THE HYDROGEOLOGICAL EFFECTS OF VARIABLE LAND USE ALONG WOLF CREEK IN THE MACKINAW RIVER WATERSHED

Scott Charles Maguffin

50 Pages August 2007

Agricultural and societal byproducts often have adverse effects on local water systems. This study investigates those effects and the potential natural attenuation of a local stream: Wolf Creek.

APPROVED:

Date Eric W. Peterson, Chair

Date Stephen J. Van der Hoven

Date Robert S. Nelson

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Wolf Creek is a small stream that first flows through several agricultural fields, then a golf course, near a new housing development, and finally through a riparian corridor. Although it is a relatively healthy stream, Wolf Creek has experienced species loss and water quality decline since the 1950's. Agricultural and societal byproducts such as nitrate and sulfate are significantly responsible for this decline. Between March of 2005 and March of 2006 this study aimed to investigate and better understand 1) the input of anions into Wolf Creek, 2) the transport of the anions throughout the stream, 3) the stream's ability to naturally attenuate nitrate, and 4) how stream channelization and natural stream evolution may influence potential attenuation.

This study included: anion water sampling at five locations along the stream, discharge measurements at four of those sampling locations, field parameter

measurements, ground water modeling using *MODFLOW*, and morphometric analyses of the watershed.

The morphometric analysis of the watershed allowed for a calculation of stream sinuosity. These data provided a way to quantify stream channelization. Stream discharge and anion concentration results allowed for the calculation of the anion flux between sampling locations. The primary focus of these data was the relationships between anion concentrations, anion mass flux, and stream sinuosity. Together, the data suggested a potential nitrate sink in the last section of the study area. The location of the sink corresponds with the highest calculated stream sinuosity values and indicates possible reduction and oxidation reactions due to the increased interactions of hyporheic, surface, and groundwater systems.

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Fulfillment of the Requirements
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S.C.M.

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CHAPTER I

INTRODUCTION

Statement of the Problem

As a result of the many activities that require the manipulation of land, agricultural byproducts often find their way into local ground and surface waters. The resulting effects on local streams are studied and regulated by state and federal agencies so that certain byproducts do not exceed maximum contamination limits and therefore, marginalize potential hazards to the environment. This study examines nitrate, chloride, and sulfate concentrations in addition to hydrologic parameters in a local creek as it flows through three distinct types of development. This work will address the dynamics between local land development and contaminants, and the potential for the natural attenuation of nitrate. It is important to note that throughout this study all references to 'nitrate' is specifically referring to NO_3^-.

The Mackinaw River Catchment

The Mackinaw River catchment is a major watershed in central Illinois spanning 2950 km^2 and six counties: Ford, Livingston, Mason, McLean, Tazewell and Woodford. The Mackinaw River and its tributaries flow through an agriculturally dependent region where 86% of the land is devoted to farming corn and soybeans (Post and Wheeler, 1997). Although the Mackinaw River and its tributaries are considered to be relatively healthy for central Illinois, flooding, urban development, erosion, pollution, sedimentation, habitat deterioration, channelization and overall water quality are still prominent issues throughout this watershed (Post and Wheeler, 1997). Agriculturally derived pollution is one of the primary concerns in this catchment as there has been a constant decline in aquatic diversity for the past 50 years (Post and Wheeler, 1997). Nearly 25% of the original fish and muscles species that once thrived in this basin are now gone. Aquatic species that require better water quality have been replaced with those that can tolerate the societal byproducts that now exist. Furthermore, this watershed is the exclusive home to several endangered species in central Illinois such as the heart-leaf plantain and the tall sunflower (Post and Wheeler, 1997). The Mackinaw River basin is a robust but delicate central Illinois watershed that is home to many native grassland species and municipal necessities whose livelihood is important to an entire region of the state.

Agricultural Contamination by Runoff and Tiles Drains

Agricultural runoff has a significant concentration of nutrients, specifically nitrogen and phosphorous. A large percentage of the nutrients in fertilizers applied to agricultural fields find their way into ground and surface water systems. Keeney and Hatfield (2001) estimate that agricultural runoff from Illinois contributes 19% of the nitrate load in the Mississippi River. This excess in nutrients contribute to a number of problems including eutrophication of inland and coastal waters by stimulating algae production and contamination of ground and surface drinking water reservoirs (Randall and Mulla, 2001). Inorganic nitrogen (N) bearing pollutants, which for this study is nitrate (NO_3^-), tend to be soluble and easily transported in surface, subsurface, and hyporheic pathways.

Organic and mineral phosphorus are primarily transported by being physically bound to appropriately sized sediment grains that are transported in surface water (Kronvang, 1990).

The primary sources of pollutants in agricultural streams are shallow groundwater flow into surface waters, intermittent tributaries from both agricultural and urban runoff, and shallow subsurface tile drainage (Schilling and Wolter, 2001; Hallberg, 1987). These sources are significant reservoirs of N not used by vegetation (Randall and Mulla, 2001). In fact, Omernik (1977) found that in the Corn Belt states, nitrate concentrations were nine times greater downstream of agriculturally developed lands than upstream. Vought et al. (1995) summarize this appropriately when they note that headwater streams and their banks are directly influenced by nearby agriculture and that agriculture and rivers have become “hydrologically and hydrochemically coupled.” Focus on headwater streams is warranted given that these are some of the most influential stretches in a watershed because they constitute most of the streams length, contribute most of the N input, and have the greatest N retention capacity (Peterson et al., 2001).

The quantity of N that finds its way into the freshwater systems within agricultural landscapes via runoff and tile drainage systems has a strong correlation with dry and wet climate cycles (Randall and Mulla, 2001). Gast et al. (1978) found that nitrogen accumulates through soil mineralization, especially during times of drought. Since the nearby stream nitrate concentrations were low, they surmised that the absence of precipitation could account for the lack of fertilizer transport during the dry periods. The following year's data support their hypothesis; as it was very wet, and consequently tile drain water yielded abnormally high nitrate concentrations.

On local and regional scales, nitrate in drinking water is a concern throughout central Illinois, an agricultural area where the majority of the land surface is fertilized and tilled. According to the Illinois Department of Agriculture, more than 28 million acres, or nearly 80%, of the state's land, is covered by farms (Illinois Department of Agriculture, 2001). In 2002, approximately 1.7 billion pounds of nitrogen fertilizer were applied to agricultural fields in Illinois (United States Department of Agriculture, 2004). Consequently, nitrate concentrations in surface water reservoirs for municipalities, e.g. the city of Bloomington, occasionally exceed the drinking water standard (Illinois State Water Survey, 2001).

Riparian Corridors and Stream Channelization

Riparian expanses along a stream have the potential to reduce nutrient loading and facilitate the denitrification of nitrate pollutants (Vought et al., 1995). The amount of denitrification that occurs is coupled with the streams specific physical and biological characteristics, namely moisture content, the organic carbon content of the subsurface, and riparian vegetation (Vought et al., 1995). Equally as important, at least with respect to central Illinois' glacial till substrate, are the interactions between surface water and ground water interactions. Van der Hoven et al. (in press) reported that hyporheic water flowing beneath a riparian covered meander exhibited a reduction in nitrates, presumably through denitrification driven by oxidation of dissolved organic carbon.

When streams flow through, near, or around populations or valuable public or private property their morphological characteristics are often controlled to a degree necessary to prevent dynamic changes. A stream's cut banks could be stabilized with rip-rap, regolith, built up levees, or deepened stream channels. These common precautions have the potential to decrease a stream's "flood buffering capacity" and can lead to increased peak flood levels and flow velocities (Petersen et al., 1987). Though more importantly, stream modification and channelization have the potential to adversely change sediment erosion and depositional patterns, stifle aquatic and proximal terrestrial life, and decrease N retention (Brookes, 1988; Kemp and Dodds, 2002). Two quantitative methods to describe characteristics such as stream channelization and catchment maturity that are implemented in this study are stream sinuosity and a compactness coefficient respectively.

CHAPTER II

DESCRIPTION OF STUDY AREA

Study Area

The focus of this study is Wolf Creek, a small, primarily agricultural stream. Wolf Creek is a north to south flowing stream located in the central region of the Mackinaw River Watershed (Figure 1). Within Wolf Creek's catchment area there is very mild topographic relief and moderate but intermittent brush and tree cover proximal to its banks. The creek originates within and flows through agricultural fields in southern Woodford County before abruptly transitioning into a developed area consisting of the El Paso Golf Club and a suburban area consisting of multi-family residences and single-family homes. After flowing through the developed area, the stream meanders through a riparian forest, or undeveloped wooded valley, before entering the Mackinaw River. Within the agricultural area through which Wolf Creek flows, there are two steadily flowing drainage tiles that contribute to the stream's discharge. These two drainage tiles were constructed to redirect water from the street drains of the southern half of the city of El Paso and nearby agricultural land (City of El Paso, 2006). The additional water from these tile drains represents the only major tributary throughout the stream.

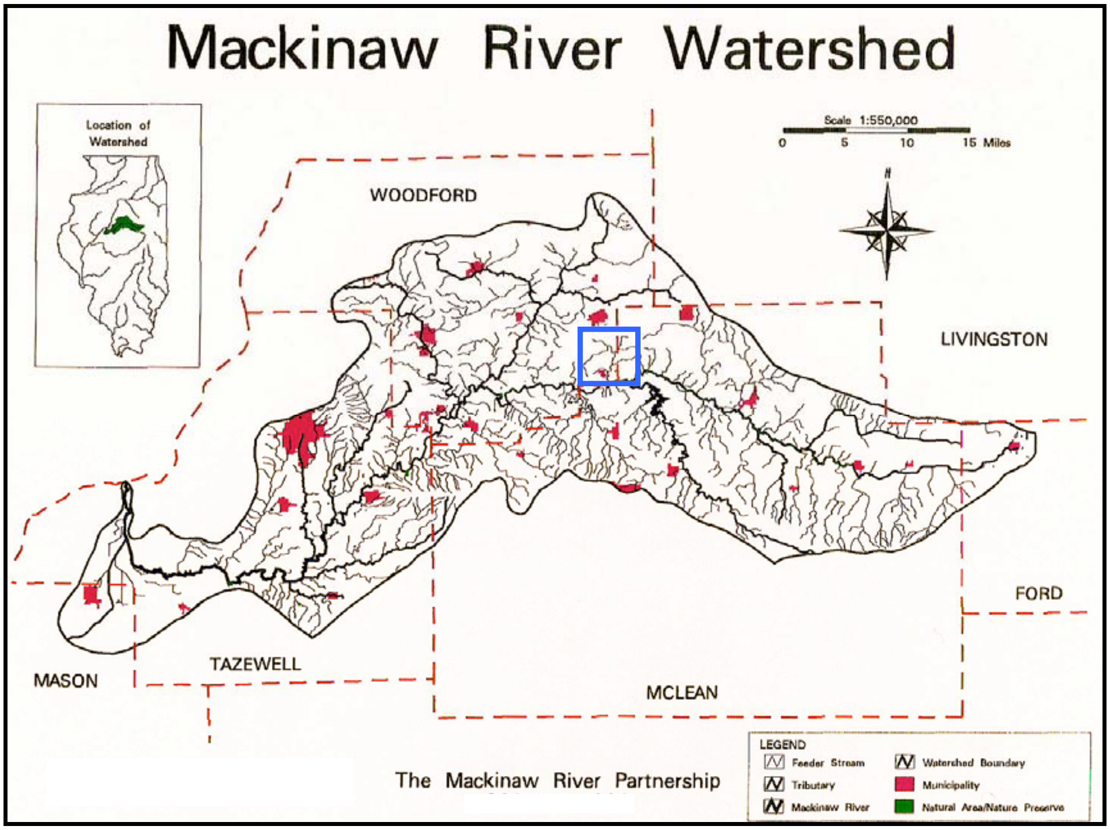

Figure 1. The Mackinaw River Watershed. Wolf Creek is within the blue box (Mackinaw, 1998).

Geologic and Hydrogeologic Setting

Mattingly et al. (1993) determined that >90% of all first order streams in central Illinois are channelized. More specifically, Gough (1997) estimates that within the Mackinaw River watershed, all 435 km of its first order streams are channeled. The Environmental Protection Agency defines a channelized stream as one that has been artificially straitened or deepened (EPA, 2006). Although Wolf Creek can be classified as a first order stream in the Mackinaw River catchment basin, there are segments of the stream subject to natural morphological evolution, specifically downstream from the agriculture land and the golf course. By and large, Wolf Creek is a gaining stream.

However, between March 2005 and November 2005, central Illinois experienced the seventh driest period since 1895 (Illinois State Water Survey, 2005). During this episode of extreme drought, it is possible that sections of Wolf Creek may have transitioned to a losing stream.

The geologic materials within the Wolf Creek watershed are of glacial origin. The stream primarily flows through mollisols, or soils formed under grassland vegetation, and generally have a silt-loam texture (Post and Wheeler, 1997). However, further downstream the streambed is much coarser indicating that glacially derived sediment is likely part of this system as well. The uppermost glacial sediments were deposited as the last glaciers retreated approximately 15,000 years ago leaving coarse cobble to silt sediment and loess deposits. A series of end moraines characterize this area; a physiographic region named the Bloomington Ridged Plain (Post and Wheeler, 1997). The closest end moraine to Wolf Creek is situated approximately 0.5 kilometers north of its headwaters and trends NW-SE. As the topographic relief of the moraine is subtle, there is no channelized flow between the moraine and Wolf Creek's headwaters. Preliminary analysis of streambed sediment at each of the sampling locations yielded a trend of increasing grain size with increasing distances down stream. It is assumed that this trend is associated with increased discharge and its effects on the stream. Bed sediment analysis indicates each site is moderately well sorted but the distribution of grain-size varies from site to site.

CHAPTER III

DESIGN OF INVESTIGATION

Objectives And Hypotheses

Wolf Creek is a small but influential local watershed that is part of and contributor to a larger and more significant regional catchment basin, the Mackinaw River basin. Addressing the effects of agricultural and urban development on a local stream is fundamental in creating an accurate understanding of the dynamics between stream systems and society's environmental influence. How much nitrate input does this stream endure? Is there a natural attenuation potential for this local watershed? If so, what effect does stream channelization have on such a potential? It is the aim of this study to address these questions by gathering relevant data for interpretation that may help answer more important questions in the future. Such as: What is the streams threshold regarding the amount of development it can sustain and still be a healthy, self attenuating, useful, and diverse habitat for both local species and society's needs? Specifically regarding Wolf Creek, the working hypothesis was that stream water downstream of agricultural and urban development would yield a greater discharge but lower concentration of chloride, nitrate, and sulfate ultimately producing inferior water quality than upstream waters.

Design of Study

Five sampling sites were established along Wolf Creek (Figure 2). Site 1 is located furthest upstream in an agricultural area about 3.2 km north north-east of the Golf Club. Water is derived from interflow or baseflow, but the stretch was either stagnant or completely dry for most of this study. At low flow, the width of the stream is at most a 0.3 m wide; while at high flow it can be approximately 1 m in width.

Site 1a is a unique site in that it is a manufactured tributary to Wolf Creek originating from two storm/tile drains redirecting southern El Paso storm water runoff. The west drain is 0.9 m in diameter and is older than its counterpart. The newer east drain is 1.2 m in diameter and is connected to several farming drainage tiles from agricultural plots between Site 1a and El Paso. Most of the water passing through these tiles drains is being diverted from their natural destination of Panther Creek into Wolf Creek. The flow from these tiles can be negligible during extreme drought conditions; however, during wet conditions, a large volume of water reaches Wolf Creek. Water that is exiting these two drains flow through an agricultural field for approximately 0.8 km before entering Wolf Creek.

Site 2 is located on private property downstream of the confluence of the tributaries associated with Site 1 and Site 1a. After the confluence there are two significant meanders before Site 2. Aside from these meanders, Wolf Creek is predominantly linear, having been channelized before Site 2. However, Site 2 is located adjacent to a sharp meander. This meander has a relatively large cut bank for the area and is just a few feet upstream of the sampling location. At this site the stream is 0.3 to 0.6 m, and about 2.5 m wide.

Site 3 is situated on the northern boundary of The El Paso Golf Club nearly 1.6 km downstream of Site 2. The site is situated at a transition point before the golf course but after agricultural fields. Wolf Creek's path has been channelized between Sites 2 and 3. For a few hundred meters before Site 3, Wolf Creek's banks are vegetated with more trees and bushes than any other location upstream. Midway through the study a small beaver dam was constructed several meters downstream of the Site 3. At Site 3 the stream can be 1.0 to 1.3 m deep and about 6 m wide at high flow.

After Site 3, Wolf Creek flows through the El Paso Golf Club property, near an apartment complex, and then through a riparian corridor before reaching Site 4. Wolf Creek meanders most within the riparian corridor during the latter half of the stretch between Sites 3 and 4. In this area, the stream is at its most natural state and has a series of three meanders in just a few hundred linear meters. At Site 4 Wolf Creek is 0.15 and 1.5 m deep, and between 2.5 to 4.5 m wide.

The design of this study included data collection at each site: samples were collected and analyzed for anion concentrations, field parameters such as dissolved oxygen, temperature, pH, and specific conductance were measured in-situ, stream discharge was calculated, and a spatial relationship between each of the sites was developed using topographic and GPS data. Lab analysis along with stream discharge data allowed was used to calculate the anion flux between sites. All of these data were used to investigate and model hydrogeologic relationships throughout Wolf Creek.

Figure 2. Sampling locations along Wolf Creek. The red box is the approximate area of the El Paso Golf Club.

CHAPTER IV

METHODOLOGY

Morphometric Analysis

Wolf Creek was studied from March 2005 to March 2006. During this period, a detailed morphometric analysis of the watershed was conducted to properly characterize and confirm map interpretations. The morphometric analysis required a more detailed cartographic representation of Wolf Creek. A Garmin® Global Positioning System (GPS) unit was used to record a trek and waypoints along the entire length of Wolf Creek between its headwaters and Site 4 as a way of ground truthing the map. These data and a topographic map were used to calculate and confirm sinuosity values, stream locations, stream lengths, spatial accuracy, basin perimeter, basin area, and the catchment's compactness coefficient.

To measure the basin perimeter a scanned topographic image was imported into *Arc GIS*. Using the topographic map's 1:24000 ratio and a computer generated measured line that was traced around the basin, the perimeter was estimated to the accuracy of the topographic map. The basin area was calculated by creating a shape file within the catchment perimeter. The area of the shape file was calculated by *Arc GIS* and was then converted using the topographic ratio. The compactness coefficient of the stream was calculated by dividing the 'real circle perimeter' by the catchments calculated perimeter.

The real circle perimeter was calculated by determining what the perimeter of Wolf Creek's catchment would be if its measured basin area were a perfect circle.

The sinuosity of the stream segment was calculated by dividing the total length of the segment by the straight-line length between the beginning and end of the segment. A sinuosity value was calculated for each section of the stream between Sites 1a and 2, Sites 2 and 3, and Sites 3 and 4. Since there is a golf course and a riparian corridor between Sites 3 and 4, the sinuosity of each of those sub-stretches was also calculated. Furthermore, due to controlled stream flow between Sites 1a and 2, two different sinuosity values were calculated, one for the upstream area of the section and one for the downstream area, then averaged together. This avoided an inflated sinuosity value due to perpendicular stream channelization.

A stream that exhibits a sinuosity that is lower than 1.5 is classified as a strait stream that either has stable, well-defined banks that may be bedrock controlled, or is a channelized stream (Gordon et. al., 2004). A segment with a sinuosity value between 1.5 and 4.0 is classified as a meandering stream that is both mature and dynamic (Gordon et. al., 2004).

Numerical Modeling

Using the *GroundwaterVista* (GWV) Platform, *MODFLOW* (McDonald and Harbaugh, 1988; Pollock, 1994) was used to model groundwater flow within the basin.

The model domain was defined by the surface drainage basin. Given the geology of the system, glacial till overlying Pennsylvanian bedrock, and the assumption that vertical groundwater flow was negligible, the system was viewed as one layer representing the glacial till (

Figure 3). The aquifer layer was treated as homogenous, isotropic, and of a uniform thickness. From the discharge measurements, Wolf Creek is a gaining stream fed by ground water. Recharge, the primary catalyst in exposing land development differences, is assumed to be uniform over the entire drainage area.

The drainage divide surrounding Wolf Creek's catchment served as a Neumann or "no flow" boundary for horizontal surface and ground water flow. The surface of the bedrock was also represented as a Neumann boundary limiting vertical flow out of the aquifer. Therefore, only horizontal flow was modeled, vertical groundwater flow was assumed to be irrelevant. The morphometric data and the detailed spatial stream data collected from the GPS were imported into GWV. This information served as a spatial backdrop to design the model around. Since Wolf Creek is the source of known head values throughout the model it was designated a Dirichlet boundary and was used to derive stream and ground water gradient values.

A 100 x 100 cell grid represented the model domain. Each cell represented 150 meters by 150 meters. To simplify the model, it was necessary to assume that Wolf Creek fully penetrated a homogenous, isotropic, and uniformly thick aquifer that is underlain by semi-impermeable bedrock, that the local hydrologic system was steady state, and that there is uniform recharge over the drainage area. Emulating Fromm's (2005) methods for the numerical modeling of a nearby location, recharge was assumed to be 10% of the daily precipitation average, which for this area of Illinois is approximately 0.002 m/day. Storativity, specific yield, dispersivity and porosity were also assumed to be constant throughout the aquifer and were designated with initial values of 0.01, 0.2, 0.15 m and 10% respectively. The hydraulic conductivity was conservatively estimated and set at 0.3 m/day.

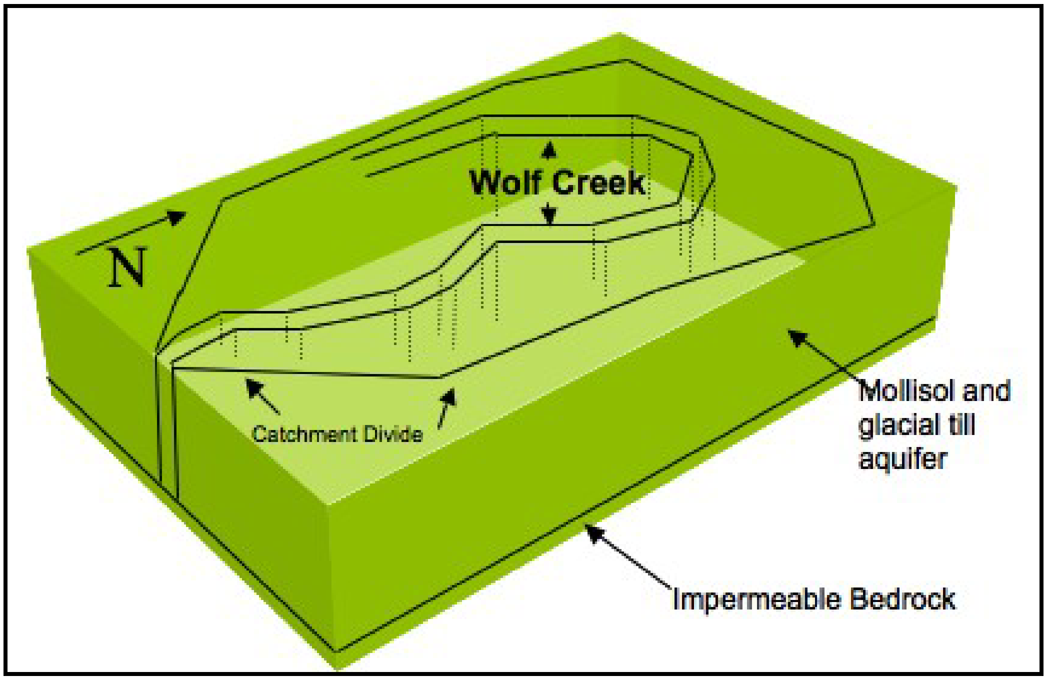

Figure 3. Conceptual diagram of the Wolf Creek watershed.

Water Sampling

Throughout the 13 months of the study, water quality was monitored at established sites during baseflow. Field-measured water quality parameters and water samples were collected and analyzed 11 times. Field parameters, temperature, dissolved oxygen, pH, and specific conductance, were measured using YSI® 63 and 85 meters. The probes were calibrated prior to use in the laboratory and consisted of a single electrode. The suite of parameters were recorded at each site simultaneous to the collection of a 250 mL water sample for anion analysis.

Anion Analysis

Water samples were collected in HDPE bottles. Each bottle was filled leaving minimal headspace, and the samples were placed and stored in a cooler until returned to the geochemistry laboratory at Illinois State University. Samples were refrigerated until they were prepared for chemical analysis. From each water sample, a 5mL aliquot was analyzed for anions using a Dionex DX-120 Ion Chromatograph (IC) and PeakNet V 6.30 software. Before a batch of water samples were analyzed, standards were analyzed and the IC was calibrated. Each set of standards consisted of known concentrations of anions; including nitrate, phosphate, sulfate, and chloride. The set of standards generated the standard curves that were used to quantify the anion concentrations in the collected water samples. After an initial analysis yielded nitrate concentrations that exceeded the upper limits of the standard curve, the samples were diluted using nano-pure water. Dilutions were either a 5:1 or a 10:1 nano-pure water to sample water ratio and were measured with adjustable calibrated volume pipettes. Quality assurance and quality control protocols were employed with the incorporation of blanks and duplicates into water sample batches as well as several trip blanks in the field. Error associated with the IC's anion analysis is inversely proportional to the measured concentration. However, an appropriate standard deviation generally used for these anion measurements is ± 10%.

Stream Discharge

Stream discharge, the volume of stream flow during a unit of time (V/t), was measured at four of the sites every few months. Discharge was measured using the velocity-area method (Mosely and McKerchar, 1993), where velocity in a vertical section (v_i) was measured at the 0.6 depth with an electromagnetic velocity meter. With the known dimensions of each traverse segment and the corresponding velocities, a total discharge (Q_tot) was calculated using :

$$Q_{\mathrm{tot}} = \sum_{i=1}^{n} v_{\mathrm{i}} A_{i}$$

where A_i is the area of each subsection of the cross-section defined by the width (w_i) of the segment and the depth (d_i) of the water in the segment (McCobb, 2003). At each of these four sites, a permanent cross section was developed allowing the stream gauging procedure to occur along the same traverse each time.

Calculating Mass Flux

Mass flux was calculated using the discharge data and the anion concentrations for each site. Concentrations of nitrate, chloride, and sulfate between Sites 1, 2, 3, and 4 were multiplied by its corresponding measured discharge. This yielded a value of mass flux for each parameter in mg/s parameter for each site. It was important to look at chemical flux because unlike concentration, flux is independent of stream volume. In other words, it discounts dilution and characterizes the total mass of an ion passing through an area of a stream at one point in time. Differences in the mass flux between the sampling sites provided information about the removal or addition of solutes along a given stream stretch.

CHAPTER V

RESULTS

Morphometric Analysis

The characterization of Wolf Creek's catchment basin yielded values for the basin area, perimeter, and compactness coefficient (Table 1).

Table 1. Results of the morphometric analysis.

Basin Perimeter (km)	Basin Area (km^2)	Real Circle Perimeter (km)	Compactness Coefficient
15.04	24.77	13.77	0.92

Sinuosity values were calculated for each section of Wolf Creek (Table 2). The highest stream sinuosity occurring among agricultural land development was 1.11; between Sites 1 and 2. The initial sinuosity value for the section of the stream was much higher due to nearly perpendicular layout of the stream's channelization. However, this section of the stream was segmented to have two sinuosity values calculated which then were averaged. Wolf Creek's sinuosity rises to 1.38 between Sites 2 and 3. It is between these two upstream sections that Wolf Creek has the lowest sinuosity values and should be considered the most channelized. The sinuosity value is closer to describing the previous section than the one calculated for it. The stream's sinuosity increases significantly between Sites 3 and 4 to 2.03. However, this stretch of the stream was divided into two regions of sinuosity. First, Wolf Creek within the golf course yielded a sinuosity value of 1.69. With the exception of two downstream meanders, this section could be considered a strait and channelized region. Second, the riparian corridor ceded a sinuosity value of 2.37. This was the highest sinuosity value calculated for any section of Wolf Creek and is equitable to a mature and dynamic stream with little to no stream channelization.

Table 2. Sinuosity calculations of Wolf Creek.

Sites		Stream Distance (km)	Direct Distance (km)	Sinuosity
1 to 2		2.45	2.21	1.11
2 to 3		1.74	1.26	1.38
3 to 4		2.66	1.31	2.03
Upstream 3-4	Golf Course	1.30	0.77	1.69
Downstream 3-4	Riparian Corridor	1.36	0.57	2.37

Anion Sampling

The water samples collected from all sites were analyzed for chloride, nitrate, and sulfate concentrations (Tables 3,4,5,6,7).

Table 3. Anion concentrations for Site 1.

Site 1	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)
4/18/05	48.5	67.9	56.8
5/17/05	49.9	83.4	44.1
6/6/05	49.3	104.8	45.2
6/7/05	82.6	132.6	67.5
6/14/05	45.5	80.4	43.382
7/10/05	58.3	23.5	27.5

Table 4. Anion concentrations for Site 1a.

1a	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)
5/17/05	40.0	73.5	57.7
6/6/05	45.0	78.3	48.0
6/7/05	92.4	98.1	75.8
6/14/05	41.1	65.4	46.7
7/10/05	32.8	23.5	17.8
7/31/05	16.3	10.6	bdl
9/22/05	15.5	14.7	bdl
1/16/06	38.0	24.3	42.6
1/16/06	38.1	22.5	16.7
1/16/06	37.5	27.0	17.7

* bdl – below detection limit

Table 5. Anion concentrations for Site 2.

Site 2	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)
4/18/05	43.9	65.5	56.2
5/17/05	42.1	72.9	58.3
6/6/05	43.0	84.7	52.5
6/7/05	40.0	65.7	52.7
6/14/05	55.0	75.8	68.1
7/10/05	33.2	bdl	15.0
7/10/05	30.8	bdl	15.0
7/31/05	27.9	bdl	7.9
9/22/05	26.7	0.0	14.0
1/16/06	102.0	21.7	51.7

* bdl – below detection limit

Table 6. Anion concentrations for Site 3.

Site 3	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)
4/18/05	46.9	58.0	54.4
5/17/05	41.7	76.0	58.1
6/6/05	48.8	78.0	51.7
6/7/05	40.0	65.7	55.8
6/14/05	64.7	87.4	80.2
7/10/05	36.9	bdl	21.1
7/10/05	42.6	bdl	23.7
7/31/05	27.2	4.6	24.4
9/22/05	16.8	bdl	6.6
1/16/06	101.4	21.6	51.4

* bdl – below detection limit

Table 7. Anion concentrations for Site 4.

Site 4	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)
4/18/05	57.3	80.8	47.2
5/17/05	44.0	71.5	55.8
6/6/05	43.3	70.9	54.6
6/7/05	40.7	55.6	53.4
6/14/05	59.1	60.5	65.6
7/10/05	49.3	bdl	29.5
7/11/05	49.8	bdl	25.9
7/31/05	48.3	bdl	25.9
9/22/05	42.3	4.1	16.2
9/23/05	36.1	bdl	18.1
1/16/06	57.3	80.8	47.2

* bdl – below detection limit

The results of the water samples analyzed for anion concentrations were plotted with respect to sampling locations (Figure 4). Nitrate concentrations varied greatly ranging from 140 mg/L to 0 mg/L. Several times throughout the study nitrate was not detected because its concentration was below the detection limit of the ion chromatograph. In these situations, the concentrations were designated 0 mg/L. There are some distinct seasonal patterns in these data. Namely, concentration fluctuations that seem to be similar between seasons save the magnitude. Therefore, the average sulfate and nitrate concentrations were separated into concentrations collected between April and June of 2005 and July 2005 and January 2006 (Figure 5). Averages of all the anion concentration values were calculated and plotted with respect to their sampling locations.

Nitrate concentrations exhibits a decrease throughout the year between Sites 1 and 2, 1a and 2, and 3 and 4. Between Sites 2 and 3 there is little change. As mentioned earlier, nitrate concentrations differ in magnitude throughout the year but display a consistent trend between sites.

Sulfate exhibits a minor increases and decreases between sites throughout the year. However, although there are minor spatial changes in the sulfate data, they fall within the margin of error of the analysis and it would be inappropriate to extrapolate meaningful trends from these changes. That said, there is better evidence of seasonal trends in the sulfate data between the first and second half of 2006.

Although the average chloride concentration deceases between Sites 1 and 2, it steadily increased after Site 2 throughout the rest of the stream. Its greatest average increase occurred between Sites 3 and 4.

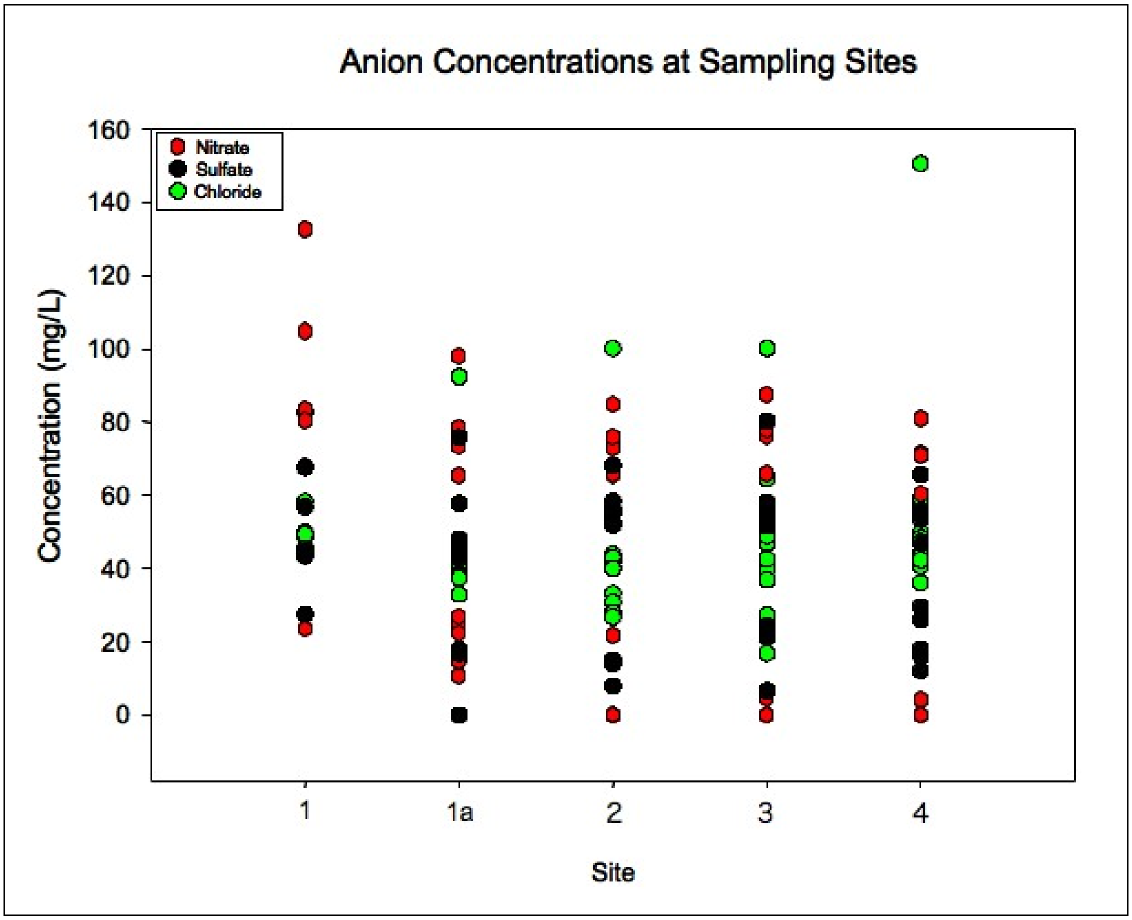

Figure 4. Nitrate, chloride and sulfate concentrations. See Tables 3, 4, 5, 6, and 7 for raw data.

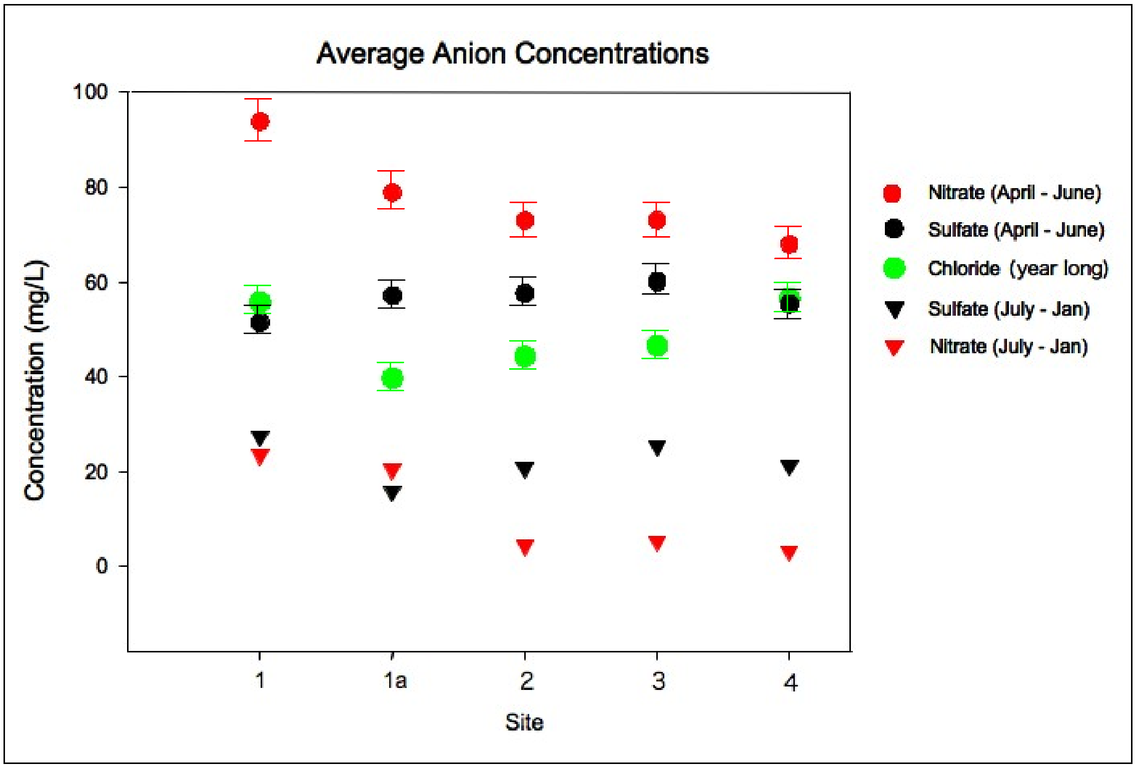

Figure 5. Seasonal average anion concentration for each study site (See Figure 4). Below approximately 30 mg/L the symbols are as large as the error bars would be.

Mass Flux Calculations

Discharge was measured five times throughout the study (Table 8). There are no discharge data for Sites 1 and 2 on April 19th, 2005 because those sites had not yet been incorporated into the study. Anion flux and its change between sites were calculated using discharge and anion concentration data (Table 9 & 10).

Table 8. Calculated discharge in L/s.

Date	Site 1	Site 2	Site 3	Site 4
4/19/05	dry	no data	149.4	dry
5/18/05	22.9	131.2	129.3	22.9
6/7/05	dry	80.7	125.5	dry
6/18/05	dry	55.2	32.3	dry
8/1/05	dry	8.22	1.86	3.49

Table 9. Anion Flux.

	Site 1	Site 2	Site 3	Site 4
Sulfate (mg/s)				
4/19/05	1299.6	bdl	8123.7	7722.0
5/18/05	bdl	7648.4	7510.1	7921.2
6/7/05	bdl	4234.5	6487.6	7734.0
6/18/05	bdl	3756.9	2590.7	2702.4
8/1/05	bdl	64.6	45.3	56.5
Nitrate (mg/s)				
4/19/05	bdl	bld	8669.8	13219.2
5/18/05	bdl	9568.5	9828.7	10144.3
6/7/05	bdl	6832.5	8249.5	7869.9
6/18/05	bdl	4182.2	2823.4	2491.9
8/1/05	bdl	bdl	8.6	14.3
	Chloride (mg/s)			
4/19/05	1109.4	0.0	7011.3	9361.2
5/18/05	bdl	5520.3	5385.0	6239.9
6/7/05	bdl	3470.2	6131.5	6124.0
6/18/05	bdl	3033.6	2089.1	2433.9
8/1/05	bdl	229.5	50.5	147.5

* bdl – below detection limit

Table 10. Change in anion flux between sites.

	Site 1-2	Site 2-3	Site 3-4
Sulfate (mg/s)			
4/19/05	-1299.6	8123.7	-401.7
5/18/05	7648.4	-138.2	411.1
6/7/05	4234.5	2253.1	1246.3
6/18/05	3756.9	-1166.2	111.7
8/1/05	64.6	-19.3	11.2
Nitrate (mg/s)			
4/19/05	0.00	8669.8	4549.4
5/18/05	9568.5	260.2	315.6
6/7/05	6832.5	1417.0	-379.6
6/18/05	4182.24	-1358.8	-331.6
8/1/05	0.00	8.6	5.7
Chloride (mg/s)			
4/19/05	-1109.4	7011.3	2349.8
5/18/05	5520.3	-135.4	855.0
6/7/05	3470.2	2661.3	-7.4
6/18/05	3033.6	-944.5	344.8
8/1/05	229.5	-178.9	967.0

The yearly and seasonal average anion concentrations between Sites 1 and 2, 2 and 3, and 3 and 4 were plotted against sinuosity (Figure 6). Between Sites 2 and 3, the average change in nitrate, chloride, and sulfate concentrations increased less than 5 mg/L. All three anions, including their seasonal breakdowns, are similar in this region showing very little change between Sites 2 and 3. The average change in nitrate concentration decreases a significant 19 mg/L between Sites 1 and 2 while chloride shows a modest decrease and sulfate remains constant. From Site 3 to Site 4 there is an average increase in chloride concentration of about 14 mg/L whereas the sulfate and nitrate values demonstrate decreases in the average concentration changes of almost 8 mg/L.

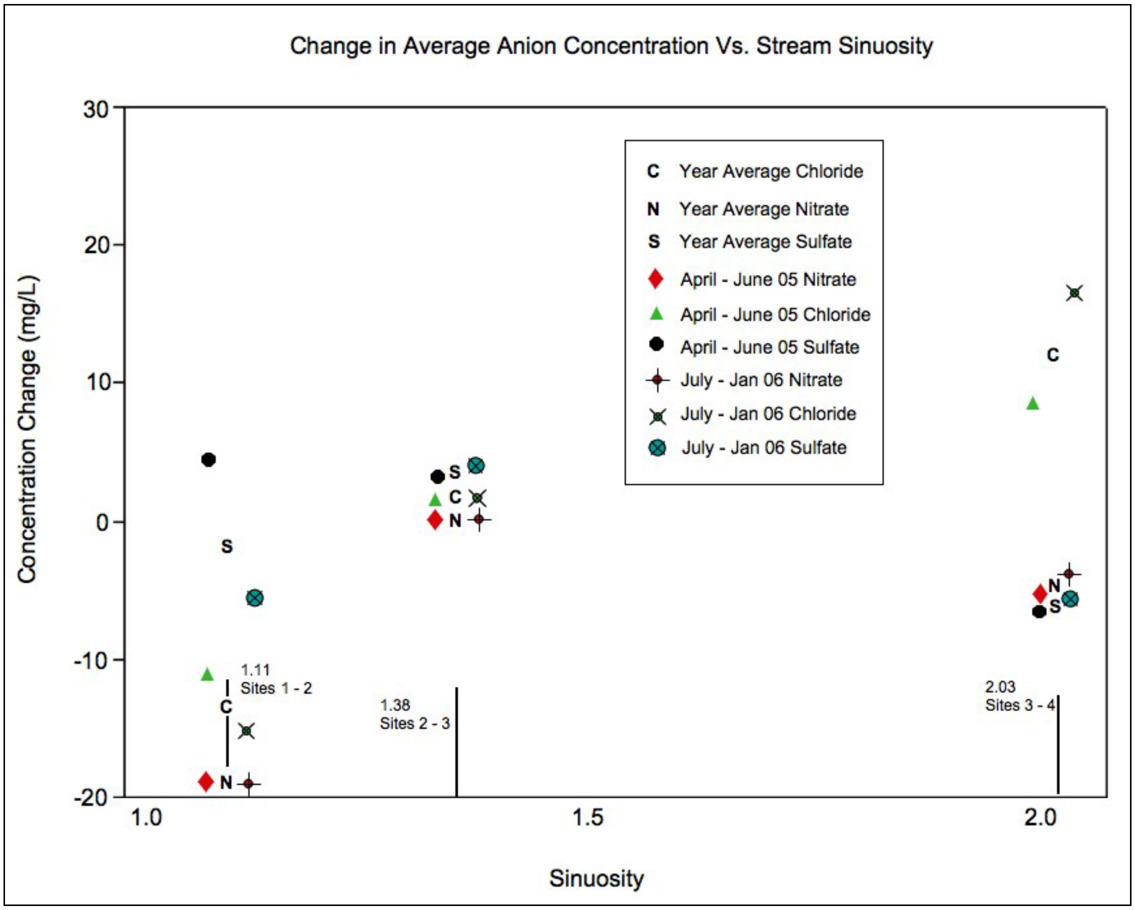

Figure 6. Seasonal average anion concentration changes between sites. See Tables 3, 4, 5, 6, and 7.

The change in chloride flux varies greatly between sections of Wolf Creek (Figure 7). In the headwaters of the stream between Sites 1 and 2, chloride flux increases significantly from the upstream site to the downstream site while between Sites 2 and 3 there are erratic changes. Between Sites 3 and 4 chloride flux tended to increase downstream but not as much as between Sites 1 and 2.

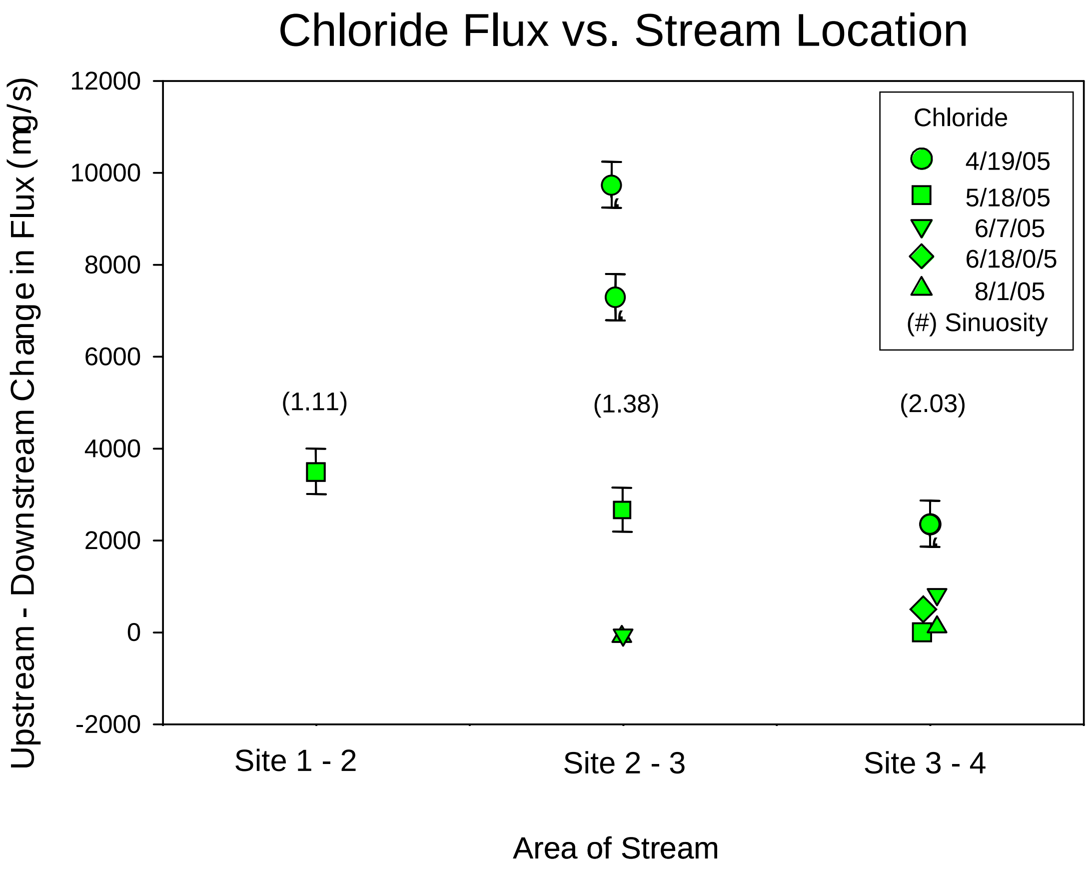

Figure 7. Change in chloride flux between Sites. See Tables 3, 4, 5, 6, and 7. Below approximately 3000 mg/L the symbols are as large as the error bars would be.

The changes in sulfate flux are very similar to the changes in chloride flux with some exceptions furthest down stream (Figure 8). Sulfate showed an increase in flux between Sites 1 and 2. Between Sites 2 and 3 the change in sulfate flux is as erratic as the change in chloride flux in the same area. However, as chloride flux consistently increased between Sites 3 and 4, sulfate flux proved to decrease.

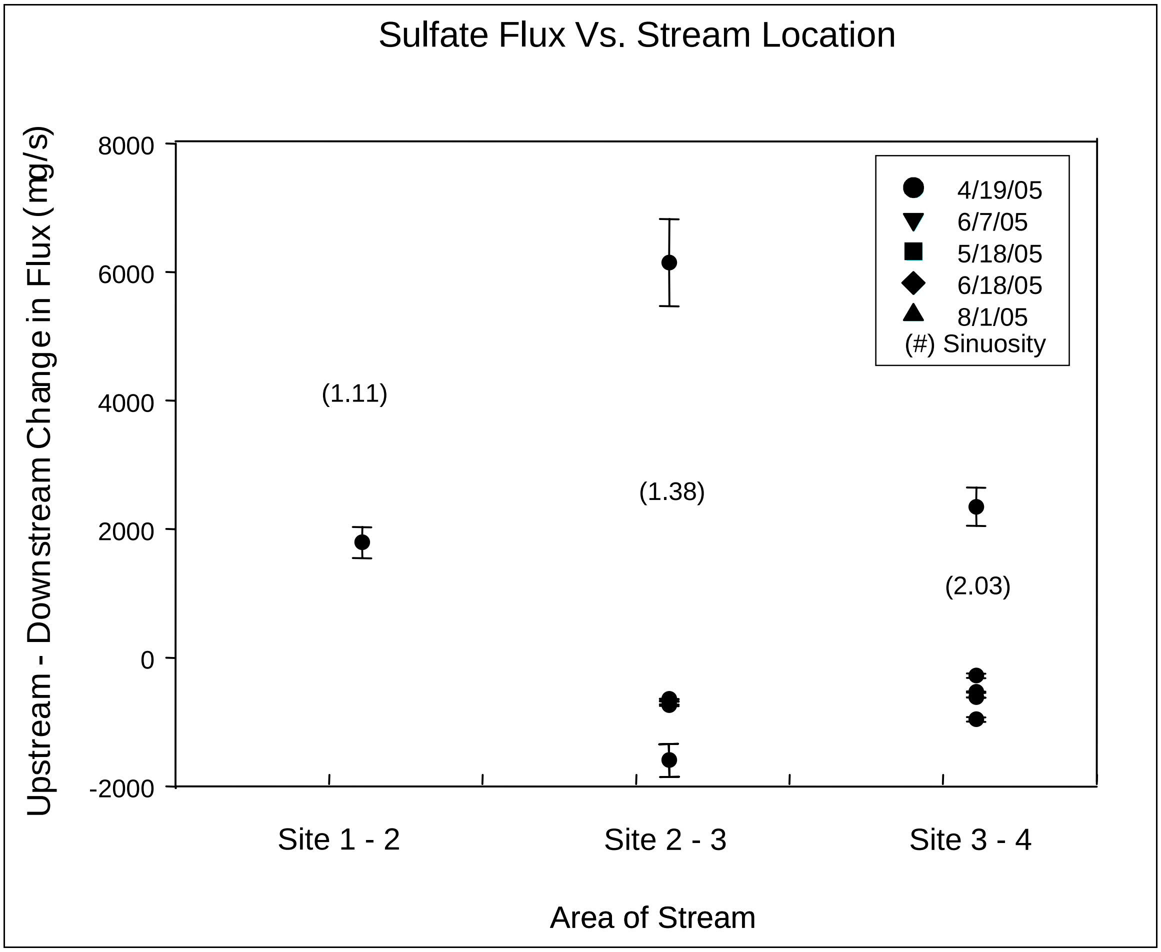

Figure 8. Change in sulfate flux between Sites. See figures 3, 4, 5, 6, and 7. Within approximately 1000 mg/L of 0 mg/L the symbols are as large as the error bars would be.

The change in nitrate flux throughout Wolf Creek's headwaters is negligible (Figure 9). The area of stream between Sites 2 and 3 generally displayed both increases and decreases of nitrate while the area between Sites 3 and 4 generally saw a negligible change with all but one data point.

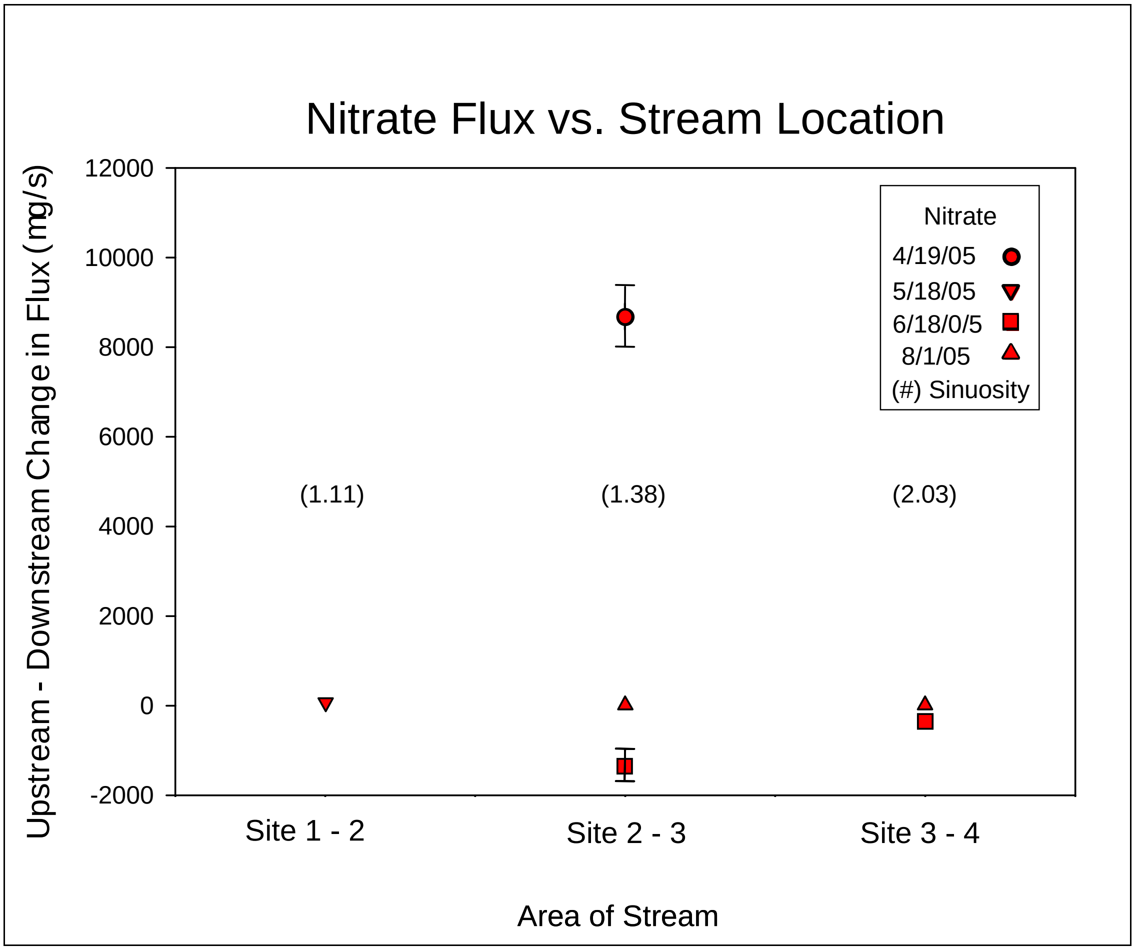

Figure 9. Change in nitrate flux between Sites. See Figures 3, 4, 5, 6, and 7. For values close to zero, the data point symbols are larger than the error bars.

Changes in chloride and nitrate flux were graphed together to better compare conservative and non-conservative anions (Figure 10). The changes in nitrate flux mimic much of the chloride flux changes between Sites 1 and 2 and Sites 2 and 3. However, nitrate does not increase as much as the chloride between Sites 3 and 4.

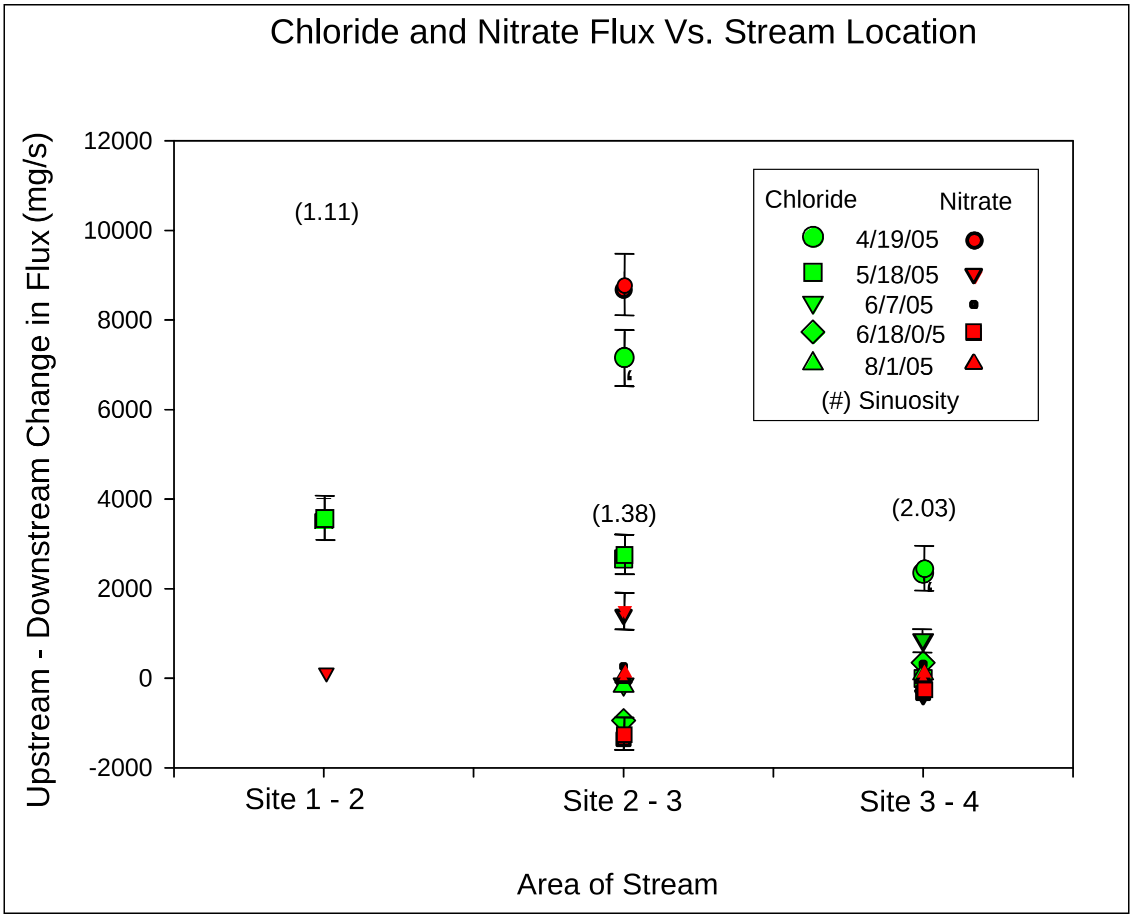

Figure 10. Changes in chloride and nitrate flux between Sites. See figures 3, 4, 5, 6, and 7. For values close to zero, the data point symbols are larger than the error bars.

Most of the parameters collected with field YSI instruments were consistent within each site throughout the year with expected variation in temperatures and specific conductance (Table 11). There was little variability in pH and salinity. Dissolved oxygen (DO) varied the most. Qualitative field notes suggest that DO tended to be low with more stagnated water and higher with higher velocity stream flow.

Table 11. Field Measured Parameters.

Site 1							
	DO %	DO mg/L	Temp ºC	pH	Spc uS/cm	Turbidity (ntu)	Salinity (ppt)
4/12/05	142.0	16.3	9.1	7.9	462.0	6.8	0.4
4/19/05	dry	dry	dry	dry	dry	dry	dry
5/18/05	n/d	n/d	12.0	7.8	455.0	7.6	0.4
6/7/05	n/d	n/d	18.4	7.9	507.0	n/d	0.4
6/17/05	119.1	10.9	19.7	7.9	513.0	n/d	0.4
6/18/05	90.7	9.2	14.5	n/d	n/d	n/d	n/d
7/11/2005 ~0930	22.7	2.0	20.5	7.6	921.0		0.7
7/11/2005 ~1130	dry	dry	dry	dry	dry	dry	dry
7/11/2005 ~1400	dry	dry	dry	dry	dry	dry	dry
8/1/05	dry	dry	dry	dry	dry	dry	dry
8/11/05	dry	dry	dry	dry	dry	dry	dry
1/7/06	dry	dry	dry	dry	dry	dry	dry
1/7/06	dry	dry	dry	dry	dry	dry	dry
Site 1a							
	DO %	DO mg/L	Temp ºC	pH	Spc uS/cm	Turbidity (ntu)	Salinity (ppt)
5/18/05	152.7	16.7	11.2	7.8	480.0	3.2	0.4
6/7/05	n/d	n/d	14.0	7.6	518.0	n/d	0.4
6/17/05	122.0	12.1	14.5	7.7	455.0	n/d	0.4
6/18/05	n/d	n/d	n/d	n/d	n/d	n/d	n/d
7/11/2005 ~0930	stagnant	stagnant	stagnant	stagnant	stagnant	stagnant	stagnant
7/11/2005 ~1130	70.3	6.7	17.0	7.9	347.0	7.5	0.3
7/11/2005 ~1400	73.5	7.2	19.4	8.0	285.0	9.0	0.2
8/1/05	62.9	6.2	17.4	6.8	641.0	n/d	0.4
8/11/05	63.3	5.8	19.4	7.9	649.0	n/d	0.4
1/7/06	75.6	8.8	8.9	n/d	788.0	n/d	0.6
1/7/06	43.3	5.0	8.5	n/d	826.0	n/d	0.6
Site 2							
	DO %	DO mg/L	Temp ºC	pH	Spc uS/cm	Turbidity (ntu)	Salinity (ppt)
4/12/05	143.4	15.6	10.9	8.1	473.0	7.8	0.4
4/19/05	n/d	n/d	n/d	n/d	n/d	n/d	n/d
5/18/05	160.8	17.8	14.9	8.1	473.0	3.0	0.4
6/7/05	n/d	n/d	17.2	8.0	499.0	n/d	0.4
6/17/05	170.4	15.3	20.7	8.4	514.0	n/d	0.4

6/18/05	110.2	10.9	15.1	n/d	n/d	n/d	n/d
7/11/2005 ~0930	38.3	2.2	22.8	7.8	484.0	5.2	0.4
7/11/2005 ~1130	26.5	2.3	22.4	8.0	497.0	6.6	0.4
7/11/2005 ~1400	37.8	3.4	23.1	8.0	501.0	2.5	0.4
8/1/05	33.0	2.9	24.0	8.0	715.0	n/d	0.4
8/11/05	98.0	3.0	25.7	7.9	765.0	n/d	0.4
1/7/06	69.6	9.0	3.9		709.0	n/d	0.6
1/7/06	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Site 3							
	DO %	DO mg/L	Temp ºC	pH	Spc uS/cm	Turbidity (ntu)	Salinity (ppt)
4/19/05	158.4	15.0	14.7	8.1	488.0	4.7	0.4
5/18/05	195.8	19.5	15.6	8.0	498.0	2.0	0.4
6/7/05	n/d	n/d	19.7	8.0	503.0	n/d	0.4
6/17/05	115.5	9.5	20.9	7.8	512.0	n/d	0.4
6/18/05	81.9	7.6	18.8	n/d	n/d	n/d	n/d
7/11/2005 ~0930	n/d	n/d	n/d	n/d	n/d	n/d	n/d
7/11/2005 ~1130	n/d	n/d	n/d	n/d	n/d	n/d	n/d
7/11/2005 ~1400	36.2	3.0	23.8	9.0	417.8	12.1	0.3
8/1/05	18.8	1.7	22.7	7.8	463.0	n/d	0.2
8/11/05	57.0	4.3	26.1	8.1	636.0	n/d	0.3
1/7/06	51.9	6.9	2.9	n/d	766.0	n/d	0.7
1/7/06	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Site 4							
	DO %	DO mg/L	Temp ºC	pH	Spc uS/cm	Turbidity (ntu)	Salinity (ppt)
4/19/05	n/d	n/d	n/d	n/d	n/d	5.6	n/d
5/18/05	203.3	19.3	18.2	8.2	509.0	4.3	0.4
6/7/05	-	-	23.1	7.8	568.0	n/d	0.4
6/17/05	122.8	10.8	21.8	8.2	304.6	n/d	0.2
6/18/05	90.5	8.1	21.0	n/d	n/d	n/d	n/d
7/11/2005 ~0930	73.0	6.4	21.3	8.2	171.0	9.5	0.1
7/11/2005 ~1130	45.0	3.9	22.3	8.0	414.1	8.4	0.3
7/11/2005 ~1400	9.8	0.9	22.9	8.5	430.0	5.4	0.0
8/1/05	15.8	1.3	24.0	7.8	809.0	n/d	0.4
8/11/05	65.3	5.3	25.9	7.8	595.0	n/d	0.4
1/7/06	72.0	10.1	2.9	n/d	699.0	n/d	0.6
1/7/06	n/d	n/d	n/d	n/d	n/d	n/d	n/d

*n/d indicates there were no data collected

Ground Water Model

Given that Wolf Creek is a primarily gaining stream, Wolf Creek's geographical and spatial data were used to model the local groundwater interacting with it (Figure 11). The basin scale ground water flow model indicates a general flow direction of south-southeast. The thicker and darker blue line represents Wolf Creek and is spatially derived data from both a topographic map and data points collected with a GPS unit. The black line surrounding the model is an estimation of Wolf Creek's drainage divide. Since it is a Neuman or no flow boundary, proximal flow is parallel to the divide. It is important to note that since the modeled data have been extrapolated from data points along the stream, modeled information furthest from the stream is probably unreliable. For example, the northern portion of the catchment has modeled groundwater flow based upon data kilometers away. Furthermore, as a result of the method of data extrapolation, the model has supposed that Wolf Creek is a ubiquitously gaining stream. This is evident in the relationship between Wolf Creek and the ground water elevation contours. Although this would be consistent with most of the data, it may not be accurate for all points at all times throughout the study. To better model this area, ground and surface water elevations would be required as well as a better characterization of the El Paso end moraine.

A simple calibration procedure was used to refine the model. Since the primary quantitative values used in this model were the Dirichlet boundary hydraulic head values, those values were used as target values. The minimization of the residual, the difference between the modeled values and the observed, resulted from minor adjustments of hydraulic conductivity and porosity. The final hydraulic conductivity value used was 0.5 m/day whereas the porosity remained at 10%.

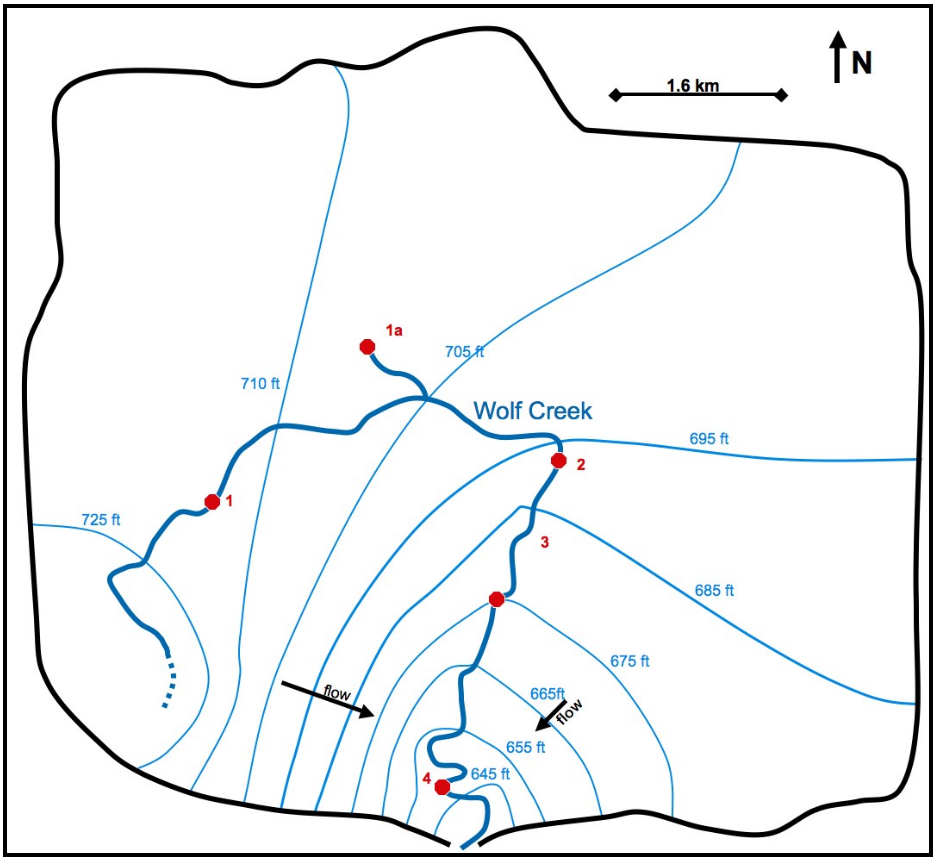

Figure 11. Ground water flow model of the Wolf Creek's catchment basin. Contour interval = 10 feet.

CHAPTER VI

DISCUSSION

Morphometric Analysis

Subtle relief throughout the flood plain and a compactness coefficient value of 0.916 indicates that the Wolf Creek's basin is developed and moderately mature. If most of this stream was not channelized it would likely have significantly more meandering than it does now.

The calculated sinuosity values provide a way of further examining the development of Wolf Creek by characterizing the sections between each of the study sites. The initial sinuosity value between Sites 1 and 2 of nearly 2.00 is interesting because it suggests that Wolf Creek is not principally channelized in this region when in fact the opposite is true. This discrepancy can be attributed to several linear stretches aligned in a non-linear fashion, therefore skewing the linear distance used to calculate sinuosity. The recalculation of the sections two primary stretches yielded a more reasonable value of 1.11.

One of the more channelized regions of Wolf Creek exists between Sites 2 and 3 with a sinuosity value of 1.38. This is primarily due to Wolf Creek being a boundary between two properties for nearly 1.5 km and needing to be stable. Since Wolf Creek flows through two distinct environments between Sites 3 and 4 it was necessary calculate the sinuosity for each one. Not surprisingly, the El Paso Golf Club had a lower sinuosity of 1.69. One of the most important features for any golf course is successful irrigation and drainage control. This would include jurisdiction over the surface water and its flow paths throughout the area. However, Wolf Creek is not completely linear within the golf course as it does have several small meanders towards the southern region of the property. The sinuosity of the riparian corridor is the highest calculated for any part of the stream: 2.37. Naturally vegetated, un-engineered property yielded a natural morphological evolution of Wolf Creek that is reflected in this sinuosity value.

These sinuosity values are characteristic of large-scale stream morphology and meandering and thus indicative of potential hyporheic and ground water interaction with stream water (Fromm, 2005; Peterson and Sickbert, 2006). Hyporheic zones can oxygenate the ground water and influence denitrification with the advection of dissolved oxygen and solutes (Triska et al., 1993). So, if there is a greater frequency of meandering, there could be a greater potential for the reduction of terminal electron acceptor and contaminant species (Fromm, 2005; Peterson and Sickbert, 2006). Congruent with this study's data, Fromm's (2005) research suggests that higher sinuosity within a stream segment should result in a decrease in nitrate.

The discharge data gathered from Wolf Creek is that of a primarily gaining stream. Throughout the study the downstream site has generally had greater discharge than an upstream site. However, there were some inconsistencies between Sites 2 and 3 regarding discharge. Site 2 has had significantly less water than Site 3 several times but there have been instances when the opposite has also been true. These discharge anomalies cannot be explained with certainty although several possible explanations present themselves:

As previously stated, about halfway through the study a beaver dam was constructed downstream of the Site 3 sampling location. To stay consistent with past visits, discharge and water sample collection was done just upstream of the beaver dam. The beaver dam may have had an effect on stream velocity both upstream and downstream of the dam and therefore may have skewed some discharge results.

An additional explanation for the discharge inconsistencies could be groundwater and drought complications. It is possible that during the 2005 drought that Wolf Creek became a losing stream between Sites 2 and 3. In the numerical model of the Wolf Creek watershed, the change in ground water elevation between Sites 1 and 3 is much less than the change between Sites 3 and 4. More simply put, the ground water table would have to fall a relatively short distance to not intersect with the stream channel in the vicinity of Site 2. That said, and the facts that Site 1 ran dry at the very beginning of the drought and that there is an outside input of water via Site 1a's drainage tiles a short distance from Site 2, it is possible that the water table fell below enough near Site 2 where Wolf Creek could have became a losing stream.

Numerical Modeling

Although the basin ground water flow model lacks credibility in the northern section due to the lack of hydraulic head data to extrapolate from, the model does offer a general idea of what the general ground water flow patters are likely to be within areas of the Wolf Creek catchment proximal to the stream. It is also congruent with field gathered data that indicates that Wolf Creek is primarily a gaining stream. Regarding larger scale flow patterns, analogous models in similar hydrological situations have shown that within a highly sinuous section of a stream hyporheic and ground water interactions with stream water can advect many dissolved species across a meander (Fromm, 2005).

Chemical Data

When considering chloride mass flux (Figure 6) it is important to reiterate several things. First, Wolf Creek interacts with the most amounts of roads between Sites 1 and 2 and has at least some storm sewer water input from the City of El Paso via the tiles drains at Site 1a. Second, there are no road intersections with the stream between Sites 2 and 3. Third, there is only one road crossing within the El Paso Golf Club property but Wolf Creek does navigate near the road several times. Fourth, the suburban area down stream of the agricultural region is primarily set up to have private septic systems for each residence. As stated earlier, this is a potentially significant source of chloride in the ground and stream water.

Since chloride is a conservative anion that consistently exhibits an increase in the average concentration between upstream and downstream sampling areas throughout the year, it is logical to interpret that data as an accumulation of the anions. Plotted changes in chloride flux demonstrate a positive input of chloride between Sites 1 and 2, 2 and 3, and 3 and 4. This is not surprising since chloride is a conservative anion and would be subject to few ‘sinks’ that could lead to a negative flux.

Given the very low stream flow and nearly dry conditions at Site 1 that results in abnormally high species concentrations, the negligible change in nitrate flux between

Sties 1 and 2 can be explained by further dilution and the unavoidable addition of more contaminant anions. As expected, the region between Sites 2 and 3 experiences both increases and decreases in nitrate flux, however, between Sites 3 and 4 there is essentially no discernible trends. All three of these regions have some source of nitrate, the latter being the least significant as the fertilizer application on a golf course is dwarfed by that of agricultural farmland. The negligible change in nitrate flux between Sites 3 and 4 is highlighted in its comparison with chloride flux. This localized precedent of diverging trends between chloride and nitrate flux suggests a nearby chloride source, possibly residential septic systems, and potentially some nitrate reducing reactions.

Average nitrate concentration trends were consistent through the first and latter half of the year and generally showed concentrations decreasing downstream. This general decrease in nitrate concentration seen between upstream and downstream sites could be attributed to several stream processes. Foremost, dilution is likely a primary cause of concentration decreases downstream. Dilution, combined with the diminishing source of nitrate further downstream would also generate a decrease in anion concentration. Still, differences between chloride and nitrate flux concentration suggest there could be significant amounts of denitrification further downstream where hyporheic and ground water interactions with stream water are more likely to occur. In a nearby watershed, Fromm (2005) and Buyck (2005) both estimated that between 0.07 to 2.1% N was lost by denitrification under meanders and within the hyporheic zone.

With the exception of sulfate concentrations decreasing between Sites 1 and 2 throughout late 2005, sulfate tended to increase slightly between upstream and downstream sites until Site 3 where there seems to be a decrease in concentration between Sites 3 and 4. Although these averages do show minor trends between sites, they are very close, if not within, the margin of error of the analytical process and therefore cannot be a significant source of reasoning hydrogeological relationships.

Although there was not a sampling location between the riparian corridor and the golf course, it can be assumed that the golf course did contribute to some of the nitrate, chloride, and sulfate input into Wolf Creek. Whereas sulfate concentrations and sulfate flux probably begin decreasing slightly after Site 3 and nitrate consistently decreased throughout the stream, chloride consistently increased throughout the entire stream. Considering all this, it seems that dilution is doing its part to decrease concentrations throughout the stream for all anions. However, as chloride, nitrate and sulfate all experience this dilution, there seems to be an additional chloride input between Sites 3 and 4, namely.

While between Sites 3 and 4 there is a negative change in average nitrate and sulfate concentrations, a positive change in chloride concentrations, an increase in chloride flux, and a negligible change in sulfate and nitrate flux, between Sites 3 and 4as chloride concentrations increase between Sites 3 and 4 (Figure 5). This decrease in nitrate and sulfate concentration could potentially be attributed to dilution, however, the comparison of nitrate flux, chloride flux, and sulfate flux all suggest otherwise (Figure 7-Figure 10). Consistent throughout the flux data there is an overall decrease in sulfate and nitrate anions between Sites 3 and 4. Furthermore, up to Site 3, chloride and nitrate flux share nearly identical patterns between sites, then between Sites 3 and 4 the patterns deviate.

This trend seen throughout the data also correlates with the sinuosity data (Figure 6). Although the average nitrate concentration does decrease a great deal between Sites 1 and 2, this is almost exclusively because of the extremely low flow, high infiltration and evaporation setting causing localized concentration increases and the great deal of dilution that occurs enroute to Site 2. This is supported by the change in nitrate flux between Sites 1 and 2. That said, the greatest genuine nitrate and sulfate decrease in concentration seen in the study occurs with the most sinuous stream path. This is true for both the seasonal and yearly averages.

CHAPTER VII

CONCLUSIONS

Conclusions

Like many water systems in central Illinois, Wolf Creek, as it has for decades, will continue to endure and adapt to the dynamic progression of its surroundings. As long as there is fertile land, infrastructure, and society's resolve to flourish, there are potential hazards to the environment. Regarding Wolf Creek and its catchment, chloride and agricultural byproducts such as nitrate and sulfate have long since been a source of surface water pollution.

The original hypothesis of this study was that stream water downstream of agricultural and urban development would yield a higher flux but lower concentration of chloride, nitrate, and sulfate, ultimately producing inferior water compared to upstream waters. However, chloride was the only species to show consistent positive flux throughout the stream. This is likely because chloride is characteristically a conservative species, and a negative flux would indicate that the chloride is being used somewhere between each of the sites. Secondly, there are several sources of chloride throughout the nearby stream area ranging from residual sodium chloride from winter road salting to residential septic tanks.

Although the concentration of nitrate decreased downstream of Site 1 and 1a through Site 4, its flux demonstrated inconsistencies. Nitrate and sulfate generally had either a very positive or somewhat minor flux before Site 3, but between Sites 3 and 4 nitrate and sulfate flux was negligible and beyond the resolution of this study. With these data, it is difficult to conclude the hydrogeological relationship between the riparian corridor and potential nitrate and sulfate reduction.

Another question posited at the beginning of the study was if Wolf Creek possessed the potential for the natural attenuation of some stream contaminants. It is possible that allowing a stream to revert to a more natural state may enhance the natural attenuation of solutes introduced upstream. Although these data do not contradict this assertion, they do not have enough clout to support it. Ground water chemical analysis and an additional sampling location between the riparian corridor and the golf course may provide meaningful data.

Although no irrefutable evidence of Wolf Creek's natural attenuation and its link to a vegetated, naturally evolved, and sinuous stream path has resulted from the analysis of the Wolf Creek watershed, indications of just that situation are present. That said, this study has not, nor attempted to, answer other very important and perhaps soon to be timely questions regarding Wolf Creek's tolerance concerning society's future environmental impact. Specifically, how vital is a naturally attenuating riparian corridor to a watershed? Is there a minimum requirement of such a region, and if so, is there a maximum flux or concentration of contaminants that it could withstand without collapsing.

Wolf Creek, as well as many other watersheds across the country, are involved in a relentless contest in search of equilibrium between the necessities of a civilization and the reaction of earth processes. Such a balance needs to be established for the benefit of both.

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