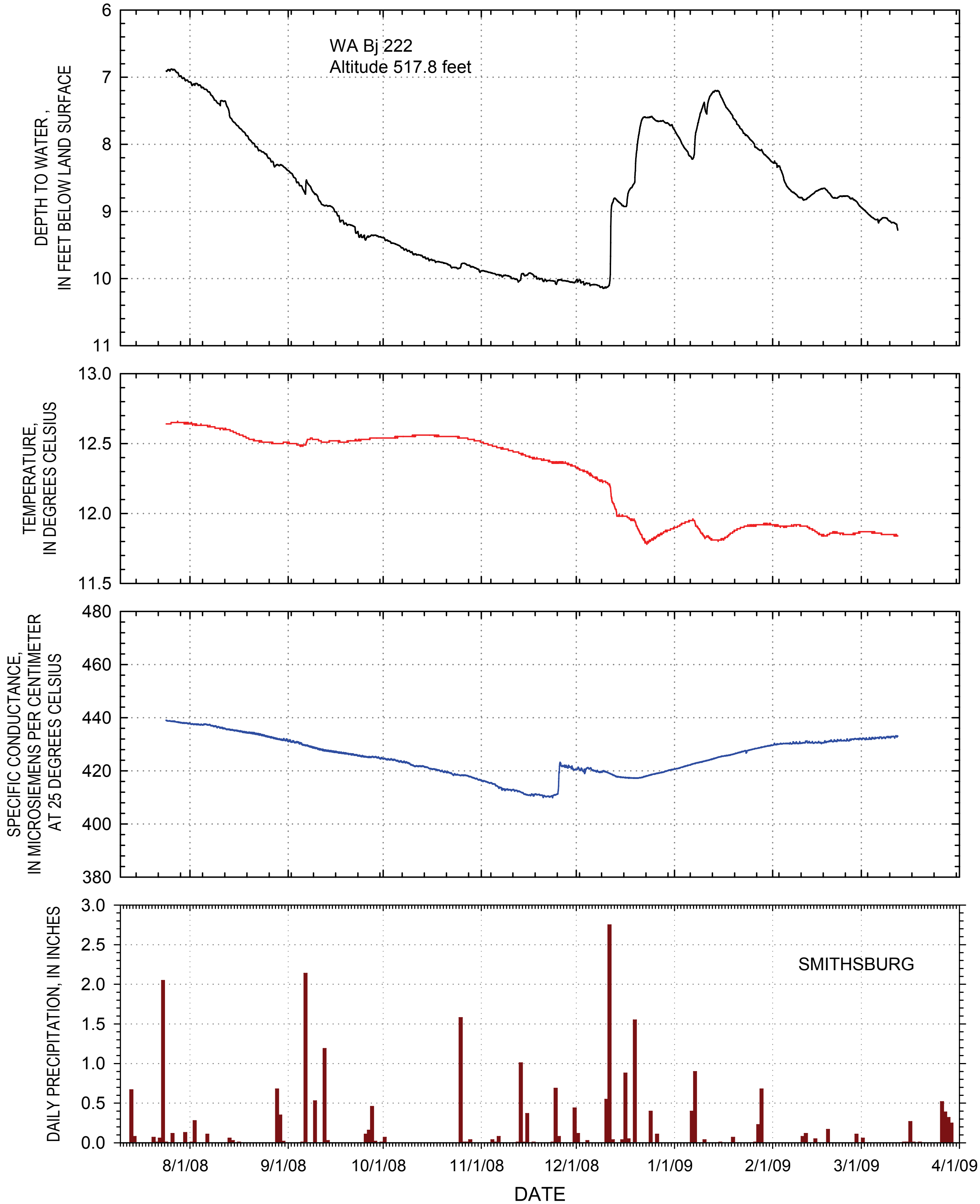

Figure 6. Water level, temperature, and specific conductance recorded in well WA Bj 222 and precipitation at Smithsburg. Precipitation data from SmithsburgWeather.com.

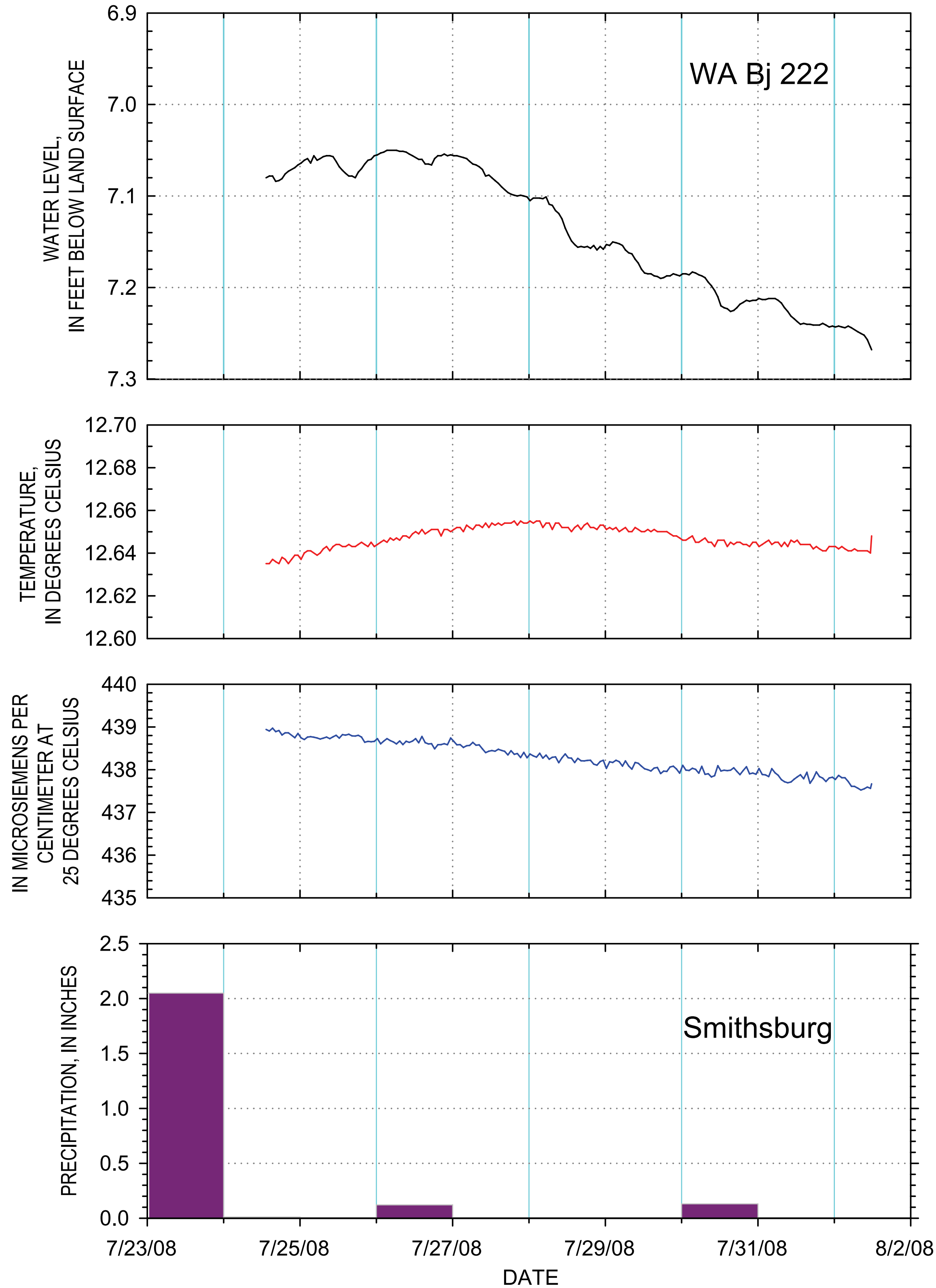

Figure 7. Detail of data in figure 6 for July 24, 2008–August 2, 2008, showing diurnal fluctuation in water level in well WA Bj 222.

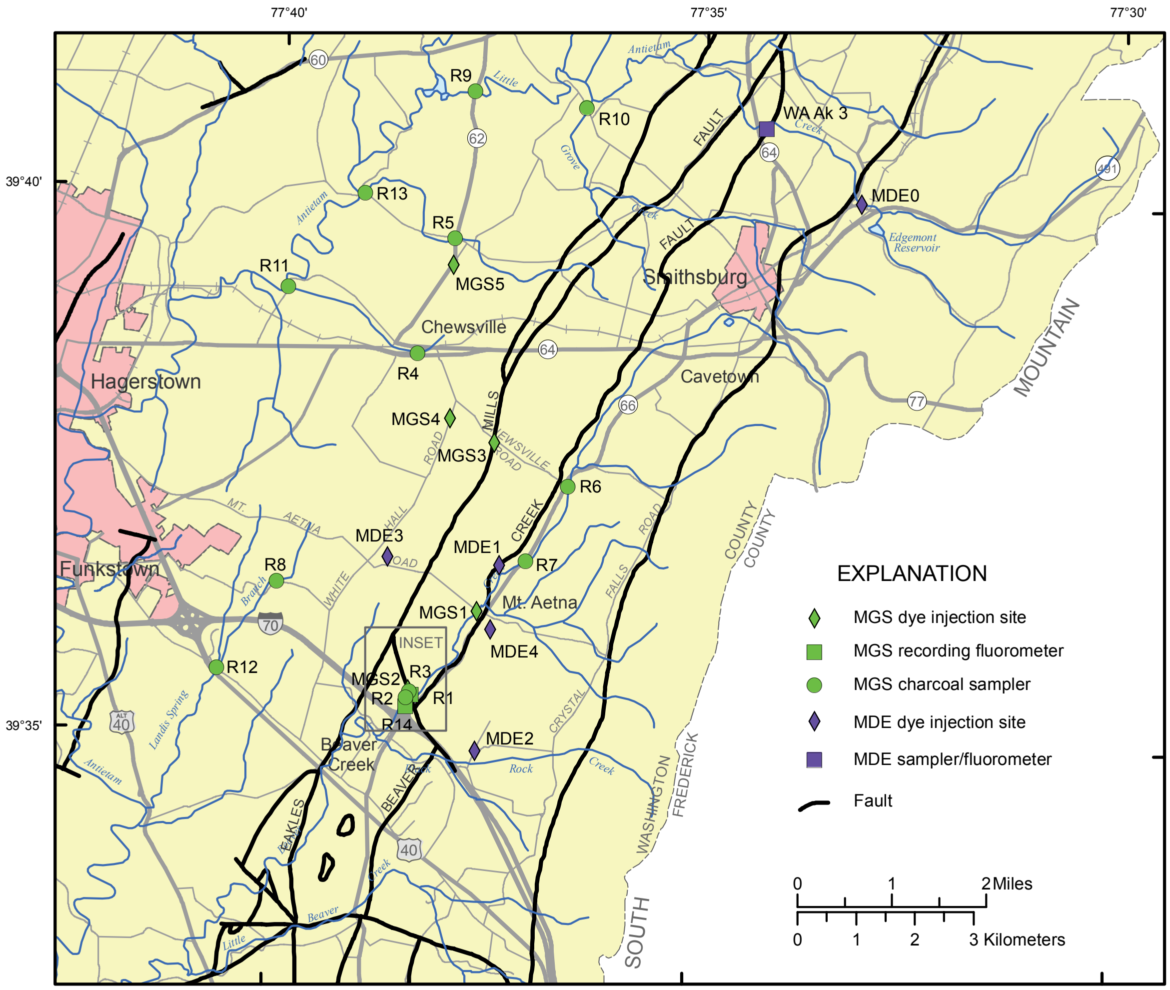

Figure 8. Locations of dye-tracing injection and recovery sites.

interface (thus not being detected at samplers in Beaver Creek upstream from the hatchery) and some part of it subsequently flowed to the hatchery spring. This scenario accounts for dye recovery at the spring and (because spring discharge is directed from the hatchery to the creek) in Beaver Creek at sites downstream from the spring.

Maryland Geological Survey Traces, 2007–08

MGS conducted five traces in 2007 with the assistance of Malcolm Field, U.S. Environmental Protection Agency, who operated a pair of continuously monitoring and logging fluorometers and estimated the amount of dye to be injected. The injection sites are shown in figure 8, as are the locations of the fluorometers and sites where activated charcoal samplers ("bugs") were placed for detection of dye. For each of these traces, one fluorometer monitored spring WA Bj 4 at the hatchery, and one monitored Beaver Creek just above the point at which the creek leaves the hatchery property. Background dye concentration was measured by the fluorometers and subtracted from subsequent measured concentrations (reported concentrations are therefore concentrations above background).

Quantitative dye tracing would be very useful in gaining an understanding of the

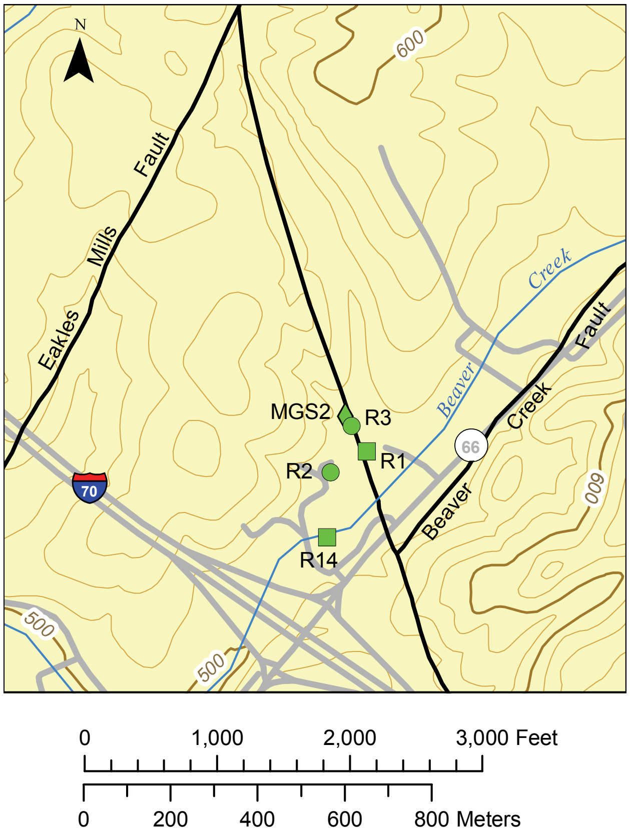

Figure 8. (Continued) Inset showing detail of dye injection and sampling sites on hatchery property.

hydrology of the study area. Accurately measuring times, concentrations, and dye masses can help estimate time-of-travel, how much water moves along different flow routes, and elucidate surface-water/groundwater relations. The dye traces MGS conducted, however, are qualitative to semi-quantitative. The results provide "from–to" information with some travel-time estimates, but did not account for dye mass. Besides allowing some conclusions to be drawn, these traces can be used as guidance for future quantitative tracing.

Maryland Geological Survey Trace 1

The first trace addressed the question of whether surface water leaking through the bed of Beaver Creek contributed to flow at the hatchery spring. Approximately 1,100 grams (g) of fluorescein dye was injected at about 7:45 p.m. on October 4, 2007 into Beaver Creek at Mt. Aetna Road (site MGS1 in fig. 8). The release point was about 600 ft below the confluence of Beaver Creek and Mt. Aetna Creek and about 6,800 ft upstream from the spring. Above the confluence of the two streams, the streambed of Beaver Creek was dry; Mt. Aetna Creek flows perennially into Beaver Creek. Beaver Creek was flowing at 0.647 ft^3/s at Mt. Aetna Road, but streamflow had dropped by about 21 percent as measured just above the hatchery (tab. 2; fig. 9).

The amount of dye transported in Beaver Creek exceeded the maximum concentration that the fluorometer monitoring the creek could measure (up to 75 micrograms per liter [μg/L]). Fluorometer data from the hatchery spring show a definite response pulse having a maximum concentration of about 1.2 μg/L in the spring (fig. 10), clearly indicating a contribution from Beaver Creek to springflow. The dye reached both fluorometers in about one day. The broad concentration decay seen in the graph for the spring may be ascribed to the location and length of stream bottom through which dye-bearing water seeped into the ground plus the effect of post-injection rainfall. The month preceding injection was quite dry (0.79 in. of rain since September 1; the Smithsburg station has not been in operation long enough to compute normal precipitation, but the normal at Hagerstown 1E for September is 3.07 in. (Keefer, no date, at http://i4weather.net/norms.txt). Three storms in October produced 0.50 in., 1.53 in., and 3.05 in. of rain.

A small diurnal fluctuation in concentration can be seen in the graph for the spring. A similar fluctuation is present in the graph for Beaver Creek as well, which can be seen when plotted at the same scale as the concentration in the spring. The cause of this fluctuation is uncertain; it may be due to daily temperature changes (instrument response is somewhat sensitive to temperature).

Table 2. Stream- and springflow for groundwater trace 1

Site	Total discharge (cubic feet per second)	Streamflow loss	
		Cubic feet per second	Percent
Beaver Creek at Mt. Aetna Rd.	0.647	--	--
Beaver Creek near Md. Route 66, 0.6 miles below Mt. Aetna Rd.	.620	0.027	4
Beaver Creek above hatchery	.513	.107	17
Hatchery spring WA Bj 4	4.932	--	--

All flows measured October 3, 2007 by U.S. Geological Survey. Springflow includes water diverted from main spring discharge.

Maryland Geological Survey Trace 2

The purpose of the second trace was to check for a hydraulic connection between a well (site MGS2 in fig. 8, located on the hatchery property about 400 ft northwest of spring WA Bj 4) and the spring and the creek. The driller reportedly hit water at 65 ft below land surface at the top of a 5-ft zone described in the well completion report as "brown limestone" having "gray limestone" above and below. The well is cased at 37 ft. Geologic mapping (S.C. Bell, unpublished Funkstown geologic quadrangle map, Maryland Geological Survey files) shows the beds dip about 22 degrees toward the southeast. I considered the brown zone likely to be a weathered zone that permits groundwater flow; therefore, the dye was introduced into the well through a pipe extending to that depth. Approximately 100 g of fluorescein dye was injected on November 8, 2007, and the well was flushed with a few hundred gallons of water.

No dye pulse was seen in either spring WA Bj 4 or Beaver Creek within 21 days of monitoring (fig. 11). Dye was detected on charcoal bugs placed in spring WA Bj 8 (site R2 in fig. 8) which is located approximately 440 ft south-southwest of the well, along strike. The bugs were deployed beginning November 8, 2007. The last one was removed September 5, 2008. Every one showed a positive detection of fluorescein. (The charcoal samplers were added as an afterthought. Had they been the primary detectors, they would have been deployed and changed well in advance of dye injection.) Dye injected by MDE in December 2004 (at site MDE3 shown on fig. 8) also was undetected at hatchery spring WA Bj 4, as discussed above.

The mass of the dye has not been accounted for, but the evidence suggests the boundary of the groundwater flow system that discharges at the hatchery spring lies between the spring and well WA Bj 222 and extends past injection site MDE3 some distance to the east of it. There apparently was no flow from the well to the spring, nor from the well to Beaver Creek above the fluorometer.

Maryland Geological Survey Trace 3

The third trace was an exploration for the northwestern segment of the contributing-area boundary. On December 4, fluorescein dye (2.064 kilograms [kg]) was injected into a sinkhole on the south side of Chewsville Road (site MGS3 in fig. 8), approximately 2.8 mi from the spring in the vicinity of the hypothesized boundary, and flushed with about 3,600 gallons (gal) of water. The strike of the Elbrook Formation in the vicinity of this sinkhole is northeast-southwest, and the dip is to the southeast.

Dye was detected at the hatchery spring within two days of injection (fig. 12). The multiple peaks and the broad peak (about 10 to

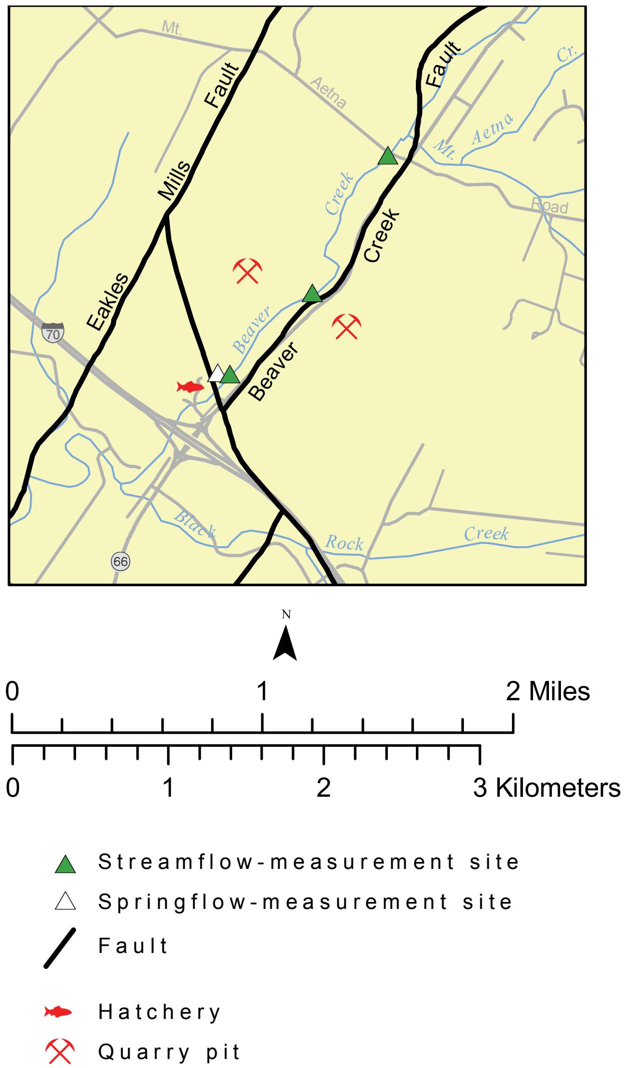

Figure 9. Locations of sites where streamflow and springflow were measured in Beaver Creek as part of trace 1.

16 days after injection) may be a consequence of anastomosing groundwater flow paths and several episodes of rain, in addition to dispersion in the course of the approximately 3-mi trip.

A narrow concentration peak occurred in Beaver Creek 12 days after injection. Rising groundwater levels following the larger of the December rains may have reversed the hydraulic gradient adjacent to Beaver Creek in the vicinity of the hatchery, changing this part of the stream from a losing to a gaining reach. Curiously, the peak fluorescein concentration in Beaver Creek (0.438 μg/L at about 12 days) was higher than the peak concentration in the spring (0.237 μg/L at about 2½ days), which may indicate a flow path taken only when groundwater levels are high.

Maryland Geological Survey Trace 4

For the fourth trace, eosin dye was injected on April 3, 2008, into a sinkhole on the west side of White Hall Road about 2.9 mi north of the spring (site MGS4 in fig. 8). Eosin was used mainly for convenience, as the pre-mixed fluorescein supply was nearly used up. Several points of apparent elevated eosin concentration were recorded by the fluorometer in the hatchery spring (fig. 13), but these are single points. The measurement frequency was hourly and it is highly unlikely that a slug of dye-bearing groundwater could move through the spring so rapidly as to produce a concentration peak consisting of only a single point. The elevated values likely were temporary interference from turbidity or another substance having similar fluorescence properties. Three peaks, each hundreds of micrograms per liter, were measured in Beaver Creek, coinciding with significant rainfalls. Data following the second and third peaks were lost owing to electrical failure providing power to the instrument. These two peaks may be due to the pump, used to deliver stream water to the instrument for analysis, clogging with sediment and stopping; as muddy water remaining in the instrument warmed, the apparent concentration rose. When water began to flow through the pump again, the apparent concentration began to decrease. Beaver Creek was visibly quite turbid at this time owing to the heavy rains, and turbidity can be read as dye concentration by this fluorometer.

The first eosin concentration peak in Beaver Creek, occurring about 8 days after injection, has the appearance of a real dye-recovery peak. Turbidity cannot be ruled out as the cause, but there are no reports of turbidity in Beaver Creek at that time and there was no pump clogging. How can recovery in Beaver Creek of the dye

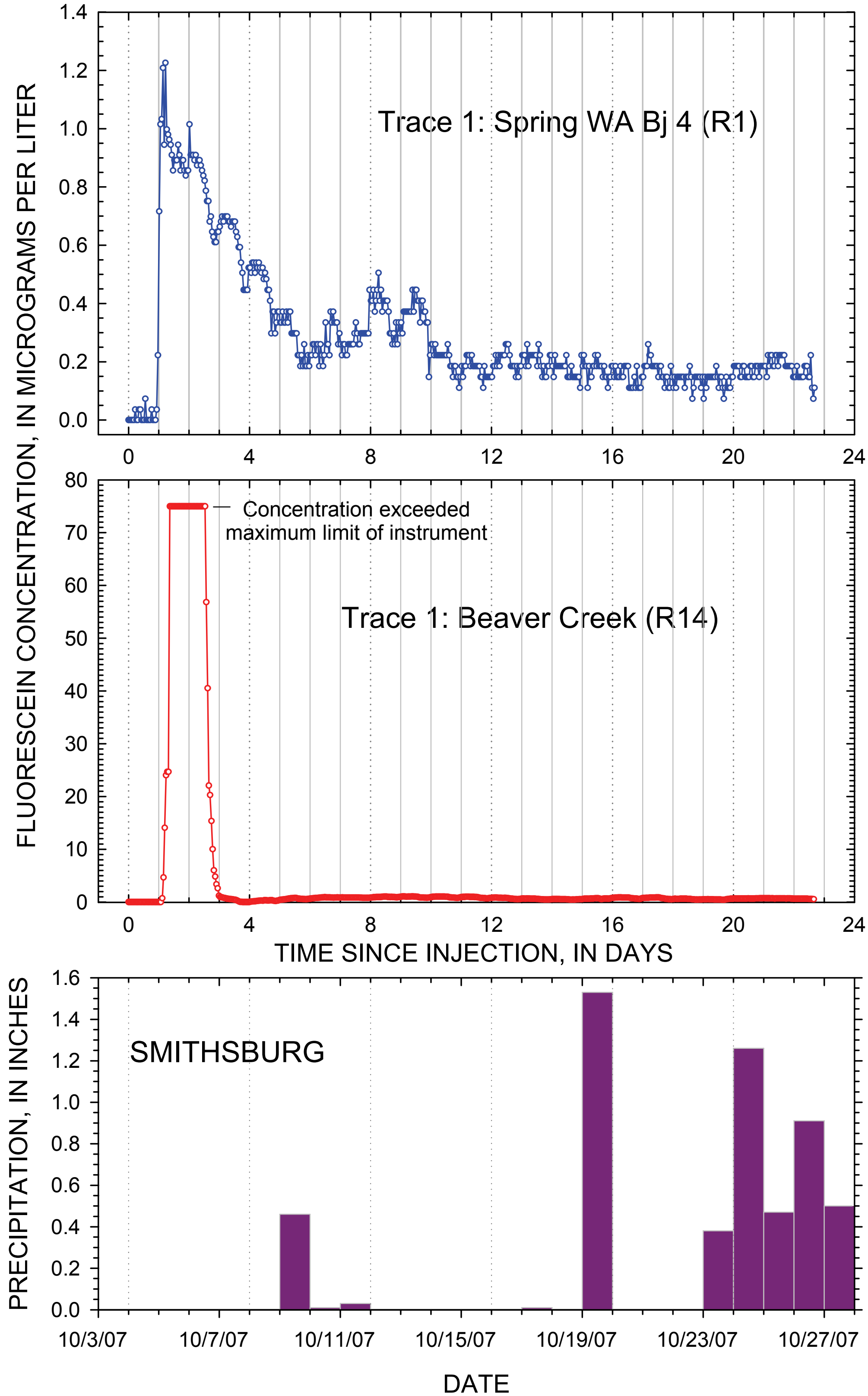

Figure 10. **Dye concentrations in hatchery spring WA Bj 4 and Beaver Creek, and precipitation at Smithsburg, trace 1. Precipitation data from http://SmithsburgWeather.com.**

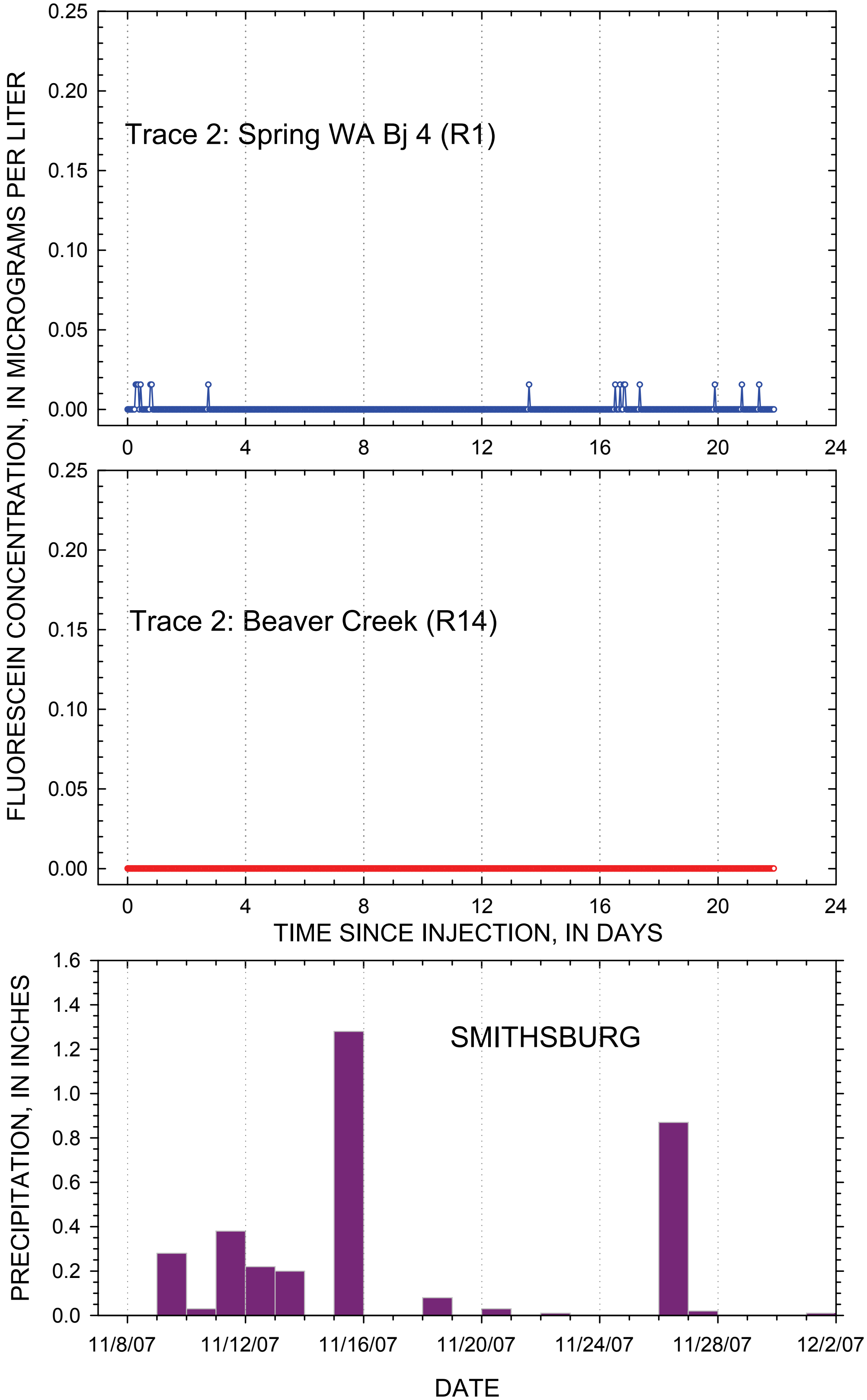

Figure 11. Dye concentrations in hatchery spring WA Bj 4 and Beaver Creek, and precipitation at Smithsburg, trace 2. Precipitation data from http://SmithsburgWeather.com.

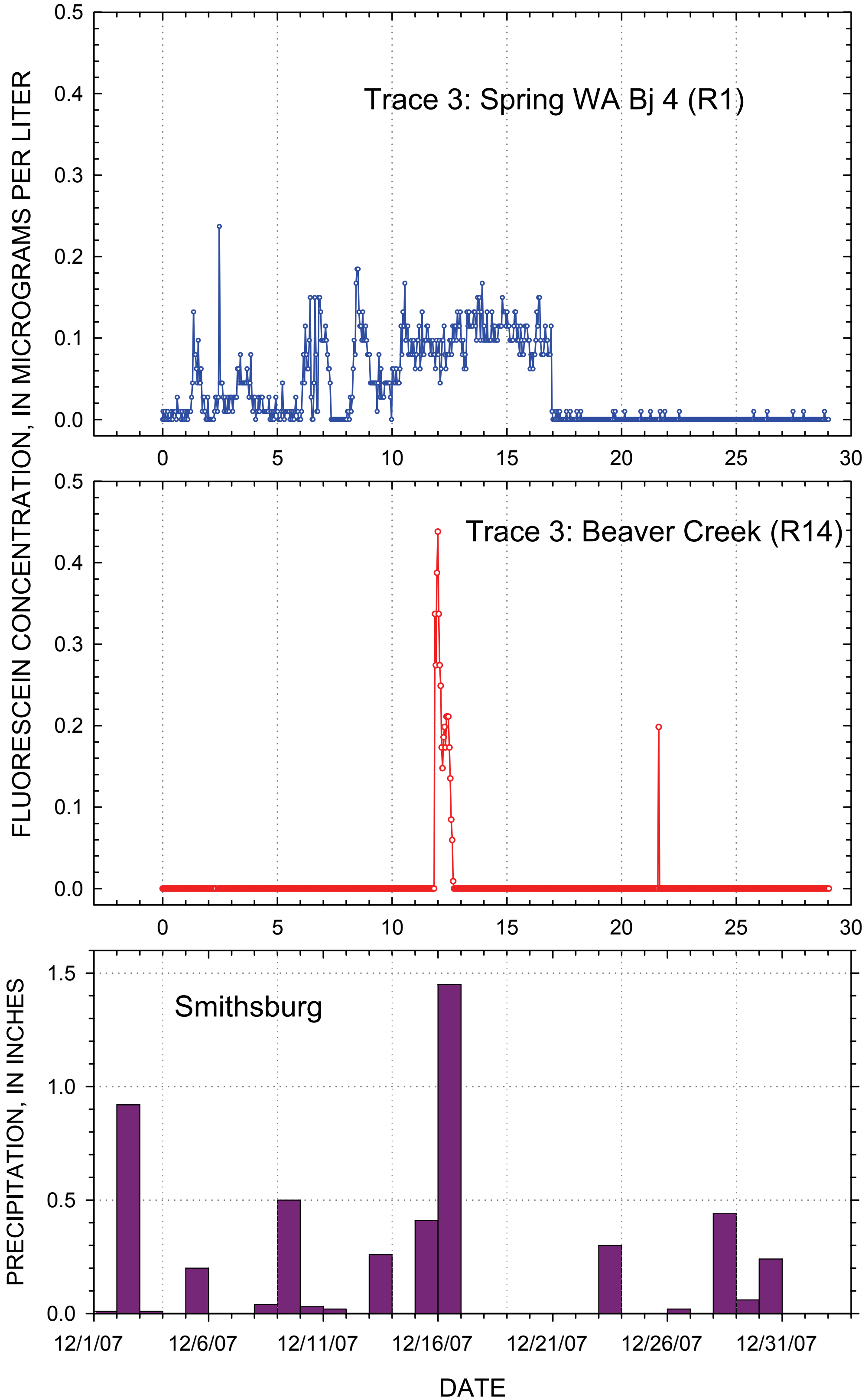

Figure 12. Dye concentrations in hatchery spring WA Bj 4 and Beaver Creek, and precipitation at Smithsburg, trace 3. Precipitation data from http://SmithsburgWeather.com.

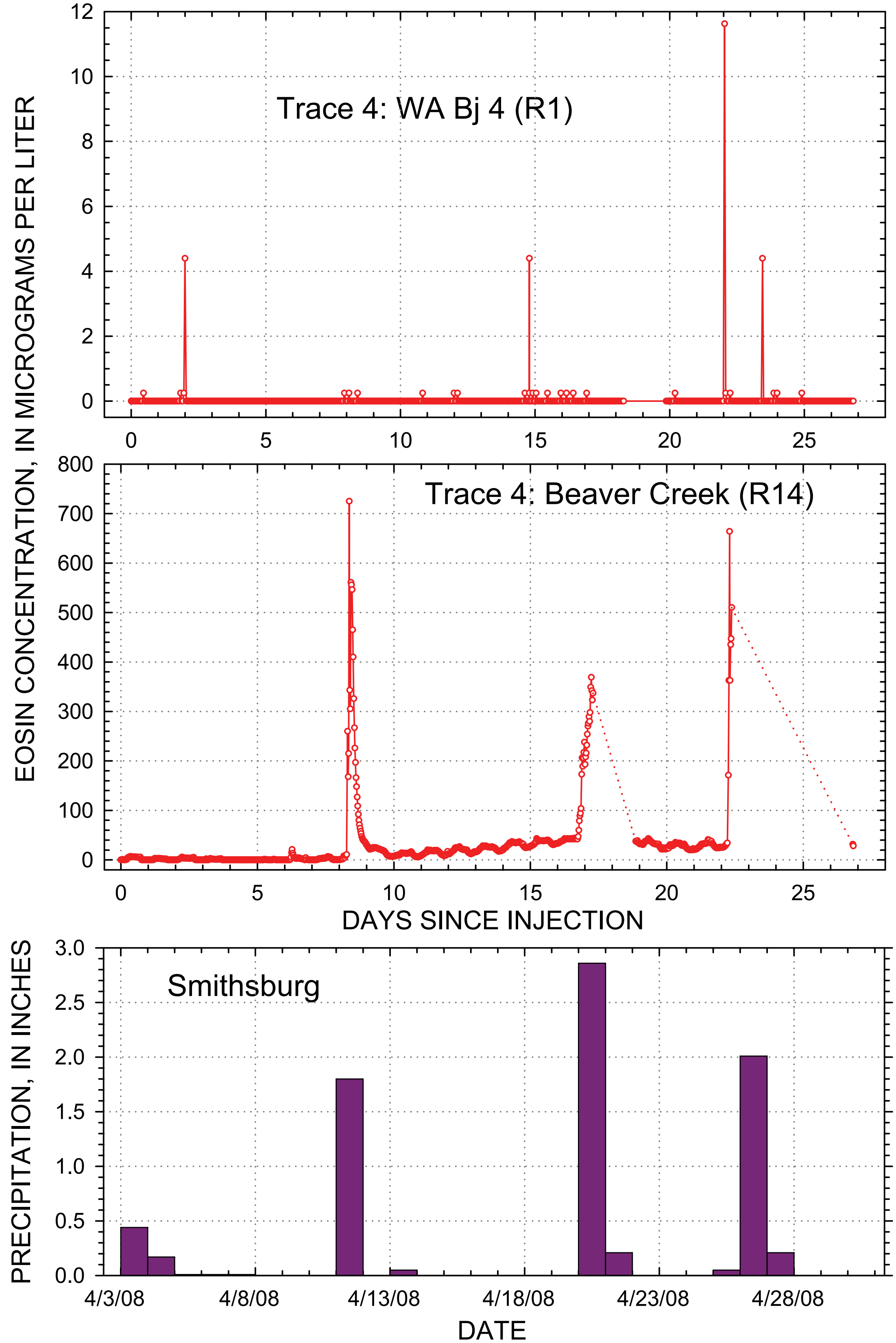

Figure 13. Dye concentrations in hatchery spring WA Bj 4 and Beaver Creek, and precipitation at Smithsburg, trace 4. Precipitation data from http://SmithsburgWeather.com.

injected at White Hall Road be reconciled with the absence of recovery in the hatchery spring, considering the spring lies between the injection site and the creek, and the injection site is on the other side of the Eakles Mills Fault?

Groundwater levels were moderately high in April and the hydraulic head may have been higher in the ground than in the creek. It is possible that, under conditions of high water level, groundwater may flow from the injection point toward the southwest, along strike, until a high-water route leading to Beaver Creek is taken. The cross fault extending from the Eakles Mills Fault through the hatchery property and across Beaver Creek could be such a route. Spring WA Bj 5 is located near the fault and near well WA Bj 222, and ceases to flow during prolonged dry weather. The same scenario can explain the trace conducted by MDE, in which dye injected at site MDE3 (fig. 8) was detected in Beaver Creek downstream from the hatchery but not in the spring. Groundwater levels as measured in well WA Bj 222 during the MDE trace in 2004–05 were similar to levels when MGS traces 4 and 5 were conducted (see hydrograph, fig. 5 for December 2004–January 2005, and April 2008).

There is also a similarity with trace 3, in which there was a fluorescein concentration peak at about 12 days after injection. Groundwater levels were lower for that trace (based on measurements in well WA Bj 222). However, about 2 in. of rain fell on December 13-16, 1.43 in. of which fell on December 16, coinciding with the dye concentration peak. During trace 4, 1.80 in. of rain fell on April 11, coinciding with the first eosin concentration peak. In contrast to the second and third peaks, attributed to power disruption and very turbid water, power was not lost when the first peak passed, nor was the pump clogged and jammed. The apparent dye concentration peak of trace 4 took just over 8 days to travel about 2.9 mi (straight-line distance); that of trace 3 took about 12 days to travel approximately 2.8 mi (straight-line distance).

Maryland Geological Survey Trace 5

The injection site for the fifth trace (MGS5 on fig. 14) was a sinkhole approximately 4.6 mi north of the hatchery spring. It was thought to be west of the presumed northern end of the contributing area. Electric power losses prevented data collection from the fluorometer in Beaver Creek and loss of data from the spring for the first eight days. Beginning about 20 days after injection, there is a dye-concentration peak that appears significant, yet is perplexing because (1) it was expected that groundwater flow from the injection point would not be in the direction of the spring; (2) the concentration jumped from background to maximum with no intermediate concentration and fell steeply down to background; and (3) the width of the peak is only about two days (compare with trace 1 and trace 3, figs. 10 and 12, respectively). It is possible that under high water-level conditions (as prevailed during trace 5), the groundwater divide in the vicinity of Chewsville (Duigon, 2007, fig. 10) may shift to the north beyond injection site MGS5, but such a conclusion remains tentative until recovery can be replicated or otherwise substantiated.

THE AREA CONTRIBUTING GROUNDWATER FLOW TO THE HATCHERY SPRING

Results of groundwater tracing and revisions in geologic mapping have led to some revision of the area contributing groundwater flow to the hatchery spring as delineated by Duigon (2007, p. 25). The Beaver Creek Fault is still hypothesized (on the basis of the type of fault and related characteristics) to act as an impediment to groundwater flow, forming the boundary of the contributing area on the east (fig. 15). Water-level data reported from well completion reports and springs (mostly obtained from topographic maps having 20-ft contour intervals) indicated a groundwater divide

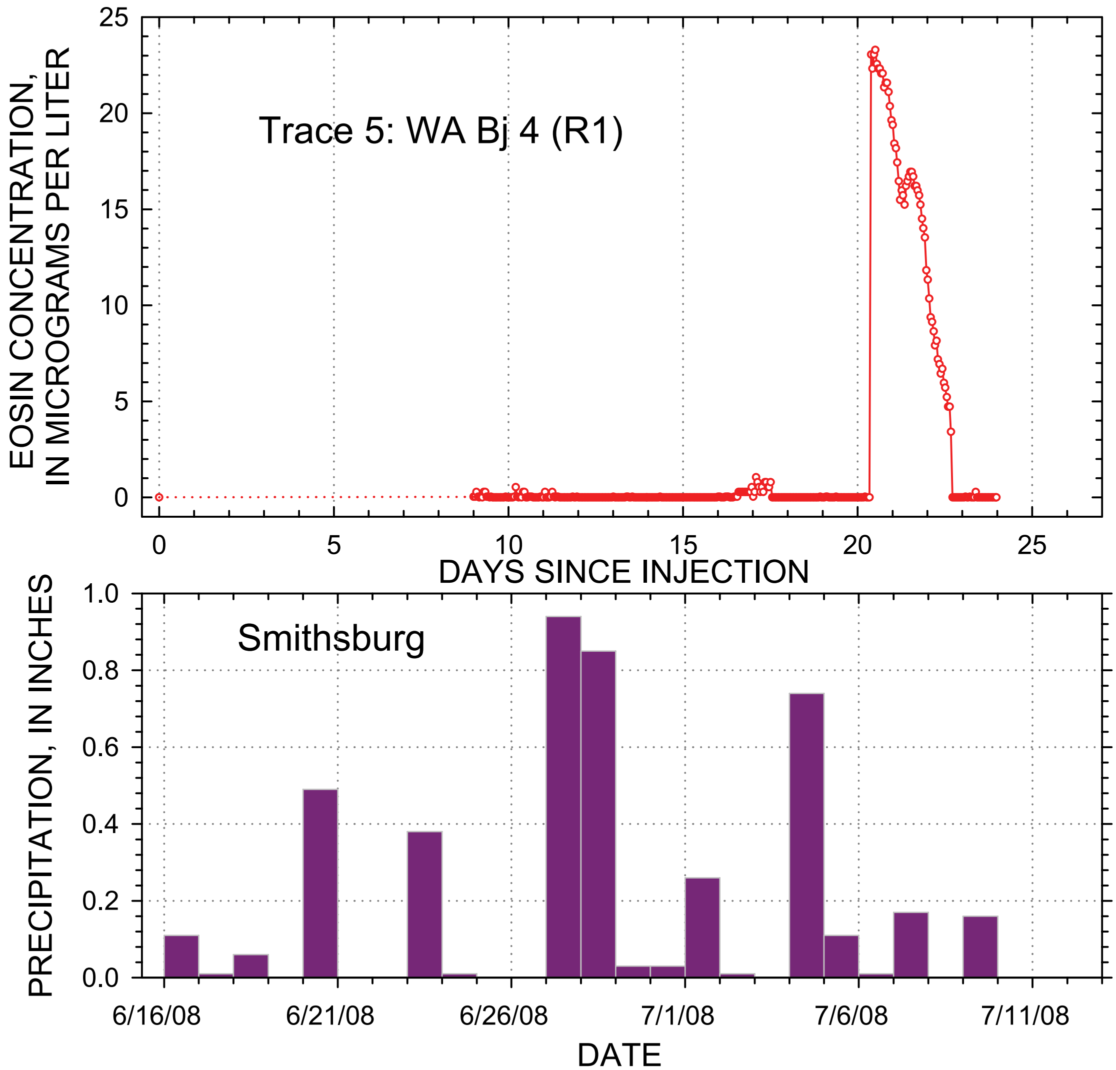

Figure 14. Dye concentrations in hatchery spring WA Bj 4, and precipitation at Smithsburg, trace 5. Precipitation data from http://SmithsburgWeather.com.

trending approximately east-west near Md. Route 64 (Smithsburg to Hagerstown). I hypothesize that north of that divide, groundwater flows toward several tributaries of Antietam Creek, particularly Little Antietam Creek and its tributary, Grove Creek. Results of the fifth dye trace appear to negate this hypothesis. Perhaps the groundwater divide shifts northward during periods of high groundwater levels. This area requires further investigation under conditions of both high- and low-groundwater levels. The contributing-area delineation is therefore modified to encompass additional area to the north and west. This is a conservative interpretation, because if the contributing area grows in this direction, following a shifting groundwater divide, it is excessive for periods of low water levels but appropriate for conditions of high water levels. The size of the contributing area as modified (8.2 mi^2) is nearer in agreement to the estimates derived from baseflows presented by Duigon (6.8 to 9.5 mi^2; 2007, p. 27).

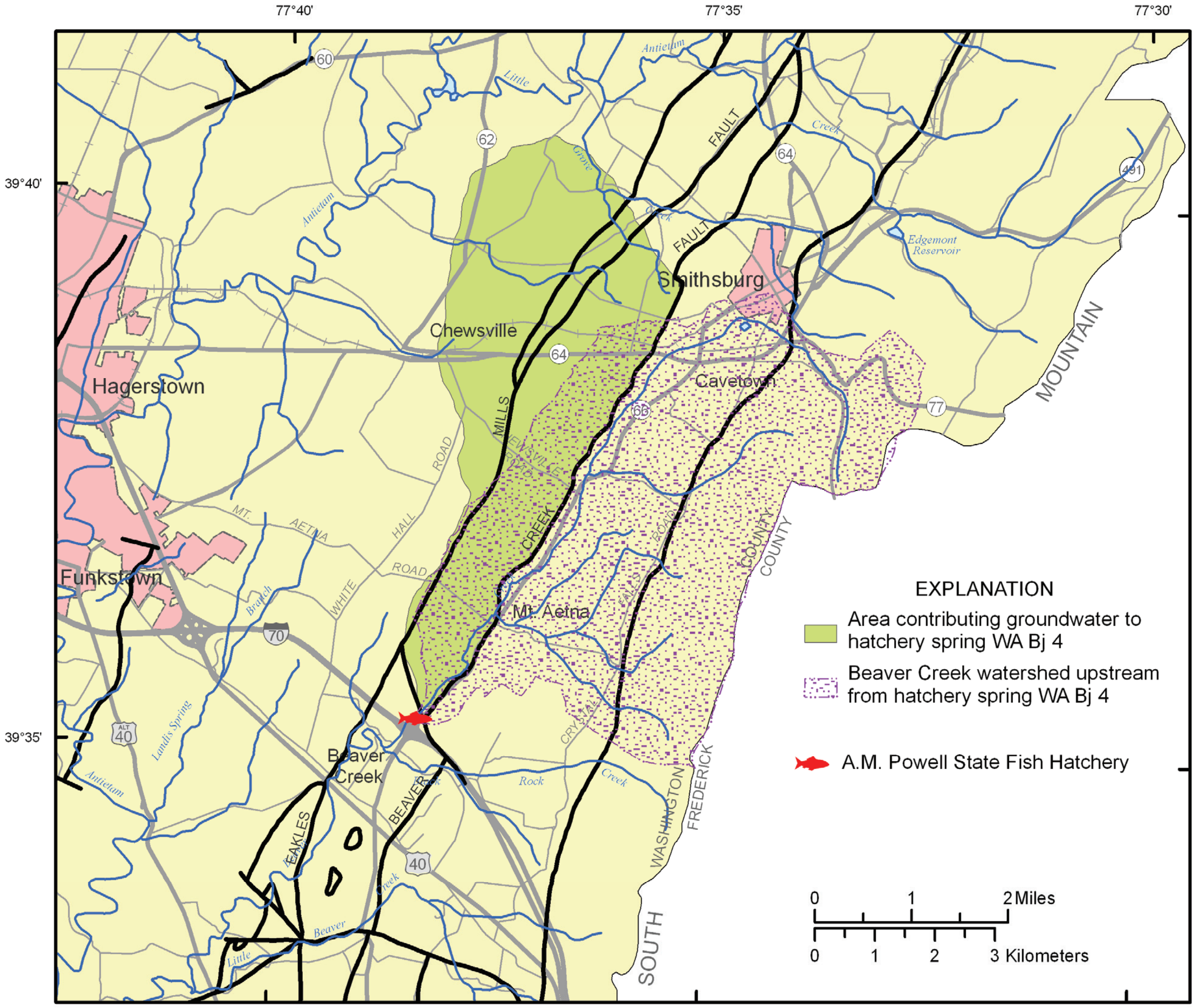

Figure 15. Area contributing groundwater flow to the hatchery spring as currently hypothesized.

South of Md. Route 64, Beaver Creek, Landis Spring Branch and several small ephemeral tributaries to the west flow south-southwestward, parallel with the general geologic structure. The Eakles Mills Fault may create the western boundary of the contributing area if it provides a zone of enhanced permeability, because if it does, groundwater flowing eastward from White Hall Road or beyond would be directed along the fault and flow to the south-southwest. Similarly, some groundwater flow near the east side of the fault may be redirected to flow along the fault. Groundwater flowing along the fault zone may drain to Beaver Creek south of I-70, although during periods of high groundwater levels, some of that water may be diverted by the cross fault extending across the hatchery property and discharge at the upper hatchery spring, WA Bj 5, and to Beaver Creek near the southern end of the hatchery.

After crossing Md. Route 64, Beaver Creek flows approximately parallel with the Beaver Creek Fault to just beyond the hatchery, where the trace of the Beaver Creek Fault is offset to the east by a cross fault. Beaver Creek originates on the eastern (overthrust) side of its eponymous fault, but crosses to the western (underthrust) side of the fault at Mt. Aetna. Above that crossing, which is just above the confluence with Mt. Aetna Creek (a perennial, spring-fed stream), Beaver Creek is frequently dry during the drier part of the year, at least to a point just south of Md. Route 64, sometimes further upstream. The entire length of Beaver Creek from Smithsburg to beyond the hatchery is alluviated, although the bed is rocky in places. Duigon (2001, App. D) reported losing reaches of Beaver Creek and its tributaries during seepage runs conducted in August, 1995 and September, 1996. There are no swallets where the entire flow of the stream goes underground. Could seepage through the bed of Beaver Creek contribute to the flow of the hatchery spring? Quantitative dye tracing can be used to estimate how much water leaks through a stream bed and appears at a spring (Field, 2006); however, for the present study, dye tracing was used only to confirm a springflow contribution from streambed leakage (MGS trace 1). This contribution from streamflow potentially could affect the quality (and to a lesser extent, the quantity) of the spring water. Protection of the spring thus requires consideration of the entire area of the Beaver Creek watershed upstream from the hatchery, about 14.08 mi^2. This area is also shown in figure 15.

WATER QUALITY

Two sets of samples were collected from the hatchery spring in 2008. Samples were analyzed for physical properties and inorganic ions, pesticides and wastewater compounds, radioactivity, and optical brighteners. The samples provide an evaluation of current water quality at the spring, and can also be used for comparison with quality of the spring water in the future. Water-quality data from a sample collected in 1958 is presented for additional comparison.

PHYSICAL PROPERTIES AND INORGANIC IONS

The physical properties (measured in the field) and major ion concentrations (tab. 3) are typical of groundwater from the Elbrook Formation in Washington County (Duigon, 2001, tab. 7). The water is very hard with total-dissolved solids concentration just over 300 milligrams per liter (mg/L). Nitrate concentrations in the two samples taken in 2008 were 5.36 and 6.08 mg/L (as N), suggesting some nutrient input from the basin (which is largely in agricultural and residential use). Fifteen of 24 trace elements were detected in the two samples (tab. 4). The U.S. Environmental Protection Agency (USEPA) has compiled nationally recommended water-quality criteria for the protection of aquatic life for nine of the inorganic constituents that were analyzed (USEPA, 2009). None of these criteria were exceeded in the samples (tab. 4).

The sample collected from the hatchery spring in October 1958 is puzzling. It is uncertain under what hydrologic conditions this sample was collected, but it appears inconsistent with more recent data; too much to be attributed to changes in analytical methods since 1958. The specific conductance of this sample was 411 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C), comparable to values recorded during the period December 2005–October 2006 (which are generally in the range of 450 to 530 µS/cm at 25°C, with a minimum of 413 µS/cm at 25°C). Dissolved calcium, sulfate, chloride, and nitrate, however, are lower in the 1958 sample than in the two samples collected in 2008, and $[Ca^{2+}]/[Mg^{2+}]$ is also lower (1.020 compared to 1.976 and 1.925). If these differences are real, then they may indicate a change in land use or some aspect of the hydrology since 1958, perhaps due to a sinkhole opening or closing or an effect due to construction in the area.

Table 3. Physical properties and major inorganic ions in water samples from A.M. Powell State Fish Hatchery spring WA Bj 4

[All analyses reported as milligrams per liter (mg/L) of dissolved (passing 0.45-µm filter) species unless stated otherwise; ft^3/s, cubic feet per second; µS/cm at 25º, microsiemens per centimeter at 25 degrees Celsius; ºC, degrees Celsius; --, not reported; E, estimated]

Property or constituent	10/8/1958	4/1/2008	6/17/2008
Discharge (ft^3/s)	—	8.74	9.49
Specific conductance (µS/cm at 25˚C)	411	508	550(1)
pH	7.8	7.3	7.3
Temperature (˚C)	12.0	12.0	13.3
Dissolved oxygen	—	6.2	7.8
Hardness (as $CaCO_3$)	180	260	270
Calcium	37	69.7	71.1
Magnesium	22	21.4	22.4
Sodium	—	10.4	9.72
Potassium	—	2.57	2.73
Total bicarbonate (as HCO_3^-)	233	249	261
Alkalinity (as $CaCO_3$)	191	204	214
Sulfate	4.8	24.1	22.9
Chloride	3.6	23.2	20.5
Fluoride	0.30	0.26	0.27
Silica	—	10.7	10.8
Solids, residue at 180˚C	—	312	311
Solids, sum of dissolved constituents	—	309	316
Nitrate (as N)	1.90	—	—
Nitrate+nitrite (as N)	—	5.36	6.08
Nitrite (as N)	—	<0.002	<0.002
Ammonia (as N)	—	<0.02	<0.02
Phosphorus	—	<0.04	0.03(E)
Orthophosphate (as P)	—	0.013	0.012
Organic carbon	—	1.4	0.7
Noncarbonate hardness (filtered, as $CaCO_3$)	—	58	56
Noncarbonate hardness (unfiltered, as $CaCO_3$)	0	—	—
Carbon dioxide	5.9	21	21

(1) Reported to 2 significant figures

PESTICIDES AND WASTEWATER COMPOUNDS

A suite of pesticides and wastewater compounds in whole water were sampled according to U.S. Geological Survey (USGS) protocols and analyzed by the USGS laboratory in Denver, using the continuous liquid-liquid extraction and capillary-column gas chromatography/mass spectrometry method described by Zaugg and others (2006), including blanks and replicates for quality control (tab. 5). Some compounds associated with wastewater and some pesticides are endocrine-disrupting compounds. Such chemicals are of concern for their effects on fish in their native habitat; therefore, concern over these chemicals in water supplying a fish hatchery is obvious. None of the pesticides and wastewater compounds for which the sample collected in April 2008 were analyzed were detected except for the herbicide atrazine and its degradation product CIAT (deethylatrazine), and tetrachloroethylene (a solvent, degreaser, and dewormer). In the sample collected June 17, 2008, six compounds were detected: atrazine; CIAT and another degradation product, CEAT (deisopropylatrazine); the herbicide meto-

Table 4. Trace elements in water samples from A.M. Powell State Fish Hatchery spring WA Bj 4

[All analyses for dissolved (passing 0.45-µm filter) forms reported in micrograms per liter unless stated otherwise. E, estimated; CMC, Criteria Maximum Concentration; CCC, Criterion Continuous Concentration]

Element	Date			
	4/1/2008	6/17/2008	CMC	CCC
Aluminum	<1.6	<1.6	--	--
Antimony	<0.14	<0.14	--	--
Arsenic	0.08	0.06	340	150
Barium	95	102	--	--
Beryllium	<0.008	<0.01	--	--
Boron	6(E)	8	--	--
Cadmium	<0.04	<0.04	2.0	0.25
Chromium	0.23	0.24	16*	11*
Cobalt	0.05	0.07	13	9.0
Copper	<1	<1.0	--	--
Iron (unfiltered)	10	17	--	--
Iron	<8	<8	--	--
Lead	<0.08	<0.08	65	2.5
Lithium	5.4	6.1	--	--
Manganese (unfiltered)	0.5	1.1	--	--
Manganese	0.2(E)	0.4	--	--
Mercury	<0.010	<0.010	1.4	0.77
Molybdenum	0.2(E)	0.1(E)	--	--
Nickel	0.31	0.60	470	52
Selenium	0.17	0.15	--	5.0
Silver	<0.1	<0.1	3.2	--
Strontium	469	442	--	--
Thallium	<0.04	<0.04	--	--
Uranium	0.45	0.50	--	--
Vanadium	0.14	0.15	--	--
Zinc	2.0	3.4	120	120

*Chromium (IV)

lachlor; the flame retardant tris(2-chloroethyl) phosphate; and the common plasticizer, bis(2-ethylhexyl)phthalate (DEHP). Atrazine and DEHP are known endocrine-disrupting compounds; tris(2-chloroethyl) phosphate is suspected of having endocrine-disrupting potential (Zaugg and others, 2006, p. 3-4). All detections were below the laboratory reporting levels and therefore the values are listed as “estimated” or “present but not quantifiable.” Pentachlorophenol, the only organic compound analyzed that has a recommended water-quality criteria established, was not detected in either sample.

Agriculture and domestic lawns and gardens throughout the vicinity of the hatchery may account for the presence of the herbicides and their degradation products. Sinkholes can provide opportunities for the other products to reach the aquifer, especially if used for disposal. Automotive service centers, commercial development, and an automobile junkyard are in the hypothesized groundwater contributing area of the Beaver Creek watershed. Seepage through the soil, or runoff into sinkholes or into Beaver Creek are possible routes leading from these potential sources to the aquifer.

Table 5. Pesticides and wastewater compounds in unfiltered water samples from A.M. Powell State Fish Hatchery spring WA Bj 4. Shading indicates compound was detected.

[Analyses by U.S. Geological Survey. All analyses in micrograms per liter unless noted otherwise. Endocrine-disrupting potential from Zaugg and others, 2006, p. 3-4; E, estimated; P, present but not quantified; K, known; S, suspected; --, no data; CMC, Criteria Maximum Concentration; CCC: Criterion Continuous Concentration]

Compound	Endocrine-disrupting potential	4/1/2008	6/17/2008
1-Methylnapthalene	--	<0.2	<0.2
2,6-Dimethylnapthalene	--	<0.2	<0.2
2-Chloro-4-isopropylamino-6-amino-s-triazine (Deethylatrazine, CIAT)	--	0.2 (E)	.2 (E)
2-Chloro-6-ethylamino-4-amino-s-triazine (Deisopropylatrazine, CEAT)	--	<0.2	0.2
2-Methylnapthalene	--	<0.2	<0.2
3,4-Dichlorophenyl isocyanate	--	<2	--
3*beta*-Coprostanol (skatol)	--	<0.8	<0.8
3-Methyl-1H-indole	--	<0.2	<0.2
3-*tert*-Butyl-4-hydroxyanisole (BHA)	K	<0.2	<0.2
4-Cumylphenol	K	<0.2	<0.2
4-n-Octylphenol	K	<0.2	<0.2
4-Nonylphenol (all isomers)	K	<1.6	<2
4-Nonylphenol diethoxylate	K	<3.2	<3
4-Nonylphenol monoethoxylate	K	<2	<2.0
4-tert-Octylphenol diethoxylate	K	<0.32	<0.32
4-tert-Octylphenol monoethoxylate	K	<1	<1
4-*tert*-Octylphenol	K	<0.2	<0.2
5-Methyl-1H-benzotriazole	--	<1.6	<2
Acetophenone	--	<0.3	<0.3
Acetyl-hexamethyl-tetrahydro-naphthalene (AHTN, Tonalide)	--	<0.2	<0.2
Alachlor	--	<0.1	<0.1
Ametryn	--	<0.1	<0.1
Anthracene	--	<0.2	<0.2
9,10-Anthraquinone	--	<0.2	<0.2
Atrazine	K	0.0130 (E)	0.17(E)
2,2',4,4'-Tetrabromodiphenyl ether (BDE 47)	--	<0.2	<0.2
Benzo[*a*]pyrene	K	<0.2	<0.2
Benzophenone	S	<0.2	<0.2
beta-Sitosterol	--	--	<0.8
Bis(2-ethylhexyl)phthalate (DEHP)	K	<2	1 (E)
Bisphenol A	K	<0.4	<0.4
Bromacil	--	<0.2	<0.2
Butachlor	--	<0.1	<0.1
Butylate	--	<0.1	<0.1
Caffeine	--	<0.2	<0.2
Camphor	--	<0.2	<0.2
Carbaryl	K	<0.2	<0.2
Carbazole	--	<0.2	<0.2
Carboxin	--	<0.2	<0.2
Chlorpyrifos	K	<0.2	<0.2
Cholesterol	--	<0.8	<0.8
Cotinine	--	<0.8	<0.8
Cyanazine	--	<0.2	<0.2
Cycloate	--	<0.1	<0.1

Table 5. Pesticides and wastewater compounds in unfiltered water samples from A.M. Powell State Fish Hatchery spring WA Bj 4—Continued

Compound	Endocrine-disrupting potential	4/1/2008	6/17/2008
DEET (N,N-Diethyl-*meta*-toluamide)	--	<0.2	<0.2
Diazinon	K	<0.2	<0.2
Dichlorvos	S	<0.2	<0.2
Diethyl phthalate (DEP)	K	<0.2	<0.2
Diphenamid	--	<0.1	<0.1
d-Limonene	--	<0.2	<0.2
Fluoranthene	--	<0.2	<0.2
Hexahydrohexamethyl-cyclopenta-benzopyran (HHCB)	--	<0.2	<0.2
Hexazinone	--	<0.2	<0.2
Indole	--	<0.2	<0.2
Isoborneol	--	<0.2	<0.2
Isophorone	--	<0.2	<0.2
Isoquinoline	--	<0.2	<0.2
Menthol	--	<0.2	<0.2
Metalaxyl	--	<0.2	<0.2
Methyl salicylate	--	<0.2	<0.2
Metolachlor	--	<0.2	(P)
Metribuzin	--	<0.1	<0.1
p-Cresol	--	<0.2	<0.2
Pentachlorophenol	S(*)	<0.8	<0.8
Phenanthrene	--	<0.2	<0.2
Phenol	--	<0.2	<0.2
Prometon	--	<0.2	<0.2
Prometryn	--	<0.1	<0.1
Propachlor	--	<0.1	<0.1
Propazine	--	<0.1	<0.1
Pyrene	--	<0.2	<0.2
Simazine	--	<0.1	<0.1
Simetryn	--	<0.1	<0.1
Terbacil	--	<0.2	<0.2
Tributyl phosphate	--	<0.2	<0.2
Triclosan	S	<0.2	<0.2
Triethyl citrate	--	<0.2	<0.2
Trifluralin	--	<0.1	<0.1
Triphenyl phosphate	--	<0.2	<0.2
Tris(2-butoxyethyl) phosphate	--	<0.2	<0.2
Tris(2-chloroethyl) phosphate	S	<0.2	0.1 (E)
Tris(dichloroisopropyl) phosphate (FUROL FR 2)	S	<0.2	<0.2
Vernolate	--	<0.1	<0.1
1,4-Dichlorobenzene	S	<0.2	<0.2
Isopropylbenzene	--	<0.2	<0.2
Naphthalene	--	<0.2	<0.2
Tetrachloroethylene	--	(P)	<0.4
Bromoform (Tribromomethane)	--	<0.2	<0.2

(*) CMC: 19 micrograms per liter (at pH 7.8)
CCC: 14 micrograms per liter (at pH 7.8)

Table 6. Alpha and beta radioactivity in water samples from A.M. Powell State Fish Hatchery spring WA Bj 4

[Filtered samples collected 4/1/2008. All analyses reported in picocuries per liter. ND, not detected]

Alpha radioactivity (Reference radionuclide: Th-230)		Beta radioactivity (Reference radionuclide: Cs-137)	
Measured within 72 hours after sample collection	Measured 30 days after sample collection	Measured within 72 hours after sample collection	Measured 30 days after sample collection
0.9	ND	2.3	2.8

RADIOACTIVITY

Samples collected from the hatchery spring April 1, 2008 were analyzed for alpha and beta radioactivity (tab. 6). Long-term (measured 30 days after sample collection) and short-term (measured within 3 days of sample collection) radioactivity was measured for both alpha and beta radiation. The reported values are counts of nuclear disintegrations and do not directly identify which radionuclides are present. The difference between short-term and long-term radioactivity can help identify the presence of isotopes having half lives less than 30 days. The USEPA has not recommended water-quality criteria for the protection of aquatic life for radioactivity. Both short-term and long-term alpha radioactivities are low (<1 picoCurie per liter [pCi/L]) in relation to federal drinking-water standards (15 pCi/L).

OPTICAL BRIGHTENERS

Optical brighteners are present in laundry detergent and may therefore be expected to show up in domestic wastewater. Plain (unbrightened) cotton pads, sold at drugstores for cosmetics application and removal and hygiene, were attached to wire holders placed in the flow of streams and springs along with the charcoal samplers used for capturing tracing dyes (Aley, 1985). The cotton pads were retrieved after periods ranging from a few days to weeks, rinsed, dried, and examined under ultraviolet light. When present, optical brighteners are readily apparent on the cotton pads (fig. 16). However, no optical brighteners were detected in this qualitative reconnaissance (tab. 7; site locations shown in fig. 8).

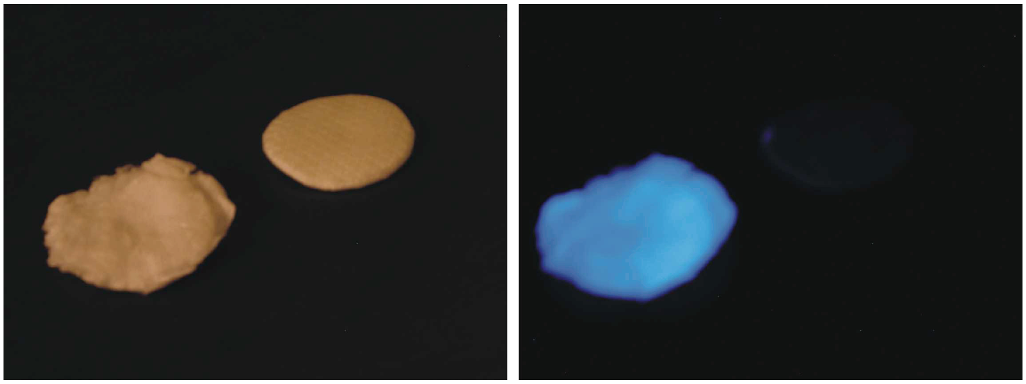

Figure 16. Detection of optical brighteners on cotton pads. The pad on the left has been exposed to optical brighteners. The photo on the left was taken under ordinary incandescent light. The photo on the right was taken under ultraviolet light (long wave).

Table 7. Sites sampled for optical brighteners

[All results were negative]

Site no.	Site name	Date of placement of cotton pad	Date of removal of cotton pad
R1	WA Bj 4	11-8-2007 4-30-2008	11-16-2007 5-13-2008
R2	WA Bj 8	11-8-2007 6-25-2008	11-16-2007 7-16-2008
R3	WA Bj 5	4-30-2008 6-23-2008	6-12-2008 7-16-2008
R4	WA Bj 72	6-12-2008	6-23-2008
R9	Little Antietam Creek at Md. Route 62	6-13-2008	6-16-2008
R10	Grove Creek at Brook Lane	6-13-2008	6-16-2008
R11	Antietam Creek Tributary at Trovinger Mill Road	6-13-2008	6-16-2008

CONCLUSIONS

WA Bj 4, the spring supplying the A.M. Powell State Fish Hatchery, is the terminus of a groundwater flow system that extends to the northeast, broadening to the north and west. The contributing area is partly controlled by faults. On the east, the Beaver Creek Fault is an old, mylonitized thrust fault that probably acts as a barrier to groundwater flow from the east (the barrier could be breached by cross faults). The lower end of the west side lies just to the west of the Eakles Mills Fault, which in contrast to the Beaver Creek Fault, is a younger, high-angle fault whose wall rocks reacted to faulting in a brittle manner, allowing development of fractures that subsequently could be enlarged by dissolution, thereby facilitating groundwater flow. To the north, the western boundary of the contributing area lies farther west from the fault, at least during periods of moderate to high groundwater levels. The fault drains water toward the southwest to discharge into Beaver Creek south of Interstate 70, although some of the water may be diverted via a cross fault to drain into Beaver Creek at the hatchery.

Dye tracing demonstrated a contribution of stream water from Beaver Creek to the hatchery spring via leakage through the stream bed, at least during dry periods of the year. Surface runoff coming into the creek thus needs to be considered in planning for the protection of the hatchery spring in order to assess all sources of water and potential contamination. Dye injected into a well located about 400 ft northwest of the spring was not detected in the spring or in Beaver Creek, suggesting that groundwater flow at that point is approximately parallel to the adjacent flow toward the spring, and that the contributing area narrows toward the spring. Dye injected into a sinkhole located about 2.8 mi north-northeast of the spring was detected in the spring; the peak concentration took about 2½ days to reach the spring. The injection site was just outside of the drainage basin for Beaver Creek above the hatchery. This is evidence that the groundwater flow system does not exactly coincide with minor surface-water drainage boundaries. Dye injected into a sinkhole west of the Eakles Mills Fault was not detected at the spring, consistent with the hypothesis that this fault intercepts groundwater that might be flowing from the west, draining it to the southwest. If the apparent peak concentration in the spring following the fifth trace was indeed the injected dye, it indicates that groundwater reaches the spring from north of Chewsville, perhaps as the groundwater divide shifts during periods of high groundwater levels.

Two sets of samples were collected from the hatchery spring in 2008 for water-quality analysis. The water is very hard with a total-dissolved solids concentration just over 300 mg/L. Nitrate concentration in two samples taken from the spring suggest some nutrient input from the basin (which is largely agricultural and some residential). Arsenic (0.08 and 0.06 µg/L) was among a few detectable trace elements.

Most pesticides and wastewater compounds were below detection limits. The herbicides atrazine and two of its degradation products, CIAT and CEAT, and metolachlor were detected. Their presence likely is due to agricultural (corn and soybeans) and(or) lawn and garden pesticide use in the vicinity. The common plasticizer bis(2-ethylhexyl)pthalate, the flame retardant tris(2-chloroethyl)phosphate, and the solvent and degreaser tetrachloroethene were also detected in either the April or the June sample (but not both). There are a number of possible source areas for these contaminants, but it has not been determined where the contaminants originated. All detections were below the laboratory reporting limits, and the concentrations are reported as "estimated" or "present but not quantifiable."

Optical brighteners were not detected at seven sites using a qualitative reconnaissance method of deploying cotton pads and examining the retrieved pads under ultraviolet light, suggesting domestic waste has little impact on the streams and springs sampled.

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DNR Publication Number 12-1192009425
November, 2009

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