State University of New York – College at Brockport

Scholars Day: April 7, 2010

Determining the Source of Conduit Flow at Buttermilk Falls, Le Roy NY

The purpose of this study is to characterize groundwater and stream water in a study area surrounding Buttermilk Falls. Buttermilk Falls is formed from Oatka Creek eroding the Onondaga Escarpment and exposing the fractures and bedding plains of limestone. Oatka Creek is a karst stream that interacts with sinkholes, fractures and exposed bedrock, making it highly susceptible to groundwater-surface water interactions. Samples were collected throughout the study area to represent groundwater, stream water, conduit flow and downstream flow. After statistical analysis only calcium, magnesium, total phosphorous and soluble reactive phosphorous could be applied to the mixing models. Two end member mixing models were run to calculate percentages for conduit flow and downstream flow. The mixing models showed that the conduit flow could be comprised of anywhere from 97% to 34% stream flow. The downstream mixing model showed that it could be comprised of anywhere between 91% to 45% stream water.

Presenter: Jill Libby (Undergraduate Student)

Topic: Earth Science

Location: 104 Holmes

Article I. Using a Mixing Model to Estimate Complex Mixtures within Conduits of Dissolution karst: A Case Study near Le Roy, NY

Jill Libby

Section 1.01 Introduction

The Earth's surface is covered by approximately 10 to 20% karst terrain that formed by dissolution of soluble bedrock that commonly creates intricate conduit systems (Palmer, 1991). These terrains are known for having thin to absent surface soils that allow pollutants to enter directly into groundwater systems easily polluting large aquifers. It was not long ago that there was little to no knowledge of karst terrains and their ability affects surface water, groundwater, or the potential hazards they can produce. Understanding of groundwater and surface water hydrology has increased in the past decades by further understanding and quantifying the development of conduits, caves and sinkholes while also adding to the understanding of the water chemistry of karst bedrock aquifers. The knowledge we gain from this research will help insure future generations have a clean and continual supply of groundwater from karst bedrock aquifers.

Watersheds that transverse limestone formations tend to have direct groundwater-surface water interaction as well as a mixture of these waters in the conduit systems. If a given formation has a large topographic escarpment, streams commonly create a waterfalls that allows this mixture to emerge from the conduits exposed by the falls. The results are that streamwater upstream and downstream of a bedrock escarpment may not have the same characteristics. A change in characteristics in the stream quality in a short distance to cross a bedrock escarpment could result in major changes in the fauna and flora of the stream and have an overall degradation effect on the aesthetics of the downstream water bodies.

A case study for this process is the Oatka Creek watershed which transverses the Onondaga escarpment. Oatka Creek forms Buttermilk Falls at this point and allows for conduit flow to emerge from the fractures, joints and bedding plains exposed at the vertical falls. In this study, mixing models will be used to evaluate the alternating mixtures of groundwater and stream water as conduits move through the formation. These mixing models estimate the proportions of groundwater and stream water within the conduit system of the bedrock. By estimating these proportions we can have a better understanding the differences between upstream and downstream characteristics of Oatka Creek and have contribute to the further understanding of karst bedrock systems.

Section 1.02 Geology and Hydrology of Buttermilk Falls

(a) Location

Buttermilk Falls (BM Falls) is located in western New York approximately 40km south of Lake Ontario along the Onondaga escarpment. BM Falls is the focus of this study and is located on the border of the northern portion of the Alleghany Plateau in the LeRoy NY 7.5 minute quadrangle in New York State at 43°00'17.40"N and 77°58'23.86"W (Figure 1). The elevation at the top of BM Falls is 237m and less then 215m at the base. The Oatka Creek watershed is approximately 557 km^2 and is elongated in a northeast-southwest direction. The headwaters of the Oatka Creek watershed are at approximately 500m and 156m when the creek enters the Genesee River. The watershed is dominated by agricultural land with some small townships, wetlands, quarries and very few industrial areas.

(b) Geology

The Onondaga formation spans the state of New York and outcrops along the Onondaga Escarpment, from the Niagara region to the Hudson Valley. This formation crosses the northern edge of most of the Finger Lakes. West of the Genesee River, the Onondaga formation intercepts northward flowing surface water and groundwater from the Alleghany Plateau by shunting it towards the east. Paleozoic formations in this area generally dip slightly to the south; this dip formed the Niagara and Onondaga escarpments across the region. Near BM falls, the Onondaga formation is divided into four major members: the Edgecliff, Nedrow, Moorehouse and Seneca as described by Oliver; however the Seneca member has been locally removed from this study area(1962, 1956).

The Edgecliff member is the lowest member in the Onondaga formation with thicknesses ranging from several centimeters to about a meter. This member is light grey coarsely grained limestone; the upper sections of this member contains some rare to few chert nodules that increase in abundance in eastern New York. The Nedrow member is above the Edgecliff member and ranges in thickness from 3 to 5m. This is a shaly limestone which grades up into a fine-grained massive limestone which has bedding plains spaced from 5 to 12cm. The Moorehouse member is 5m to 15m thick across the state. It is a medium gray fine-grained limestone with abundance black chert nodules that are visible within the study area.

(c) Geomorphology of the Onondaga Formation

The Onondaga formation is fractured and jointed throughout the study area and as a result is able to transmit large amounts of water through the formation very rapidly. The ENE trending fractures and joints were formed from the Alleghenian deformation and are visible in many of the Paleozoic rocks within the region (Engelder and Geiser, 1980). Studies of these joints and fractures found that they provided preferential pathways for groundwater in the formation, especially along the lower most unconformity of the Onondaga Formation and along other bedding plains within the formation (Kappel and

Miller, 1996). These preferred pathways causes groundwater within the Onondaga Members to have a very short residence time. As these fractures, joints, and bedding plains experience dissolution from acid water over time they become a system of enlarged karst conduits which are able to move large amounts of water very rapidly through the system and also are capable of moving insoluble solids (Daniluk, 2008).

Some of these conduits can intersect the land surface and create karst dissolution features like solution valleys, collapse sinkholes, and solution sinkholes (Palmer, 1991). Several of these sinkholes have been indentified throughout the study area. Two large sinkholes are located within the study area, one within the creek bed of Oatka Creek, and the other one is in the southwestern part of the study area. Flooding and draining events that produce over 9 meters of water level fluctuations have been recorded in as little as 30 hours (Rhinehart, 2005).

(d) Soils

Soils in the study area began forming after the last glaciation that covered New York State. The USDA Soil Survey shows that soils of the study area are dominantly characterized by thin and immature soils (USDA, 2009). The diamicton that was laid down by the glacier was fairly thin; it is common throughout the study area for large sections of the Onondaga limestone to be exposed. Surrounding BM Falls the soils are 48.6% Inceptisols, the other 51.4% of the land is divided amongst Alfisols, Histisols, Entisols and some ponding surface water at the base of the quarries. The most common soil in the study area is the Benson series which is an Inceptisol, it has an average depth to bedrock of 10 to 20 inches and is excessively drained on glaciated uplands. The second most dominate soil type is rubble land and quarries which are areas of exposed bedrock dominated by rocks, cobbles and boulders with no soil material present.

(e) Oatka Creek and Buttermilk Falls

Oatka Creek headwaters begin in the southern tier of New York State and flows to the north across the Allegany Plateau. The creek eventually flows over the Onondaga Limestone in the study area, makes an abrupt easterly turn at the Onondaga Escarpment, to the Genesee River and then to Lake Ontario (Vertloh, 2009). Oatka Creek has an average discharge of 1.5 cubic meters per second directly upstream of the Onondaga formation. As Oatka Creek flows north over the Onondaga formation it carries little to no basal lag. During dry summer months when there is no surface discharge the dissolution fractures of the Onondaga limestone are clearly visible (figure 2). As Oatka Creek crosses the Onondaga Escarpment it forms BM Falls, a large horseshoe shaped waterfall that exposes all of the lower Onondaga Members (figure 3). BM Falls has a vertical drop of over a 15m drop, and during the winter discharges of over 4 cubic meters per second are common. During the summer the creek is almost always dry except after large storm events. However, during the winter and summer there is always water emerging from the conduits exposed at BM Falls in the different members of the Onondaga limestone.

Section 1.03 Methodology

(a) Discharge Data

Stream flow measurements are taken using a velocity transducer to calculate discharge of Oatka Creek at several locations in the study area. There are 6 locations that are used for collecting discharge data that represents Oatka Creek at several locations upstream, on, and downstream of the Onondaga Limestone outcrop area. These are labeled on the study area map (figure 1). The Route 5 Bridge, Cemetery, and NSRB are measurements upstream of BM Falls and represent the cumulative ‘stream flow’ data. Also at the Cemetery site are two different discharge locations that represent upstream and downstream of a sinkhole located within the creek. Downstream of BM Falls is measured at a New York State Department of Environmental Conservation (NYSDEC) Fishing Access and during 2008 at Garbutt. Measurements at Garbutt were downloaded from the USGS National Water Information System for Real-time data.

Discharge was measured and recorded over the summers of 2008 and 2009 on a weekly basis. The measurements were taken by recording the depth and velocity at several locations across the stream and summing the data together. Velocity was assumed to be average at 60% down the water column. The following equation represents the equation used to calculate the discharge at each location (Fetter, 2001):

$$Q = \sum_{i+1}^{m} (Velocity_{i} * Depth_{i} * Width_{i})$$

(b) Water Characterization

Water samples were collected from the Route 5 Bridge, Le Roy Cemetery Site and NSRB to represent stream water. The samples characterize the soluble reactive phosphorous, total phosphorous, calcium, magnesium, sodium, potassium nitrate and sulfate that are part of the dissolved load. Temperature for stream water was also collected using transducers that recorded water temperature ever 30 minutes for the past two years. Downstream water samples were collected and tested for the same dissolved constituents.

Groundwater samples were collected from 8 different wells on the Onondaga Limestone. The wells were both private and NYSDEC wells drilled to monitor the conditions of the groundwater aquifer. These wells were on both east and west sides of Oatka Creek and were as close to Buttermilk Falls and Oatka Creek as access permitted (figure 1). The samples for groundwater were tested for the same parameters as the stream water; temperature was also collected using transducers.

Characteristics of conduit flow at BM Falls were sampled and tested in the same conditions as all other three sources of water. The conduit used for sampling is a fracture that discharges water approximately 10m from the base of the west wall of the falls and flows steadily all year round. This conduit provided the best access since the large pool at the base of the falls and hanging rocks inhibits access to other springs around the falls. This conduit is accessible for sampling during the winter as well.

Water samples collected from all of the listed sites during the spring to the fall. A total of 44 samples of 500ml each were collected using procedures outlined by Eaton (1992). For the anion and cation analysis the samples were filtered through .45µm filters and run on an Ion Chromatograph. Standards of 200ppm, 80ppm, 40ppm, 10ppm, 1ppm and .1ppm which contained sodium, calcium, magnesium, nitrate, sulfate and potassium where run on the ion chromatograph to create standard peaks. The water samples were then run and compared to the standard peaks to derive concentrations of the dissolved constituents.

Soluble reactive phosphorous (SRP) was measured by running the water samples through .45µm cellulose filters, and running them through a spectrophotometer using standards varying from .01 to .2 mg/l of phosphorus. Total phosphorous was run after digesting them according to Eaton (1992) and running them through the same spectrophotometer as SRP. Both the SRP and TP standard linear graphs had R^2 values of .999 or better.

(c) Descriptive Statistics

Dissolved load constituents for all of the sites were compared with two sample T-tests to determine if statistical differences exist between the samples. The T-tests were run for all parameters to ensure that there was a statistical difference between stream water and groundwater so the constituents could be run on the mixing models. If a given parameter was found to not have a statistical difference between stream water and groundwater, it was excluded from the model because a viable difference between the two sources is required.

(d) Modeling

Parameters that were significantly different from each other were entered into a two end member mixing model equation to estimate the percent mixtures. There are two different sets of equations that have to be run: the first set of mixing model calculations is for the mixture of stream water and groundwater that formulate the conduit flow. The second mixing model set is for the calculation of the mixture of stream water and groundwater that combine to form the downstream water. The end member mixing model equation was altered so that the calculation is a representation of the amount of groundwater present in the mixture represented in a percent form where C represents concentration.

$$\%Groundwater = [(C_{Conduit} - C_{Stream}) / (C_{Gwater} - C_{Stream})]*100$$

Section 1.04 Results

(a) Discharge Data

The first discharge graph shows the locations upstream and downstream of BM Falls for three different days that reflect all of the measurements that were taken during the two summers (figure 4). All three of the measurements show that after the Route 5 bridge locations, just upstream of the Onondaga limestone, Oatka Creek begins rapidly loosing discharge. By the time Oatka Creek flows under NSRB there is no discharge for any of the days. Since NSRB is just upstream of BM Falls this also means that during all of the measurements and samples taken there was no discharge over BM Falls. After BM Falls Oatka creek slowly beings gaining discharge but at a slower rate then when it was loosing discharge. The distance between BM Falls and the Garbutt site is more than twice the stream length then from the Route 5 Bridge and BM Falls, and yet when Oatka Creek reaches Garbutt it still has less discharge then upstream of the Onondaga limestone.

The next discharge was graphed for the Cemetery site on a much smaller scale (Figure 5). A large sinkhole located in the creek bed separates the upstream and downstream sites by 70 meters. The sinkhole is at least 12 meters deep and has a 20 to 30 meter diameter depending the season. The seven discharge measurements show an overall decrease in Oatka Creek's discharge after the sinkhole. A large portion of the discharge lost between the Route 5 bridge and NSRB is lost directly to this sinkhole.

(b) Water Characterization and Descriptive Statistics

The chemistry and temperature data for the four sources (stream water, groundwater, conduit flow and downstream) was organized into tables for mean and standard deviation for each parameter (Tables 1, and 2). The two sample t-tests that were run for all of these parameters for the two sources of stream water and groundwater. Five parameters showed significance between the two sources: TP, SRP, Ca, Mg and Temperature. These parameters, TP, SRP, Ca, and Mg were graphed in box plots to show their relationship to each other (Figure 6). These graphs emphasis that stream water and groundwater can be differentiated from each other. They also confirm that conduit flow and downstream water are mixtures of the two sources because they fall within the ranges of stream water and groundwater.

(c) Modeling

In order to run the two mixing models three assumptions must be made. The first assumption is that the end members of the conduit flow are the stream flow and the groundwater flow. The second assumption is that there are no unknown inputs of water into the system. The final assumption is that the parameters used in the mixing model are behaving conservatively. The first two assumptions are true because sampling throughout the area encompassed all possible stream water and groundwater inputs.

I justify the third assumption based on the following three observations. First, soils are thin to nonexistent in the study area, suggesting that biogeochemical interaction with the soils is minimal. Second is that groundwater fluctuations in the study area are dynamic and can respond faster than 3 meters per day implying very fast water residence times (Rhinehart, 2005; Richards and Rhinehart, 2006; Daniluk et al, 2008). The third assumption is that 10cm wide fracture voids in quarries suggest that some fractures are wide enough to allow fully-turbulent flow in the subsurface (Fronk, 1991). These three factors suggest that subsurface groundwater resident times are short enough to enable even patently non-conservative species such as Ca, and Mg to behave conservatively.

Temperature is a complicated parameter because during the summer the temperature is warm at the surface and decreases with as depth into the subsurface increases until it reaches the regional subsurface temperature of about 7 degrees celsius. Thus, temperature would require a more complicated, non linear, mixing model that is not going to be outlined in this study. Therefore, the four parameters used for the two mixing models are TP, SRP, Ca and Mg. The mixing models that were run resulted in a percent stream flow of 34% to 97% for conduit flow and at 33% to 91% for downstream water (Table 4).

Section 1.05 Discussion

Discharge measurements throughout the study area demonstrate two points. 1) All of Oatka Creek's discharge is lost to the Onondaga Limestone upstream of Buttermilk falls during the summer months, except after large storm events. 2) This discharge is directly lost through fractures and sinkholes within the creek bed (Figure 4 & 5). Once the creek's discharge enters the conduit system of the Onondaga limestone, it flows along preferred pathways by the conduits. However, in this case it was postulated that the stream water was emerging at BM Falls, which is contrary to regional groundwater trends for the study area. Regional groundwater in the area trends in the easterly direction, for local water to be emerging at BM Falls it would have to be flowing through the conduits perpendicular to regional trends.

The mixing models showed that the sampling conduit could be comprised of anywhere from 34% to 97% stream water. This is a fairly wide range and shows that the conduit flow has a large variation of mixing between the groundwater and the stream water. Since during the summer the conduits can be completely dominated by stream water to only having 34% stream water demonstrates that the discharge lost upstream of BM Falls in Oatka Creek is emerging out of the conduits. The upstream water is being discharged at the conduits because based on the assumptions developed for the mixing model, groundwater characteristics are conservative in nature and there is no other input of water, thus stream water from Oatka Creek must be emerging at the conduits. The variation in the mixture of groundwater and stream water for the conduits can be attributed to the fluctuating groundwater table in the formation due to its short residence time. A high groundwater table would result in higher concentrations of groundwater in the conduit mixture while a lower water table would result in a higher stream water concentration. During the winter season, when Oatka Creek discharges continually over BM Falls, the fracture is probably almost entirely comprised of groundwater because the water table would be much higher than many fractures.

The downstream mixing model showed that it could be comprised of anywhere between 33% to 91% stream water. These results show that areas downstream of BM Falls never have higher concentration of stream water than the conduit mixture. This is because downstream of BM Falls receive water from the conduits and from the groundwater. There are no sources of downstream discharge separate from what it receives from the conduit flows during the summer when Oatka Creek has no discharge over the falls.

The implications of these results are that stream water entering the conduit system directly through joints, fractures, and sinkholes in the channel bed does not reflect groundwater trends of the region. It also shows that concentration levels of conduit flows at BM Falls are dependent on groundwater fluctuations in the region and gradually alternate from groundwater dominated to streamwater dominated discharges with raising and falling water table levels. Downstream flow is only recharged from the stream water emerging at the conduits and receives the rest of its recharge from the regional groundwater.

The joints and fractures are a regional characteristic of the Onondaga limestone as well as the escarpment that transverses the state. On a statewide scale there are hundreds of creeks and rivers just like Oatka Creek that flow over the Onondaga Formation creating falls resembling BM Falls. This case study can be applied to many similar watersheds to understand the patterns of groundwater and stream water flows that are emerging from the conduits.

The findings of this study also can be applied in general to bedrock formations that contain dissolution fractures, joints, bedding plains, and sinkholes with an intricate conduit system emerging across a topographic escarpment. The implied ideas of this case study show that the behavior of stream water entering conduit systems of a limestone formation will not necessarily reflect the regional groundwater trends. Also, a stream losing discharge to the conduit system will recharge downstream of the formation with groundwater. At any given depth within bedrock, the mixture of water in conduit systems is probably dependent on the depth to the water table. A high water table will have a higher propensity of emerging at the conduits of an escarpment waterfall while a lower water table will be below the conduits and allow for stream water discharge out of the conduit system.

Section 1.06 Conclusion

As the Oatka Creek transverses the Onondaga Limestone it changes from being dominated by stream water to a widely varying mix of stream water and groundwater. The relative proportion is dependent on the groundwater table level. This case study shows that groundwater and surface water interactions in karst topography allow for characteristic changes in surface hydrology upstream and downstream of the formation. The mixing model was used to effectively estimate the different proportions of groundwater and stream water within the conduit system. This mixing model is fairly simple to use and can be applied to any water quality parameter as long as the trend of concentration and discharge is linear and conservative in nature. Differentiation between upstream and downstream surface water characteristics should be performed on more karst streams in different climate regions as well as during different seasons.

Section 1.07 References

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Section 1.08 Appendix

Captions

Figure 1. Study area near LeRoy, New York. Outcrop of the Onondaga formation is shaded gray. Stars represent wells that were used for groundwater sampling. Circles represent sites used for surface water sampling at Rt 5 Bridge, Cemetery and NSRB sites. The square represents the location of Buttermilk Falls (BM Falls) and the triangles represent sampling at the DEC access site. The dark black line through these points is Oatka Creek. Light gray lines represent roads.

Figure 2. Photographs from upstream of BM Falls looking downstream in the winter of 2007 (A) and in the summer of 2009 (B).

Figure 3. BM Falls during the spring of 2008 (A) and at the same location during the winter of 2007 (B).. These photographs contrast the variations in flow that occur seasonally, and show that the conduits flow all year regardless discharge of Oatka creek.

Figure 4. Discharge variations in Oatka Creek for June 22, 2009 (A), July 17, 2008 (B), and August 20, 2008 (C). During the summers of 2008 and 2009, over 20 discharge measurements were taken and all of them followed the same pattern. The relative locations are identified in figure 1 except for Garbutt which is near the Oatka Creek confluence with the Genesee River, approximately 16 km downstream of the study area. The USGS discharge measurements at Garbutt stopped functioning in the summer of 2009.

Figure 5. The solid line represents the discharge of Oatka Creek 20 meters upstream of the sinkhole at the Cemetery and the dashed line represented discharge 30 meters downstream of the sinkhole. Discharge data was collected in the fall of 2008.

Figure 6. Box plots of total phosphorous, calcium, magnesium, and soluble reactive phosphorous concentrations used in the mixing models. The four sampling sources are graphed for each parameter that had a statistical difference between stream water and groundwater. The sampling sources of surface water refer to Rt 5 bridge, Cemetery and NSRB, groundwater represents all wells sampled. Conduit flow represents BM falls and downstream water is the DEC fishing access. Mean values and ranges show that conduit flow is never outside the ranges for stream water and groundwater concentrations.

Table 1. Mean and standard deviations for total phosphorous (TP), soluble reactive phosphorous (SRP), magnesium (Mg), calcium (Ca), temperature (T), nitrate (NO_3), potassium (K), sodium (Na), and chloride (Cl) at the four water sources. TP and SRP measurements are not related to each other because their measurements are not from the same sample sets.

Table 2. Mixing models results for the average concentrations of the parameters for each of the sources. Mixing model A is the percentage of stream flow in the conduit flow. Mixing Model B is

the percent of stream water that is in the downstream flow. These two mixing models show that conduit flow is between 35% to 97% stream flow and the downstream flow is from 34% to 92%.

Figure 1

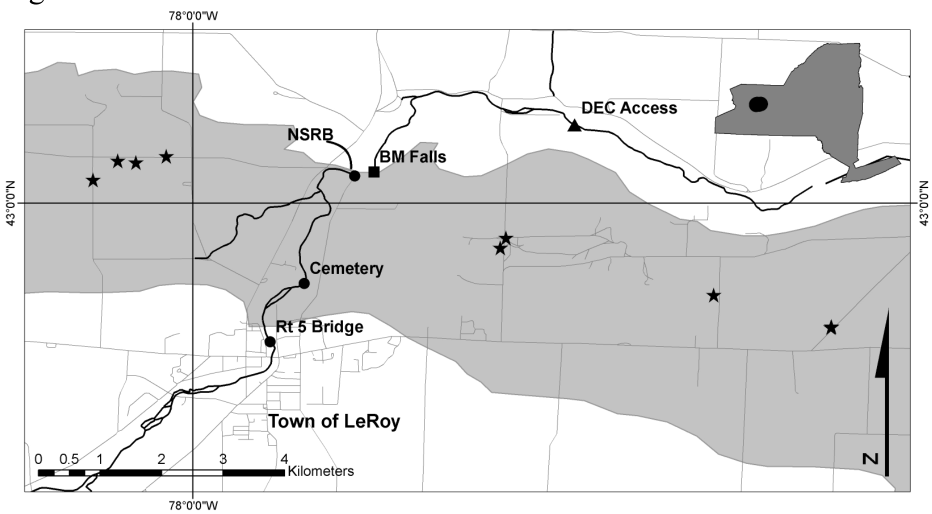


Figure 2

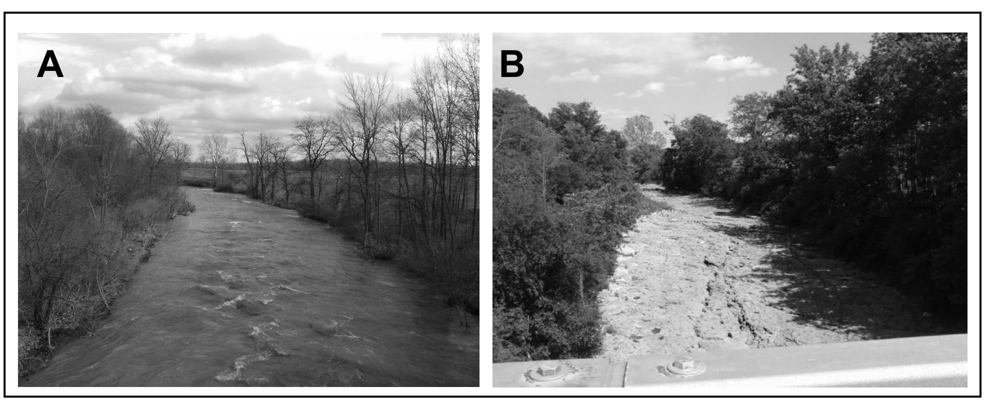


Figure 3

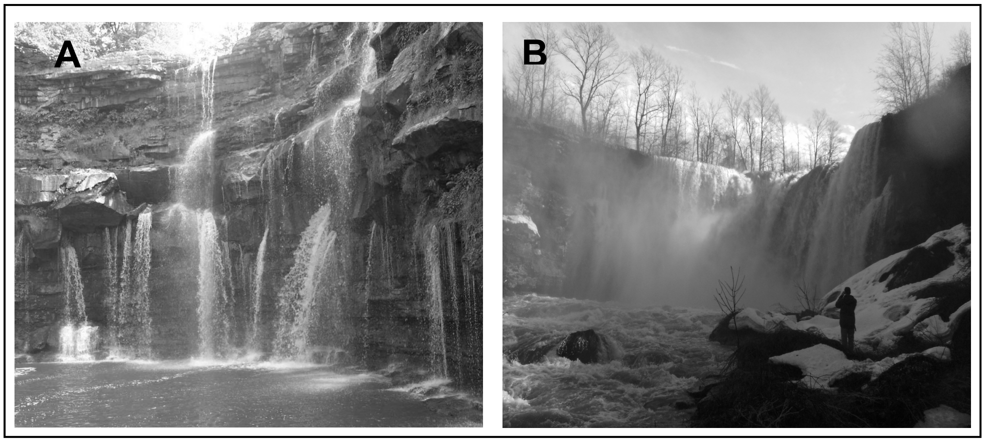


Figure 4

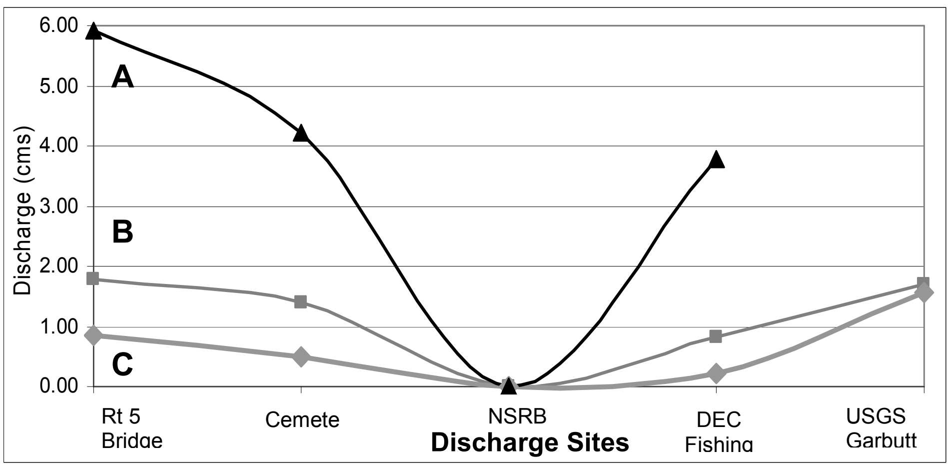


Figure 5

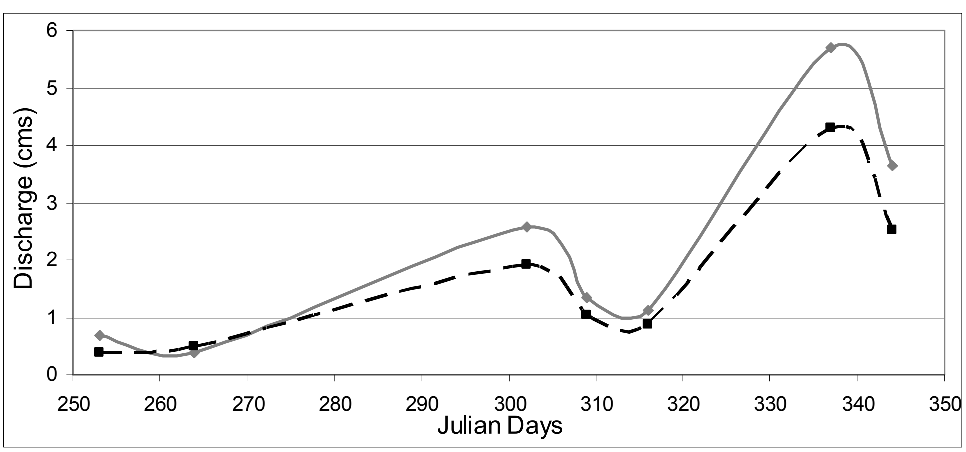


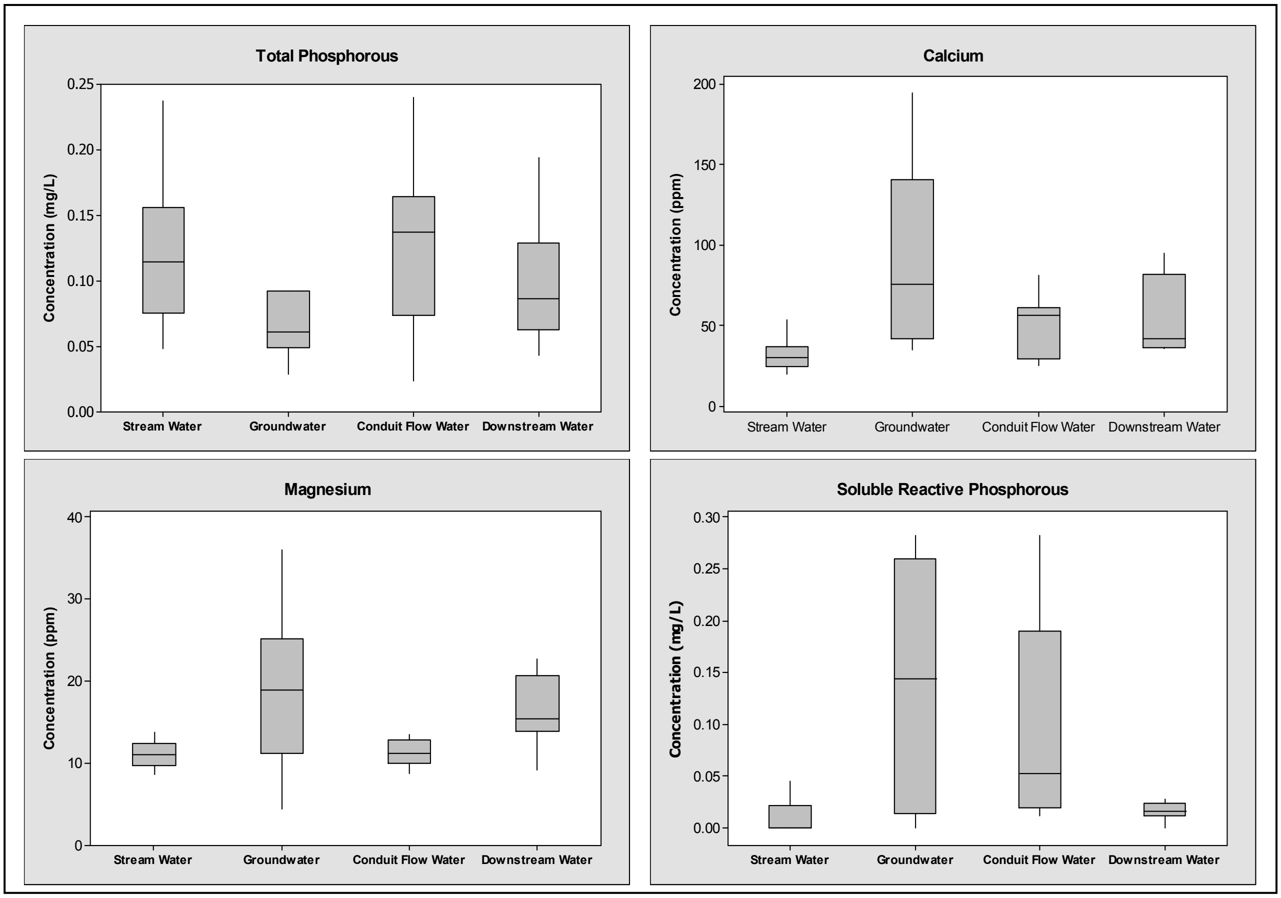
Table 1

Combined Data								
	Surface Flow		Ground water		Conduit Flow		Down stream	
Parameters	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
TP	0.13	0.08	0.07	0.02	0.13	0.06	0.10	0.05
SRP	0.01	0.01	0.14	0.13	0.09	0.10	0.02	0.02
Mg	11.16	1.55	19.08	9.64	11.40	1.73	16.41	4.25
Ca	31.94	8.51	96.33	55.95	50.70	20.28	57.07	24.59
T	7.02	0.56	23.78	2.24	20.71	1.81	17.41	2.45
NO3	3.96	2.11	8.35	4.60	4.90	2.90	5.42	2.65
K	2.92	1.05	3.23	2.64	2.92	0.94	2.68	0.56
Na	27.78	4.57	30.08	27.40	21.87	12.20	33.98	7.55
Cl	48.87	9.50	36.88	30.74	54.00	12.01	68.03	8.21

Table 2

Parameter/Location	Stream Flow	Ground water	Conduit Flow	Down stream	Mixing Model A	Mixing Model B
Total Phosphorous	0.13	0.07	0.13	0.1	92.64	45.51
Soluble Reactive Phosphorous	0.01	0.14	0.09	0.02	34.92	91.92
Magnesium	11.16	19.08	11.39	16.41	97.10	33.15
Calcium	31.93	96.33	50.698	57.07	70.86	60.96

Figure 6.


Total Phosphorous
Concentration (mg/L)
0.00
0.05
0.10
0.15
0.20
0.25
Stream Water
Groundwater
Conduit Flow Water
Downstream Water
Calcium
Concentration (ppm)
0
50
100
150
200
Stream Water
Groundwater
Conduit Flow Water
Downstream Water
Magnesium
Concentration (ppm)
0
10
20
30
40
Stream Water
Groundwater
Conduit Flow Water
Downstream Water
Soluble Reactive Phosphorous
Concentration (mg/L)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Stream Water
Groundwater
Conduit Flow Water
Downstream Water