

## PROJECT REPORT

### Assessment of Source Areas to Big Spring and other Cumberland County PA Springs by Dye Tracing

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#### Project Summary

Karst (limestone) springs of south-central Pennsylvania support productive wild fisheries, trout hatcheries, and water supplies, but their contributing areas are unknown. Flow in limestone aquifers occurs via solution channels, fractures, and bedding planes, rather than through homogenous pores. Therefore fluorescent dye-traces (FDT) are the only definitive method for determining source areas, direction, and velocity of groundwater flow. FDTs are not documented for the region, resulting in uncertainty in both groundwater flow and in potential for runoff contamination, even though their use is widely accepted in Europe and karst areas of the south-east U.S.A.. This study was the first documented FDT for Cumberland County, PA, where low levels of fluorescent dyes were used to detect regional flowpaths at concentrations in parts per trillion, several orders of magnitude below visual detection limits.

Major surface drainages in this part of the Great Valley include the Yellow Breeches and Conodoguinet creeks, each flowing east and north to the Susquehanna. Big Spring, the focus of this study, flows at an average of 868 L/s (26 cubic feet per second) and northward across the Great Valley to the Conodoguinet. Temperature is relatively constant at 10-11 degrees C (53-54°F), with turbidity typically <10 NTU. We released uranine (URA) into a losing reach of the Yellow Breeches, 5.2 km to the south, and sulforhodamine B (SRB) to a sinkhole collapse in a failing detention basin 8.9 km to the west of Big Spring. SRB traveled to Big Spring within 3.5 days, parallel with geologic strike. West and East source springs of Big Spring responded differently, with a clear SRB peak in the west spring (316 ppt), and much less distinct SRB peak occurring in the smaller east spring. Fl did not cross the valley from the Yellow Breeches watershed, but rather was detected one month later 9.5 km to the east at springs of Huntsdale state fish hatchery. Neither dye was detected in springs bracketing Big Spring to the west and east, including a second contributing east spring (Cool Spring) that serves as water supply to Newville, PA. Major springs are fed by regional flow systems along strike, and may receive rapid, regional transport of surface runoff from sinkholes. Both conduit flow

through underground streams, and more diffuse flow through colluvium (erosional material from South Mountain) and karst fractures are apparent in the differing results between springs and basic physiochemical characteristics of the springs.

Groundwater flow to both Big Spring and Huntsdale Hatchery Springs was nearly perpendicular to that determined by quarry wells within the Big Spring surface watershed that indicated northward flow across the valley, and approximately 500-4,000 times greater in velocity. Given this discrepancy, more dye-tracing clearly needs to be done to characterize contributing areas of these springs and to protect groundwater quantity and quality.

A preliminary background fluorescence analysis (BFA) of spring and well waters was also done, with particular focus on organic acids from forested source waters and human or animal waste from valley sources. Results for spring, 2003 indicated relatively low levels of hydrocarbon, sewage, or animal wastes in groundwater associated with valley springs. A more intensive background fluorescence analysis over time would demonstrate changes in water quality due to these factors, and serve to protect drinking water and ecological integrity of Big Spring and other spring creeks.

## **Introduction and Project Setting**

Big Spring, including both source springs, and other springs studied (Green Spring, Bullshead Branch, Cool Spring, Mt. Rock Spring, Alexander Spring, and Huntsdale Hatchery Springs) are located in Cumberland County Pennsylvania (Figure 1) in the Cumberland Valley, part of the Great Valley section of the Ridge and Valley Physiographic Province which extends from Maine to Georgia (Van Diver 1990, Chichester 1996). These springs support productive aquatic ecosystems, wild fisheries, trout hatcheries, and public water supplies, due to generally predictable flows of clear, cold water from the karst (limestone) aquifer(s), but are susceptible to modified flow, and decreased water quality from quarry activity, infiltration galleries and stormwater basins, and generally any pollutant that rapidly infiltrates fractured limestone (Veselic 2003).

Geologic materials consist mostly of the Cumberland Valley sequence, sedimentary rocks of Cambrian and Ordovician age. Triassic diabase intrusions or dikes also occur within the eroded sedimentary limestones and dolostones that create the broad valley. To the north, this sedimentary basin is bordered by Blue Mountain, locally known as North Mountain, consisting of quartzitic sandstone underlain by shale and greywacke of the Martinsburg Formation (Chichester 1996, Becher and Root 1981). The southern flank is bordered by South Mountain, the northernmost extension of the Blue Ridge Physiographic Province, and is underlain by a sequence of carbonate rocks overlain with a mantle or wedge of colluvium (Becher and Root 1981). This mantle is very thick at boundary of South Mountain (resistant quartzite), and thins gradually to limestone near Rt. 174 (Walnut Bottom Rd.). In general, geologic units tend east-northeast as a result of the regional anticline that has its axis in South Mountain (Becher and Root 1981, Chichester 1996). The region is peri-glacial, i.e. without direct influence of the most

recent glaciations. The limestone is composed of calcite and calcium carbonate from pre-existing rocks that have then precipitated (Van Diver 1990). Dolostone is similar to calcite except it contains more of the element magnesium.

In the section of the Great Valley east of Shippensburg, The Conodoguinet drains 1311 km<sup>2</sup> (506 mi<sup>2</sup>), including area to the south of Blue Mountain and most of the limestone/dolomite valley. The Yellow Breeches drains 567 km<sup>2</sup> (219 mi<sup>2</sup>) from the northern flank of South Mountain and a narrower strip of the limestone/dolomite region (Becher and Root 1981).

Additionally, the Conodoguinet drains part of South Mountain via Middle Spring Creek and its tributaries near Shippensburg, PA, the only tributary that crosses the valley up gradient of the Yellow Breeches. This stream will likely be claimed by the Yellow Breeches in geologic time, as others have been, as it erodes into the colluvium beneath South Mountain (pers. comm. Doug Chichester U.S.G.S.). For now, the present study suggests strongly that the Middle Spring watershed loses water directly to Big Spring, via regional flow through limestone. Tributaries of Middle Spring and the Yellow Breeches are sinking or losing streams, i.e. their water is lost to the underlying limestone. Chichester (1996) estimated that up to 564 L/s (12.9 million gallons of water per day or 20 cubic feet per second (cfs) is lost to the Conodoguinet from the Yellow Breeches in this manner. Becher and Root (1981) noted that only 174 L/s (3.3 million gallons per day or 3.12 cfs) of estimated 884 L/s (16.8 million gallons per day or 26.04 cfs) flow in Big Spring was derived from the surface watershed. While it has been suggested that the remainder came directly south of Big Spring from sinking reaches of the upper Yellow Breeches (Clapsaddle 2003, and all simulated groundwater elevation contour and velocity vector model figures in Continental Placer, unpublished), the results of this study suggest this is not the case.

It is this hydrogeologic setting that makes Big Spring and similar springs unique, with supply of cool spring water, buffered against acidity by the carbonate flow system. While protected from acidity, natural and anthropogenic acids (carbonic acid from soil respiration and sulfuric and nitric acids from acid deposition) readily dissolve the carbonate rocks, creating preferential flow paths of water through solution channels that typically occur along bedding planes and fractures. This activity is responsible for cave and sinkhole formation in the area. These features, along with closed depressions, dry valleys, and springs of substantial discharge are typical of karst environments (Chichester 1996), and should be acknowledged along with inter-basin, regional groundwater flow in any development of groundwater or geologic resources in the area.

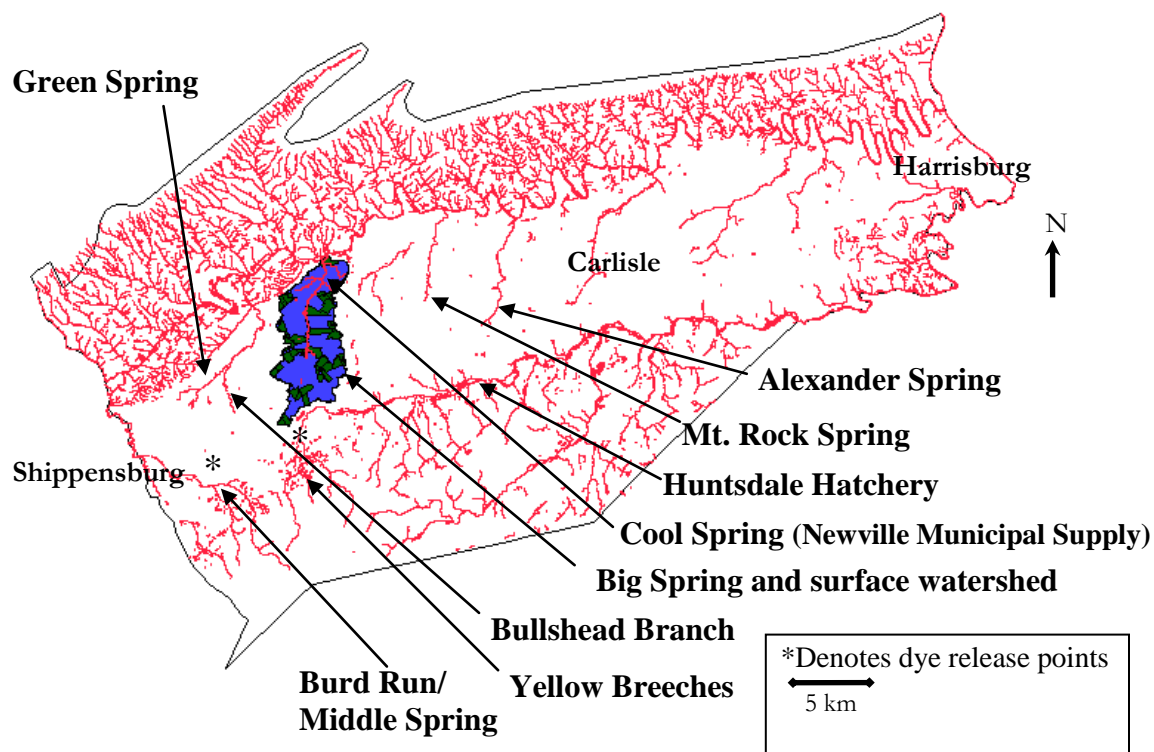


Figure 1. Study area and monitored springs within Cumberland County, PA. Burd Run/Middle Spring was not monitored for dye breakthrough, but is shown for reference. The surface watershed of Big Spring is indicated, as are dye release points outside this surface watershed.

## Materials and Methods

Activated coconut charcoal dye receptors were placed weekly in duplicate at 8 springs, and sampled and analyzed following the Crawford Hydrology Lab protocol (Crawford Hydrology Lab, 2004), August-October, 2005. Sulforhodamine B and Uranine (URA, aka Na-Fluorescein) were released August 2005. Water samples were collected several times per day from Big Spring east and west in the first week, tapering to 1/week during weeks 2-7. Eluent from receptors, and water samples were analyzed using a scanning spectrofluorophotometer at the labs of Dr. Nicholas Crawford (Crawford Hydrology Lab) and Dr. Martin Otz (Nano Trace Technologies<sup>TM</sup>). Preliminary background fluorescence of valley springs and mountain streams was assessed in April and May 2003 using synchronous spectrofluorometry at the lab of Dr. Martin Otz.

Almost 1 kg (2 lb) of URA was released into a losing reach (last 50 m of wetted channel) of the Yellow Breeches in Walnut Bottom PA on August 25, 2005, 8:00 p.m., 5.2 km south of Big Spring. URA infiltrated the channel overnight, such that only a trace was observable on the edge of the wetted channel by dawn on August 26. No dye was visible at this site by 11:00 am on August 26.

One kilogram (2 lb.) of Sulforhodamine B (SRB) was released into a collapsed sinkhole near Shippensburg on August 27, 2005 around 9:00 p.m during a rain event. This site is 8.9 km south-west of Big Spring. A report was filed with the county sheriff's on August 25, 2005 informing about the release near the Rt. 174 bridge in Walnut Bottom, and permission was secured from the owner of the second release site and the owner notified by telephone upon release. Tracers chosen were two widely used dyes with strong tracing properties (low detection limits) deemed non-toxic for humans and aquatic organisms (Field et al. 1995 and MSDS).

Breakthrough concentrations of dye were determined by diluting known concentrations of dye into a subsample of the pre-release water sample, measuring relative fluorescence intensity (RFI), then calculating concentration in parts per trillion (ppt) from the linear regression relationship between these variables for water samples analyzed for RFI ( $r^2=0.9998-0.9999$ ). Detection limits were 10 ppt and 15 ppt for SRB in East and West source springs of Big Spring, respectively.

Preliminary BFA (Otz et al. 2005) of spring and well water was assessed in spring 2003. Water samples were collected in brown glass bottles, kept at 3-5°C, and analyzed with a Shimadzu RF5301-PC spectrofluorophotometer at the lab of Dr. Martin Otz.

## Results

SRB traveled to Big Spring within 3.5 days, parallel to geologic strike (Fig. 2). West and East source springs of Big Spring responded differently, with a clear SRB peak in the west spring (316 ppt), and much less distinct SRB peak occurring in the smaller east spring (Figs 3 and 4). URA did not cross the valley from the Yellow Breeches watershed, but rather was detected one month later 9.5 km to the east at springs of Huntsdale state fish hatchery. Neither dye was detected in springs adjacent to Big Spring, including a second contributing east spring (Cool Spring) that serves as water supply to Newville PA. Background levels of SRB indicated in Bullshead Branch using the charcoal receptors were too close to the detection limit of this method and were concluded as a non-detect.

Even the slower traveling URA demonstrated linear velocities that were approximately 500 times hydraulic conductivities determined by well drawdown and recovery on the Pennsy Quarry property (Table 1) within the Big Spring surface watershed. Hydraulic conductivity or linear velocity demonstrated by the SRB in route to Big Spring was approximately 4000 times that of hydraulic conductivities determined by these tests (Table 1). Well yield and level data from the Pennsy site show variable yield, and change in level over time between wells, with only the deeper supply well yielding substantially (75 vs. 1-15 gallons per minute for monitoring wells on which model was based (Continental Placer Monitoring Well Data, unpublished)). Based on these data and a model that did not account for potential conduit flow (Continental Placer Quarry Dewatering Impact Evaluation, unpublished), groundwater flow was estimated to flow north from the site, with hydraulic conductivities of only 3-6 m per day. However, both fluorescent dyes used in this study showed groundwater flow to the east and north, at velocities of 0.3 – 3.0 km per day.

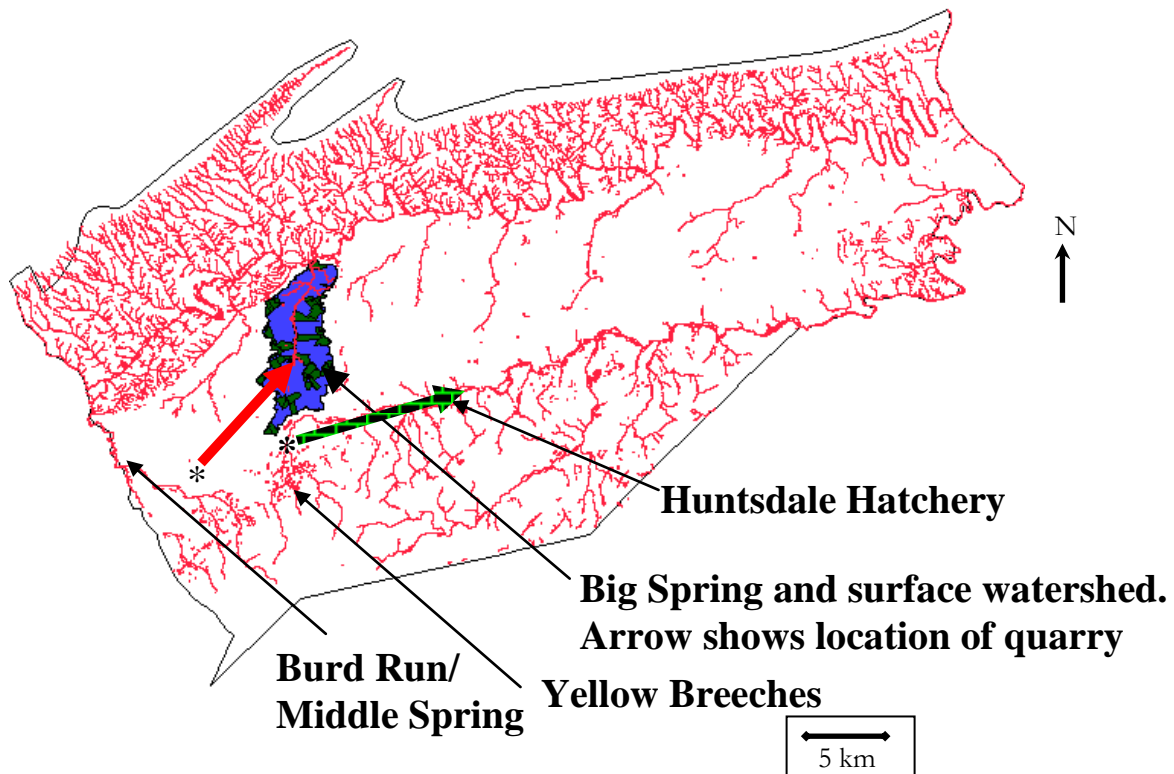
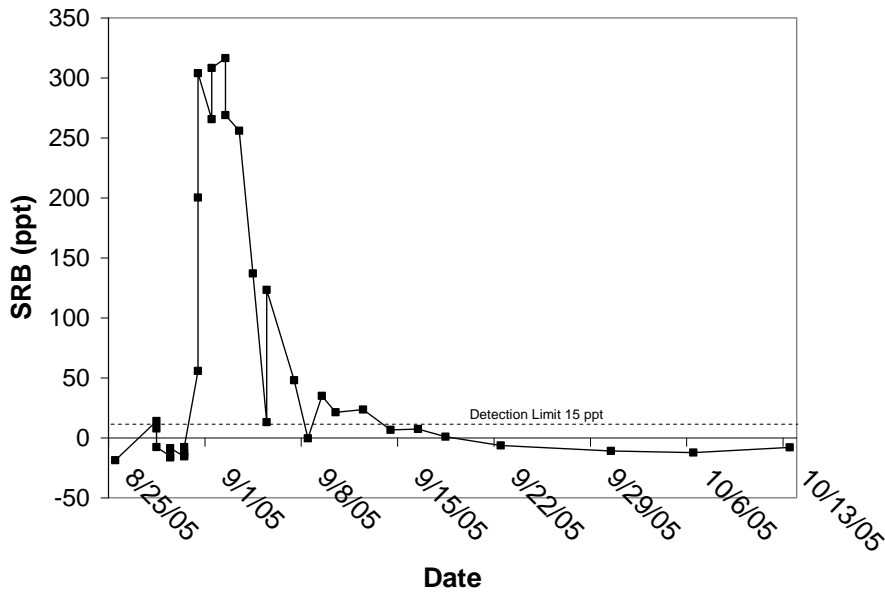


Figure 2. Travel of Sulforhodamine B to Big Spring Source Springs and Uranine/Na-fluorescein to Huntsdale Hatchery Springs in Cumberland County, PA. Results demonstrate regional groundwater flow with contributing area of Big Spring within the Burd Run/Middle Spring watershed of Shippensburg, and contributing area of Huntsdale Springs in the upper Yellow Breeches. Neither fluorescent dye was detected in the other springs studied.

Table 1. Comparison of groundwater flow direction and velocity between fluorescent dye-tracing test, and Quarry Dewatering Impact Evaluation (Continental Placer, unpublished), demonstrating that quarry monitoring wells on which permit models were based were not accessing predominant regional flowpaths.

Study	Flow Direction	Linear Velocity or Hydraulic Conductivity m/day (ft/day)
Fluorescent Dye-Tracing (present study) Linear Velocity	East/Northeast	320-3000 (1039 – 9733)
Dewatering Impact Study Hydraulic Conductivity	North	0.3-0.6 (1-2)

A.



B.

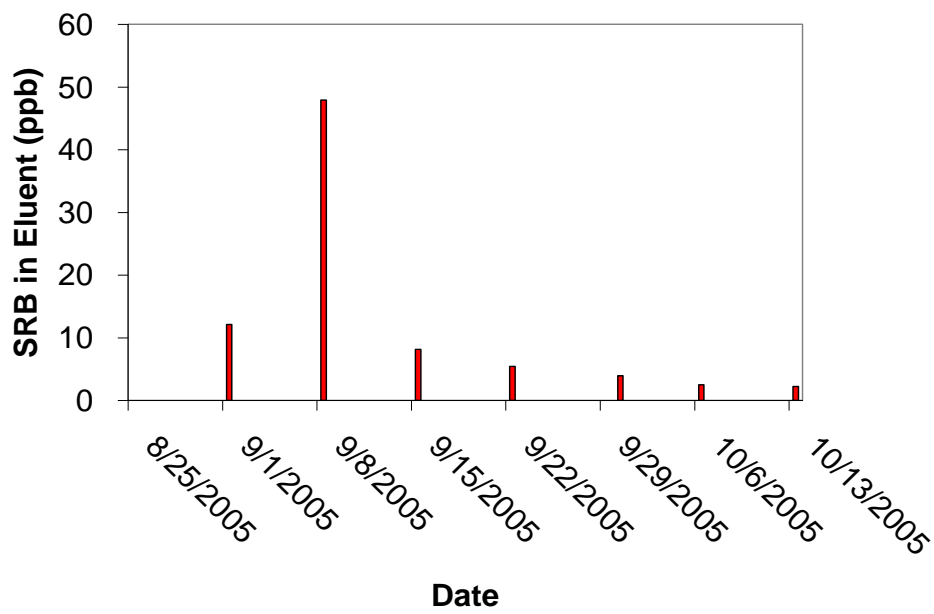
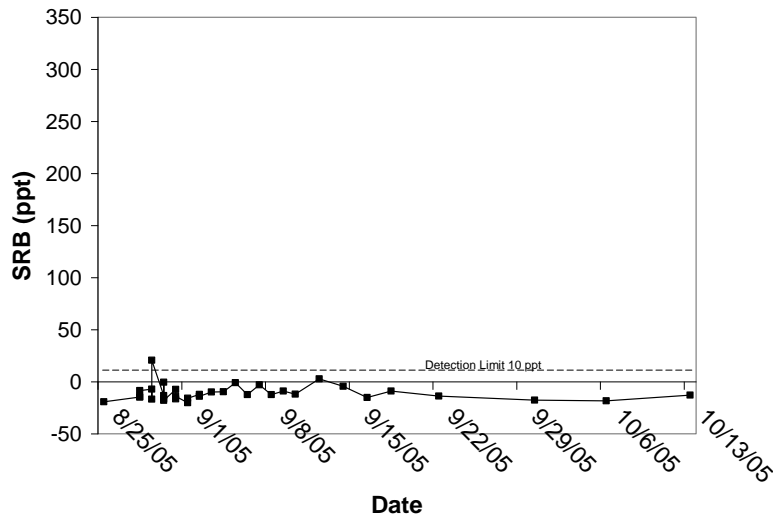
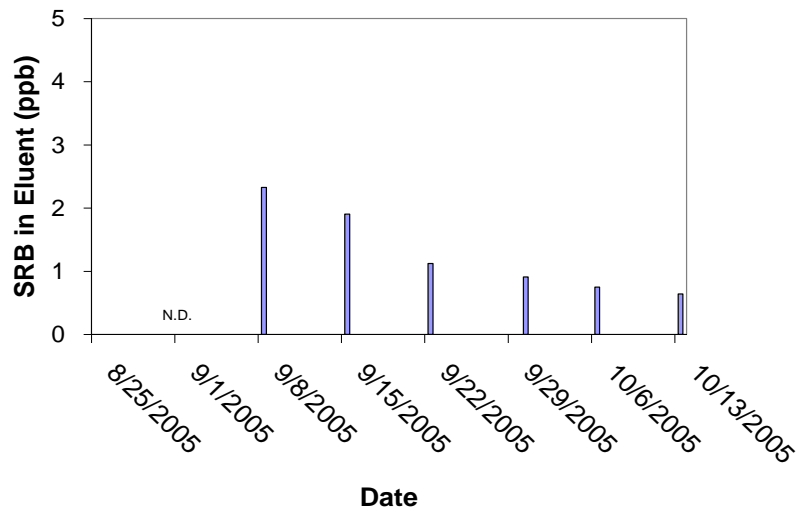


Figure 3. Breakthrough of Sulforhodamine B to the West (largest) source spring of Big Spring following release 8.9 km (5.5. miles) away the evening of August 27, 2005. A. Actual breakthrough determined by water samples (detection limit 15 ppt). B. Detection on Receptors, attaining most confident positive designation of hydrological connection by the Crawford Hydrology Lab.

A.



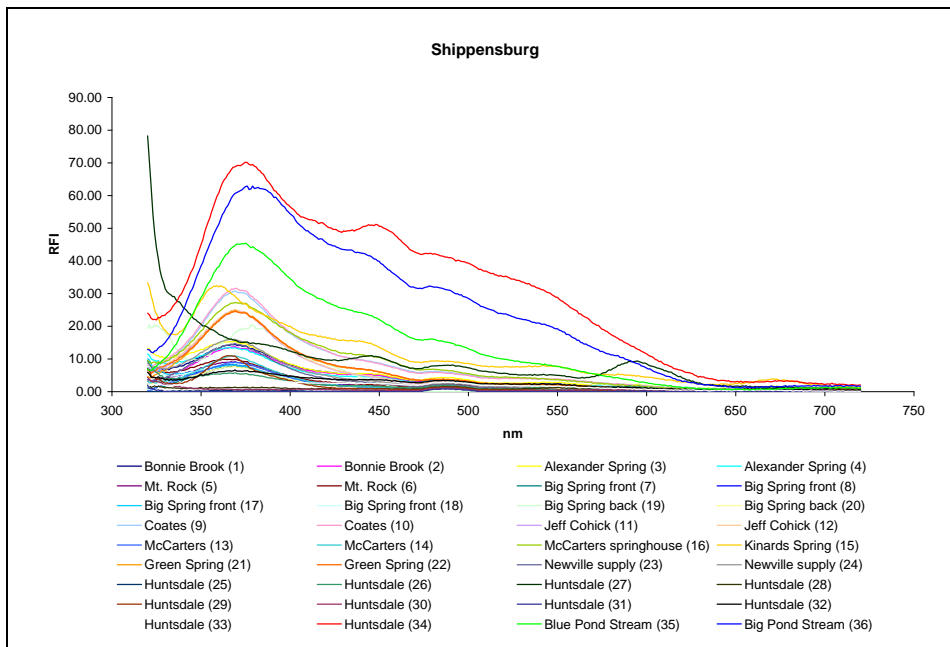
B.



**Figure 4. Breakthrough of sulforhodamine B in the East source spring of Big Spring, detected confidently only on receptors. Much lower concentrations of dye from up-valley in this spring suggests more diffuse flow through a potentially differing contributing area. A. Results of water samples (detection limit 10 ppt). B. Positive connection determined by dye receptor analysis, Crawford Hydrology Lab.**

The release of uranine, 5.2 km south of Big Spring, was detected 9.5 east of the release point at Huntsdale Hatchery springs. This dye was not detected in Big Spring or other springs draining to the north. Flow to the Huntsdale Springs was comparatively slow (approximately 0.3 km/day vs. 2.5-3 km/day between the sink hole collapse and Big Spring), likely due to retention in the colluvial mantle after loss from the Yellow Breeches channel.

Background fluorescence analysis (BFA) of spring and well waters from spring 2003 showed similar dissolved organic carbon content between springs, springs and wells along Big Spring, and two south mountain tributaries (upper Yellow Breeches at Big Pond and Blue Pond Hollows). Fulvic acid peaks were similar to uncontaminated waters of South Mountain tributaries in nearly all samples, with some springs showing possible organic enrichment at 500-600 nm, with a shift in excitation vs. emission wavelength of 21 nm – Fig. 5). More such surveys would be valuable in characterizing temporal changes in water quality, as Otz (2003 and 2005) has successfully utilized BFA to detect hydrocarbons (cutting oil), human sewage, and liquid cow manure in groundwater. Additionally, groundwater nutrients (nitrate and phosphorus) are elevated in Big Spring and other spring waters of the valley (Phillips et al. 2006; Burd Run Watershed at [www.ship.edu/~geog/burdrun/](http://www.ship.edu/~geog/burdrun/)), and thus contribute to degradation of downstream ecosystems.



**Figure 5. Background fluorescence of valley springs, wells, and two mountain tributaries (Blue Pond Stream and Big Pond Stream). Note similar organic acid peaks at 370 nm and 450 nm and minor organic contamination of some springs between 500-600 nm. RFI = Relative Fluorescence Intensity**

## Conclusions and Recommendations

Regional groundwater flow patterns generally follow the valley along the geologic strike (bedding planes of rock formations), nearly perpendicular to flow estimated from quarry wells and models within the surface watershed of Big Spring (Continental Placer

Unpublished), and at linear velocities 500-4000 times greater than hydraulic conductivities determined by pump tests in the quarry wells.

Partial contributing areas determined for Big Spring and Huntsdale Springs occur far up-valley, and in the case of Big Spring, indicate rapid inter-basin flow from the Burd Run/Middle Spring watershed. Surface runoff in this area directly enters the groundwater system, originating in zones of development (trucking warehouses, residential, and business) and from a drainage system open to highway spills near the Rt. 81 and 174 interchange. Further dye-tracing from this area with monitoring of additional springs would be valuable to better characterize regional groundwater flow patterns in the valley, as preliminary estimates suggest < 10% of dye released at this point was recovered in Big Spring. Additionally, best management practices in storm water drainage should be used given the patterns of land use and known rapid transport to Big Spring.

West and East Sources of Big Spring are somehow connected. Strong conduit flow occurs to the West source from the above-mentioned area. The East spring exhibits more diffuse flow character, and likely different contributing area that should be fluorescent dye traced from release points closer to, or on the east side of the surface watershed of Big Spring.

The municipal spring of Newville supply (Cool Spring) that flows into Big Spring 5 km to the north apparently belongs to a separate flow system (no dyes were detected), and source areas should be determined if use of this spring is continued or expanded. Potential dye release points are on the east side of the Big Spring surface watershed, and on the northwest side of the Big Spring Surface watershed if groundwater is following strike and passing beneath the Big Spring channel. Additional FDTs directly from the upper Big Spring channel to Cool Spring should also be conducted to determine with certainty that the supply spring is not susceptible to contamination that is rapidly transported to Big Spring.

Dye was not detected in Cool Spring, Green Spring, Bullshead Branch, Mt. Rock Spring, or Alexander Spring, indicating that these are either separate flow systems (parallel bands within the valley), that connection exists in a regional aquifer further up-gradient than dyes were released in this study, or that greater quantities of dye than used in this initial study may be necessary to trace larger regional sharing of source waters.

The upper Yellow Breeches does not appear to contribute to Big Spring or other spring creeks studied. Flow from this release site was slower, toward springs adjacent to the Yellow Breeches 9.5 km down-gradient at Huntsdale Hatchery. It is possible that different amounts of dye placed at other injection locations, and a longer study could demonstrate inter-basin flow from the Yellow Breeches to north-flowing spring creeks in the valley center, particularly those further to the east (e.g. Letort Spring), but no positive connections were demonstrated for the springs monitored in the present study. A future FDT could be done from the higher, losing tributaries of the Yellow Breeches and Middle Spring, or perhaps from iron ore pits that exist in the vicinity of these tributaries to avoid the chances of slowing or losing the dye in South Mountain colluvium.

In regards to the Pennsy Supply Quarry, recently permitted in 2004 within the surface watershed of Big Spring, FDTs should be conducted from highest yielding (supply) well on the site and from the infiltration galleries to determine which springs may be regionally connected, including Big Spring (particularly the East source), Newville Municipal supply and springs down-valley toward Carlisle (Mt. Rock, Alexander Spring, and the Letort) to assess any impact on the regional ground water flow regime.

Based on a limited number of well data and models that ignored the likelihood of high hydraulic conductivities via fractures and conduits, groundwater flow was estimated to flow north from the site, with hydraulic conductivities of only 1-2 feet per day (Continental Placer Quarry Dewatering Impact Evaluation). However, both fluorescent dyes used in this study showed that groundwater moved to the east and north, at velocities of 0.3 – 3.0 km per day. It is surprising that the mining division of PA-DEP was satisfied with the hydrological models to grant the quarry permit. This study has demonstrated the need for dye tracing to accurately characterize, and thus protect groundwater resources in karst areas. Karst characteristics and FDT techniques are very well known (Käss 1998, Crawford Hydrology Lab, Häuselmann et al. 2003, Veselic 2003), and PADEP divisions and municipalities should work closely together and aggressively to protect groundwater resources and karst springs based on the appropriate application of these techniques.

Infiltration galleries in the region can fail with sinkhole collapse (Feeney, T. pers. comm.) and so should be closely monitored by PA-DEP at the Pennsy quarry and asphalt production facility. A fluorescent dye-tracing (FDT) should be conducted from sinkholes or conduits that develop in the near future or during operation on and adjacent to Pennsy's property, particularly before mining occurs to the water table. This study has demonstrated that cost-effective FDTs can be done successfully using low quantities of dyes that pose no harm to ecological health or to public health and perception, and in addition provide irrefutable results.

Preliminary background fluorescence analysis (BFA) suggests low levels of contamination for the time period sampled, with very similar source waters between springs, and between springs and wells along Big Spring. Organic acid peaks are similar to uncontaminated waters of South Mountain tributaries in nearly all samples. A 1-2 year study should be conducted for springs that evidence impairment based on nutrient loads, algal blooms, and pollution tolerant invertebrates using this technique, in order to further define primary sources of organic loadings.

Demonstrated regional conduit flow to Big Spring shows the potential for this and similar springs to be rapidly and significantly contaminated by surface runoff via sinkholes in stormwater basins, infiltration galleries, and agricultural settings. This pattern has also been recently recognized by additional research in the region (Lindsey et al. 2006). Regional planning and source water protection strategies that take into account these flow patterns and velocities need to be established soon if the quality and quantity of water to Big Spring, and similar springs in the region are to be maintained.

## Acknowledgments

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