Appendix 5a – Interpretation of fluorometric tracer tests done in the USGS Leetown Science Center, West Virginia

Tracer Test No. 1

The first tracer test was initiated on April 20, 2004, at 11:34 AM by releasing 0.635 pounds (lbs) of Rhodamine WT dye into the south branch of Hopewell Run just below the Owen's Farm Spring pond (fig. 25 and table 12). Possible dye recovery sites monitored were the south and east branches of Hopewell Run (points f and g on fig. 25), Gray, Blue, Balch, and Tabb Springs (sites a, c, h, and i on fig. 25 and table 13), and two wells at the Center (sites d and e on fig. 25 and table 13).

Peak dye recovery occurred at the monitoring point (point f on fig. 25) on the south branch of Hopewell Run at 4:38 PM on April 20, 2004, indicating an approximate five hour time of travel within the stream and through several ponds in the area (app. 5, fig. 1). Ground-water discharge to the south branch of Hopewell Run could not be firmly established because of the surface water transport of the dye. However, small dye peaks approximately three days and six days after injection could reflect recovery of dye from upstream leakage of surface water into ground water.

Peak dye recovery in the ball field well (Jef-0590 – site 48 on fig. 1 and in table 1) (point d on fig. 25) on the Center occurred at 7:30 AM on May 02, 2004, indicating a 12-day time of travel (app. 5, fig. 2) and a linkage between surface and ground water, most likely as the south branch of Hopewell Run crosses the thrust faults which occur adjacent to the Center. The distance from the injection point to the ball field well is 5,181 ft which translates into a flow velocity of 430 ft/d. Base-flow discharge measurements conducted on the east and south branches of Hopewell Run indicate a loss of streamflow as the streams cross the thrust faults.

An isolated peak concentration of dye was detected in Balch Spring (Jef-0327S – site 4 on fig. 1 and in table 1) at 8:50 AM on April 22, 2004, which may be a result of induced capture of water by pumping of Balch Spring. The south branch of Hopewell Run flows across the thrust fault on which Balch Spring is located. The time of travel for peak arrival to Balch Spring was approximately six days (app. 5, fig. 3), but the exact path of travel is not known and is likely associated with the thrust faults which cross the area. The distance from the injection point to Balch Spring is 6,099 ft which translates into a flow velocity of about 1,020 ft/d.

A weak multimodal recovery of dye was obtained at the monitoring point on the east branch of Hopewell Run (point g on fig. 25) with a peak recovery occurring at 8:00 AM on April 24, 2004 indicating a time of travel of about four days (app. 5, fig. 4). This erratic recovery probably reflects spillover of Balch Spring water into the east branch and possibly a slight rise of dye along a portion of its length. This hypothesis was not tested, however. With a straight-line travel distance of 6,358 ft and assuming that the peak dye recovery reflects a discharge of ground water to the east branch of Hopewell Run, the estimated flow velocity is 1,600 ft/d.

Tracer Test No. 2

The second tracer test was initiated on May 17, 2004, at 10:30 AM by injecting 0.635 lbs of Rhodamine WT dye into the east branch of Hopewell Run just below Bell Spring (fig. 25 and table 12). Resurgence was monitored at the same sites monitored for the first tracer test with the addition of a second site on the east branch of Hopewell Run below two intermittent springs (site j on fig. 25 and table 13).

Peak dye recovery occurred at the on the east branch of Hopewell Run at the Leetown gaging station (site g on fig. 25) at 7:10 PM on May 18, 2004, indicating a slightly less than 1.5-day time of travel within the stream and through a large reservoir (app. 5, fig. 5). The distance from the injection point to the sampling station is 7,120 ft and yielded a calculated streamflow velocity of 4,750 ft/d, although this is likely an indication of the stream velocity only. A second smaller peak in the breakthrough curve (BTC) occurred on May 26, 2004, 9 days after injection with a subsequent flattening of the curve indicating dye recovery and a streamflow velocity of about 790 ft/d.

Dye peaks were detected at Gray and Blue Springs (app. 5, figs. 6 and 7, respectively) (sites a and c on fig. 25), although data are limited and recoveries at Gray Spring were very poor. Such poor breakthrough data indicates that the sampling frequency was insufficient for this particular test. However, the smooth distribution of data allowed for modeling the breakthrough curves. Peak dye recovery occurred at Gray Spring on May 21, 2004 and at Blue Spring on May 22, 2004, approximately 4 and 5 days after injection, respectively. The travel distances to Gray Spring was 4,860 ft and to Blue Spring was 5,130 ft, providing calculated flow velocities of 1,220 ft/d and 1,030 ft/d.

The dye resurgences at Blue and Gray Springs provide an indication of a connection between surface and ground water, but the limited sampling data around the recovery times is problematic. The geologic map for the area indicates a thrust fault crossing through the areas adjacent to the south branch of Hopewell Run and the springs, indicating a possible connection between the two.

A strong multimodal recovery of the dye was also obtained at the ball field Well (Jef-0590 – site d on fig. 25) where peak recovery exceeded 7 µg/L (>6 µg/L when the ~1 µg/L background concentration is subtracted from the measured peak concentration) (app. 5 fig. 8). Peak recovery occurred at 7:35 AM on May 18, 2004, indicating a 21 hour (.875 d) time of travel (app. 5, fig. 8). The multimodal nature of the breakthrough curve cannot be easily explained, but may be a result of leakage (losing reaches) along the east branch of Hopewell Run. An alternative explanation may be that dye leaked into the well at various fractures along the well bore.

An early peak indicates fairly rapid transit by the bulk of the dye, but the long strong tail also is indicative of slow leakage from tighter fractures. The distance from the injection point to the ball field well is 5,680 ft, providing a calculated flow velocity of approximately 6,490 ft/d). These results indicate recoveries at the ball field well from both tracer tests 1 and 2. The travel time discrepancy (travel times from the April 20, 2004, release were much longer than the travel times from the May 17, 2004, release) is not easily resolved, but probably reflects the proximity of the east branch of Hopewell Run to the ball field well relative to the south branch of Hopewell Run.

Very low peak dye recoveries were obtained at Balch Spring, at Hopewell run just below the two intermittent springs, and on the south branch of Hopewell Run at the Leetown gaging station. The recoveries at Balch Spring were very low, multimodal and occurred on May 19, 2004, and May 22, 2004, yielding travel times of about 2 and 5 days, respectively (app. 5, fig. 9). The distance from the injection point to Balch Spring is 6,190 ft, indicating flow velocities of 1,240 and 3,100 ft/d. Similar results were obtained from the two intermittent springs. The peak recovery occurred on May 24, 2004, seven days after injection (app. 5, fig. 10). The recovery point is 3,760 ft from the injection site, indicating a flow velocity of 540 ft/d was calculated.

A somewhat erratic recovery was also obtained at the Hopewell Run at Leetown gaging station on the south branch of Hopewell Run with the main peak dye recovery occurring on May 26, 2004, about nine days after injection (app. 5, fig. 11). The recovery point is 7,200 ft from the injection point, indicating a calculated flow velocity of about 800 ft/d.

Although the dye recoveries at Balch Spring, Gray Spring, the east branch of Hopewell Run just below the two intermittent springs, and on the south branch of Hopewell Run were quite low, their travel distances and peak times of recovery were comparable with each other and with the other sampling sites where stronger recoveries were obtained. This relation indicates that the weak recoveries are probably real. The first two tracer tests were based on injections into streams while the remaining tests concentrated on injections into ground water through sinkholes or shallow wells.

Tracer Test No. 3

The third tracer test was initiated on June 17, 2004, at 11:20 AM by injecting 1.05 lbs of Rhodamine WT dye into a sinkhole on the Center north of the east branch of Hopewell Run near Hite Road (site 3 on fig. 25 and table 12). Resurgence sites were monitored on the south (site f on fig. 25) and east branches of Hopewell Run (sites g, j, and k on fig. 25 and table 13), and at the confluence of two small intermittent springs down gradient of the injection sinkhole (site l on fig. 25 and table 13).

Peak dye recovery occurred at the confluence of the two intermittent springs (site l on fig. 25) on July 8, 2004 (app. 5, fig. 12), at the east branch of Hopewell Run downstream of the confluence of the two springs (site j on fig. 25) also on July 8, 2004, and on the east Branch of Hopewell Run at the Leetown gaging station on July 9, 2004. The estimated time of travel from the injection sinkhole for peak arrival at the two intermittent springs was approximately 21 days. The distance between the sinkhole and the confluence of the two overflow springs is approximately 1,580 ft, yielding an approximate flow velocity of 75 ft/d.

Tracer Test No. 4

The fourth tracer test was initiated on July 22**,** 2004, at 9:30 AM by injecting 1.05 lbs of Rhodamine WT dye into a 46 ft deep piezometer drilled in bedrock along a fracture zone. This piezometer is located on a cross-strike fracture zone (fig. 25 and table 12) that parallels a nearby cross-strike fault and connects to a small intermittent spring approximately 1,490 ft up-gradient of Gray Spring. Resurgence sites were monitored on the south and east branches of Hopewell Run (points f and g on fig. 25 and table 13), at Gray, Blue, and Balch Springs, and at the small tributary stream that starts at Gray Spring (sites b, a, h, and c on fig. 25 and table 13).

Peak dye recovery occurred at Blue Spring on July 23, 2004, six days after injection (app. 5, fig. 13), at Gray Spring on July 24, 2004, about seven days after injection (app. 5, fig. 14a), and at the tributary just below Gray Spring on July 23, 2004, about six days after injection (app. 5, fig. 14b). Dye recoveries were very low with multiple peaks, indicative of poor flushing from the piezometer. The estimated peak time of travel from the injection piezometer to the tributary monitoring point was approximately six days indicating the overflow receives water from Blue Spring before Gray Spring. The straight line distance between the piezometer and Blue Spring was approximately 1,910 ft, yielding an approximate groundwater flow velocity of 320 ft/d. The straight line distance between the piezometer and Gray Spring is approximately 1,490 ft, yielding an approximate ground-water flow velocity of 210 ft/d.

Dye was also recovered at Balch Spring at extremely low concentrations, again with erratic multiple peaks (app. 5, fig. 15). Poor flushing of the dye from the piezometer is a possible reason for the very poor tracer recovery. Peak recovery at Balch Spring occurred on July 29, 2004, about 12 days after injection. The distance between the injection piezometer and Balch Spring is 3,860 ft, indicating a calculated flow velocity of 320 ft/d.

This poor flushing may be evidence that the piezometer was not in good hydraulic connection with the main flow system, at least at the depth where the dye was released. Alternatively, although precautions were taken to control the rate of release of dye into the piezometer, it is possible that the slow rate of dye injection into the top of the piezometer, followed by chaser water, was too great for the piezometer to be able to absorb the injected water. The net effect would be that the head in the piezometer may have been sufficiently raised as to force the dye up into the vadose zone. Such an occurrence would result in a slow, perhaps pulsing release of the dye back into the piezometer and subsequent release into the aquifer over a relatively long period of time.

Tracer Test No. 5

The fifth tracer test was initiated on August 31, 2004, at 11:22 AM by injecting 3.5 lbs of Rhodamine WT dye into a 6 ft deep augered hole in a dry stream channel (point 5 on figure 25) coincident with a thrust fault that connects to Gray Spring (fig. 25 and table 12). Resurgence sites were monitored on the south and east branches of Hopewell Run (sites f and g on fig. 25 and table 13) and at Gray, Blue, Balch and Tabb Springs (sites a, c, h, and i on fig. 25 and table 13).

Peak recovery occurred at Blue and Gray Springs on September 29, 2004, 29 days after injection (app. 5, figs. 16 and 17, respectively); at Tabb Spring on September 28, 2004, 28 days after injection (app. 5, fig. 18); at Balch Spring on September 15, 2004, 15 days after injection (app. 5, fig. 19); and on the south and east branches of Hopewell Run on September 29, 2004, 29 days after injection (app. 5, figs. 20 and 21, respectively).

Interestingly, breakthrough curves for the south and east branches of Hopewell Run are remarkably similar in appearance to each other. Similarly, Blue and Gray Springs also have similarly appearing curves. The similarity in breakthrough curves between the two branches of Hopewell Run and between Blue and Gray Springs lend themselves to confirmation of recovery. Even more significant was the more rapid recovery of dye at Balch Spring where peak recovery was approximately 14 days sooner than the nearby Blue, Gray, and Tabb Springs. The rapid transport to Balch Spring might be related to (1) solution enlargement of fractures and faults between the injection site and Balch Spring and (2) due to the pumping of Balch Spring or both. The distances between the augered injection hole and Balch, Blue, Gray, and Tabb Springs are approximately 3,540, 1,260, 810, and 1,910 ft respectively; resulting in calculated peak ground-water flow velocities of approximately and 240, 44, 28, and 68 ft/d, respectively.

Tracer Test No. 6

The sixth tracer test was initiated on October 7, 2004, at 10:20 AM by injecting 0.66 lbs of sodium fluorescein dye into a 37.5-ft deep piezometer (site 54 on fig. 1 and in table 10) completed in shallow bedrock on a thrust fault that connects to Balch Spring (fig. 25 and table 12). Resurgence sites were monitored on the south and east branches of Hopewell Run (sites f and g on fig. 25 and table 13) and at Gray, Blue, Balch and Tabb Springs (sites a, c, h, and i on fig. 25 and table 13).

Peak dye recovery occurred at the east branch of Hopewell Run at the Leetown gaging station on October 30, 2004 (app. 5, fig. 22), and in Balch Spring on December 10, 2004 (app. 5, fig. 23). An even stronger resurgence occurred at Balch Spring on December 17, 2004 just as sampling was terminated due to freezing of equipment. As a result, final recoveries at Balch Spring could not be determined.

These data indicate approximately 25 days for peak time of travel to Hopewell Run and approximately 64-71 days for peak time of travel to Balch Spring. The distances between the injection piezometer and Balch Spring is 970 ft and to the Hopewell Run at Leetown gaging station is 1,390 ft. These data yielded a calculated peak flow velocity to Balch Spring of 14-15 ft/d and to the east branch of Hopewell Run of 56 ft/d. The differences in flow velocities to Balch Spring and to Hopewell Run indicate that different fractures associated with the fault zones are connected to the two sites.

In August 2005 an aquifer test was conducted on a 6-in. diameter well (Jef-0586, site 60 on fig. 1 and in table 1) adjacent to the injection piezometer (Jef-0599, site 54 on fig. 1 and in table 1) used for injection of dye in the sixth tracer test. A 72-hour aquifer test was conducted on the well and water was withdrawn from the well at rates varying from 100 to more than 300 gal/min. Visible concentrations of sodium fluorescein were detected in a down gradient monitoring well approximately 200 ft from the injection piezometer. Sodium fluorescein dye had remained trapped in the aquifer for more than 10 months, possibly in the clay filled area between pinnacles or isolated voids in the epikarst. The documentation of this phenomenon is important, as historically, only very low concentrations of dye are retrieved as a result of fluorometric tracer injections conducted in the region. The long-term trapping of water and solutes in the epikarstic zone has been documented in other karstic terranes (Even and others, 1986). Long-term trapping in the epikarstic zone is indicative of poor hydrologic connections between the vadose zone and the phreatic zone until heavy precipitation mobilizes the stored solutes.

Tracer Test No. 7

The seventh tracer test was initiated on October 7, 2004, at 12:30 PM by injecting 6.0 lbs of Rhodamine WT dye into a sinkhole 1 mile southeast of Leetown (fig. 25 and table 12). This was a repeat of a former tracer test conducted by Jones and Deike (1981). Resurgence sites were monitored on the south and east branches of Hopewell Run (sites f and g on fig. 25 and table 13) and at Gray, Blue, Balch and Tabb Springs (sites a, c, h, and i on fig. 25 and table 13). Unfortunately, freezing of automatic samplers at several sites forced a discontinuance of sampling. However, sampling was continued at several other sites for most of the winter and at Gray Spring through March, 2005.

Peak dye recovery occurred at Gray Spring on February 26, 2005, with a secondary peak on March 2, 2005 (app. 5, fig. 24). These recoveries indicate ground-water time of travel to Gray Spring of 142-146 days, respectively. The distances between the injection sinkhole and Gray Spring is 4,540 ft, yielding an approximate flow velocity from the injection sinkhole to Gray Spring of 31-32 ft/d.

Peak dye recovery occurred at Blue Spring on January 19, 2005, (app. 5, fig. 25), and at Balch Spring on October 19, 2004, with a secondary peak on November 21, 2004 (app. 5, fig. 26), although the recovery concentrations at Balch Spring are quite low. No data was available for these sites in early 2005 due to freezing of automated samplers. Because data were unavailable for Balch and Blue Springs, flow to these sites may not be representative of peak ground-water travel times. Estimated time of travel to Blue Spring was 104 days and to Balch Spring was 12 days with a secondary peak 45 days since injection. The apparent rapid transit of dye to Balch Spring was probably induced by pumping of Balch Spring.

Estimated flow velocities are equally uncertain. The distance from the injection sinkhole to Blue and Balch Springs are approximately 5,020 and 7,180 ft, respectively. Estimated flow velocities were approximately 48 ft/d to Blue Spring and 160–600 ft/d to Balch Spring. The previous tracer test conducted by Jones and Deike (1981) reported a transit rate of 81 ft/d to Gray Spring, 86 ft/d to Blue Spring, and 127 ft/d to Balch spring (Jones and Deike, 1981). The apparent discrepancy in flow velocities are probably a result of higher precipitation during this study.

Tracer Test No. 8

The eighth and final tracer test was initiated on April 19, 2005, at 11:22 AM by injecting 11.9 lbs of Rhodamine WT dye into a sinkhole northeast of Leetown (fig. 25 and table 12). Resurgence sites were monitored on the east branch of Hopewell Run at the Leetown gaging station (site g on fig. 26 and table 13) and at Gray, Blue, and Balch Springs and the confluence of the two intermittent springs just down gradient of the injection sinkhole (sites a, c, h, and l on fig. 25 and table 13). Resurgence sites were also monitored on the east branch of Hopewell Run above and below the confluence of the discharge of the two intermittent springs on the east branch of Hopewell Run (sites j and k of fig. 25 and table 13) and downstream from a spring fed pond (site m on fig. 25 and table 13).

Unfortunately, the three springs nearest the injection sinkhole ceased flowing at the end of May 2006. These springs were likely resurgence sites for the tracer test. It is possible that a peak dye recovery occurred on May 4, 2006 at the two intermittent springs (site l on fig. 25) indicating a 15-day time of travel (app. 5, fig. 27). Dye was also detected in the east branch of Hopewell Run downstream of the two overflow springs (site j on fig. 25). The first peak on the Hopewell Run downstream of the two intermittent springs occurred on May 8, 2005 (19 days after injection), with a second and larger peak on June 1, 2005 (43 days after injection); and subsequent smaller peaks occurring later in the year (app. 5, fig. 28).

The distance between the injection sinkhole and the two intermittent springs is 6,240 ft and the Hopewell Run monitoring site downstream of the two intermittent springs is 6,250 ft. These data indicated an estimated flow velocity of 420 ft/d for flow to the two intermittent springs and an estimated flow velocity of 150 to 330 ft/d to the Hopewell Run monitoring site downstream of the two intermittent springs.

Spiked dye peaks were detected on the east branch of Hopewell Run at the Leetown gaging station (app. 5, fig. 29) at about the same time, but may represent flow in the east branch of Hopewell Run after resurgence from the upstream site. Transit times and velocities to the gage were, therefore, not determined.

Dye was also detected at two monitoring wells drilled on anticlinal (Jef-0589) and synclinal (Jef-0588) axes (sites n and o on fig. 25) down gradient of the injection sinkhole on November 4, 2005 (app. 5, figs. 30 and 31, respectively). The monitoring wells were not continuously sampled and dye may have emerged at the site prior to November 4, 2005. However, assuming the depicted dye peaks are representative of peak travel times, transport to the two wells was 199 days. The distances from the injection point to the anticline and the syncline monitoring wells are 2,450 and 2,870 ft respectively, indicative of flow velocities of 12 and 14 ft/d. A previous tracer test conducted in the area in 1979 documented a transit rate of 150 ft/d (Jones and Deike, 1981). The discrepancy is most logically explained by the fact that the monitoring wells were not continuously sampled, especially earlier in the test. Also, wells are notoriously poor recovery locations for tracer tests in karstic terranes. As a result, ground-water flow velocities to these wells are likely faster than the velocities presented here.

Similar appearing breakthrough curves occurred at Blue, Gray, and Balch Springs with peak recoveries occurring on May 4, May 8, and May 11, 2005, respectively, yielding calculated travel times of 15, 19, and 22 days (app. 5, figs. 32, 33, and 34, respectively). This is significant because these springs are the main sources of water to the Center. The distance from the injection point to Blue, Gray, and Balch Springs are 8,030; 8,070; and 7,700 ft, indicating flow velocities of 540, 430, and 350 ft/d. It is also possible that the recoveries at Balch, Blue, and Gray Springs may have been the result of secondary or tertiary recoveries of dye from a previous test. However, a previous tracer test showed a connection between the area and Gray Spring so the test is considered to be representative of ground-water flow the area.

Appendix 5b: Data from dye tracing experiments at the Leetown Science Center, Leetown, West Virginia.

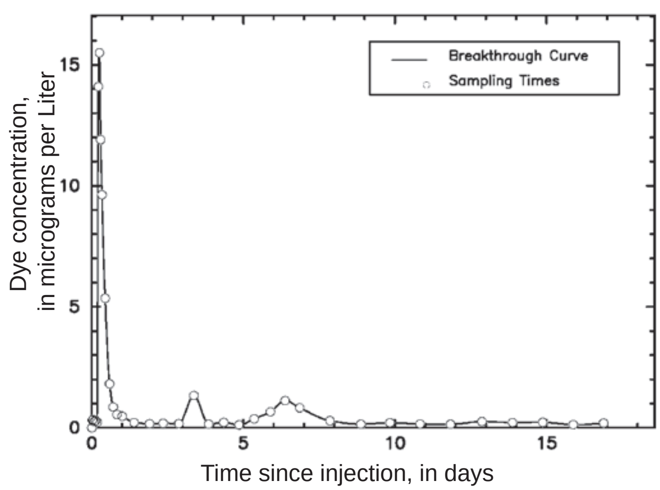


Figure 1. Tracer breakthrough curve at the gage on the south branch of Hopewell Run from the April 20, 2004 dye tracer test (Test 1). Early sharp peak probably represents flow in Hopewell Run while the later smaller peaks may represents ground-water inflow into Hopewell Run.

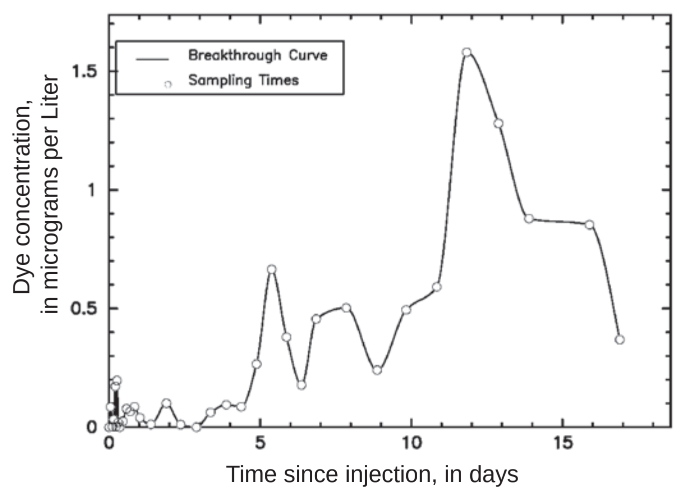


Figure 2. Tracer breakthrough curve at the Ball Field Well from the April 20, 2004 dye tracer test (Test 1).

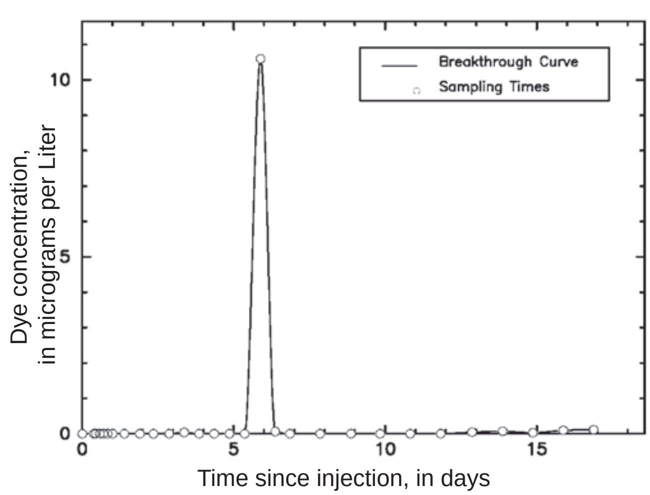


Figure 3. Tracer breakthrough curve at Balch Spring from the April 20, 2004 dye tracer test (Test 1) . Sharp peak recovery is probably representative of forced gradient extraction of ground water as a result of pumping Blach Spring.

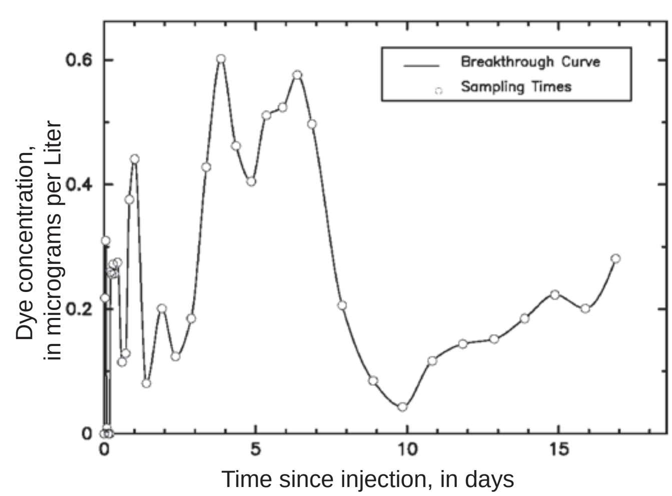
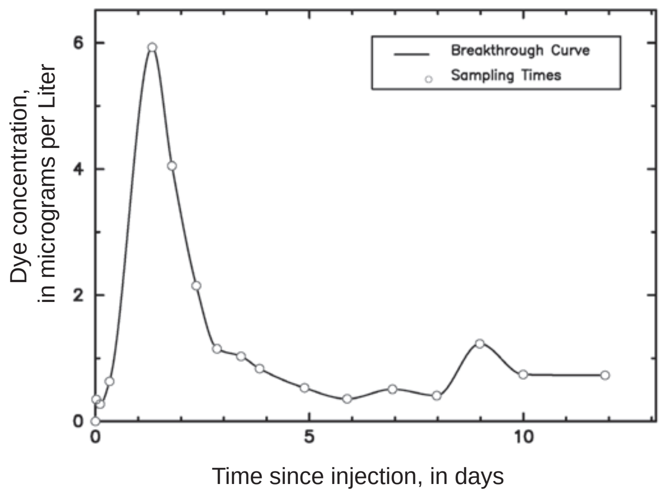


Figure 4. Tracer breakthrough curve at the gage on the east branch of Hopewell Run from the April 20, 2004 dye tracer test (Test 1). The multipeaked nature of the Break-through curve may represent both flow from Balch Spring and ground-water rise into Hopewell Run.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.



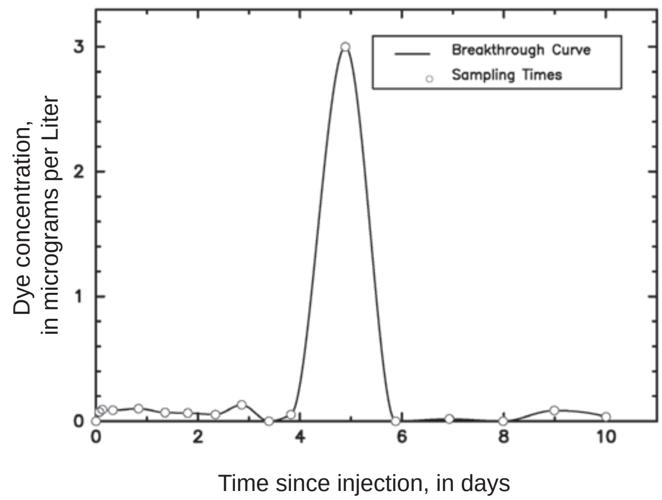
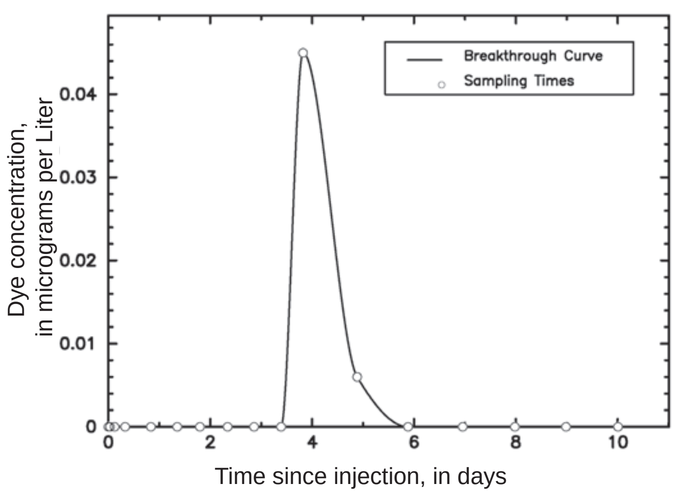


Figure 5. Tracer breakthrough curve at the gage on the east branch of Hopewell Run from the May 17, 2004 dye tracer test (Test 2). Early smooth peak probably represents flow in Hopewell Run while the later smaller peak may represent ground-water inflow into Hopewell Run.

Figure 6. Tracer breakthrough curve at Blue Spring from the May 17, 2004 dye tracer test (Test 2). Strong smooth peak is indicative of tracer recovery from ground water.



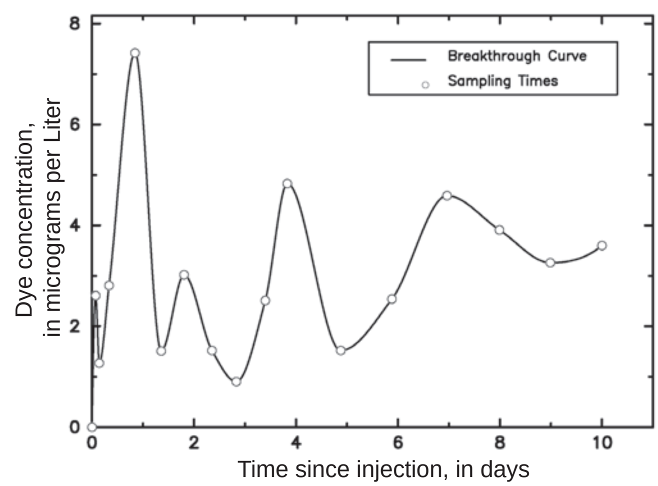


Figure 7. Tracer breakthrough curve at Gray Spring from the May 17, 2004 dye tracer test (Test 2). Strong smooth peak is indicative of tracer recovery from ground water. Skewness suggests some tracer detention in immobile flow zones.

Figure 8. Tracer breakthrough curve at the Ball Field Well from the May 17, 2004 dye tracer test (Test 2). The strong multipeaked breakthrough curve may be due to leakage of ground water into the well from differing fractures.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

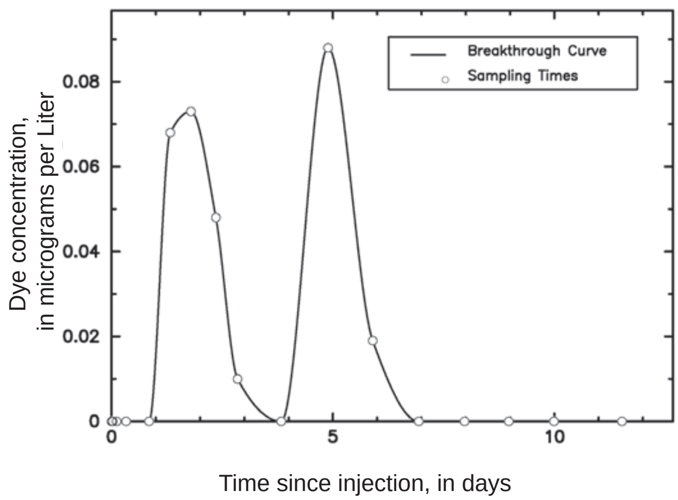


Figure 9. Tracer breakthrough curve at Balch Spring from the May 17, 2004 dye tracer test (Test 2). The very low dual peaked Breakthrough curve may be a result of forced recovery of small quantities of tracer dye detained in immobile flow regions as a result of pumping Balch Spring.

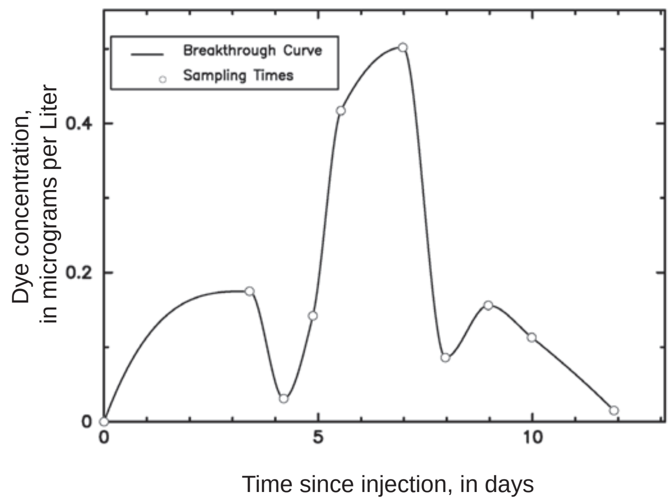


Figure 10. Tracer breakthrough curve at two high-level overflow springs from the May 17, 2004 dye tracer test (Test 2).

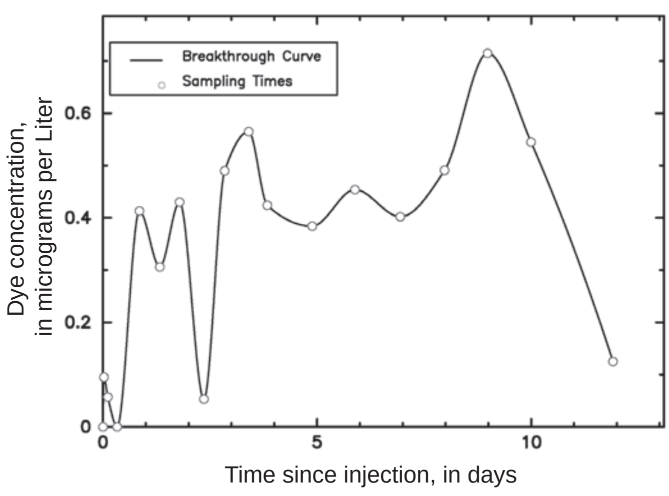


Figure 11. Tracer breakthrough curve at the gage on the south branch of Hopewell Run from the May 17, 2004 dye tracer test (Test 2). Tracer recoveries are a result of ground-water rise up into Hopewell Run.

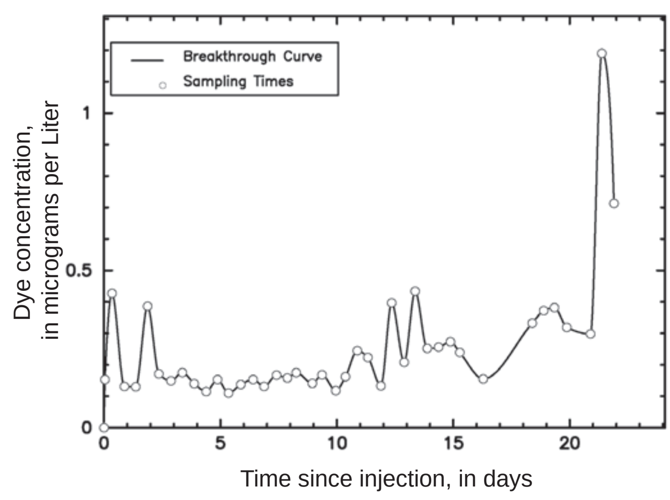


Figure 12. Tracer breakthrough curve at two high-level overflow springs from the June 17, 2004 dye tracer test (Test 3). The late peak was substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

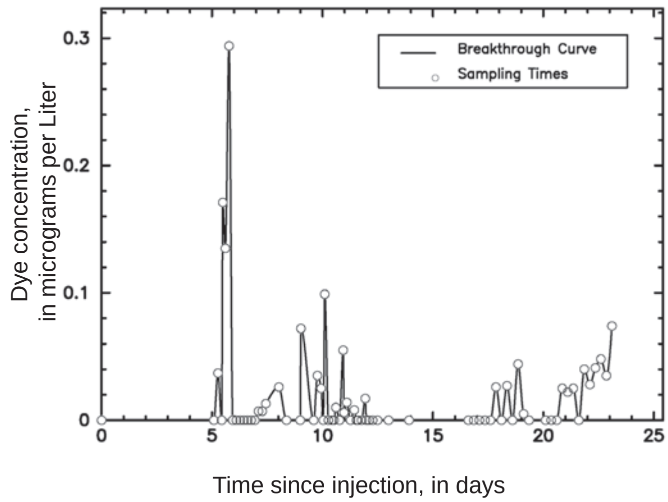


Figure 13. Tracer breakthrough curve at Blue Spring from the July 17, 2004 dye tracer test (Test 4). The very low multi-peaked breakthrough curve may be a result of slow release from the injection piezometer.

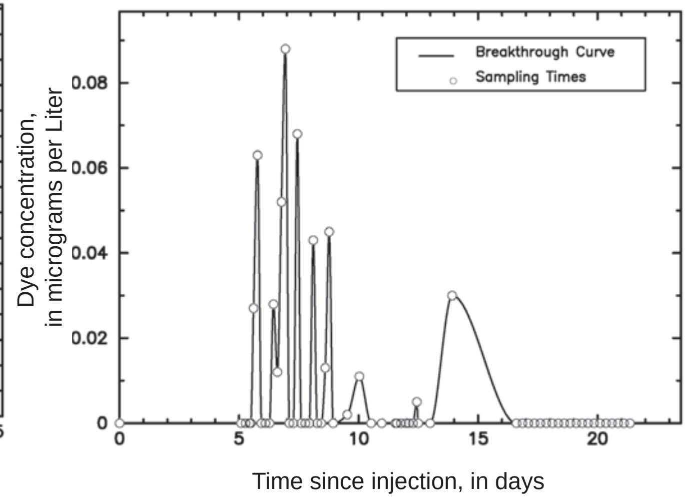


Figure 14a. Tracer breakthrough curve at Gray Spring from the July 17, 2004 dye tracer test (Test 4). The very low multi-peaked breakthrough curve may be a result of slow release from the injection piezometer.

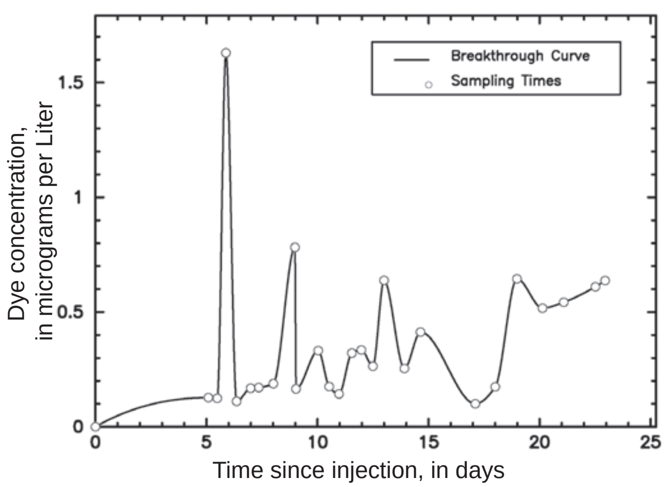


Figure 14b. Tracer breakthrough curve at the Gray Spring Overflow from the July 17, 2004 dye tracer test (Test 4).

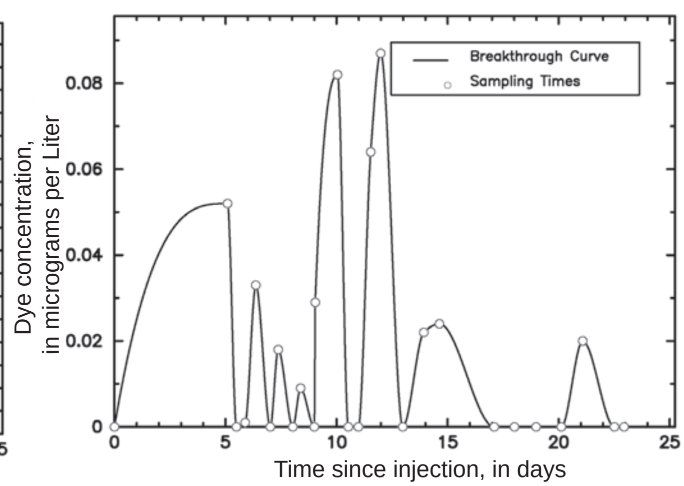


Figure 15. Tracer breakthrough curve at Balch Spring from the July 17, 2004 dye tracer test (Test 4). The very low multi-peaked breakthrough curve may be a result of slow release from the injection piezometer.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

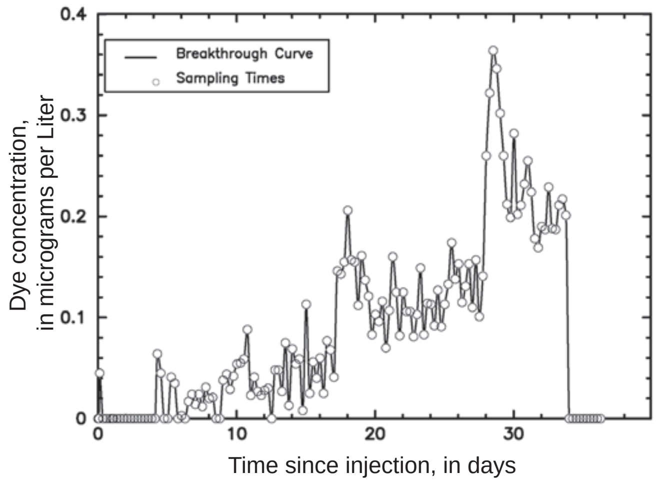


Figure 16. Tracer breakthrough curve at Gray Spring from the August 31, 2004 dye tracer test (Test 5).

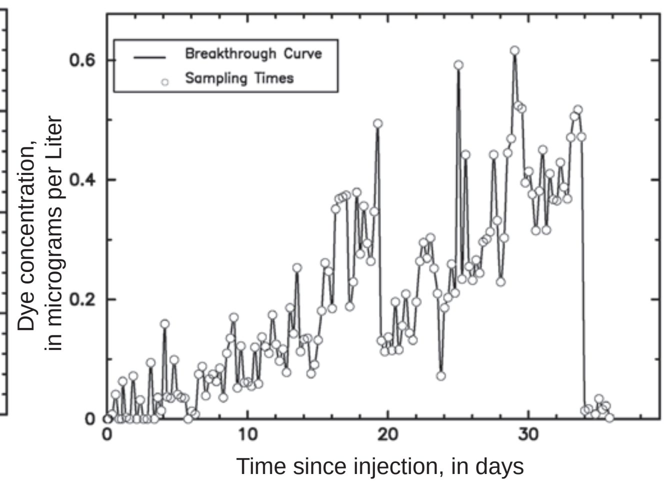


Figure 17. Tracer breakthrough curve at Blue Spring from the August 31, 2004 dye tracer test (Test 5).

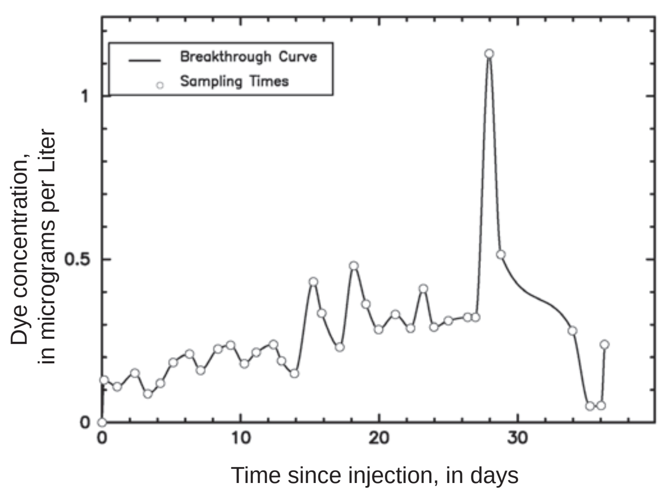


Figure 18. Tracer breakthrough curve at Tabb Spring from the August 31, 2004 dye tracer test (Test 5). The late peak was substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

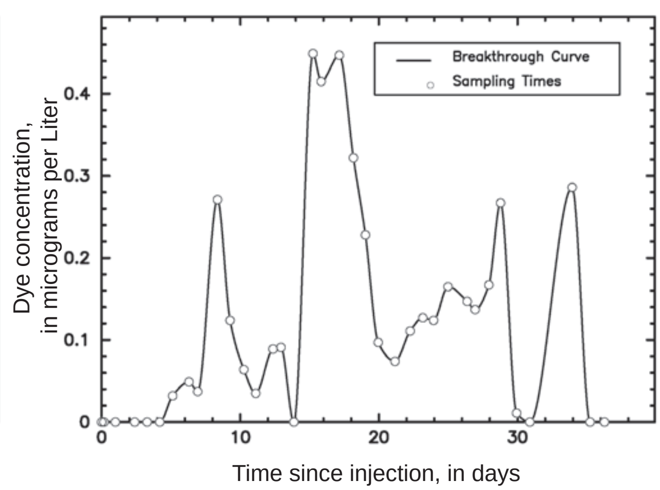


Figure 19. Tracer breakthrough curve at Balch Spring from the August 31, 2004 dye tracer test (Test 5).

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

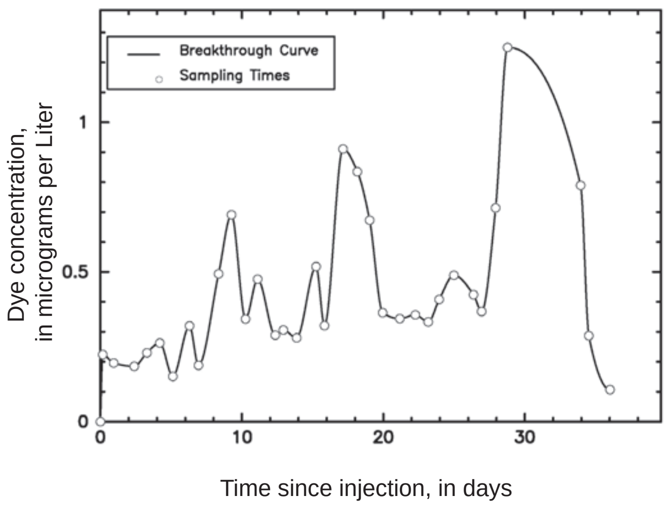


Figure 20. Tracer breakthrough curve at the gage on the south branch of Hopewell Run from the August 31, 2004 dye tracer test (Test 5). The late peaks were substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

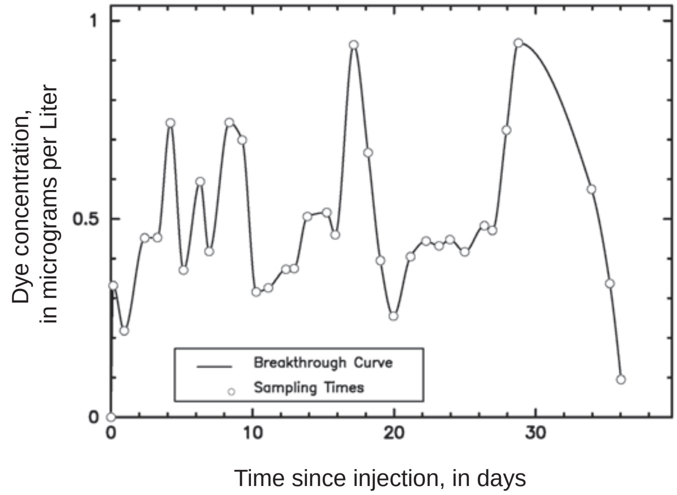


Figure 21. Tracer breakthrough curve at the gage on the east branch of Hopewell Run from the August 31, 2004 dye tracer test (Test 5). The late peaks were substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

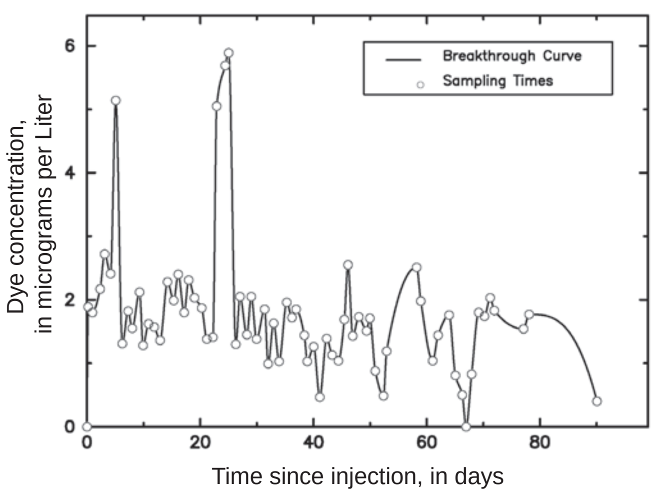


Figure 22. Tracer breakthrough curve at the gage on the east branch of Hopewell Run from the October 7, 2004 (1020 in the morning) dye tracer test (Test 6 & 7). The early peaks were substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test. Recoveries were greater and occurred earlier than occurred at Balch Spring which proves that apparent recoveries were not due to releases from Balch Spring.

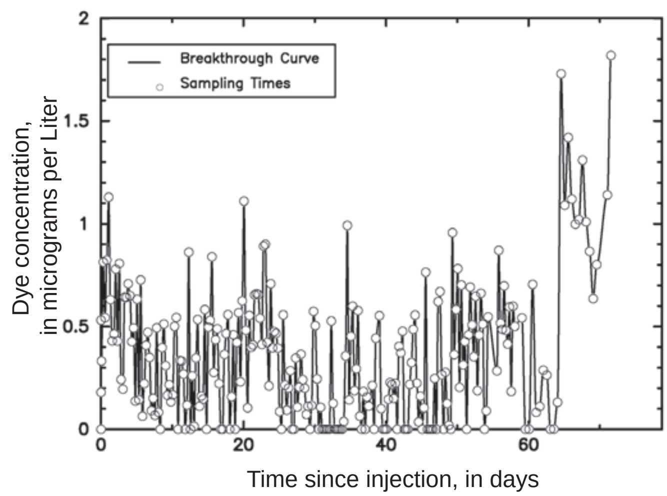


Figure 23. Tracer breakthrough curve at Balch Spring from the October 7, 2004 (1020 in the morning) dye tracer test (Test 6 & 7). The late peaks were substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

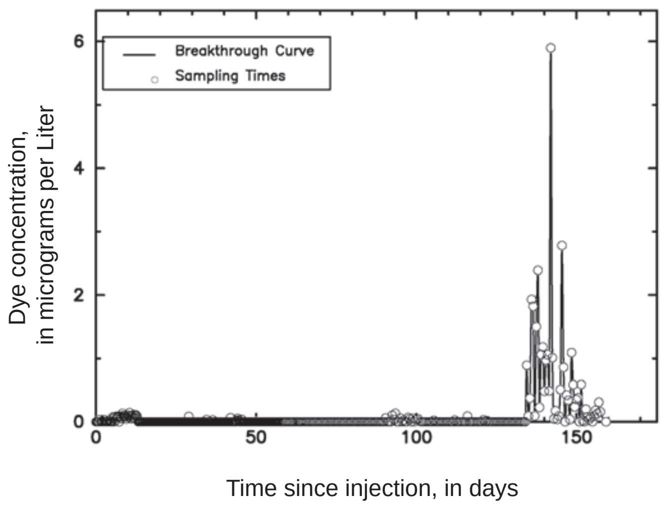


Figure 24. Tracer breakthrough curve at Gray Spring from the October 7, 2004 (1230 in the afternoon) dye tracer test (Test 6 & 7).

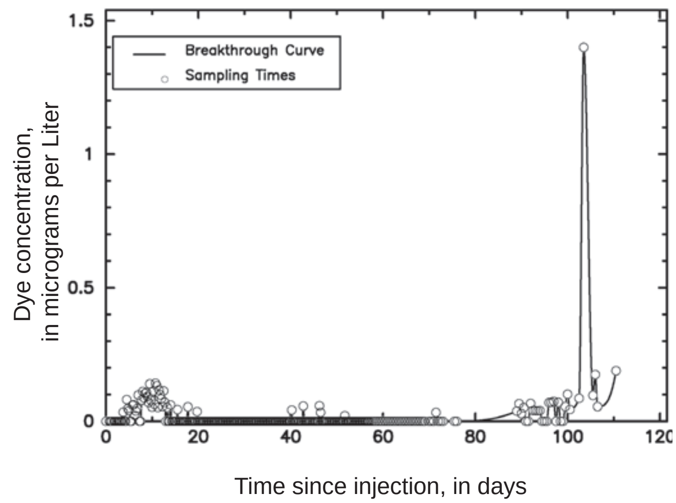


Figure 25. Tracer breakthrough curve at Blue Spring from the October 7, 2004 (1230 in the afternoon) dye tracer test (Test 6 & 7).

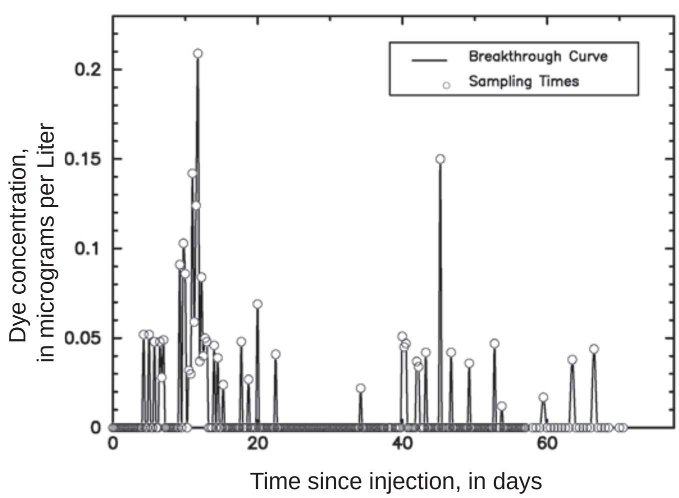


Figure 26. Tracer breakthrough curve at Balch Spring from the October 7, 2004 (1230 in the afternoon) dye tracer test (Test 6 & 7).

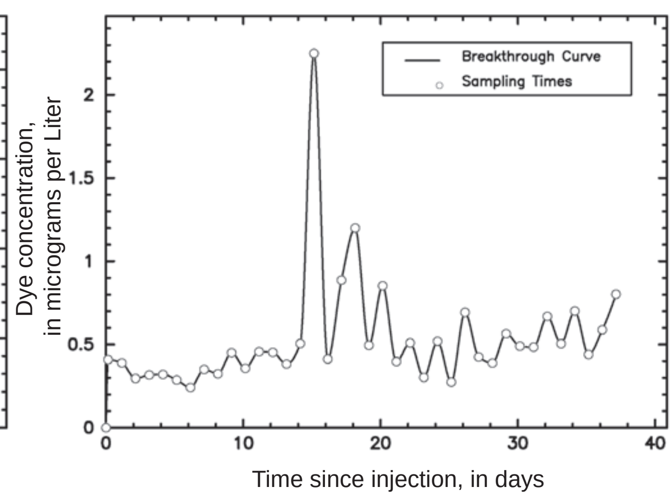


Figure 27. Tracer breakthrough curve at two high-level overflow springs from the April 19, 2005 dye tracer test (Test 6 & 7). The strong peak was substantially greater than the strong background dye levels suggesting good dye recovery from the tracer test.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

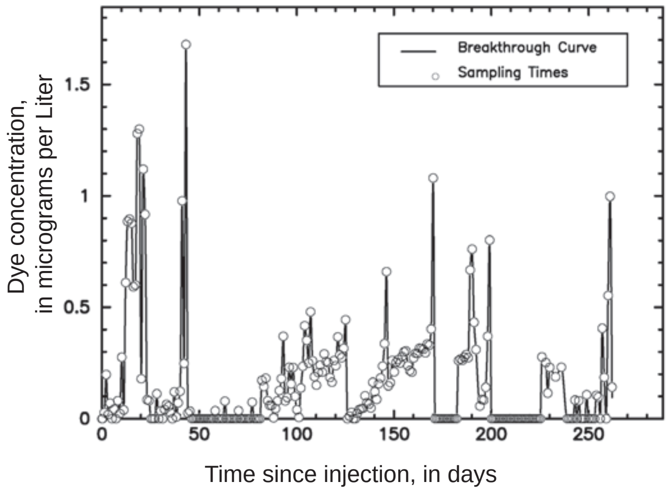


Figure 28. Tracer breakthrough curve downstream of the two high-level overflow springs from the April 19, 2005 dye tracer test (Test 8).

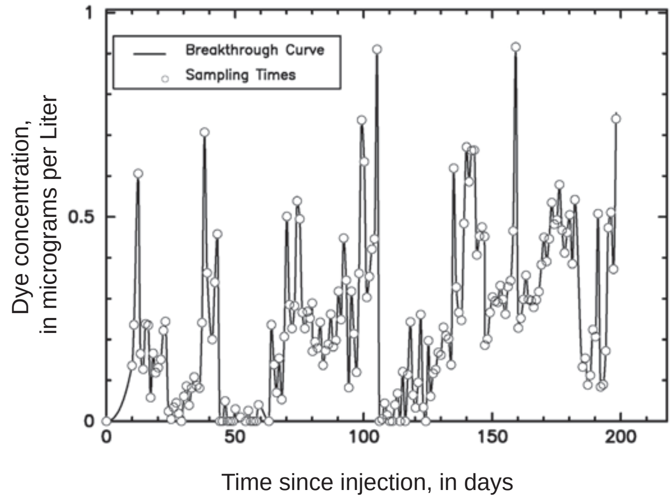


Figure 29. Tracer breakthrough curve at the gage on the east branch of Hopewell Run from the April 19, 2005 dye tracer test (Test 8).

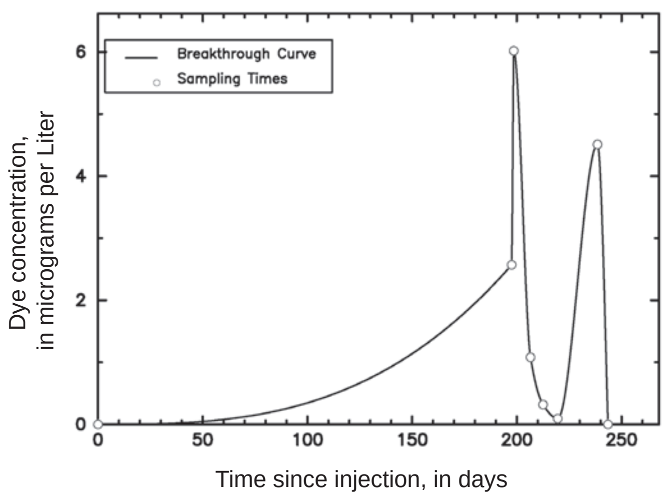


Figure 30. Tracer breakthrough curve at the Anticline Well from the April 19, 2005 dye tracer test (Test 8). The strong peaks suggest good tracer dye recovery, but the late start of sampling may have resulted in earlier dye peaks being missed.

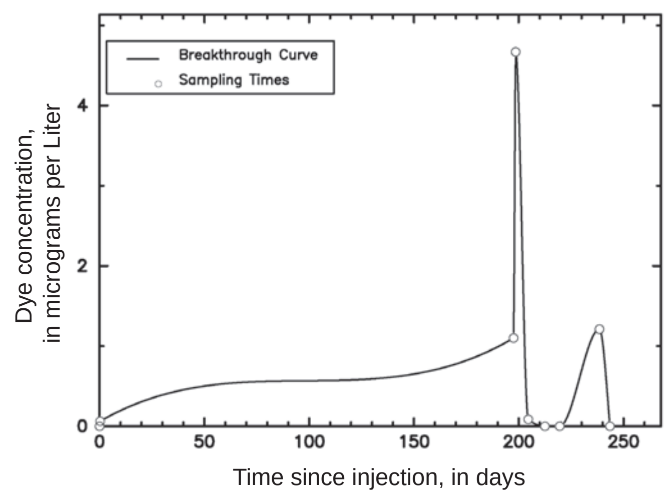


Figure 31. Tracer breakthrough curve at the Syncline Well from the April 19, 2005 dye tracer test (Test 8). The strong peaks suggest good tracer dye recovery, but the late start of sampling may have resulted in earlier dye peaks being missed.

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

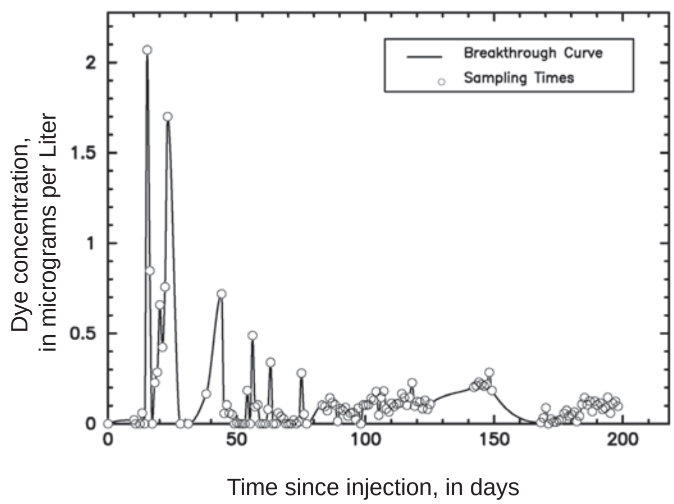


Figure 32. Tracer breakthrough curve at Blue Spring from the April 19, 2005 dye tracer test (Test 8).

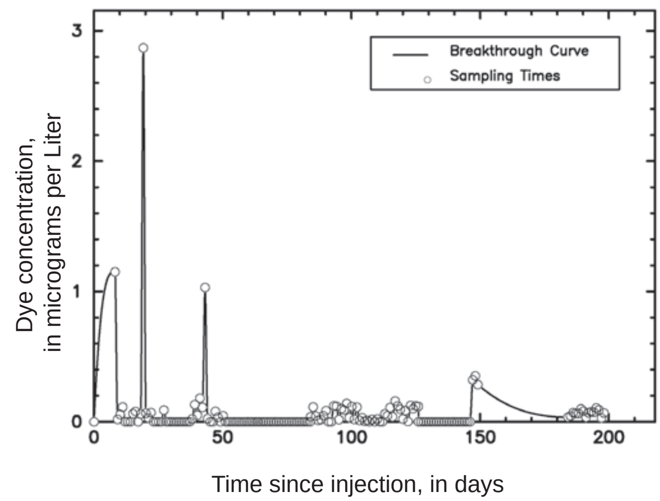


Figure 33. Tracer breakthrough curve at Gray Spring from the April 19, 2005 dye tracer test (Test 8).

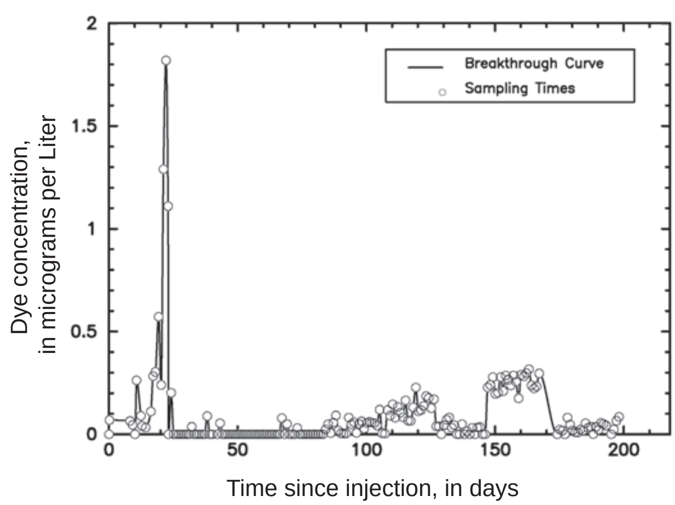


Figure 34. Tracer breakthrough curve at Balch Spring from the April 19, 2005 dye tracer test (Test 8).

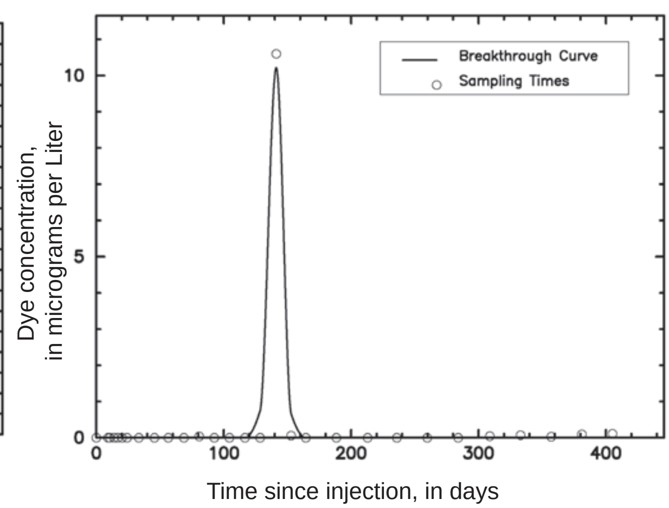


Figure 35. CXTFIT model fit to the Balch Spring breakthrough curve from the April 19, 2004 dye tracer test (Test 8).

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.

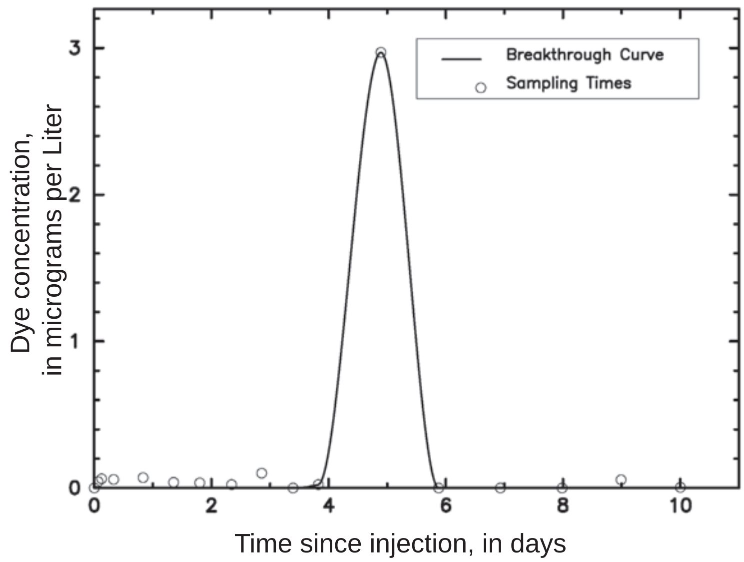


Figure 36. CXTFIT model fit to the Blue Spring breakthrough curve from the May 17, 2004 dye tracer test (Test 2).

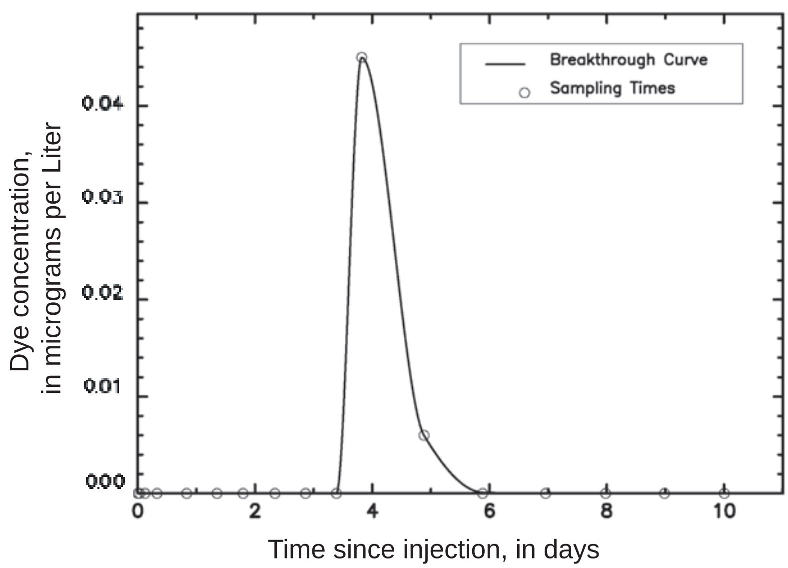


Figure 37. CXTFIT model fit to the Gray Spring breakthrough curve from the May 17, 2004 dye tracer test (Test 2).

Appendix 5b. Data from dye tracing experiments in the Leetown area, West Virginia.