Estimating catchment zones for streams located in karst systems in south-central Pennsylvania

Shanna Hawkins, Department of Biology, Shippensburg University
Dan Weichel, Department of Biology, Shippensburg University

Abstract: When studying aquatic ecological systems, it is important to consider abiotic factors influencing the system such as the area of land from which it drains, known as the catchment zone. Determining a catchment zone's impact on a stream can be difficult in karst regions, due to irregular groundwater flow. This study is intended to illustrate the differences in land cover proportions at nine karst underlain stream sites by using traditional catchment zone delineation methods, and methods developed by the EPA that take into account karst features. Catchment zone areas determined using the EPA estimation methods varied from traditionally delineated catchment zone areas. The proportion of land cover within each catchment zone determined by the two methods also varied. If nothing else, this study shows the significance of considering land cover's relation to aquatic systems in karst regions differently than in non-karst regions.

Table of contents

Tables and figures

Introduction:

When studying ecological systems, aquatic and terrestrial environments must be considered differently. Aquatic systems are comprised of not only the stream, river, or lake itself, but also the surrounding terrestrial systems that contribute in both abiotic and biotic processes in the aquatic ecosystem. This fact alone shows that aquatic systems can be more vulnerable than terrestrial systems (Everest and Reeves 2007). For this reason, it is common for studies of aquatic systems to also consider what is known as the catchment area. The catchment area of a stream can be thought of as the corresponding terrestrial area in which the rain and groundwater flow to the stream of interest (Allan et al. 1997). To delineate a catchment area for a stream, information on the amount and direction of water moving through a stream can be combined with other hydrologic parameters and elevation, which can then all be used to calculate how much of the surrounding terrestrial area is influencing the stream. Once the catchment area for a stream site is delineated, the corresponding precipitation, land use/land cover, geology, soil types, and many other characteristics can be applied to the conditions of the stream in order to get a more accurate indication of influential factors.

The underlying geology of a stream and its catchment area may be one of the most influential parts not only in terms of abiotic influences on the stream ecosystem but in terms of delineating the terrestrial catchment area as well (Allan 2004). In the case of streams in south-central Pennsylvania many of them are underlain with limestone and dolomite calcareous geologic formations. Formations comprised of limestone and dolomite rocks are very susceptible to dissolution over time, which leads to the formation of karst features (Winter et al. 1998, Fetter 2001). Common karst features include caves, sinkholes, surface depressions, and surface mines to name a few. When these karst features are found in catchment areas of aquatic systems, regular delineation methods cannot be applied due to the unknown conduit flow moving through the underlying karst-ridden geology (Doerfliger et al. 1999). This leads to many complicated problems and models when it comes to attempting to delineate catchment areas of karst streams, but estimations can be made. The Environmental Protection Agency has a published document on the rules of thumb for estimating the catchment zones of aquatic systems that correspond with karst geology and the methods outlined can produce at least an idea of a general catchment area for a stream (Ginsberg and Palmer 2002). An estimation of a catchment area for a karst-related stream system is much better than merely accepting a standard catchment area for that system for the simple reason that the geology is being considered as a critical factor in the ecology of the stream. Even if an accurate catchment area cannot be estimated for karst-related stream systems at least the study can be expanded to include the idea that those types of streams are particularly vulnerable and must be considered differently than streams unrelated to karst geology.

It is essential to consider catchment areas when studying aquatic systems, especially smaller freshwater streams as they can be strongly influenced by the surrounding terrestrial environment. That being said, it is also just as important to be as accurate as possible in estimating those catchment areas if the study stream should happen to be underlain with karst-ridden limestone or dolomite geologic formations. There are now automated programs available in which standard catchment areas can be delineated very easily and quickly by the public (U.S. Geological Survey 2012), but what about streams with underlying karst geology? In this study, catchment areas will be estimated for those streams related to karst geology and they will then be compared to the standard catchment areas delineated by readily available automated programs. The extent of differences between standard and karst-estimated catchment areas could mean very different things for the stream in question. How does precipitation, land use/land cover, geology, soil type, etc., in which catchment area is dependent, differ between standard and karst-estimated areas? If nothing else, this study will display the need for serious and extremely careful consideration when stream ecology is investigated within a karst environment.

Research questions:

1) How do you delineate catchment zones for streams that are associated with karst geology?

2) What are the catchment zones for sites that are located in streams that are associated with karst geology?

3) How do the estimated catchment zones for streams in karst systems differ from the catchment zones calculated by the USGS StreamStats program in terms of area and land cover?

Data and methods:

Study area:

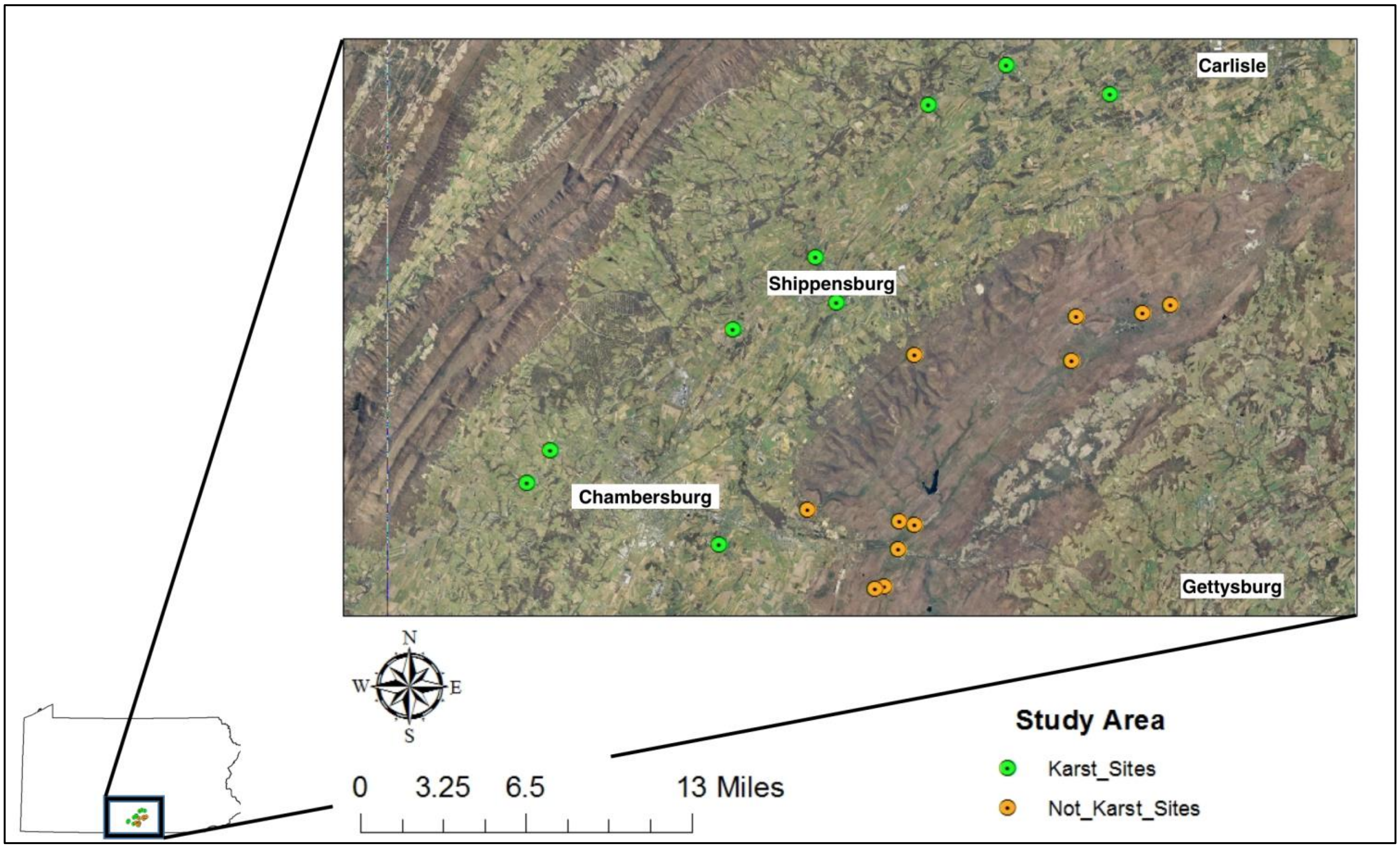

Figure 1. Study area with points representing non karst sites (orange) and karst sites (green) and relevant municipalities with labels. (PAMAP Program and PA DCNR 2007)

The study area is comprised of 20 stream sites located in south-central Pennsylvania in the Conococheague (Potomac), and Conodoguinet and Yellow Breeches (Susquehanna) watershed drainages. Ten of the study sites are located on the mostly shale and sandstone underlain headwater streams on South Mountain, whereas the remaining ten sites are located in the valley in the spring-fed carbonate streams.

Table 1. Study sites with stream names and detailed location data.

Stream	USGS Quadrangle	Township/ Municipaility	County	Latitude	Longitude
Conococheague Creek	Caledonia Park	Franklin	Adams	39.917834	-77.461295
Toms Run	Dickinson	Cooke	Cumberland	40.036327	-77.340786
Iron Run	Dickinson	Cooke	Cumberland	40.037839	-77.291862
Mountain Creek	Dickinson	Cooke	Cumberland	40.011236	-77.345195
Sage Run	Dickinson	Cooke	Cumberland	40.042529	-77.270684
Reservoir Hollow Run	Walnut Bottom	Southampton	Cumberland	40.014972	-77.460893
Burd Run	Shippensburg	Southampton	Cumberland	40.070693	-77.534117
Green Spring Creek	Newville	North Newton	Cumberland	40.157180	-77.450395
Middle Spring Creek	Shippensburg	Shippensburg Boro	Cumberland	40.044784	-77.519041
Big Spring Creek	Newville	North Newton	Cumberland	40.179816	-77.392298
Mt. Rock Spring Creek	Plainfield	West Pennsboro	Cumberland	40.162739	-77.315308
Carbaugh Run	Caledonia Park	Greene	Franklin	39.904170	-77.473610
Rocky Mountain Creek	Caledonia Park	Greene	Franklin	39.881390	-77.491110
Racoon Creek	Caledonia Park	Greene	Franklin	39.883330	-77.484440
Hosack Run	Caledonia Park	Greene	Franklin	39.920401	-77.472678
Cold Spring Run	Scotland	Greene	Franklin	39.926670	-77.540280
Falling Spring Branch Creek	Scotland	Guilford	Franklin	39.906670	-77.606390
Rowe Run	Shippensburg	Southampton	Franklin	40.029720	-77.595560
Back Creek	Chambersburg	Hamilton	Franklin	39.961390	-77.731110
Wilson Run	Chambersburg	St. Thomas	Franklin	39.941940	-77.748330

Data sets:

The geographical information system (GIS) data used to initiate this analysis included a vector layer of *x, y* coordinate points representing study sites (Hawkins 2015), a vector layer of *x, y* coordinate points representing Pennsylvania karst features (DCNR 2007), a vector layer of National Hydrography Dataset (NHD) flowline data representing Pennsylvania streams (USGS 2005), a vector polygon layer representing catchment areas of all sites generated by USGS' StreamStats program (USGS 2012), a raster layer of National Land Cover Data from 2011 (NLCD) representing land cover within the catchment areas (Homer et al. 2015), and a vector layer representing the geologic formations of Pennsylvania and fault lines (Berg et al. 1980). All GIS data were projected in the State Plane coordinate system for southern Pennsylvania. Discharge data for each of the study sites was collected during base flow conditions using USGS wadeable methods for collecting stream discharge (Stuckey 2006; Turnipseed and Sauer 2010).

Methods:

In order to estimate new catchment areas for our study sites associated with underlying karst geology, we needed to look at where their expected catchment areas were in relation to known karst features and geologic formations. This was done by inputting all 20 study sites into the USGS StreamStats program (U.S. Geological Survey 2012) to generate "traditionally" delineated catchment areas based on elevation, flow/flow direction (Stuckey 2006, Roland and Stuckey 2008, Stuckey et al. 2012). These catchment areas were exported as shapefiles and imported into ArcGIS. They were then overlaid with the karst features data points as well as the Pennsylvania geologic formation data layer. This allowed for identifying the nine study sites that had expected catchment zones in karst regions.

Table 2. Study sites with expected catchment zones in karst regions.

Stream	County	Latitude	Longitude
Burd Run	Cumberland	40.070693	-77.534117
Green Spring Creek	Cumberland	40.157180	-77.450395
Middle Spring Creek	Cumberland	40.044784	-77.519041
Big Spring Creek	Cumberland	40.179816	-77.392298
Mt. Rock Spring Creek	Cumberland	40.162739	-77.315308
Falling Spring Branch Creek	Franklin	39.906670	-77.606390
Rowe Run	Franklin	40.029720	-77.595560
Back Creek	Franklin	39.961390	-77.731110
Wilson Run	Franklin	39.941940	-77.748330

Once karst overlapping study sites were identified, a new estimated catchment area needed to be calculated for these sites. The new area was calculated using a discharge to area ratio based on data from the non-karst sites. This ratio was made up of averaged discharge data collected in the field at non-karst sites, and averaged catchment areas calculated from USGS StreamStats for the same sites. Dividing the average discharge by the average catchment area gave a discharge to area ratio for non-karst sites. This ratio was applied to the karst study sites to calculate a new catchment area by dividing each stream's discharge by the ratio value to give area.

These estimated catchment areas were then used to manually draw new catchment areas in ArcGIS. Karst geologic formations, strike lines and fault lines were treated as conduits for groundwater flow when estimating catchment areas "upstream" from the study sites (Ginsberg and Palmer 2002). In cases in which the calculated area estimate was considerable smaller than the StreamStats area, there was difficulty in finding area available to redraw the catchment areas. In these cases, the estimated areas were drawn as close as possible to the calculated area.

NLCD for Pennsylvania from 2011 was then reclassified to Anderson level 1 classifications of urban, forest, agriculture, and other land cover types (Anderson et al. 1976). The StreamStats vector shape files were used to tabulate expected proportions of each land cover type for each study site's catchment zone in karst regions; and the manually drawn estimated shape files were used to tabulate estimations of actual proportions of each land cover type for each study site's catchment zone. Microsoft Excel was used to visually display how the land cover types changed between the USGS StreamStats catchment areas and the estimated areas.

Results:

How do you delineate catchment zones for streams that are associated with karst geology?

In this study, catchment zones for streams associated with karst geology were delineated based on a previously calculated discharge/area proportion which was applied to the specific discharge data of each stream to find their estimated area values. The estimated area values were then used to manually draw catchment areas upstream of each study site while geologic characters such as strike lines and formation fracture lines were used as boundaries.

Table 3. Study sites with StreamStats catchment areas and calculated karst-estimated catchment areas in square kilometers.

Stream	StreamStats area (km^2)	Karst estimated area (km^2)
Burd Run	51.80	10.11
Green Spring Creek	4.79	14.01
Middle Spring Creek	46.88	2.60
Big Spring Creek	31.08	120.59
Mt. Rock Spring Creek	1.55	6.89
Falling Spring Branch Creek	6.89	71.29
Rowe Run	18.08	3.80
Back Creek	51.80	8.18
Wilson Run	29.27	9.79

What are the catchment zones for sites that are located in streams that are associated with karst geology?

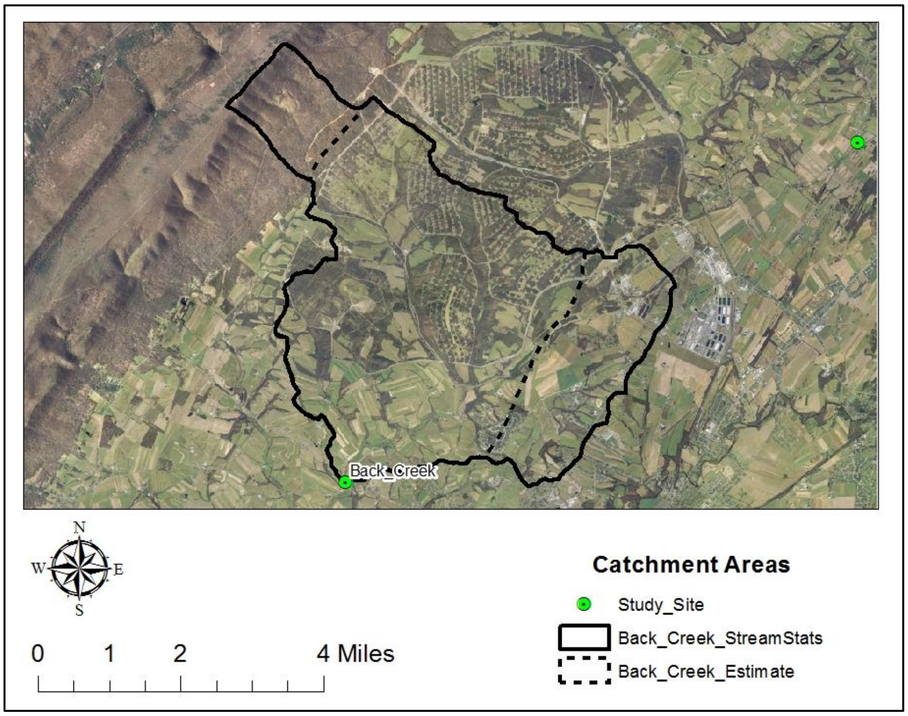

Figure 2. Catchment areas for Back Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

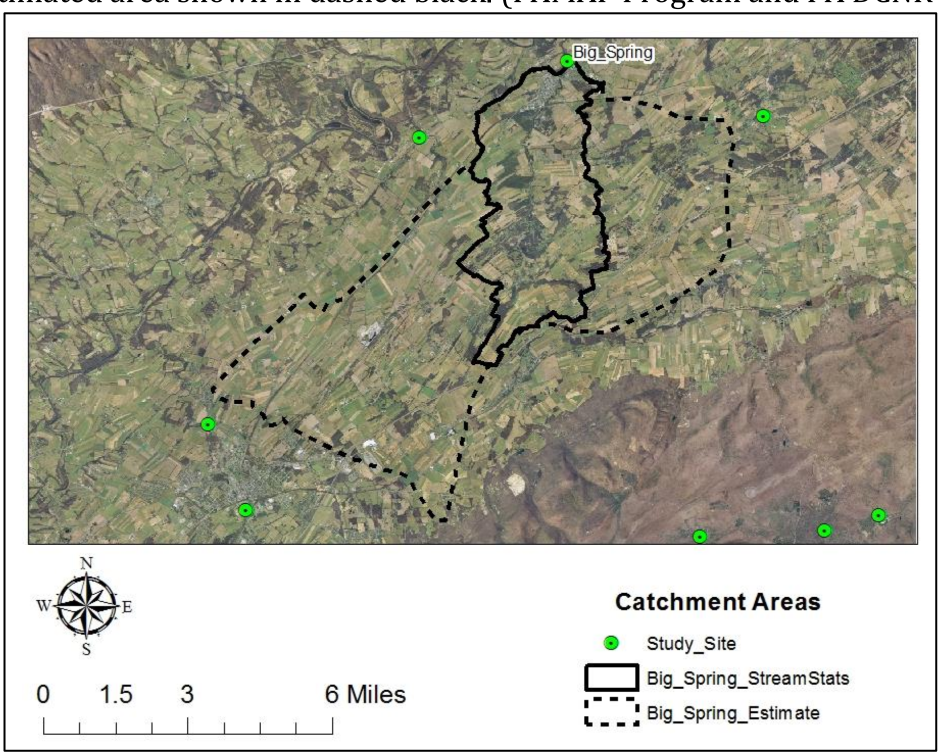

Figure 3. Catchment areas for Big Spring Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

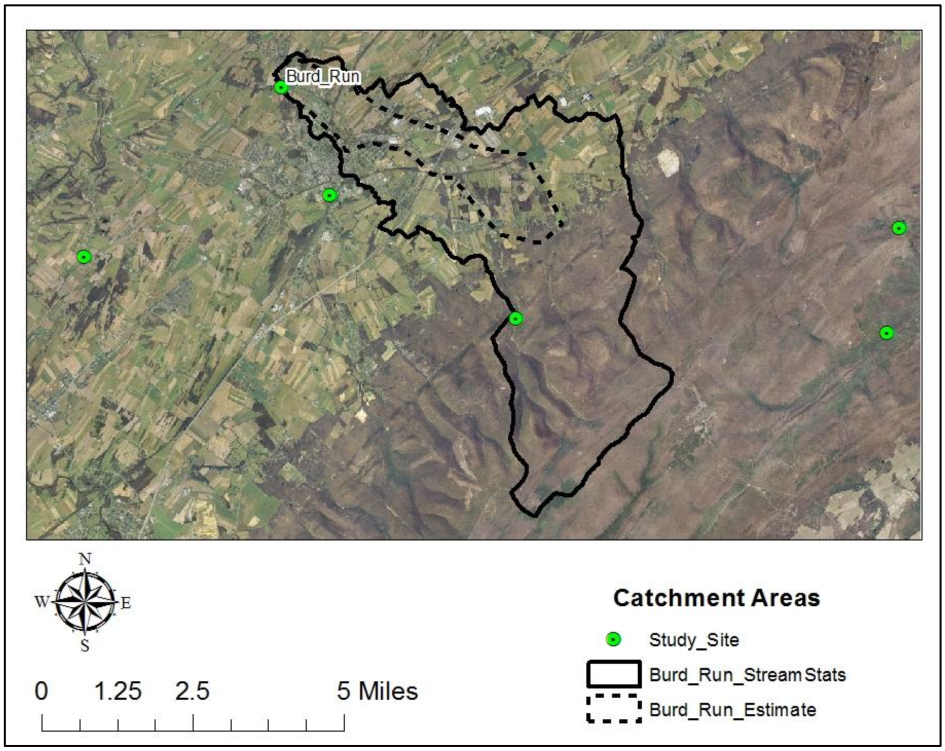

Figure 4. Catchment areas for Burd Run with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

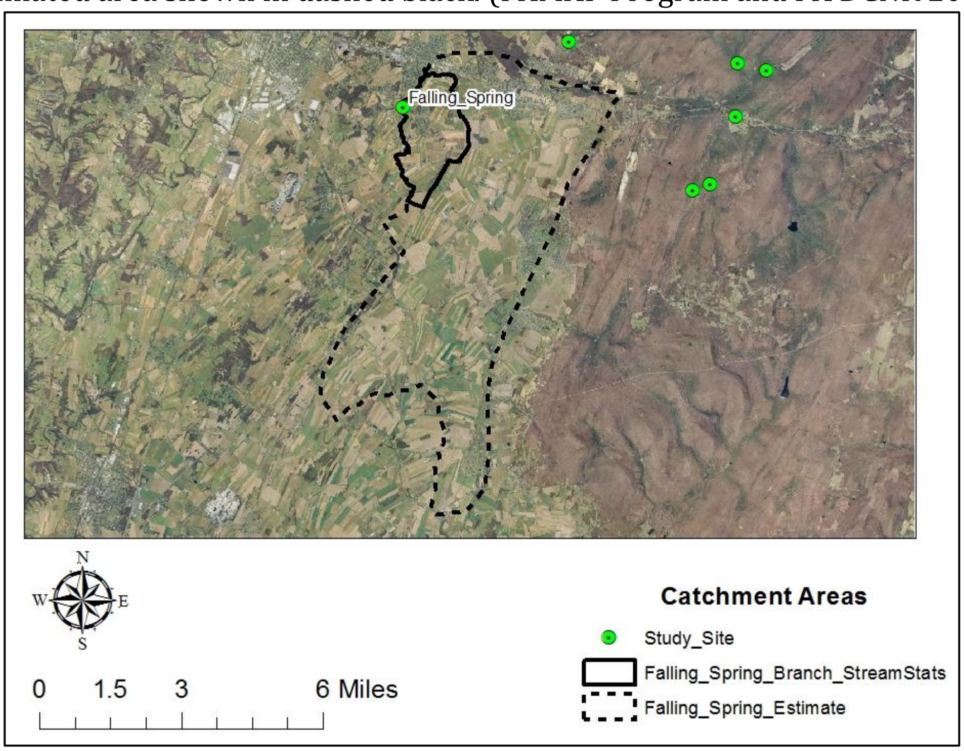

Figure 5. Catchment areas for Falling Spring Branch Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

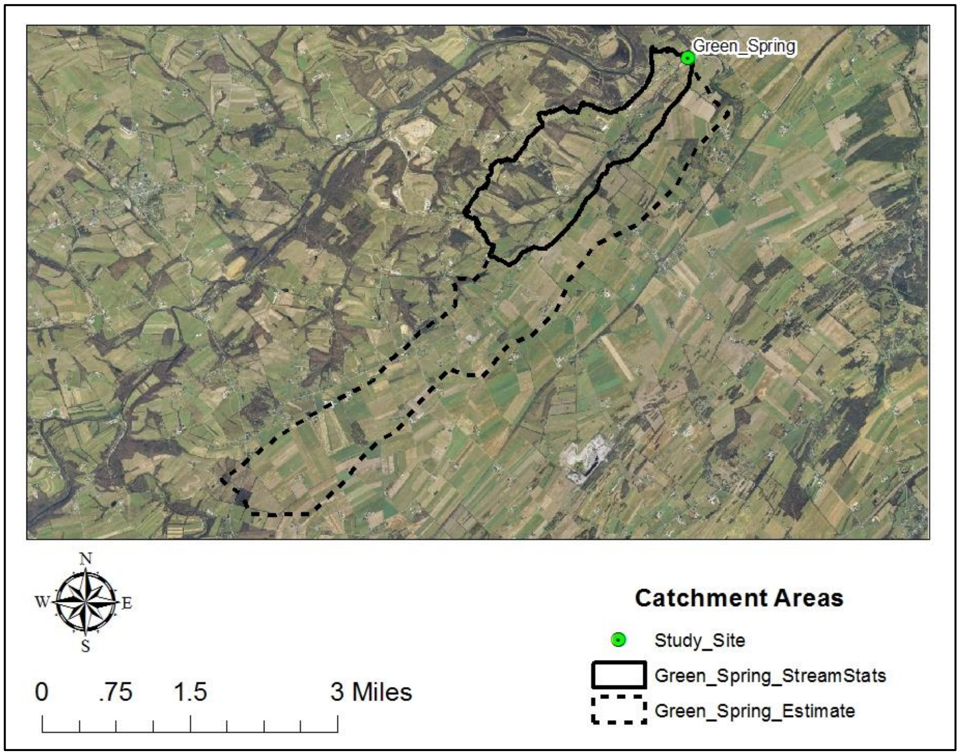

Figure 6. Catchment areas for Green Spring Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

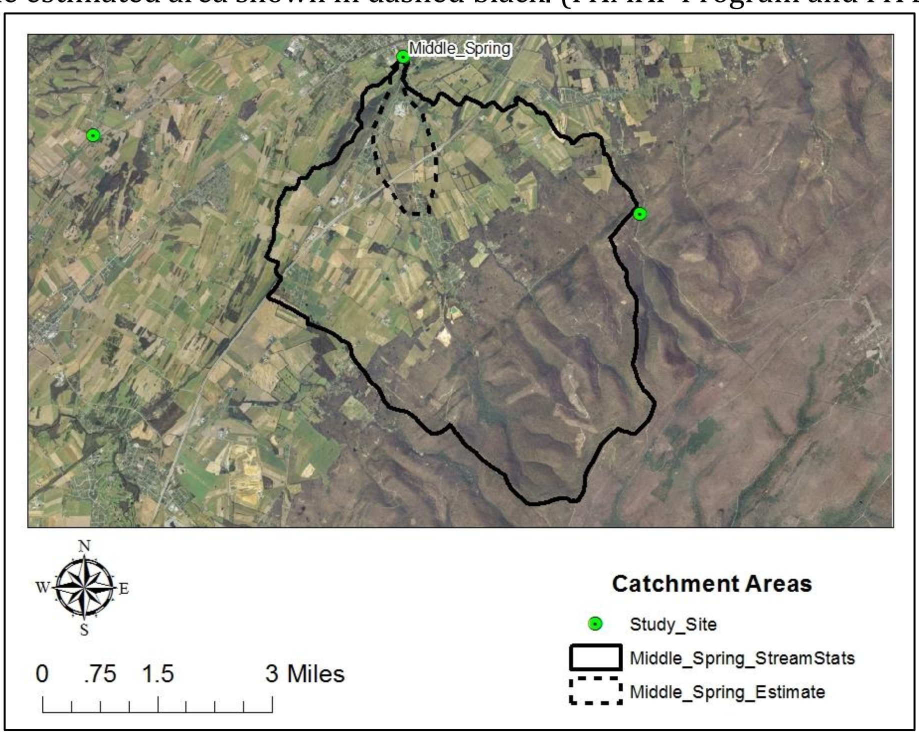

Figure 7. Catchment areas for Middle Spring Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

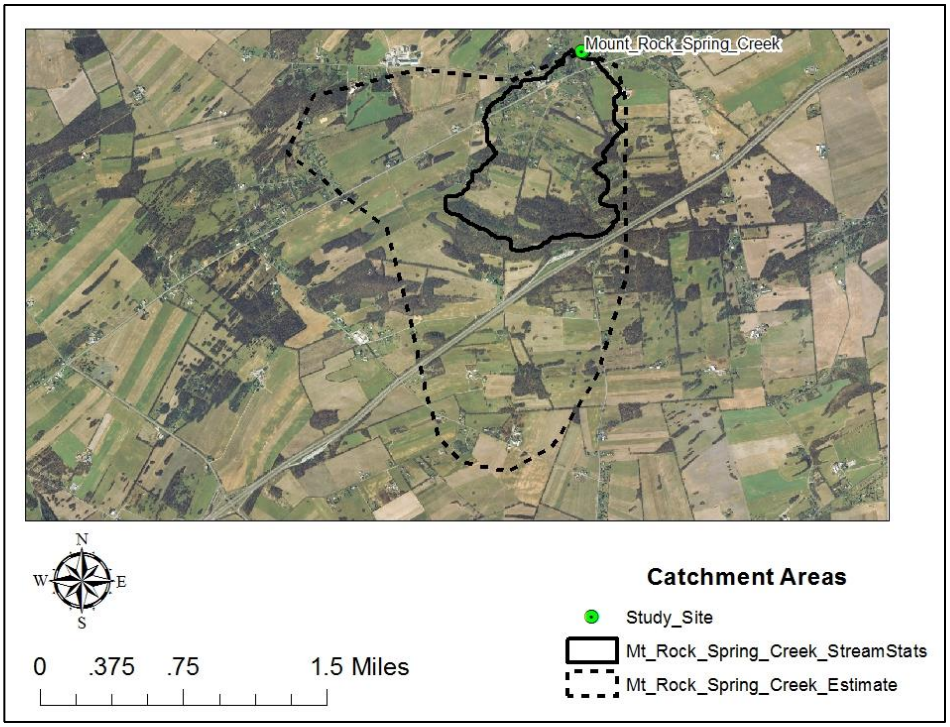

Figure 8. Catchment areas for Mt. Rock Spring Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

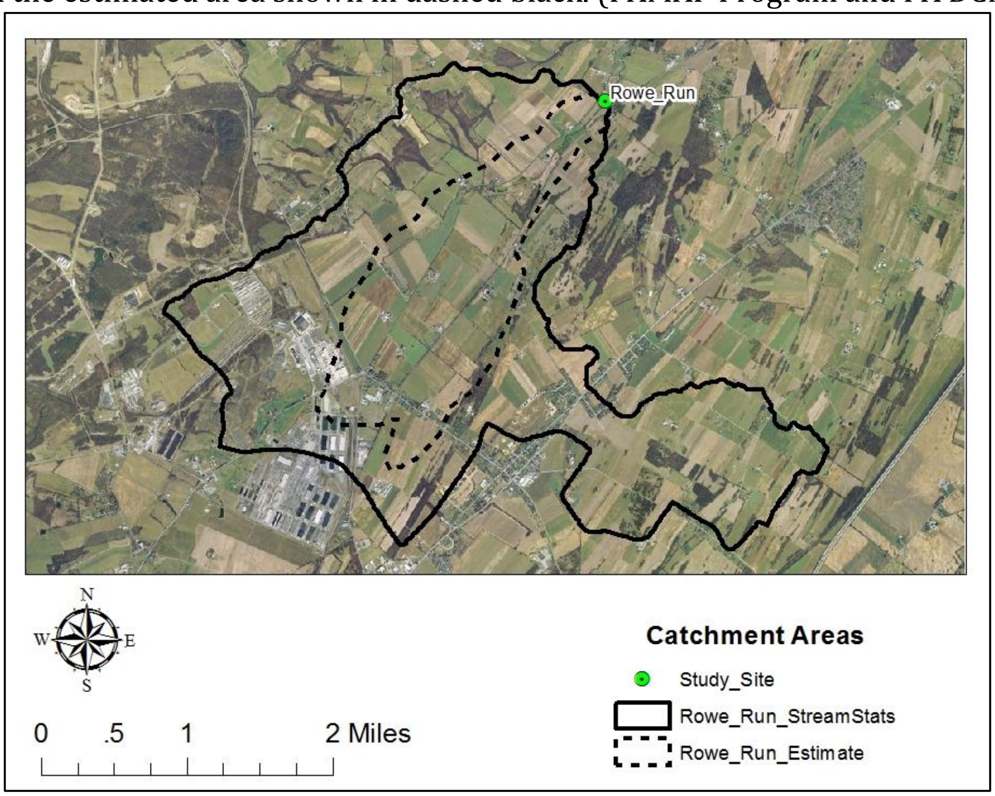

Figure 9. Catchment areas for Rowe Run with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

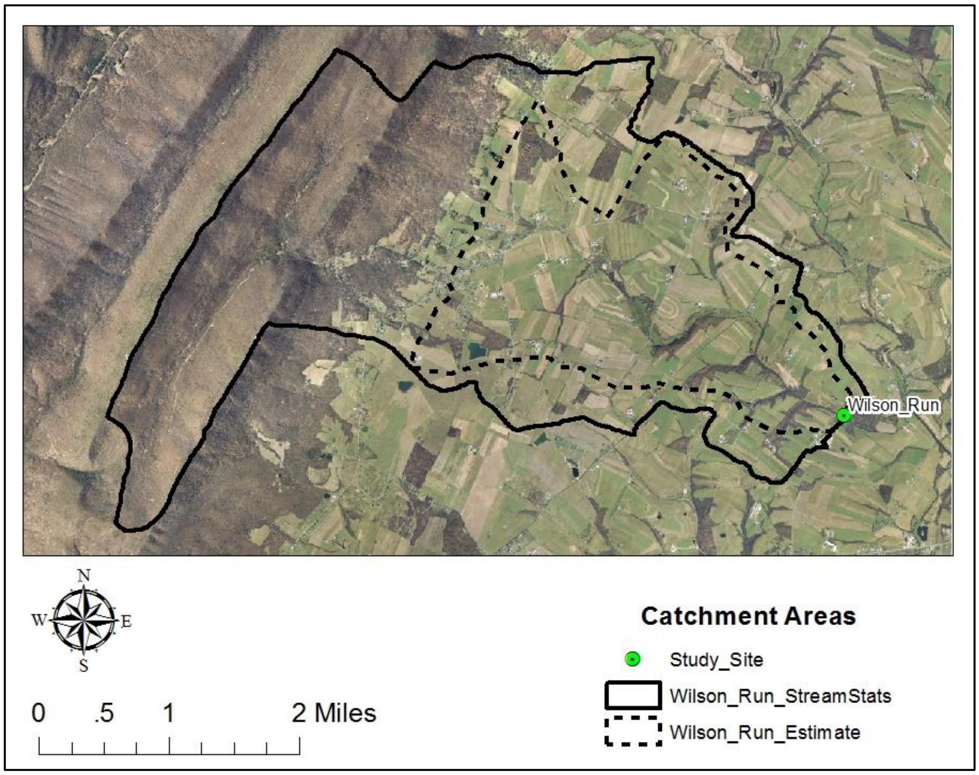

Figure 10. Catchment areas for Back Creek with StreamStats area shown in solid black and the estimated area shown in dashed black. (PAMAP Program and PA DCNR 2007)

How do the estimated catchment zones for streams in karst systems differ from the catchment zones calculated by the USGS StreamStats program in terms of area and land cover?

The estimated catchment zones for streams in karst systems were all different in terms of both area and land cover when compared to the USGS StreamStats generated areas. Five sites had estimated areas that were considerably less than the StreamStats areas and four sites had estimated areas that were larger than the StreamStats areas (Table 3). In terms of land cover, some of the compositions were very similar between StreamStats and estimated sites while the majority of sites showed major changes between the two catchment areas (Table 4, Figures 2-10). Throughout the sites that showed major land use composition changes between the StreamStats and estimated catchment areas, all of them showed major decreases in percent forest land cover as well as slight decreases in developed land, but never decreases in agricultural cover (Big Spring, Figure 12: Burd Run, Figure 13: Green Spring Creek, Figure 15; Middle Spring Creek, Figure 16; Mt. Rock Spring Creek, Figure 17; and Wilson Run, Figure 19). Also interesting to note is the fact that there were only three study sites that showed the major land cover type in the StreamStats estimated catchment area to be anything other than agriculture (agriculture land cover is yellow, Burd Run, Figure 13; Middle Spring Creek, Figure 16; Mt. Rock Spring Creek, Figure 17).

Table 4. Land cover percentages for USGS StreamStats catchment areas and karst estimated catchment areas for nine study sites associated with karst geology. Land cover composition is classified into four classes, developed, forest, agriculture, and other.

		Other	Developed	Forest	Agriculture
Back Creek	StreamStats	0.96	19.96	36.01	43.07
	Karst estimate	1.20	19.70	35.89	43.21
Big Spring Creek	StreamStats	1.21	13.89	19.29	65.62
	Karst estimate	0.59	12.23	11.11	76.07
Burd Run	StreamStats	0.38	18.21	50.20	31.21
	Karst estimate	1.18	28.56	16.01	54.25
Green Spring Creek	StreamStats	0.90	10.52	17.91	70.67
	Karst estimate	0.34	6.25	8.20	85.20
Falling Spring Branch Creek	StreamStats	0.55	16.28	3.17	80.00
	Karst estimate	1.23	18.15	2.78	77.83
Middle Spring Creek	StreamStats	0.41	10.00	53.60	35.99
	Karst estimate	0.58	27.20	8.79	63.43
Mt Rock Spring Creek	StreamStats	2.39	29.14	32.11	36.36
	Karst estimate	0.58	17.24	20.33	61.85
Rowe Run	StreamStats	0.04	23.01	4.05	72.90
	Karst estimate	0.07	17.37	0.68	81.89
Wilson Run	StreamStats	1.13	6.37	42.30	50.20
	Karst estimate	3.00	8.80	7.49	80.71

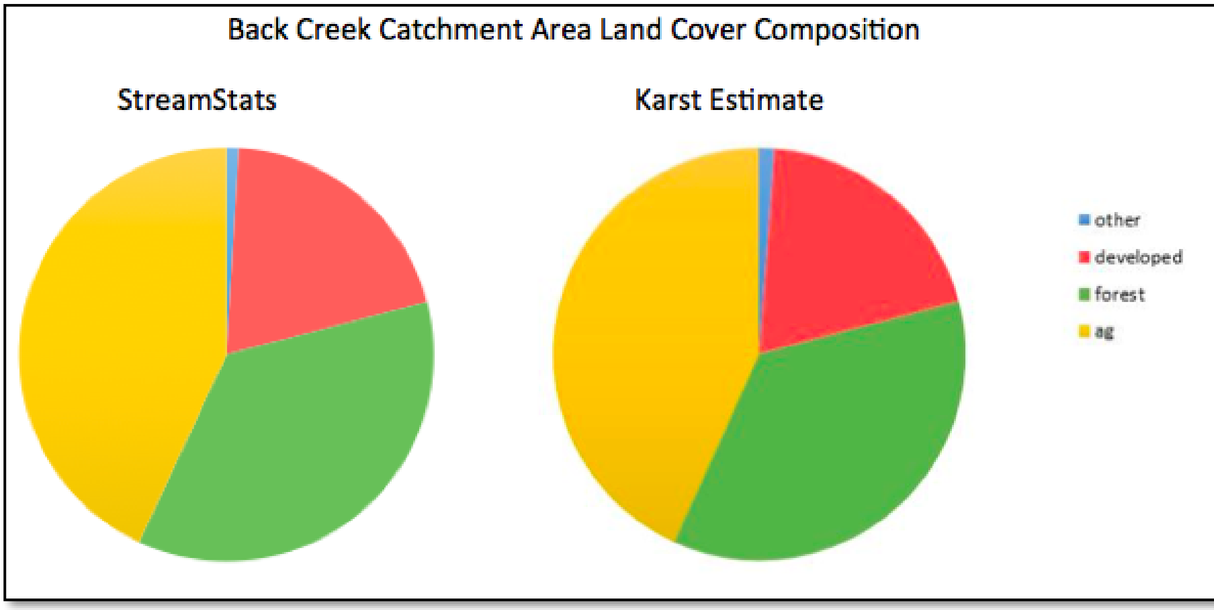

Figure 11. Proportions of land cover in the catchment area for Back Creek in the USGS StreamStats estimated area and the karst estimated area.

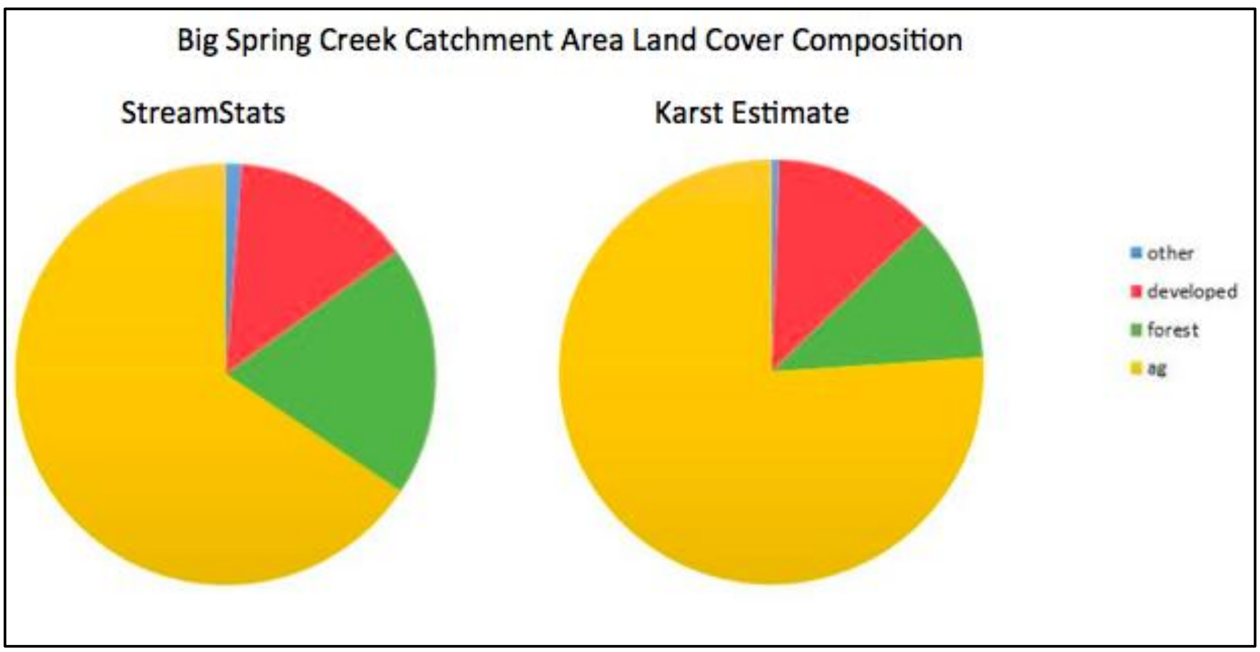

Figure 12. Proportions of land cover in the catchment area for Big Spring Creek in the USGS StreamStats estimated area and the karst estimated area.

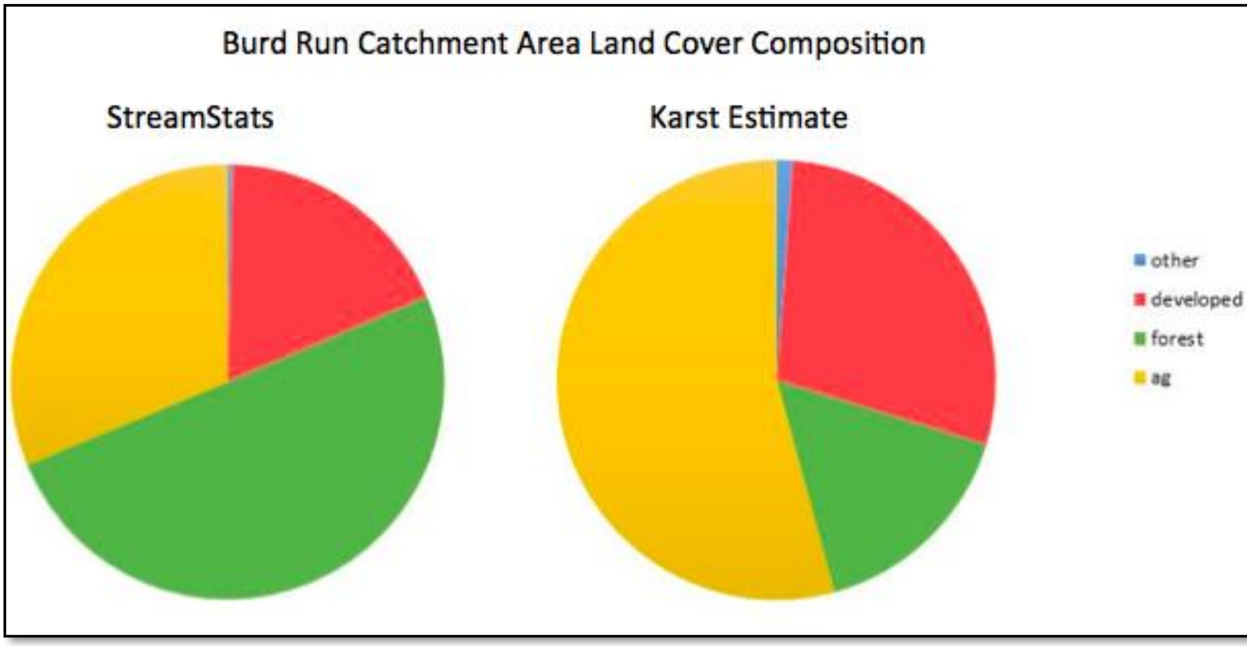

Figure 13. Proportions of land cover in the catchment area for Burd Run in the USGS StreamStats estimated area and the karst estimated area.

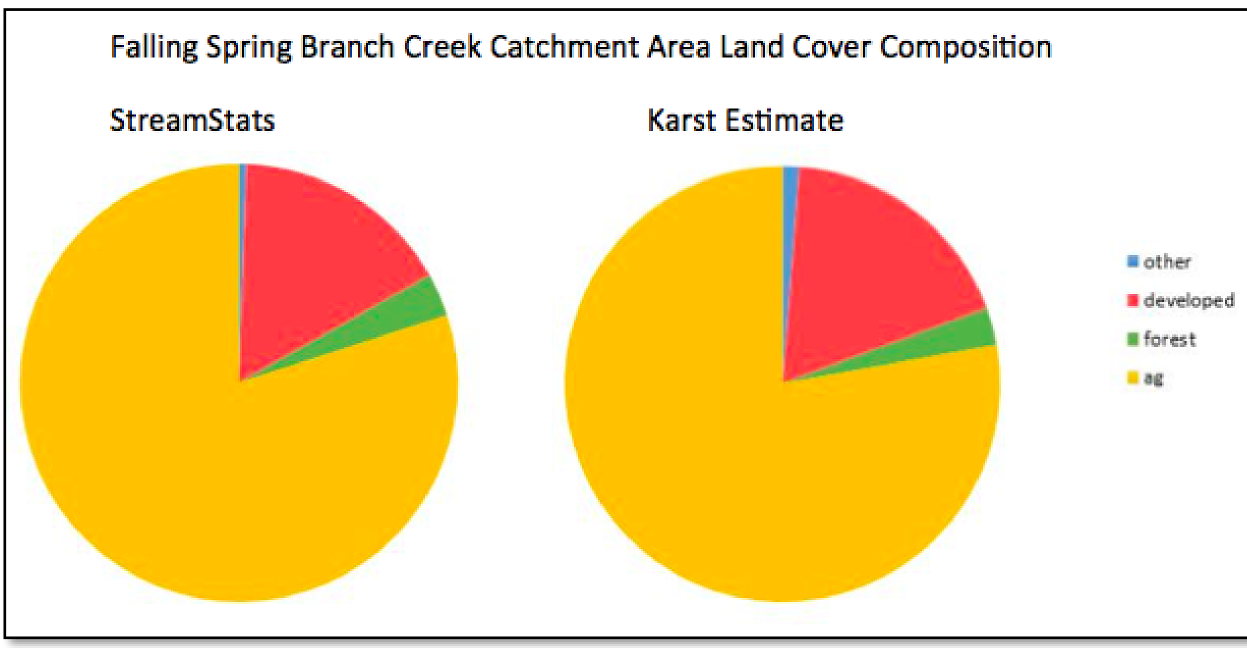

Figure 14. Proportions of land cover in the catchment area for Falling Spring Branch Creek in the USGS StreamStats estimated area and the karst estimated area.

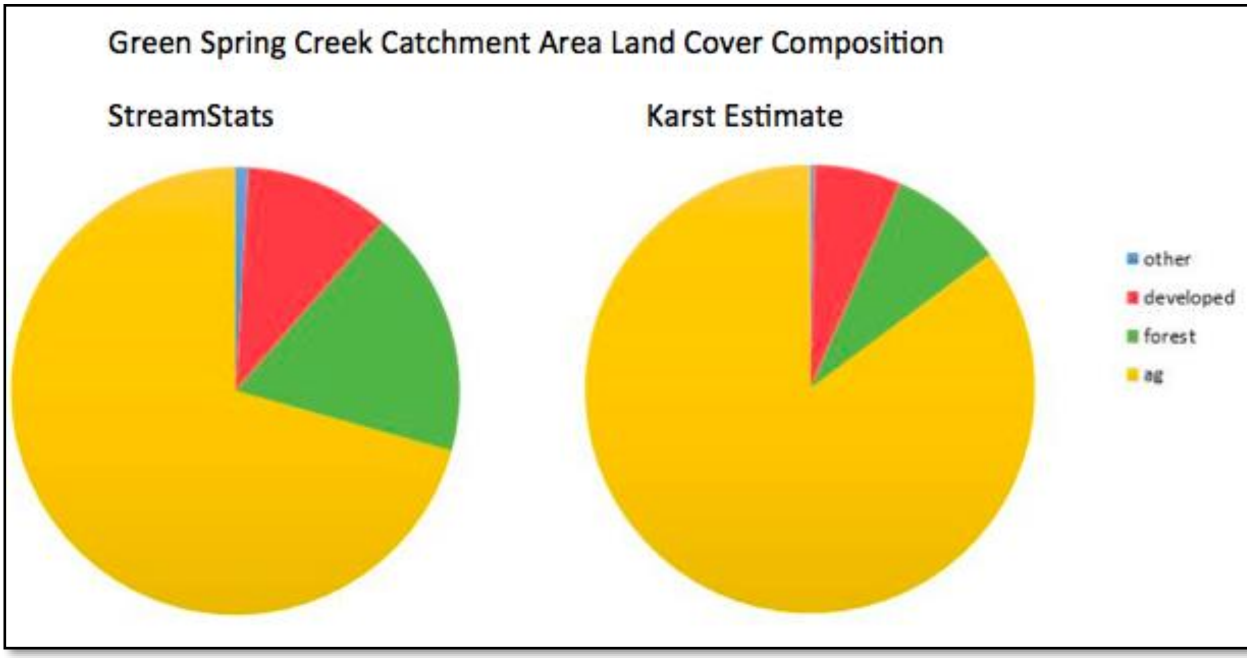

Figure 15. Proportions of land cover in the catchment area for Green Spring Creek in the USGS StreamStats estimated area and the karst estimated area.

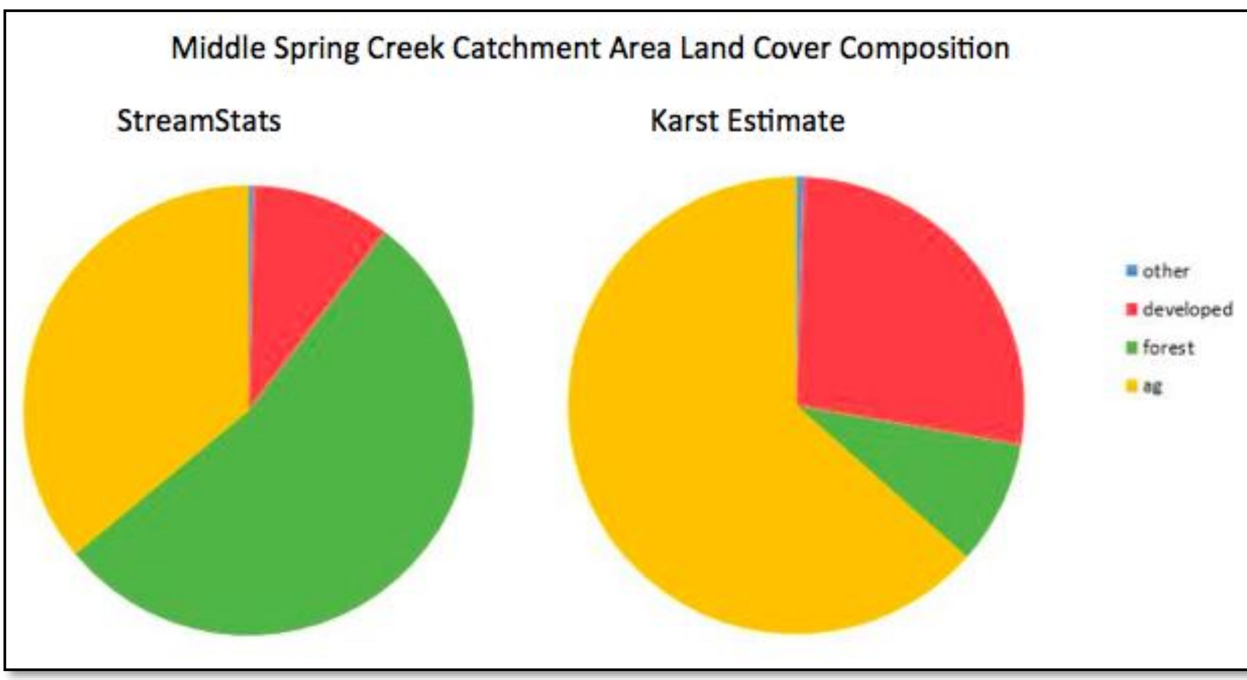

Figure 16. Proportions of land cover in the catchment area for Middle Spring Creek in the USGS StreamStats estimated area and the karst estimated area.

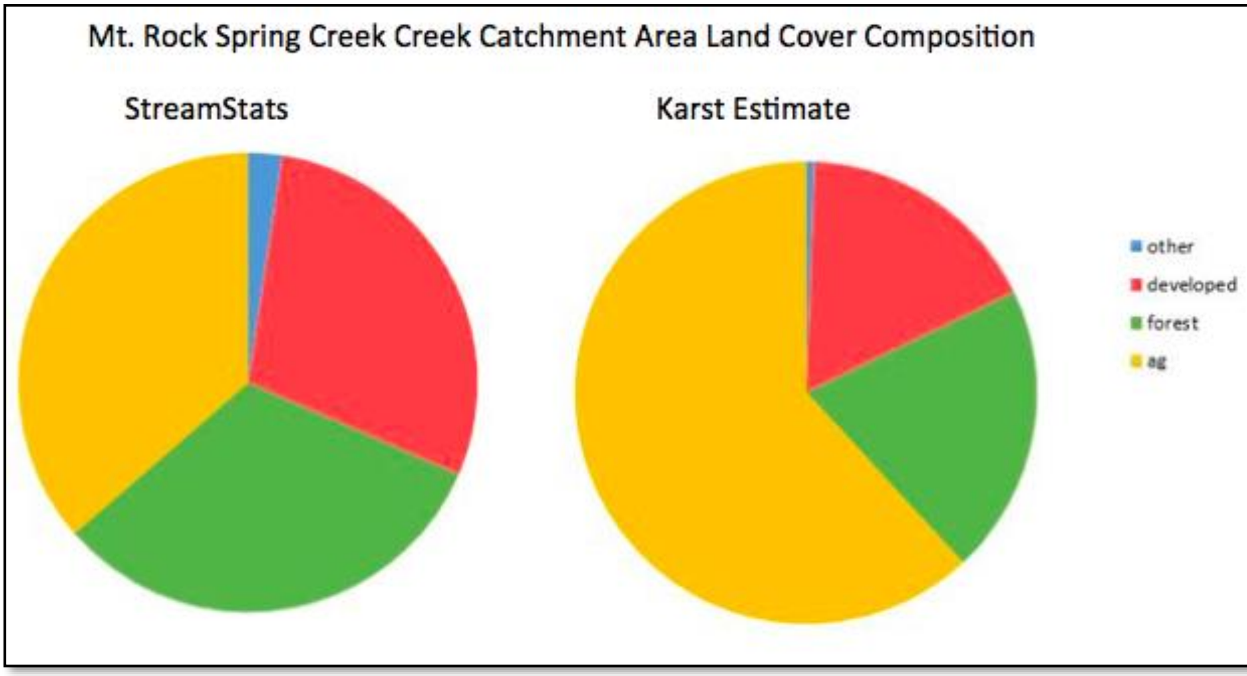

Figure 17. Proportions of land cover in the catchment area for Mt. Rock Spring Creek in the USGS StreamStats estimated area and the karst estimated area.

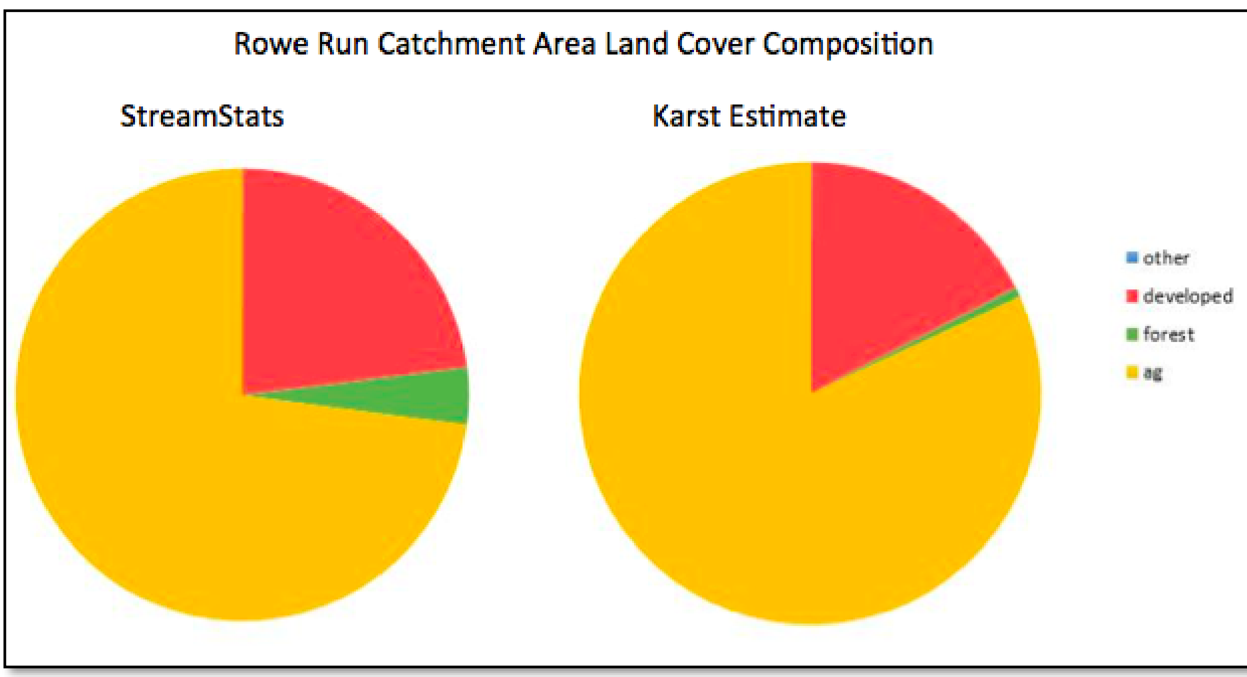

Figure 18. Proportions of land cover in the catchment area for Rowe Run in the USGS StreamStats estimated area and the karst estimated area.

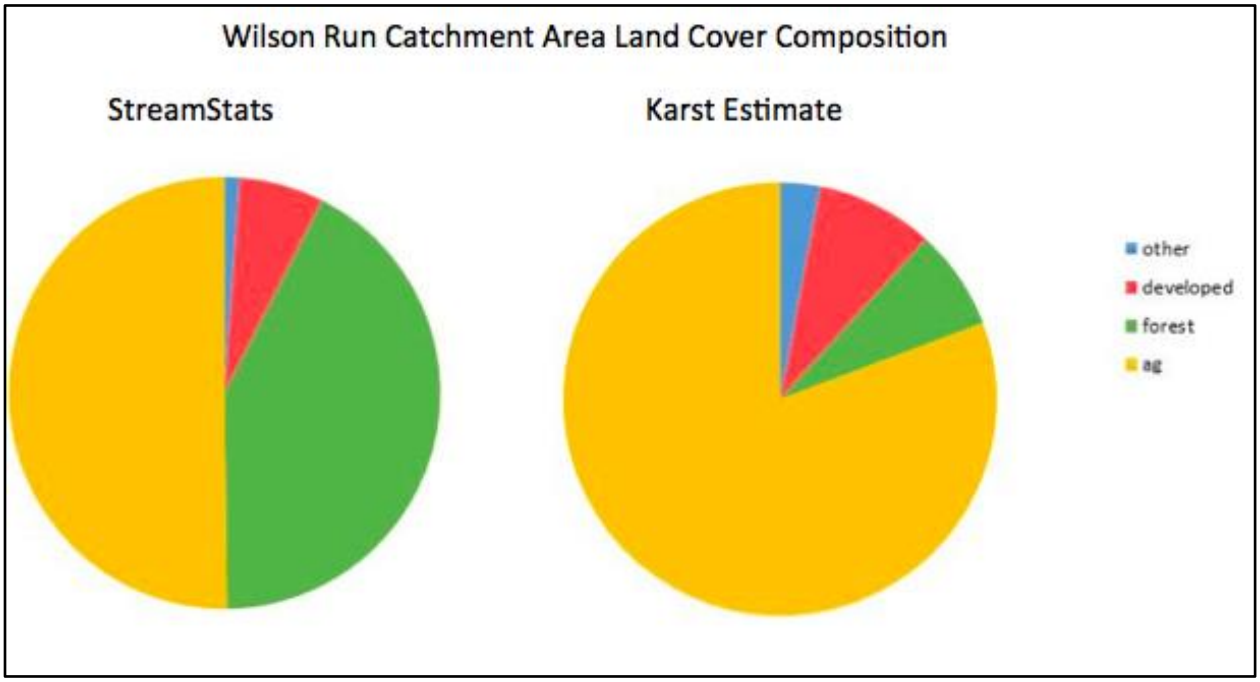

Figure 19. Proportions of land cover in the catchment area for Wilson Run in the USGS StreamStats estimated area and the karst estimated area.

Discussion:

How do you delineate catchment zones for streams that are associated with karst geology?

There is more than one way to delineate a catchment zone for any stream and that holds true with delineating karst streams as well. For streams not associated with karst geology online models, such as StreamStats, that ask you to input *x,y* coordinate data can be used which will automatically generate catchment areas based on flow and elevation or all of the data can be measured and collected in the field (Turnipseed and Sauer 2010). Velocity measurements can be taken in the stream, elevation can be measured, and the field site could be examined for geologic features that could alter groundwater flow as an alternate option to electronic modeling. With karst streams however, there are different options that yield results with different levels of accuracy. The more accurate the delineation, the more time, energy, money, and field work is required. A relatively inexpensive and time efficient way to estimate the karst catchment areas was implemented in this project and included a combination of field measurements and models. Even though this estimate yielded different areas than the general StreamStats generated catchment area, there is no easy way to validate the methods utilized in this study, which makes these estimated areas less reliable than other potential methods could estimate. That being said, the only way to come close to finding the true catchment area of a stream in a karst environment would be to dye trace (Ginsberg and Palmer 2002). Dye tracing requires extensive experience, relatively expensive chemicals and equipment, and even that method does not always yield positive or readily interpreted results. So even with the most reliable delineation method, it is very difficult to accurately represent or even know for sure what the true catchment area is for streams overlaying karst geology.

What are the catchment zones for sites that are located in streams that are associated with karst geology?

With the knowledge that even the most reliable delineation methods for streams in karst geology cannot yield results that can be 100% validated, any estimated catchment zones need to be used and analyzed accordingly.

Regardless of their relationship to the StreamStats catchment areas, all of the karst estimated areas originated from the *x,y* coordinate study site point and encompasses an area of land upstream from that coordinate point. Some of the catchment zones estimated in this study are smaller than the traditionally estimated areas and some are larger, but none of them are exactly the same as the StreamStats catchment areas for those sites. It was critical to delineate catchment areas for those study sites in a different way than the StreamStats program generated catchment areas because StreamStats does not take karst geology and the corresponding features into account. Even though these catchment zones for streams with underlying karst geology are very rough estimates, the results of this study can at least show that karst streams must be considered differently than non-karst streams in fear of grossly under- or overestimating contributing areas to streams.

How do the estimated catchment zones for streams in karst systems differ from the catchment zones calculated by the USGS StreamStats program in terms of area and land cover?

As it was mentioned in the previous section, all of the study sites showed differences in the StreamStats and estimated catchment areas. Back Creek, Burd Run, Middle Spring Creek, Rowe Run, and Wilson Run all resulted in estimated catchment areas that were less than the StreamStats catchment area while Big Spring Creek, Falling Spring Creek, Green Spring Creek, and Mt. Rock Spring Creek all resulted in larger estimated catchment areas than StreamStats areas (Table 3). In addition to the changes in area between the estimated and StreamStats catchment zones, the land cover compositions also changed at all study sites between estimated and StreamStats catchments (Table 4). Land cover compositions of catchment areas for Back Creek (Figure 11), Falling Spring Branch Creek (Figure 14), Green Spring Creek (Figure 15), and Rowe Run (Figure 18) were all relatively similar between StreamStats and the estimated areas. The remaining five sites, Big Spring Creek (Figure 12), Burd Run (Figure 13), Middle Spring Creek (Figure 16), Mt. Rock Spring Creek (Figure 17), and Wilson Run (Figure 19) all showed relatively different land cover compositions between the StreamStats and estimated catchment areas. Interestingly, forest cover decreased the most in estimated catchments compared to StreamStats catchments in the sites that showed very different land cover compositions between the two areas while developed area was the second cover type to decrease. Agricultural land cover was the greatest percentage of land cover for almost all study sites in both StreamStats and estimated catchment areas (Table 4, Figures 11-19). The fact that agricultural land cover was so prominent in all catchment areas is not surprising given the nature of the study area, but it should be recognized as a serious potentially influential factor on the streams of this study.

Implications for delineating catchment zones in karst regions

This study and at least a handful of other studies have attempted to delineate catchment areas for streams with underlying karst geology. This is not an easy process or one that comes with 100% accuracy regardless of which specific methods are used. Even without the 100% accuracy guarantee, these studies raise awareness on the importance of treating streams in karst systems differently than streams in non-karst systems. The importance of treating them as different systems in terms of delineating catchment areas is only one of many things to consider. Those catchment areas are commonly analyzed in terms of land use/land cover, precipitation, soil type, vegetation composition, and geologic formations among many other characteristics which all have the ability to influence the aquatic system of interest. If inaccurate catchment areas are used to analyze factors that may be influencing the corresponding streams, important information could be easily overlooked or not even considered. Analyses at the catchment scale are becoming more commonly used and widely accepted when it comes to stream ecology and water quality in general, which means that when there is karst in the catchment area, traditional delineation does not apply.

Literature Cited:

Allan J. D. 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. Annual Review of Ecology, Evolution, and Systematics 35:257–284.

Allan J. D., Erickson D. L., Fay J. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater biology 37:149–161.

Anderson JR, Hardy EE, Roach JT, Witmer RE. 1976. A land use and land cover classification system for use with remote sensor data. Professional Paper Report No.: 964.

Berg TM, Edmunds WE, Geyer AR, and others compilers. 1980. Geologic map of Pennsylvania (2nd ed.): Pennsylvania Geological Survey. 4th ser. Map 1. 3 sheets. Scale 1:250,000. Available from: http://www.dcnr.state.pa.us/topogeo/publications/pgspub/map/map1/index.htm.

Bureau of Toppographic and Geologic Survey, Department of Conservaton and Natural Resources. Digital data set of mapped karst features in south-central and southeastern Pennsylvania. 2007. [accessed 2015 Oct 9]. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=DCNR_PAKarst.xml&dataset=3073

Doerfliger N, Jeannin P-Y, Zwahlen F. 1999. Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). Environmental Geology 39:165–176.

Everest F, Reeves GH. 2007. Riparian and aquatic habitats of the Pacific Northwest and Southeast Alaska: Ecology, Management History and Potential Management Strategies. USDA Report No.: PNW-GTR-692.

Fetter CW. 2001. Applied hydrogeology. 4th ed. Upper Saddle River, N.J: Prentice Hall.

Ginsberg MH, Palmer AN. 2002. Delineation of source-water protection areas in karst aquifers of the Ridge and Valley and Appalachian Plateaus physiographic provinces: rules of thumb for estimating the capture zones of springs and wells. US Environmental Protection Agency, Office of Water.

Hawkins S. 2015. Scuplin sites. Unpublished data.

Homer C, Dewitz J, Yang L, Jin S, Danielson P, Xian G, Coulston J, Herold N, Wickham J, Megown K. 2015. Completion of the 2011 National Land Cover Database for the Conterminous United States–Representing a Decade of Land Cover Change Information. Photogramm. Eng. Remote Sens. 81:345–354.

PAMAP Program, PA DCNR. 2007. PAMAP_cycle2.

Roland, M. A., and Stuckey, M. H. 2008. Regression equations for estimating flood flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57 p.

Stuckey, M. H. 2006. Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84 p.

Stuckey, M. H., Koerkle, E. H., and Ulrich, J. E. 2014. Estimation of baseline daily mean streamflows for ungaged locations on Pennsylvania streams, water years 1960–2008 (ver 1.1, August 2014): U.S. Geological Survey Scientific Investigations Report 2012–5142, 61 p., *http://pubs.usgs.gov/sir/2012/5142*.

Turnipseed, D. P., and Sauer, V. B. 2010. Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p.

U.S. Geological Survey. 2012. The StreamStats program for Pennsylvania, online at http://water.usgs.gov/osw/streamstats/pennsylvania.html.

U.S. Geological Survey in cooperation with U.S. Environmental Protection Agency, USDA Forest Service, and other Federal, State and local partners. 2005. National Hydrography Dataset (NHD) - High-resolution: flowline features clipped to PA state border. 2005

Winter, T. C., J. W. Harvey, O. L. Franke, and W. M. Alley. 1998. Ground water and surface water: a single resource. Denver, Colorado: U.S. Geological Survey (U.S. Geological Survey circular).