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Use of Dye Tracing to Determine Ground-Water Movement to Mammoth Crystal Springs, Sylvan Pass Area, Yellowstone National Park, Wyoming

Prepared in cooperation with the
NATIONAL PARK SERVICE, YELLOWSTONE NATIONAL PARK

Scientific Investigations Report 2006-5126

U.S. Department of the Interior
U.S. Geological Survey

Cover photo: Mammoth Crystal Springs about 1 day after injection of fluorescein dye. Photograph taken by David Susong, U.S. Geological Survey, June 22, 2005.

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Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
	Mass	
pound (lb)	0.4536	kilogram (kg)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Altitude, as used in this report, refers to distance above the vertical datum, in feet.

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Concentration of dye in water is reported in micrograms per liter (µg/L). Micrograms per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million.

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Abstract

At the request of and in cooperation with the Geology Program at Yellowstone National Park, the U.S. Geological Survey conducted a hydrologic investigation of the Sylvan Pass area in June 2005 to determine the relation between surface water and ground-water flow to Mammoth Crystal Springs. Results of a dye-tracing investigation indicate that streamflow lost into talus deposits on Sylvan Pass enters the ground-water system and moves to the southeast to discharge at Mammoth Crystal Springs. Ground-water travel times to the springs from a distance of 1.45 miles and a vertical relief of 500 feet were less than 1 day, indicating apparent rates of movement of at least 8,000 feet per day, values that are similar to those in karst aquifers. Peak dye concentrations were reached about 2 days after dye injection, and transit time of most of the dye mass through the system was almost 3 weeks. High permeability and rapid travel times within this aquifer also are indicated by the large variation in springflow in response to snowmelt runoff and precipitation, and by the high concentration of suspended sediment (turbidity) in the water discharging into the spring-fed lake.

Introduction

On August 3, 2004, Yellowstone National Park staff reported a milky white color in Middle Creek near the east entrance to Yellowstone National Park. The white turbidity appeared to be caused by fine angular rock fragments in suspension and originated from Mammoth Crystal Springs, a spring-fed lake that discharges into Middle Creek on the east side of Sylvan Pass and about 6 mi upstream from the east entrance to the park (figs. 1 and 2). To determine the source of water to the springs and the potential for transport of suspended sediment through the aquifer supplying the springs, the U.S. Geological Survey (USGS), in cooperation with the Geology Program at Yellowstone National Park, conducted a hydrologic investigation of the Sylvan Pass area in June 2005, focusing on the relation between surface water and ground-water flow to Mammoth Crystal Springs. This report presents the results of an investigation to determine if streamflow lost to the subsurface on Sylvan Pass discharges at Mammoth Crystal Springs.

Description of Study Area

The Sylvan Pass study area is roughly defined as the area from Sylvan Lake, about 1 mi west of Eleanor Lake, to the junction of Mammoth Crystal Springs and Middle Creek (fig. 1). Identification and location of monitoring and other sites shown in figure 1 are summarized in table 1. Mammoth Crystal Springs discharge into a small lake on the east side of Sylvan Pass at an altitude of about 8,000 ft and about 500 ft lower than the pass. The lake is about 200 ft in length, 100 ft in maximum width, and less than 10 ft deep. The springs discharge from openings between blocks of talus along the western margin of the lake (fig. 2) and also from several depressions on the bottom of the lake, as indicated by the substantially greater amount of flow observed at the outlet of the lake than at the inlet on the opposite side. Because of the multiple inputs, springflow was measured about 200 ft downstream from the outlet (fig. 1, site 8). Streamflow measurements made intermittently from early June through late August (fig. 3A) and continuously recorded from late July through late September (fig. 3B) of 2005, indicate that discharge of the springs ranged from less than 1 ft^3/s to at least 15 ft^3/s following snowmelt runoff. Outflow from the spring-fed lake merges with the flow of Middle Creek about 300 ft downstream (fig. 1).

Eleanor Lake is located northwest of the summit of Sylvan Pass and about 1.5 mi northwest of Mammoth Crystal Springs, at an altitude of about 8,480 ft (fig. 1). Outflow from Eleanor Lake occurs only for a short period during the snowmelt runoff when several small streams flow into the lake. During late summer, the lake level declines substantially as a result of evaporation and seepage. During September 2005, water from a tributary was observed to flow into the lake and presumably was lost through the bottom of the lake. Outflow from the lake converges with flow from several other tributaries to form the headwaters of Clear Creek, which then flows to the west and past Sylvan Lake about 1 mi downstream (fig. 1). East of Eleanor Lake, several waterfalls lose water into talus deposits along the south side of Sylvan Pass. During the snowmelt runoff period, part of the flow from one of these waterfalls, Crecelius Cascade, enters Eleanor Lake above ground but most of the water is lost into the talus at the base of the waterfall (fig. 1, site 3). Measurements of streamflow loss into the talus from this waterfall were about 6 to 7 ft^3/s at the time of the dye injection. Crecelius Cascade gradually decreases

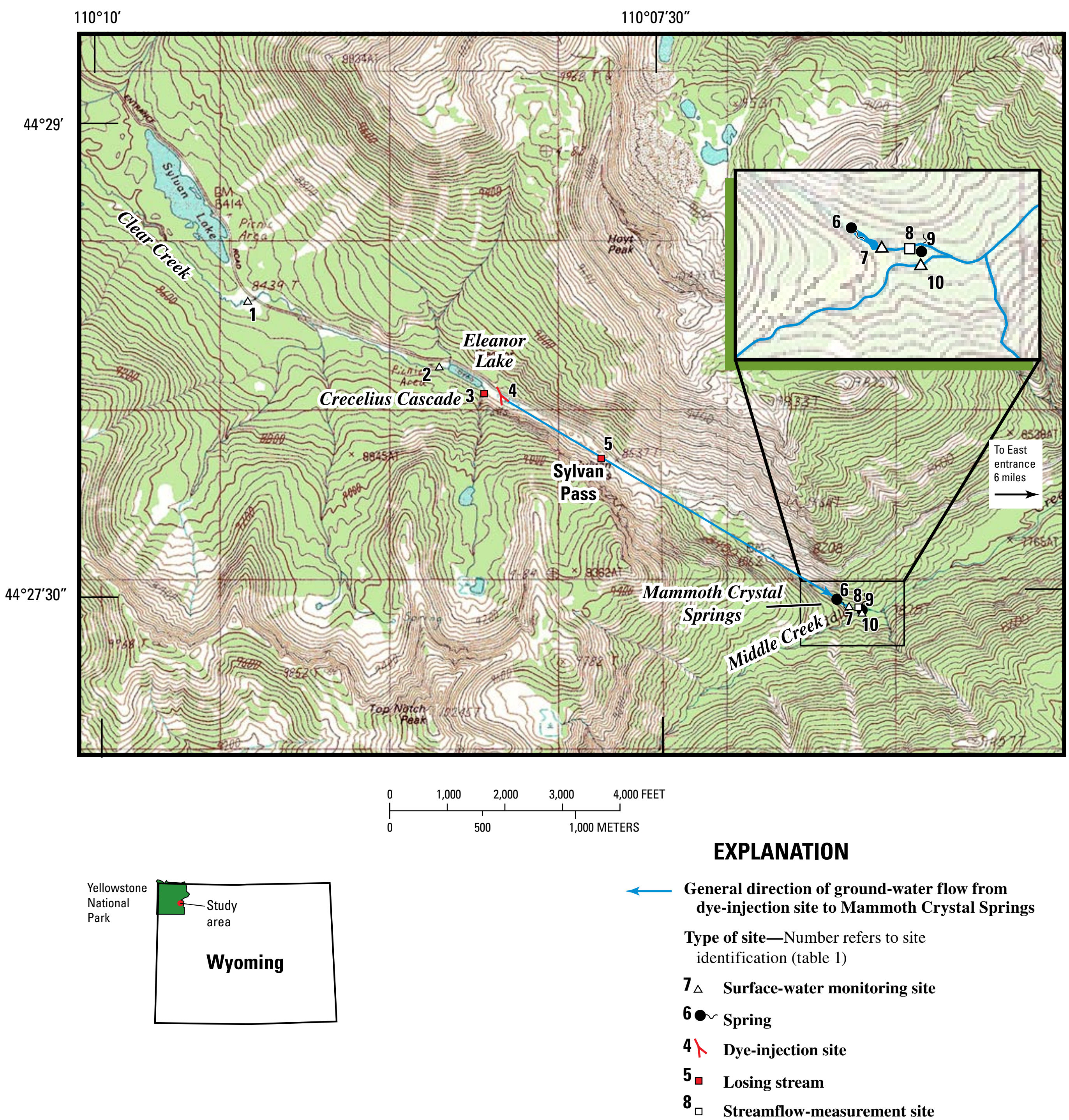

Figure 1. Location of Mammoth Crystal Springs and monitoring sites, and general direction of ground-water flow in the Sylvan Pass study area, Yellowstone National Park, Wyoming.

Figure 2. View of Mammoth Crystal Springs near Sylvan Pass, Yellowstone National Park, Wyoming.
The milky white turbidity in the lake results from very fine rock material in suspension. The springs discharge from talus at lower right. Photograph taken June 21, 2005.

Table 1. Identification and location of monitoring and other sites in the Sylvan Pass study area, Yellowstone National Park, Wyoming

[Latitude and longitude reported in degrees, minutes, and seconds]

Site number (fig. 1)	Site	Type of site	Latitude (north)	Longitude (west)
1	Clear Creek above Sylvan Lake	Dye monitoring	44 28 26	110 09 20
2	Eleanor Lake outflow	Dye monitoring	44 28 14	110 08 35
3	Crecelius Cascade	Losing stream	44 28 09	110 08 17
4	Meadow (dry lake bed)	Dye injection	44 28 06	110 08 12
5	Unnamed waterfall on Sylvan Pass	Losing stream	44 27 55	110 07 53
6	Mammoth Crystal Springs inflow	Dye monitoring	44 27 27	110 06 43
7	Mammoth Crystal Springs outflow	Dye monitoring	44 27 26	110 06 41
8	Mammoth Crystal Springs outflow	Streamflow measurement	44 27 26	110 06 39
9	Spring near measurement site	Dye monitoring	44 27 26	110 06 39
10	Middle Creek above confluence	Dye monitoring	44 27 25	110 06 35

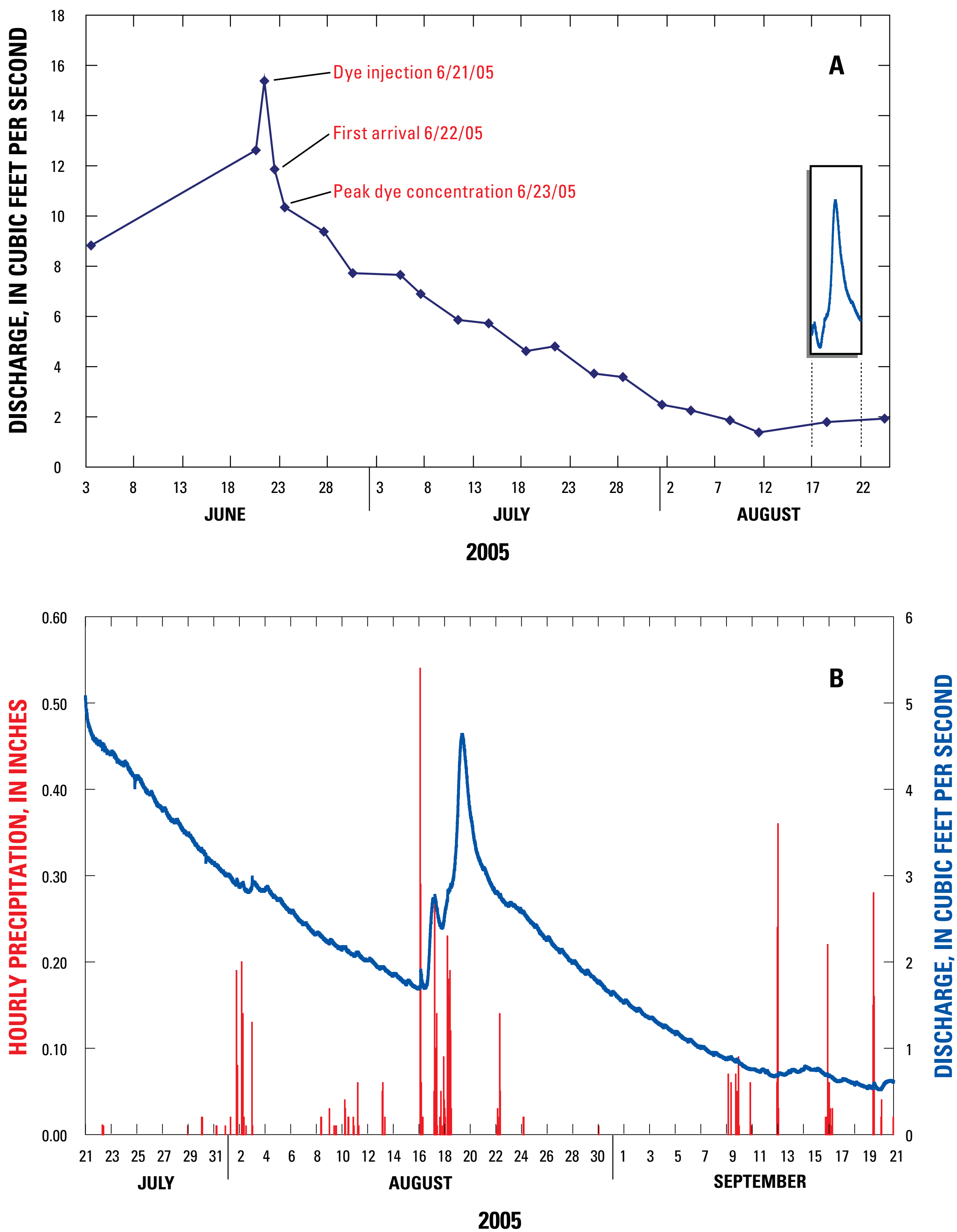

Figure 3. Discharge hydrographs showing (A) high variability in springflow and (B) rapid response to precipitation, Mammoth Crystal Springs, Yellowstone National Park, Wyoming.

in flow as the snowmelt runoff wanes and by mid-summer, no flow occurs above ground into the lake, and all flow is lost into the talus. During the study, a small part of the water lost into the talus re-emerged a short distance downslope and flowed to the east across a meadow (dry lake bed) and into talus along the base of the mountainside (fig. 1, site 4; and fig. 4). Water also is lost into talus along the north-facing cliff face directly above the summit of Sylvan Pass (fig. 1, site 5). During the runoff period, water cascading over the cliff was observed to be totally lost into the upper part of a talus slope that extends part way up the cliff face.

Geology

Sylvan Pass lies within a glacially modified valley bordered by cliffs composed of andesitic and dioritic rocks of Tertiary age that are associated with 50-million year old Absaroka volcanism (Henry Heasler and Cheryl Jaworowski, Yellowstone National Park Geology Program, written commun., 2005). The cliffs rise more than 1,000 ft above the summit of the pass, at 8,530 ft, and generally are steeper on the south side of the pass than on the north side, where they are partly mantled by talus. Bedrock outcrops along the south side of the pass are noticeably fractured. Richmond and Pierce's (1972) map of the surficial geology of Sylvan Pass shows that avalanche debris and frost rubble mantle the bedrock to an unknown depth. These materials also contain permafrost. Avalanche debris, glacial gravels, and poorly sorted glacial deposits of Pinedale age (70,000-14,000 years before present) also occur on the hillsides above Middle Creek, near Mammoth Crystal Springs. Mapping by Richmond and Pierce (1972) also shows a possible fault extending from southwest of Eleanor Lake through Sylvan Pass to Middle Creek. Although no offset of the surficial deposits on the pass can be observed, displacement along the fault, which is probably mostly pre-Quaternary, is 200 to 240 ft and downthrown to the north.

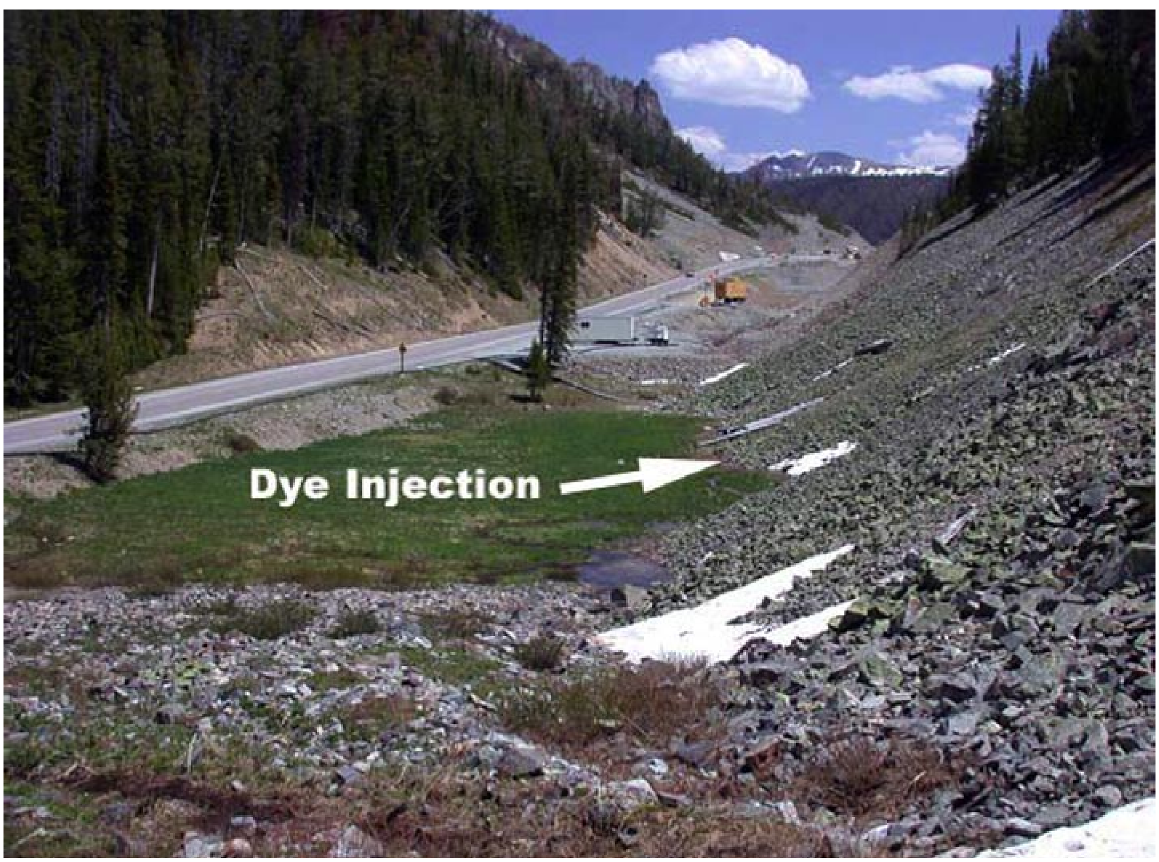

Figure 4. Dye-injection site on Sylvan Pass, Yellowstone National Park, Wyoming.
Water is lost into talus along the margin of the meadow. Dye injected at this site discharged at Mammoth Crystal Springs, 1.45 miles to the southeast and 500 feet lower in altitude. Photograph taken by Henry Heasler, National Park Service, June 20, 2005. View to the east.

Acknowledgments

The authors acknowledge the assistance of Ben Lobst and Melissa Brickl, seasonal employees with the National Park Service, for their help with discharge measurements, sample collection, and other logistics related to the tracer study. Henry Heasler, Yellowstone National Park geologist, was instrumental with regard to the logistics of this study, particularly with access to the study area, providing historical data and other information about the area, and assisting with the collection of field data. Geary Schindel and Steven Johnson with the Edwards Aquifer Authority in San Antonio, Texas, verified the analysis of selected dye samples. The help of all of these individuals throughout the study is greatly appreciated.

Methodology

Fluorescent dyes commonly are used in karst and other highly permeable terrains to determine hydraulic connections and ground-water travel times (Mull and others, 1988). Uranine (fluorescein) was selected as the most appropriate tracing agent for determining the relation between losing streams on Sylvan Pass and ground-water flow to Mammoth Crystal Springs. Characteristics of the dye include detectability at very low concentrations over long distances, very low toxicity, excellent solubility in cold water, and relatively low sorption tendencies. Although the dye can be visible in surface water at concentrations greater than about 50 μg/L, it readily degrades under ultraviolet light (sunlight).

Field Techniques

Three methods were used for detection of the fluorescein dye: direct water-sample analysis, passive adsorption onto activated charcoal, and visual observation. An ISCO Model 2900 automatic water sampler was used for direct collection of water samples. The sampler was deployed on the day of (but prior to) the tracer injection and was located about 50 ft downstream from the outlet of the spring-fed lake (fig. 1, site 7). The sampler was programmed to collect 400-milliliter (ml) samples once a day at 11:15 each morning; thus, 24 samples were collected in as many days. At the end of the 24-day period, the bottles were removed from the autosampler on-site, and about 100 ml of each sample were poured into separate containers for turbidity analysis by the National Park Service. The remaining samples were capped and transported back to the USGS Utah Water Science Center in Salt Lake City for subsequent dye analysis. Selected grab samples also were collected from the lake outflow, the spring inflow, Middle Creek, outflow from Lake Eleanor, and the injection source water (Crecelius Cascade). All samples were refrigerated until analysis to minimize degradation of the dye from bacteria and exposure to ultraviolet light.

Activated charcoal has a strong affinity for fluorescein dye and was used as a passive (cumulative) method for detection of the dye (Aley and Fletcher, 1976). Cumulative adsorption of the dye often allows detectability of very low dye concentrations that may not be possible to detect by direct water-sample analysis. Several grams of Fischer Scientific 6-14 mesh activated charcoal were placed in cylindrical nylon screen wire packets and then suspended on concrete weighted assemblies that were placed at all potential outlets for the dye. These packets also were placed at selected surface-water sites and springs 1 week prior to the dye injection to evaluate natural background fluorescence that might be present in the water. After the dye injection, the packets were collected and replaced with new ones each week for the next 2 weeks. The charcoal packets were placed into plastic baggies, labeled with the location, date, and time, and brought back to the USGS Laboratory in Salt Lake City for subsequent analysis. Samples were refrigerated until analysis to minimize potential degradation of the dye from bacteria.

Fluorescein dye is manufactured as a red powder that turns a vivid fluorescent green when placed in contact with water. The dye was injected directly as a powder into the water at the point of loss (fig. 1, site 4; and fig. 5). The injection was initiated after all of the activated charcoal detectors were in place and the autosampler had been deployed. At the request of the National Park Service, the dye was injected in a sufficient amount to enable it to be seen visually in the spring-fed lake. On the basis of formulas derived by Worthington Groundwater (Stephen Worthington, written commun., 2004) and discussions with Geary Schindel (Edwards Aquifer Authority, oral commun., 2005), it was calculated that between 15 and 20 lbs of the dye would yield a concentration of at least 500 μg/L, more than adequate for a visual trace. The amount of the injected dye was determined on the basis of the measured discharge of the springs, the distance from the injection site to the springs, and the desired peak concentration at the springs.

Laboratory Techniques

Water samples were analyzed on a Turner Designs Model 10 filter fluorometer equipped with excitation and emission filters that are specific for the detection of fluorescein dye. The fluorometer is set up to measure relative fluorescence of an aqueous sample and has four basic relative sensitivity ranges: MINS (minimum sensitivity), x3.16, x10, and x31.6 (maximum sensitivity), where each range is 3.16 times the previous one. Initially, the instrument was set on the x10 scale to accommodate samples with the highest fluorescence (concentration) values. Lower-concentration samples were then analyzed on the x31.6 range to increase detectability and improve measurement accuracy. Prior to analyzing dye samples, the instrument was calibrated to read zero or close to zero by using deionized (DI) laboratory water. DI water was analyzed every six samples to establish a baseline for instrument “drift”

Figure 5. Injection of fluorescein dye into talus on Sylvan Pass, Yellowstone National Park, Wyoming. Dye was injected beginning at 2:50 PM on June 21, 2005, and observed visually less than 1 day later at Mammoth Crystal Springs. Photograph taken by Henry Heasler, National Park Service.

and to ensure that cross or carry-over contamination from one sample to another did not occur.

Several grab samples were collected from the springs and the injection site prior to the injection to determine if any natural fluorescence in the water could potentially interfere with detection of the dye. This background fluorescence typically results from organic material such as humic acids that can fluoresce in the same wavelength range as the dye. Background fluorescence readings were subtracted from the spring and stream sample values to yield a value that was related only to the fluorescence of the dye. Analysis of the surface water entering the ground-water system and water from the springs indicated that natural fluorescence in the water was very low when compared with the measured dye concentrations.

Each spring and stream sample was analyzed twice unless the value varied by more than two units, in which case it was then analyzed a third time. Most of the samples were analyzed directly on the x31.6 scale. Samples with concentrations higher than about 50 μg/L were diluted with laboratory DI water by either 50 or 25 percent into the linear range for the dye (discussed below), analyzed on the x31.6 scale, and then the values were corrected by using the applicable dilution factor. Some of the samples were analyzed on the x10 scale and then multiplied by a factor of 3.16 to determine the equivalent value on the x31.6 scale. All results were ultimately referenced to the x31.6 scale.

A dye-calibration curve was established to convert the relative fluorescence of the samples to actual concentrations. Standards ranging from 2 to 200 μg/L were prepared by using a serial dilution technique described in Wilson and others (1986). Concentrations of fluorescein dye generally are linear only to about 50 μg/L. Higher concentrations of the dye typically result in “quenching effects” so that the fluorescence of samples with concentrations above 50 μg/L, and particularly above 100 μg/L, can actually decrease and be considerably less than what would be expected if linearity were maintained. As a result, standards of 100 and 200 μg/L were diluted to 50 μg/L before analysis and then the values were corrected by the dilution factor (2 or 4 times). Calibration standards as high as 50 μg/L were measured directly on the x31.6 scale.

Fluorescein dye was extracted from activated charcoal by using a 5-percent solution of isopropyl alcohol (70 percent) and potassium hydroxide (KOH) (Mull and others, 1988). Activated charcoal from each packet was removed and placed into a 100-ml glass beaker. The charcoal was then thoroughly rinsed with laboratory DI water until all of the sediment and organic debris were removed from the charcoal that could potentially interfere with the extraction, observation, and analysis of dye in the sample. After rinsing, the excess water was poured off and each sample was then eluted with about 20 ml of the alcohol-KOH eluent to extract the dye from the charcoal. Samples were then covered and allowed to stand overnight. Dye eluted from charcoal that has adsorbed substantial amounts of the dye generally is visible in the elutant within minutes of extraction, while samples that have adsorbed lesser amounts may take several hours or more to become visually positive. Because dye is cumulatively adsorbed onto the charcoal, measured dye concentrations are not representative of those present in the water at the time of collection. Concentrations of dye extracted from activated charcoal were reported qualitatively based on the relative strength of the visible amount of dye in the elutant.

Dye Tracing and Ground-Water Movement

On June 21, 2005, from about 14:50 to 15:25, 19 lbs of fluorescein dye were injected into each of five different losing points of a stream along the base of a talus slope on the south side of Sylvan Pass (fig. 1, site 4; and figs. 4 and 5). Total flow of the stream was visually estimated to be no more than about 1 ft^3/s, and discharge of Mammoth Crystal Springs was estimated to have peaked at about 15 ft^3/s (fig. 3A). On June 22, at about 13:50, dye was observed to be issuing from Mammoth Crystal Springs along the western margin of the spring-fed lake (fig. 6) (Henry Heasler, National Park Service, oral commun., 2005), indicating a hydraulic connection with the injection site and a ground-water travel time of about 23 hours from the time of injection. Results of analysis of a water sample collected from the spring inflow (fig. 1, site 6) at 11:00 indicate, however, that dye breakthrough (first arrival) may have been almost 3 hours earlier, or about 20 hours after

Figure 6. View of Mammoth Crystal Springs about 27 hours after injection of fluorescein dye on Sylvan Pass, Yellowstone National Park, Wyoming. Photograph taken June 22, 2005.

injection (fig. 7A). Peak dye concentration at the spring inflow (about 240 µg/L) occurred at about 10:00 on June 23 (fig. 7A) or about 43 hours after injection, and peak concentration at the lake outflow (about 170 µg/L) (fig. 1, site 7) occurred at about noon (fig. 7B). However, because of the 24-hour sampling interval, travel times and peak concentrations cannot be determined accurately. As a result, travel time to first arrival could have been earlier, time to peak concentration could have been earlier or later than that indicated, and peak concentrations were likely to have been considerably higher.

The relation between detection of dye in Mammoth Crystal Springs along the western margin (spring inflow) of the lake, based on grab samples, and detection of dye in samples collected below the outflow of the lake (autosampler) indicates that transit time across the lake may be relatively short (fig. 7). Assuming a lake volume of about 200,000 ft^3 and an average discharge of about 11 ft^3/s between the time of first arrival and peak dye concentration at the lake outflow (fig. 3A), the calculated transit time across the lake would have been about 5 hours. Dye concentrations in water from the spring inflow to the lake were consistently higher than those in water from the outflow of the lake because of dye degradation from sunlight during transit across the lake, lag time for movement of the dye across the lake, and possible dilution from undyed water entering the system through the lake bottom. Although travel time of the leading edge of the dye pulse through the aquifer was less than 1 day, transit time of virtually all of the dye mass through the system as determined from the breakthrough curve for the spring outflow was almost 3 weeks (fig. 7B).

The breakthrough curves for this trace indicate a rapidly rising leading edge with a considerably slower return to baseline on the recovery limb (fig. 7), typical of flow through open conduit systems (Jones, 1984). The extended recovery in this hydrogeologic setting may be caused by dispersion within the talus, resulting in variable-length flow paths and hence, travel times. Further, the breakthrough curve for the lake outflow represents a composite of multiple discharge points, which may also contribute to a lag in the recovery time. On the basis of the dye breakthrough curve for the lake outflow, visual concentrations (greater than 50 µg/L) in the lake were present for at least 3 days (fig. 7B).

Results of analysis of activated charcoal samples indicate that dye was still present in the ground-water system at least 2 months after injection (table 2). Samples from several discharge points for Mammoth Crystal Springs along the western margin of the lake and samples from the lake outflow near the autosampler were all rated as strongly positive for the 2-week period after injection. In addition, a sample from a small (less than 20 gal/min), unnamed spring (fig. 1, site 9) discharging into the channel near the streamflow-measurement site

Table 2. Results of analysis of activated charcoal samples from selected sites in the Sylvan Pass study area, Yellowstone National Park, Wyoming

[Dye was injected on June 21 from 14:50 to 15:25; Visual result: Relative colorimetric observation of dye in charcoal elutant, where + is positive and ++++ is very strongly positive; —, no data]

Site number (fig. 1)	Site	Detector input Date-Time	Detector output Date-Time	Visual result
1	Clear Creek above Sylvan Lake	6/21/05 16:15	7/21/05 15:10	Negative
2	Eleanor Lake outflow	6/13/05 —	6/20/05 16:10	Negative
2	Eleanor Lake outflow	6/20/05 16:10	6/27/05 15:45	Negative
2	Eleanor Lake outflow	6/27/05 15:45	7/5/05 14:30	Negative
3	Crecelius Cascade	6/21/05 14:00	6/27/05 15:35	Negative
6	Mammoth Crystal Springs inflow	6/13/05 —	6/20/05 13:10	Negative
6	Mammoth Crystal Springs inflow	6/20/05 13:10	6/27/05 14:30	+++
6	Mammoth Crystal Springs inflow	6/27/05 14:30	7/5/05 12:00	+++
6	Mammoth Crystal Springs inflow	7/21/05 13:15	8/24/05 14:05	Weak +
7	Mammoth Crystal Springs outflow	6/20/05 13:30	6/27/05 14:35	+++
7	Mammoth Crystal Springs outflow	6/27/05 14:35	7/5/05 13:30	+++
9	Spring near streamflow-measurement site	6/21/05 11:30	7/5/05 12:45	++++
10	Middle Creek above confluence	6/21/05 11:40	6/27/05 12:25	Negative

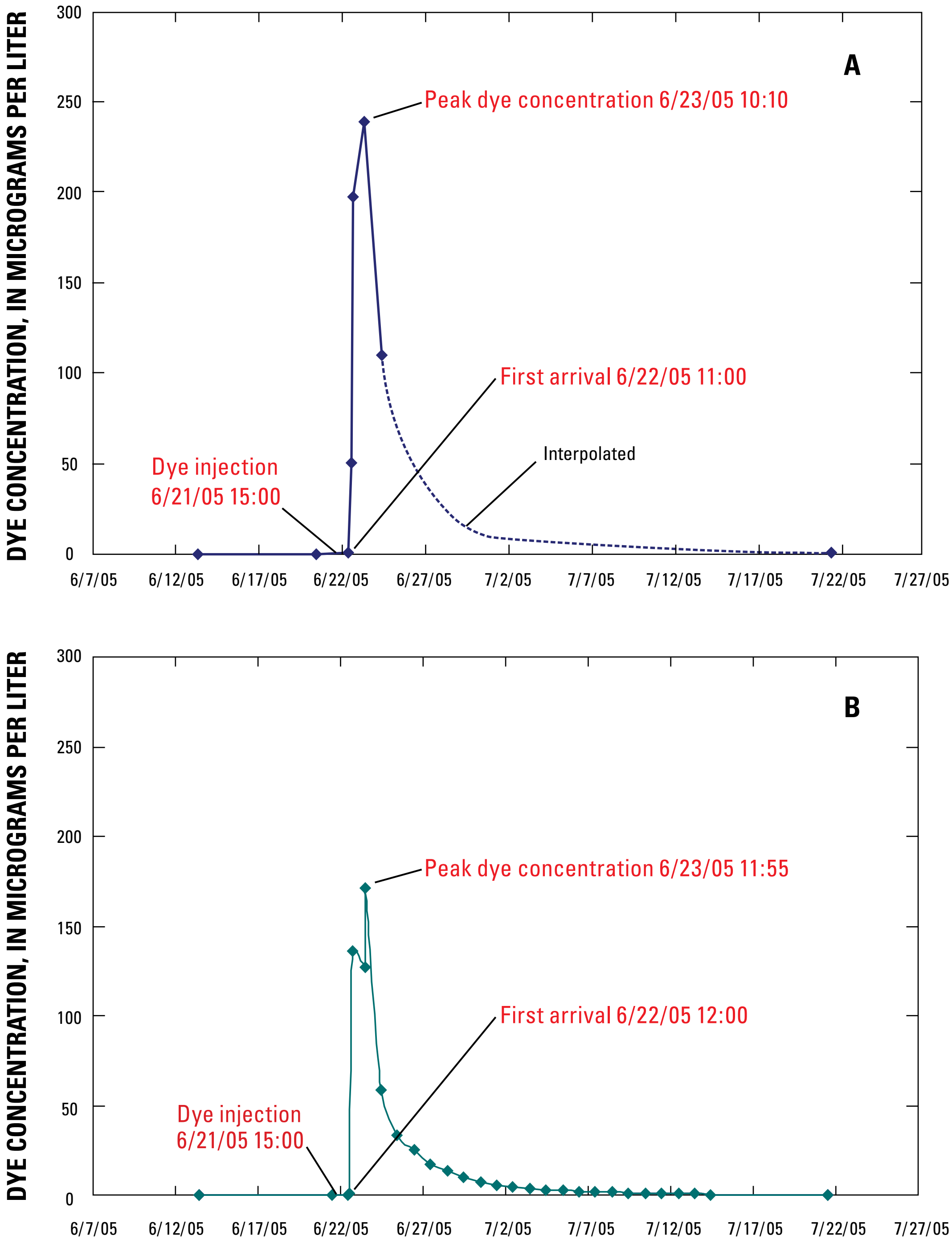

Figure 7. Fluorescein dye breakthrough curves for Mammoth Crystal Springs (A) inflow, and (B) outflow, Yellowstone National Park, Wyoming.

(site 8) and about 200 ft downstream from the lake outflow was very strongly positive. Recovery of dye from this spring could indicate a subsurface diversion from the lake outflow channel at some point upstream from the spring (between the lake outflow and the spring) or a potentially separate flow path and thus, discharge point downgradient from the main spring inflow. Activated charcoal samples from the outflow of Eleanor Lake (fig. 1, site 2) and from Clear Creek, about 0.75 mi downstream from the outflow of Eleanor Lake (fig. 1, site 1) were not positive for dye (table 2) and indicate that ground water east of the lake probably does not move to the northwest into the Clear Creek drainage or Sylvan Lake (fig. 1). These results also indicate that the surface-water divide in the vicinity of Sylvan Pass does not correspond with the ground-water divide.

Ground-water velocity between the dye-injection point on Sylvan Pass and Mammoth Crystal Springs is exceedingly rapid and comparable with that observed in highly permeable terrains such as karst. On the basis of first arrival of the dye, apparent ground-water velocity was at least 8,000 ft/d, assuming linear flow through the aquifer. Hydraulic-conductivity values in fractured karstic and volcanic (basaltic) rocks can be as high as 104 ft/d (Heath, 1989). Ground-water movement to Mammoth Crystal Springs probably occurs between the talus blocks or within spaces created by winnowing of finer materials between the talus blocks, resulting in high ground-water velocities. Melting of the permafrost also could substantially enhance permeability and create preferential pathways of rapid ground-water flow though the talus. Further evidence of highly permeable pathways through the talus is indicated by the large variation in springflow prior to and after snowmelt runoff (fig. 3A) and by the rapid increase in discharge of the springs in response to rainfall on Sylvan Pass (fig. 3B). These rapid rates of ground-water movement as shown by the tracer test and natural variations in springflow are highly conducive to the transport of suspended sediment through this aquifer.

Summary and Conclusions

Results of a tracer test in the Sylvan Pass area of Yellowstone National Park to determine the relation between surface water and ground-water flow to Mammoth Crystal Springs indicate that streamflow lost into talus deposits near Eleanor Lake enters the ground-water system and moves to the southeast to discharge at the springs. Ground water in the Sylvan Pass area east of Eleanor Lake does not appear to move to the west toward Sylvan Lake. Although only a single dye trace was conducted to document a hydraulic connection between this area and Mammoth Crystal Springs, the high discharge indicates that water from other losing streams as well as general infiltration from rainfall and snowmelt in the Sylvan Pass area also likely discharge at these springs. Further, estimates and measurements of the flow of losing streams in the Sylvan Pass area during the study roughly accounted for much of the discharge of Mammoth Crystal Springs. Ground-water movement to Mammoth Crystal Springs is probably through talus deposits that overlie the andesitic bedrock rather than through fractures in the bedrock. These talus deposits have very high hydraulic conductivities as indicated by ground-water travel times of less than 1 day and rates of movement that exceed 8,000 feet per day, values that are similar to those in karst aquifers. Transit time of most of the dye mass through the system was almost 3 weeks, although dye was detected for an additional 2 months. High permeability within this aquifer also is indicated by the large variation in springflow in response to snowmelt runoff and precipitation, and by the high concentration of suspended sediment (turbidity) in the water discharging into the spring-fed lake.

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