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Nitrate Uptake in Central Illinois Streams: a Comparison along a Transient Storage Gradient

Kristen Lynn Theesfeld
Illinois State University, kltheesl@ilstu.edu

NITRATE UPTAKE IN CENTRAL ILLINOIS STREAMS:

A COMPARISON ALONG A TRANSIENT

STORAGE GRADIENT

Kristen L. Theesfeld

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Transient storage can be influenced by channel morphology. Anthropogenic activities can alter stream morphology by straightening channels, lining channels, or even restoration of previously altered channels. This study focused on whether relative transient storage (RTS) was related to stream type – modified lined, modified unlined, or natural. The study further sought to determine if a greater RTS is correlated to a decrease in percent nitrate-N.

Eight (8) sites, encompassing three (3) different stream types - modified lines, modified unlined, and natural – were studied. Chloride and nitrate tracers were added to streams, and samples were analyzed for tracer concentrations and specific conductance. Simulated break through curves from a One Dimensional Transport with Inflow and Storage (OTIS) model were best-fit to observed data to estimate stream RTS. Solute recovery was calculated using a mass balance equation. The influence of RTS on nutrient processing was then assessed by comparing RTS to change in percent of nitrate-N.

Contrary to predictions, RTS was highest in modified unlined streams (0.361) and lowest in modified lined streams (0.131). This discrepancy was attributed to elimination of sinuosity in natural streams, which further supports the importance of sinuosity in creating transient

storage. Abundant vegetation in modified unlined streams and differential sampling following recharge events also contributed to these results. Change in percent nitrate-N was predicted to decrease with increasing RTS. Change in percent nitrate-N decreased with increasing RTS as predicted, supporting the importance of transient storage in nitrate uptake. However, results were not statistically significant ($r^2 = 0.09$, $p < 0.05$), and a larger sample size with less variation in streams could further research.

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KRISTEN L. THEESFELD

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KRISTEN L. THEESFELD

COMMITTEE MEMBERS:

Eric W. Peterson, Chair

Catherine M. O'Reilly

William L. Perry

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CONTENTS

	Page
ACKNOWLEDGMENTS	i
CONTENTS	ii
TABLES	iv
FIGURES	v
CHAPTER	
I. INTRODUCTION	1
Stream System Modification	1
Effects of Modification	2
Transient Storage	3
Restoration	4
Broader Implications	6
Hypotheses	7
Site Geology	8
General Site History	8
Site Classification	9
II. METHODS	12
Tracer Injection and Sampling	12
Data Collection and Analysis	15
OTIS Modeling	16
III. RESULTS	21
Sampling Population	21
Tracer Test and Field Data	23
OTIS Modeling and Calibration	26
Sensitivity Analysis	31

Solute Mass Balance 35

IV. DISCUSSION 40

Relative Transient Storage 40
Solute Recovery 42
RTS v. NO_3^--N 44

V. CONCLUSION 45

REFERENCES 46

APPENDIX A: Field Data 52

APPENDIX B: Sample Times and Specific Conductances 73

APPENDIX C: Probe Data 82

APPENDIX D: Nutrient Concentrations of Samples 92

APPENDIX E: Proxy Relationship 101

APPENDIX F: OTIS Parameter Values 106

TABLES

Table		Page
1.	Site Classification Based on Morphology.	13
2.	Specific Quantities of Solute Introduced at each Location.	22
3.	Parameters Calculated from Field Measurements.	26
4.	Summary of Site RTS, NRMSE, and Solute Recovery.	36

FIGURES

Figure Page

1. Hypothesized RTS Based on Stream Type. 7

2. Anticipated Relationship Between Percent Change in Nitrate-N and RTS. 8

3. Nutrient Tracer Site Map (ISGS, 2007). 9

4. Field Testing Setup. 14

5. Measurements Taken for Cross-Sectional Area and Discharge Calculations. 15

6. OTIS Conceptual Model Adapted Courtesy of USGS (Runkel, 1998) 18

7. Downstream Break Through Curves for (A) Cl^-, (B) NO_3^--N, and (C) SpC. 24

8. Initial OTIS Output. 27

9. Final OTIS Output for Sites. 28

10. NRMSE Based on Stream Type. 29

11. Measured v. Modeled Cross-Sectional Area and Discharge. 30

12. Average RTS Based on Stream Type. 31

13. Sensitivity Analyses of OTIS Models. 32

14. Solute Recovery by Stream Type. 35

15. Nitrate-N to Chloride Ratios of Samples. 37

16. RTS v. Solute Recovered. 39

CHAPTER I

INTRODUCTION

Stream System Modification

It is estimated that over 70% of all streams in the United States have been modified (Kauffman et al., 1997) while up to 100% of all first-order streams within the state of Illinois have been modified (Mattingly et al., 1993). Modification can include stream diversion, stream bank stabilization, and stream channelization. According to the USEPA Clean Water Act (2005), stream channelization is defined as "…any activity that moves, straightens, shortens, cuts off, diverts, or fills a stream channel, whether natural or previously altered…that alters the amount and speed of the water flowing through the channel." Two main catchments in McLean County, IL are the Mackinaw and Sangamon River Basins. Within the Mackinaw River basin, 1.6% of stream length attributed to 6^{th}-order streams is modified, while 73.2% of stream length in 2^{nd}-order streams has been modified (Mattingly et al., 1993). The Sangamon River has had 11.7% of 6^{th}-order stream length modified while 100% of all 1^{st}-order streams have been modified (Mattingly et al., 1993).

One form of modification widely practiced in agriculture areas is the use of tile drains (USEPA, 2012). Over 90 percent of land in Central Illinois is used for agriculture, and a large portion is tile drained (Lemke et al., 2011). Tile drains are desirable because they improve crop production by removing excess water from agriculture areas (USEPA, 2012). Additionally, streams surrounding agriculture are often straightened to aid in water transport away from fields. Another common modification is the introduction of impervious surface cover (ISC), which inhibits the ability of water to infiltrate (NHEP, 2007). Roadways, parking lots, driveways, etc. are all forms of ISC (NHEP, 2007). In highly urbanized areas, ISC can constitute up to 60% of land cover (Nowak and Greenfield, 2012). Urban streams are often lined with ISC to control erosion, further lowering the ability of water to infiltrate (USEPA, 2005).

Effects of Modification

Straightening of streams and tile drains improve crop production by removing excess water from agriculture areas (USEPA, 2012). Water runoff from drains may, however, contain increased concentrations of nitrate from fertilizers used on crops. Nitrate-N concentrations in tile drain runoff may reach levels as high as 40 mg/L, four times the USEPA's 10-mg/L guideline (Brouder et al., 2005; USEPA, 2012). While Vidon et al. (2012) found that nitrate concentrations were an average of 28% lower in-stream than in tile drain runoff, streams particularly susceptible to tile drainage influences, such as those in Central Illinois, may exhibit degraded water quality. Implementation of best management practices have decreased the occurrence of such high concentrations, however, tile drains still input elevated concentrations of nitrate-N to streams (Brouder et al., 2005; Kladivko, 2001).

ISC decreases the ability of water to infiltrate soils, leading to increased surface runoff and elevated nutrient levels compared to natural lands (Cunningham et al., 2009). Nutrients in surface runoff can accumulate because of nitrate in lawn fertilizer and industrial wastewater inputs (Mayer et al., 2002; Moorman et al., 2002). To a lesser extent, nitrification of ammonium from septic systems can also increase nitrate loads (Moorman et al., 2002). Urban streams in Baltimore were shown to have, on average, more than 20 times nitrate concentrations than unmodified forest streams (Kaushal et al., 2008).

Transient Storage

Transient storage implies the temporary detainment, or storage, of water as it moves between the main channel and storage zones, resulting in inhibited flow compared to main channel flow velocity. Backwater areas and pools, and the hyporheic zone, these define what we consider transient storage zone (Baker et al., 2011; Bencala and Walters, 1983; Briggs et al., 2009; Zarnetske et al., 2007). During low flows, water moves slower in pools than other parts of the stream (Harman and Jennings, 1999). The hyporheic zone is the interface where surface water and groundwater mix (Orghidan, 1955). Increased residence time of water allows for chemical and microbial interactions within transient storage zones (Bencala and Walters, 1983). Prolonged microbial interaction results in a greater nutrient uptake potential, particularly within the hyporheic zone. Low-oxygen environments within the hyporheic zone are conducive to anaerobic microbial activity encouraging denitrification (Boulton et al., 1998).

By definition, the process of stream modification decreases sinuosity within a stream (USEPA, 2005). By removing meanders, the hyporheic zone under meander necks is eliminated. Meander necks are thought to be crucial in the processing of chemicals such as nitrate (Peterson and Benning, 2013; Peterson and Sickbert, 2006; and Van der Hoven et al., 2008). Straightening increases stream discharge and flow velocity (USEPA, 2005). This promotes streambed scouring, discourages sedimentation, and eliminates zones of transient storage in pools and backwater areas (Harman and Jennings, 1999).

Modification removes irregularities in streambeds and regulates water flow (Bukaveckas, 2012), and decreases overall stream complexity (USEPA, 2005). Complexity can include surface water-substrate connection, backwater areas, in-stream pools, and sediment composition (USEPA, 2005). Transient storage decreases when complexity decreases, because crucial sources of nutrient uptake are being removed from the nutrient cycle (Bukaveckas, 2012). D'Angelo et al. (1993) found transient storage zones to be insignificant in constructed (channelized) streams. Transient storage was greatest in natural, first-order streams, where the ratio of transient storage area to stream area averaged 1.2 (D'Angelo et al. 1993). Decreased transient storage means decreased interaction of surface water with the hyporheic zone, and decreased potential for denitrification (O'Donnell and Galat, 2007).

Transient storage is not solely responsible for nutrient uptake; however, it is an influencing factor. Other factors including temperature and nutrient saturation affect the ability of a stream to take up nutrients (Bernot et al., 2006; Claessens et al., 2009; Hall et al., 2002). In summer, a strong, positive relationship between nutrient uptake and transient storage exists (Claessens et al., 2009; Hall et al., 2002). Hall et al. (2002) showed a relationship between relative transient storage and nutrient uptake with an r^2=0.35. In winter, the relationship is less strong, with r^2=0.14 (Hall et al., 2002). Bernot et al., 2006 showed a relationship between nutrient concentration in streams and nutrient uptake.

Restoration

Stability of chemical composition or reaching a level of equilibrium can improve water quality and biotic livelihood. Increasing nutrient levels may be mitigated through different ways. Urban developments may opt to use low impact designs (LIDs) to control nutrient concentrations in surface waters (Bedan and Clausen, 2009). LIDs allow for greater infiltration, and therefore retention, of water (Bedan and Clausen, 2009). Stream restoration aims to return these qualities by either returning streams to pre-altered conditions or reducing the effect of stressors (USEPA, 2005; Tullos et al., 2009; Violin et al., 2011). Passive restoration halts activities that degrade stream water quality while active measures, such as stream channel redevelopment, try to repair damage done (Kauffman et al., 1997).

Morphologic restoration projects are a common form of stream restoration. Restoration may create backwater areas where Bukaveckas (2007) has shown nitrate uptake rates to be as much as thirty and three times greater respectively than uptake rates measured in unrestored, channelized streams. Reintroduction of meanders and construction of riffle pools are two key features of stream restoration that encourage nutrient uptake (Kauffman et al., 1997). Meanders promote nutrient uptake by increasing residence time. Peterson and Benning (2013), Peterson and Sickbert (2006), and Van der Hoven et al. (2008) demonstrated that stream meanders foster hyporheic processes such as nitrate loss. Constructed riffle units, another form of restoration, create a significant increased connectivity to the streambed (Fanelli and Lautz, 2008). Riffles not only reconnect stream to substrate, sediment fill allows a location for anaerobic microbial activities such as denitrification.

A study conducted by Bukaveckas (2007) compared nutrient uptake and transient storage in pre- and post-restoration stream reaches. Areas were historically agricultural, and restoration had occurred over several decades. Transient storage was found to be slightly higher in restored reaches than channelized reaches, primarily due to the creation of backwater areas. Nutrient uptake was also found to be higher in restored reaches than unrestored, mostly due to restricted flow. Following modification, a stream’s potential for denitrification increases with recovery time. Likewise, Sergeant (2012) has shown restored streams have higher sedimentation rates than altered streams, increasing streambed complexity, and likelihood of nutrient uptake. Harris (2008) compared denitrification between streams 4, 7, and 30+ years post-modification. The study found the 4 and 7-year post-modification streams to have a 0.5

mg/L difference between stream and hyporheic nitrate concentrations in water. A greater recovery time, in the 30+ year post-modification stream, contributed up to 3.0 mg/L difference between stream and hyporheic nitrate concentrations.

Broader Implications

Stream modification not only has the potential to lower water quality for human consumption, it lowers the ability for diverse biological communities to thrive (Vitousek et al., 1997). In relation to stream community complications, nitrate can cause areas of low or no oxygen (Robertson and Vitousek, 2009). When excess nutrients are introduced it can lead to algal blooms and increased phytoplankton (O'Donnell and Galat, 2007). When the algae and plankton die, microbes use oxygen in the water to decompose algal matter. This creates hypoxic and anoxic conditions (Robertson and Vitousek, 2009).

Over 500 sites around the world have been identified as eutrophic zones (WRI, 2011). In the United States, eutrophication in the Gulf of Mexico is the result of nutrient loading upstream within the Mississippi River Basin (MRB) (O'Donnell and Galat, 2007). The upper Midwest contributes 56% of nitrate in the MRB, of which 74% comes from crop fertilizer application (Rabalais et al., 2002). Within the Mississippi River Basin, predevelopment nitrate levels are estimated between 0.1-1.24 mg/L. (Goolsby and Battaglin, 2001). Current nitrate-N concentrations in McLean County, Illinois have been measured in agriculture output at over 6 mg/L and urban water at over 5 mg/L (Smiciklas et al., 2008). In another study of streams in the Midwest, Bernot et al. (2006) found nitrate-N concentrations can range from 0.2-5.1 mg/L. In a national study, approximately 2% of urban streams and 30% of agriculture streams exceeded the USEPA maximum contaminant limit of 10 mg-N/L (Dubrovsky and Hamilton, 2010). To preserve water integrity, it is necessary to decrease the output of nitrate in streams.

Hypotheses

1. I hypothesize that natural streams will have the greatest average transient storage, modified (unlined) streams will have an intermediate amount of transient storage, and modified (lined) streams will have the least transient storage (Figure 1). Determining if a relationship exists between stream type and transient storage could potentially allow for a rapid characterization of streams' potential for transient storage. Efficiency of nutrient removal could be increased if certain stream types can be targeted in restoration efforts to produce the greatest benefit from reintroduction of transient storage.

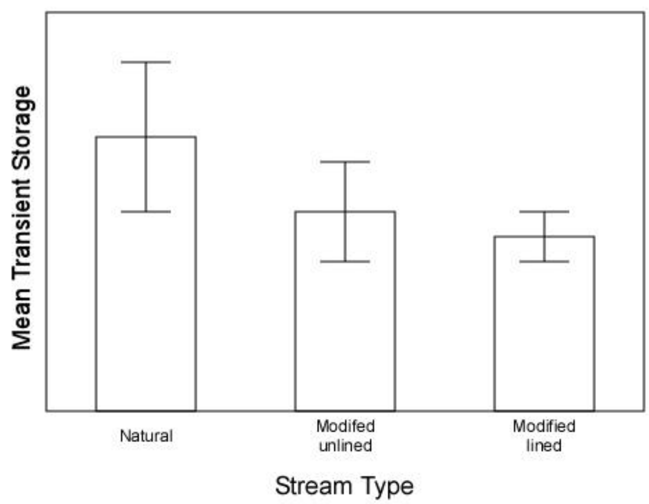


Figure 1. Hypothesized RTS Based on Stream Type.

2. Additionally, I hypothesize that streams with greater transient storage will experience greater negative change in nitrate-N mass (Figure 2). Change in nitrate-N is anticipated become more negative as relative transient storage (RTS) increases. Analyzing nutrient uptake compared to transient storage could help make basic assumptions about streams in the Midwest and their ability to remove nutrients as they progress downstream to the Mississippi River.

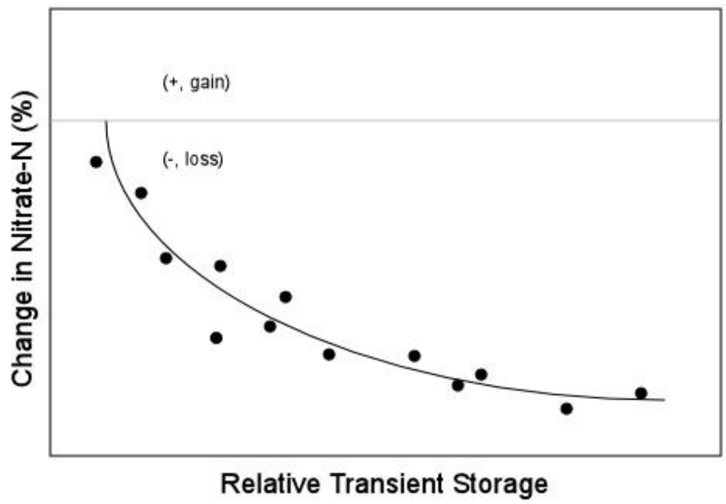


Figure 2. Anticipated Relationship Between Percent Change in Nitrate-N and RTS.

Site Geology

General Site History

Study sites were chosen within McLean County, IL for its variety of modified lined, modified unlined, natural, and restored low-order streams (Figure 3). Sampled watersheds are highlighted in blue and individual sites are denoted by markers (ISGS, 2007). All streams chosen for study sites are headwater or low-order streams. Central Illinois consists primarily of glacial deposits. Deposits present as well as unit thicknesses vary between locations in the study area, and may include the Wedron Formation, the Henry Formation, or the Cahokia Alluvium. The Wedron and Henry Formations are part of the Wisconsinan Stage of glaciation in Illinois. Layers of glacial till and moraine deposits characterize the Wedron Formation. The Henry Formation is primarily composed of outwash plain sand and gravel deposits. The Cahokia Alluvium is a flood deposit composed of sands, silts, and clays. All deposits vary in thickness throughout the study range (Kempton et al., 1982; Soller et al., 1999).

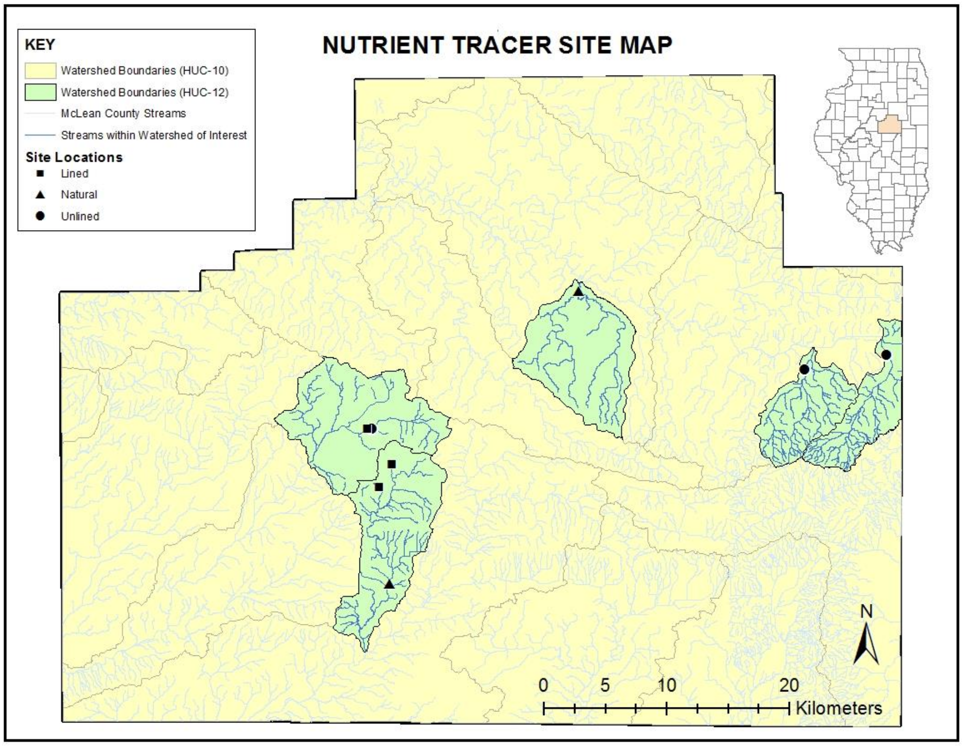


Figure 3. Nutrient Tracer Site Map (ISGS, 2007).

Site Classification

A brief summary of site classification is found in Table 1. Three sites--1900N, Crooked Creek, and Frog Alley--are located within the Mackinaw River Basin. Land use in the Crooked Creek watershed is primarily agriculture (IDNR, 1997). Crooked Creek is a 3rd-order stream that has not undergone human modification (Harris, 2008). It is classified as a natural stream. The stream has occasional meanders coupled with relatively straight portions of stream. Cutbanks in Crooked Creek expose areas of clayey silt. The streambed is primarily sandy silt. Sand and gravel with clasts up to 2cm, and few pieces 2cm+, are found mainly along point bars and longitudinal bars. There is vegetation near the banks, minimal vegetation in-stream, and biofilm found on most rocks. Undercutting beneath tree roots has created areas of low flow within the stream.

1900N and Frog Alley are also within a primarily agriculture influence watershed (IDNR, 1997). They have both been previously modified for agriculture use, straightening the streams (IDNR, 1997). 1900N was last modified 10 years ago and Frog Alley 13 years prior (Harris, 2008; Seargent, 2012). 1900N is a 2nd-order incised, straight channel that is experiencing undercutting on its banks. The streambed is comprised of sandy silt, with few gravel clasts. There is plentiful vegetation in-stream, and bars often have dense grass growth, which impedes water flow. Frog Alley is a relatively straight, 2nd-order stream with heavy vegetation on banks and in-stream. Banks are beginning to show signs of undercutting. The streambed is mainly sandy silt with few gravel clasts.

The remaining sites—Little Kickapoo Creek and Sugar Creek are found within the Sangamon River Basin. Little Kickapoo Creek is divided into three separate sites. The first site, identified as Little Kickapoo Creek – Lined, Apartments, is a modified lined, 1st-order stream. Input is derived entirely from urban sources (IDNR, 2000). Little Kickapoo Creek – Lined, Apartments has a straight channel made of jointed concrete lining. Sedimentation of sand and silt particles is occurring along the bottom of the channel. There is also vegetation growing along the banks, in joints, and in streambed sediment. The second site, Little Kickapoo Creek - Lined is also a modified lined, 1st-order stream of similar construction and land use (IDNR, 2000). What little sedimentation has occurred along the bottom of the stream is made up of sandy silt. Between the two sampling periods, Little Kickapoo Creek - Lined went from having large amounts of algae in the reach in addition to other vegetation, to being cleaned of all plant matter. The last site on Little Kickapoo Creek is a natural, unmodified reach of a 3rd-order stream (Peterson and Sickbert, 2006). Agriculture and urban land use make up the majority of the watershed (IDNR, 2000). Little Kickapoo Creek - Natural has a variable streambed composition; it contains mainly rounded gravel along the bed, with sandy silt in parts. Little Kickapoo Creek - Natural contains a few meanders, point bars, and longitudinal bars. There is little undercutting of banks, and vegetation is typically limited to stream banks.

Sugar Creek was divided into two sites, one modified lined and the other modified unlined are both 1^{st}-order. Sugar Creek – Lined is a straightened, concrete lined stream reach that receives input from urban sources (IDNR, 2000). There is little sedimentation along the bottom of the reach. Vegetation within the reach is limited to small amounts of algae along concrete lining. Sugar Creek - Unlined is located immediately upstream of Sugar Creek - Lined and immediately downstream of a constructed waterfall. The streambed of Sugar Creek - Unlined is made of sandy gravel. Stream banks are made of sandy silt, and are undercut along the entire reach. There is little vegetation in stream, and it is mostly restricted to the banks.

CHAPTER II

METHODS

Tracer Injection and Sampling

Ten (10) sets of data were collected from eight different sites (Table 1) from July-November 2013. All data were collected a minimum of 24 hours after storm events to minimize stream flow variability. These sites encompass three (3) separate stream classifications: modified lined (L), modified unlined (U), and natural (N). Physical attributes of the stream including reach length (RCHLEN), discharge (Q), cross-sectional area (A), and chemical properties of the waters incorporating background specific conductance (SpC) and nitrate concentrations were collected in the field prior to each test. Additional parameters, including background levels of SpC and ion concentrations, were measured by sampling at the downstream probe location.

Site	Morphology	Primary Substrate	Vegetation Density	Land Use	Stream Order	Location	Trial
--	--	--	--	--		*(lat, long)*	--
1900N	Modified unlined	sandy silt	dense	agriculture	2	40.553, -88.474	--
Crooked Creek	Natural	sandy silt	sparse	agriculture	3	40.599, -88.770	--
Frog Alley	Modified unlined	sandy silt	dense	agriculture	2	40.542, -88.553	--
Little Kickapoo Creek	Modified lined	concrete lining (sandy silt sedimentation)	dense	urban	1	40.455, -88.961	1
			sparse				2
	Modified lined	concrete lining (sandy silt sedimentation)	moderate	urban	1	40.471, -88.949	Apartments
	Natural	gravel, sandy silt	moderate	agriculture/urban	3	40.384, -88.951	--
Sugar Creek	Modified lined	concrete lining	sparse	urban	1	40.497, -88.972	2
	Modified unlined	sandy gravel	moderate	urban	1	40.497, -88.968	1
							2

Table 1. Site Classifications Based on Morphology.

Stream reach length was chosen to minimize the influence of sinuosity while still allowing sufficient length for potential transient storage. Reach length was defined as the distance between the upstream and downstream probes, and was predetermined to be set at 100m (Figure 4). Data input for OTIS were collected from the upstream probe location, and data were collected from the downstream probe for comparison to modeled OTIOS outputs. The upstream probe was located 20m downstream of the injection point to promote thorough mixing of solute. Wetted width measurements were taken from 10 locations and discharge was measured from one (1) to two (2) locations using the area-velocity method (Figure 5). Flow velocity was measured at 0.6 depth, representing the average velocity, using a Marsh-McBirney Flo-Mate 2000® electromagnetic velocity meter.

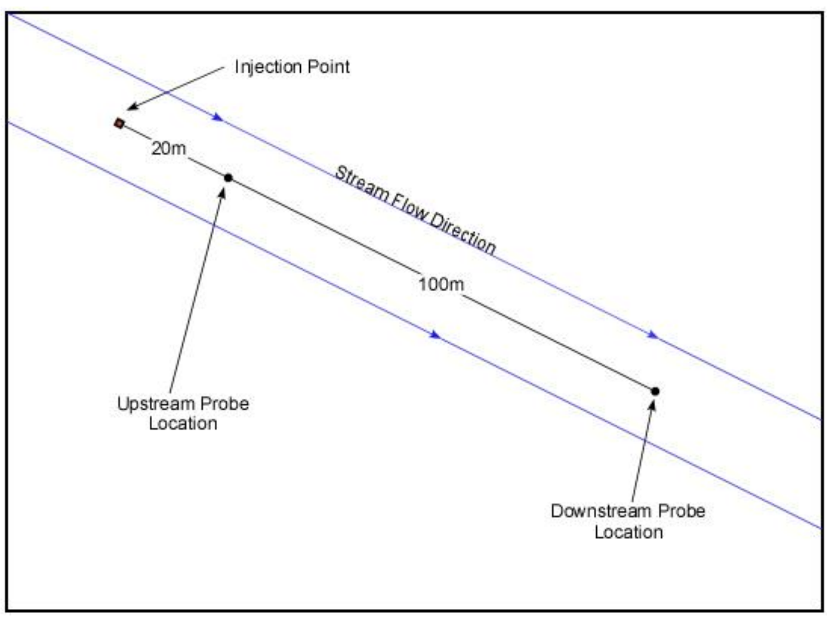


Figure 4. Field Testing Setup.

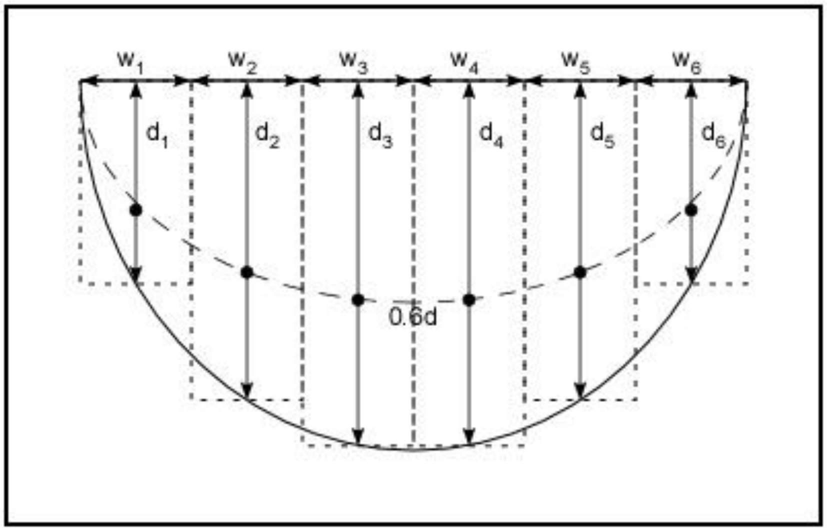


Figure 5. Measurements Taken for Cross-Sectional Area and Discharge Calculations.
Total cross-sectional area, and subsequently discharge, was estimated by segmenting each stream injection site into cross-sections. Cross-sectional area was calculated by multiplying width (w) by depth (d). Flow velocity was measured at 0.6d. Discharge for each segment was calculated by multiplying segment cross-sectional areas and multiplying by flow velocity of the segment.

Data Collection and Analysis

Background SpC, chloride, and nitrate levels were determined by collecting samples of stream water prior to tracer injection. A conservative sodium chloride (NaCl) tracer was injected at all sites to model the relative transient storage of each stream. Six of the sites were also injected with a non-conservative sodium nitrate ($NaNO_3$) tracer to calculate percent nitrate loss. Quantity of solute injected was based upon estimated stream discharge and background levels, determined from prior studies, with the purpose of raising levels measurably higher than background concentrations (Table 2).

Upstream and downstream specific conductance values were logged using YSI-556MPS and YSI-ProPlus probes at 1 to 30 second intervals dependent upon stream flow velocity. As shown in Appendix E, SpC is a suitable proxy for chloride concentration because SpC exhibits a linear relationship with chloride (Granato and Smith, 1999; Schalk and Stasulis, 2012; Windsor and Mooney, 2008). Water samples were taken at the downstream probe location throughout the test, while the upstream probe was monitored regularly until it reached background SpC, or until SpC stabilized. Twenty (20) to 30 samples were collected at each site to characterize the rising and falling limbs of the breakthrough curves. Samples were run on a Dionex ICS-1100 Ion Chromatograph to measure anion concentrations, including chloride (Cl^-), nitrate as nitrogen (NO_3-N), and sulfate (SO_4^{-2}). Resulting concentrations were used to calculate nutrient loss within the stream system by integrating the breakthrough curve.

OTIS Modeling

Each site was represented as a one-dimensional system, with solute concentration changing along the stream flow path, as well as a transient system where concentration profile changes with time. OTIS is a one-dimensional transient storage model that simulates resultant nutrient concentrations from an upstream injection point (Runkel, 1998). Within the streams it is assumed there is negligible vertical and horizontal dispersion of solute, eliminating both components and allowing for one-dimensional modeling to be used. OTIS additionally accounts for hydrologic parameters (Figure 6) including reach length (RCHLEN), main channel cross-sectional area (AREA), discharge (Q), dispersion (DISP), lateral inflow (QLATIN), lateral outflow (QLATOUT), inflow solute concentration (CLATIN), transient storage zone area (AREA2), and storage zone exchange coefficients (α) (Runkel, 1998). During modeling OTIS creates homogenous conditions within each reach. In an effort to minimize variations between streams, while still establishing heterogeneous conditions, the number of reaches per site was set to two. Upstream boundary type (USBOUND) was set to a continuous concentration profile, using conservative tracer (chloride) probe data. Downstream boundary conditions (DSBOUND) were set to reflect a dispersive flux of zero to reflect no change in concentration between the last modeled segment and any following segment. Boundary conditions began at the time of tracer injection and, once background conditions were reached or no further change was seen, extrapolated past the desired output time. Upstream probe SpC was verified for changes to background SpC if initial background levels were not reached. Simulation start and end time used for each stream model was based upon the time required for the break through curve to pass through the downstream location. Print step and integration time steps were set to reflect the time step used with recorded probe data.

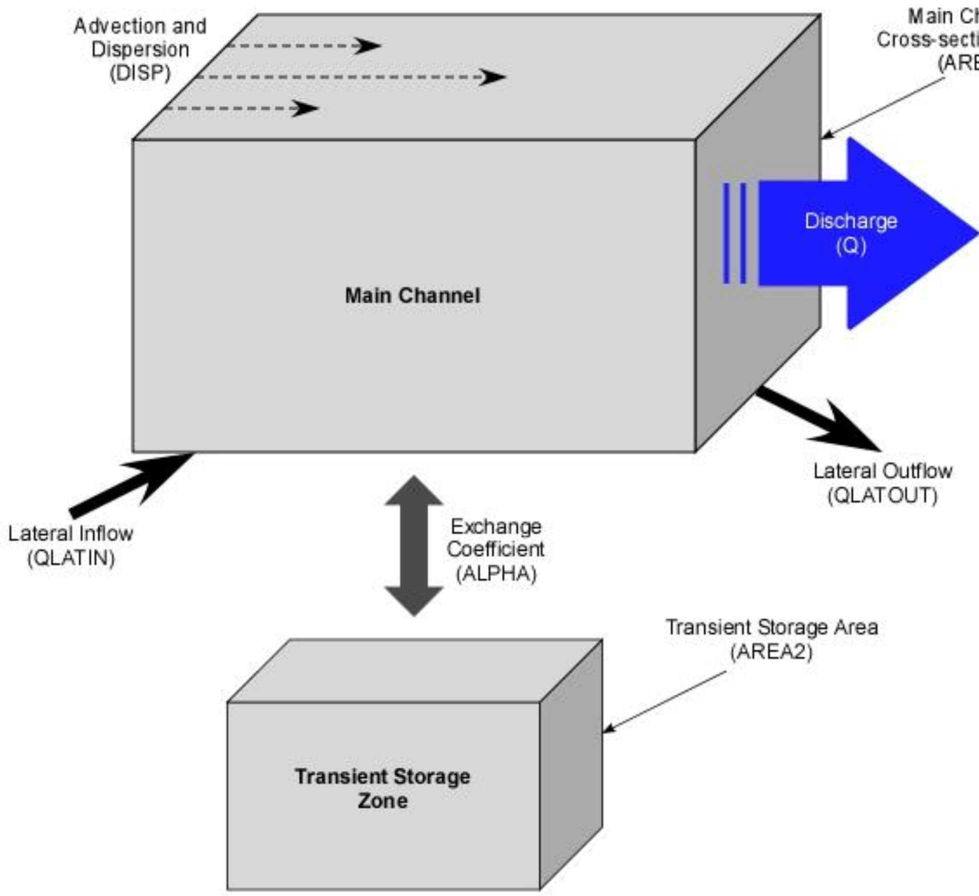


Figure 6. OTIS Conceptual Model Adapted Courtesy of USGS (Runkel, 1998).
Note that AREA2 is a combination of surface and hyporheic transient storage.

Main channel cross-sectional area (AREA) and discharge (Q) inputs were from data collected on site. Plausible minimum/maximum area and discharge values were set taking into account minimum/maximum depths, wetted widths, and flow velocities for each stream. This process was used to keep values as close to measured, realistic values as possible. Additional processes including lateral inflow (QLATIN) and outflow (QLATOUT), ion concentration of inflow (CLATIN), transient storage zone area (A_s), storage zone exchange coefficient (ALPHA), and dispersion (DISP) were estimated within the model. Dispersion and exchange rates were compared to prior studies (USEPA, 2013) to stay within plausible limits.

Each parameter was calibrated to minimize root-mean-square error (RMSE). Root-Mean-Squared Error (RMSE) was calculated as:

$$RMSE = \sum_{i=1}^{n} \sqrt{\frac{(x_{meas,i} - x_{mod,i})^2}{x_{meas,i}{}^2 n}} \quad (1)$$

where n is the number of values, $x_{meas,i}$ is the measured SpC at time i, and $x_{mod,I}$ is the modeled SpC at time i. A sensitivity analysis for each model was run to determine which parameters were primarily controlling the OTIS model. Parameters were varied ± 5%, ± 10%, and ± 15% of final calibrated model best-fit values. Greater change in RMSE indicates a greater sensitivity to a specific parameter; likewise, less change in RMSE indicates lower sensitivity to a parameter. Initial sensitivity models were used to expedite the modeling process by allowing consistently more sensitive parameters to be changed immediately, reaching a minimum RMSE more quickly. Sensitivity analyses were performed for following models to verify parameter controls.

Relative transient storage (RTS) was calculated as:

$$RTS = \frac{AREA2}{AREA} \quad (2)$$

where AREA2 is the modeled transient storage cross-sectional area and AREA is the modeled main channel cross-sectional area. RTS was plotted against percent nitrate change, which was calculated from solute mass recovery. Solute mass recovered (m_f) was calculated using sample concentration (C_i), background concentration (C_0), time between samples (Δt), and measured discharge (Q) where:

$$m_f = Q \times \sum_{i=t_0}^{t_f} (C_i - C_0)\Delta t \quad (3).$$

Percent change in solute was calculated, for streams where samples were collected and analyzed on the IC, as:

$$\%\Delta \mathrm{Solute} = \frac{(m_f - m_0)}{m_0} \times 100 \quad (4)$$

where m_f is the final mass of solute recovered and m_0 is the initial mass of solute injected. A best-fit line was used to determine if relative transient storage and percent nitrate change were correlated.

CHAPTER III

RESULTS

Sampling Population

Eight (8) separate sites (Table 1), consisting of three (3) modified lined, three (3) modified unlined, and two (2) natural stream reaches, were sampled. Of the eight (8) sampling locations, two (2) sites were sampled on two (2) separate occasions. A third site, Sugar Creek – Lined, had one additional trial which is not reported in these results. Precipitation conditions leading up to the Sugar Creek – Lined, Trial 1 test were more variable than conditions prior to the other tests. As such, Sugar Creek – Lined, Trial 1 was considered incomparable to the other tests. The final sampling population was composed of 10 tests including Cl^- only tracers, as well as Cl^- and NO_3^- injections (Table 2). Masses of ions of interest (IOI) were calculated for comparison against recovered mass of each ion.

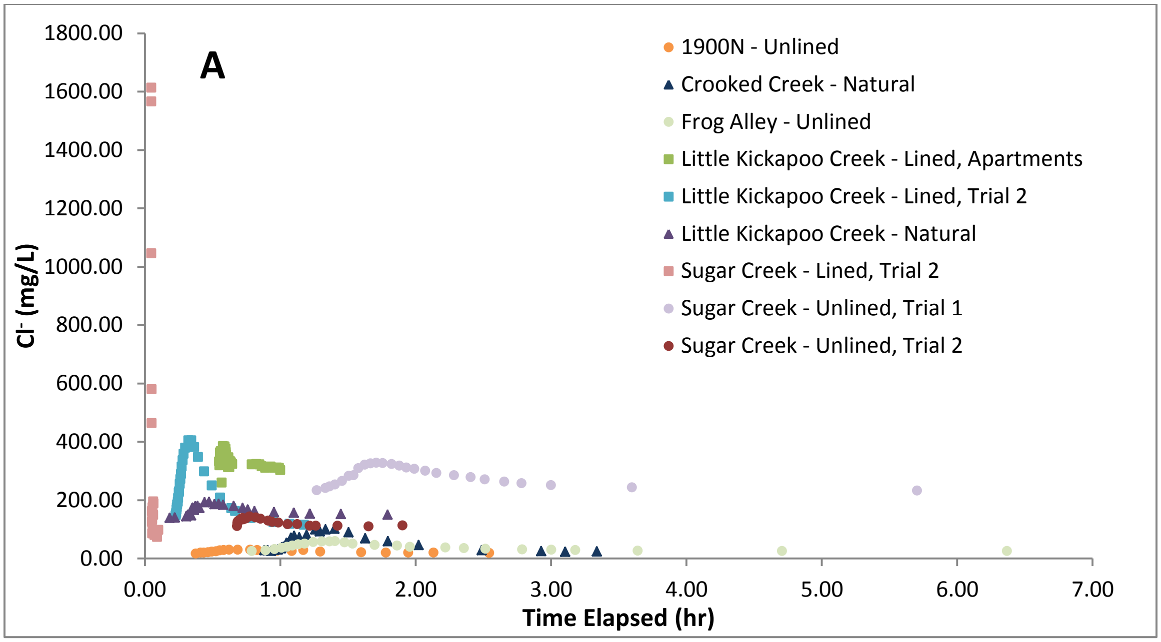
Site	Morphology	Trial	Solute	m of nutrient analyzed
--	--	--	--	*(g)*
1900N	Modified unlined	--	NaCl	1281.30 ± 0.03
			$NaNO_3$	34.67 ± 0.03
Crooked Creek	Natural	--	NaCl	7153 ± 16
Frog Alley	Modified unlined	--	NaCl	5365 ± 12
Little Kickapoo Creek	Modified lined	1	NaCl	1788 ± 4
		2	NaCl	448.72 ± 0.01
			$NaNO_3$	14.82 ± 0.01
	Modified lined	Apartments	NaCl	483.23 ± 0.01
			$NaNO_3$	11.89 ± 0.01
	Natural	--	NaCl	2577.35 ± 0.03
			$NaNO_3$	58.65 ± 0.03
Sugar Creek	Modified unlined	2	NaCl	1780.27 ± 0.02
			$NaNO_3$	224.52 ± 0.02
	Modified unlined	1	NaCl	5365 ± 12
		2	NaCl	2561.59 ± 0.03
			$NaNO_3$	72.38 ± 0.03

Table 2. Specific Quantities of Solute Introduced at each Location.

Data sets from Frog Alley and Little Kickapoo Creek – Lined, Apartments were unable to be successfully modeled in OTIS. Probe measurements were not continuous for USBOUND at Frog Alley due to unforeseen probe issues. Without adequate USBOUND measurements, an OTIS model could not be generated for Frog Alley. An OTIS model was not generated for Little Kickapoo Creek – Lined, Apartments either due to a noticeable influx of water during the tracer test. While OTIS is capable of modeling transient discharge conditions, for the purposes of this study, steady-state calculations were implemented. Frog Alley and Little Kickapoo Creek – Lined, Apartments were, however, able to be used when calculating solute mass balance, as downstream data was sufficient.

Tracer Test and Field Data

A minimum of 21 and maximum of 30 samples were collected at the downstream probe location (Appendix B). Variations in sampling populations were due primarily to more or less rapid movement of tracer downstream than preliminary tests predicted. SpC of samples was compared to probe recorded SpC (Appendix C) for sample/breakthrough curve verification (Figure 7). Curves were set to an initial background concentration equal to zero (mg/L or uS/cm respectively). Little Kickapoo Creek – Lined, Apartments experienced a noticeable increase in water depth and flow velocity over the course of sampling from what is assumed to be less conductive water, resulting in an ending SpC value that is negative relative to the starting SpC. Chloride (Cl^-) and Nitrate-N (NO_3^--N) were measured on the Dionex ICS-1100 (Appendix D) were recorded for tracer analysis. NO_3^--N values were not analyzed at Crooked Creek - Natural, Frog Alley, and Sugar Creek – Unlined, Trial 1 since they did not involve a nitrate tracer addition. Ambient chloride concentrations were highest in Little Kickapoo Creek – Lined, Apartments (317.87 mg/L) and the lowest were in 1900N (11.12 mg/L), a modified lined and modified unlined stream respectively. NO_3^--N background concentration was highest in a modified unlined stream (1900N, 3.97 mg/L) and lowest in modified lined stream (Sugar Creek – Lined, Trial 2, 0.32 mg/L).



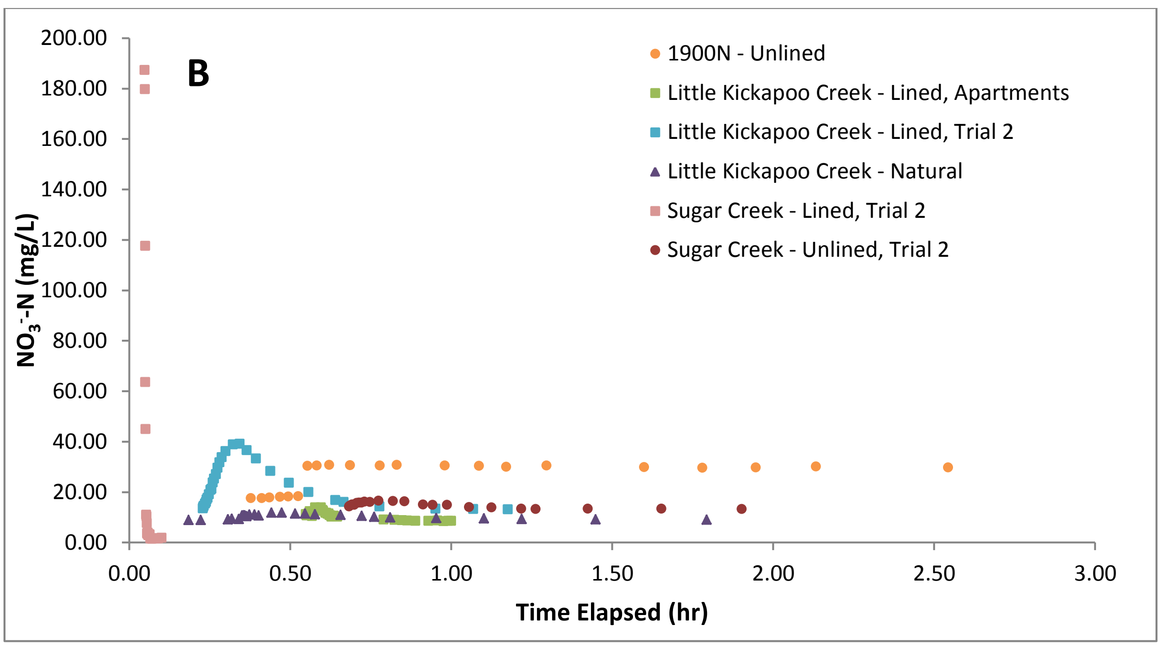


Figure 7. Downstream Break Through Curves for (A) Cl^-, (B) NO_3^--N, and (C) SpC.

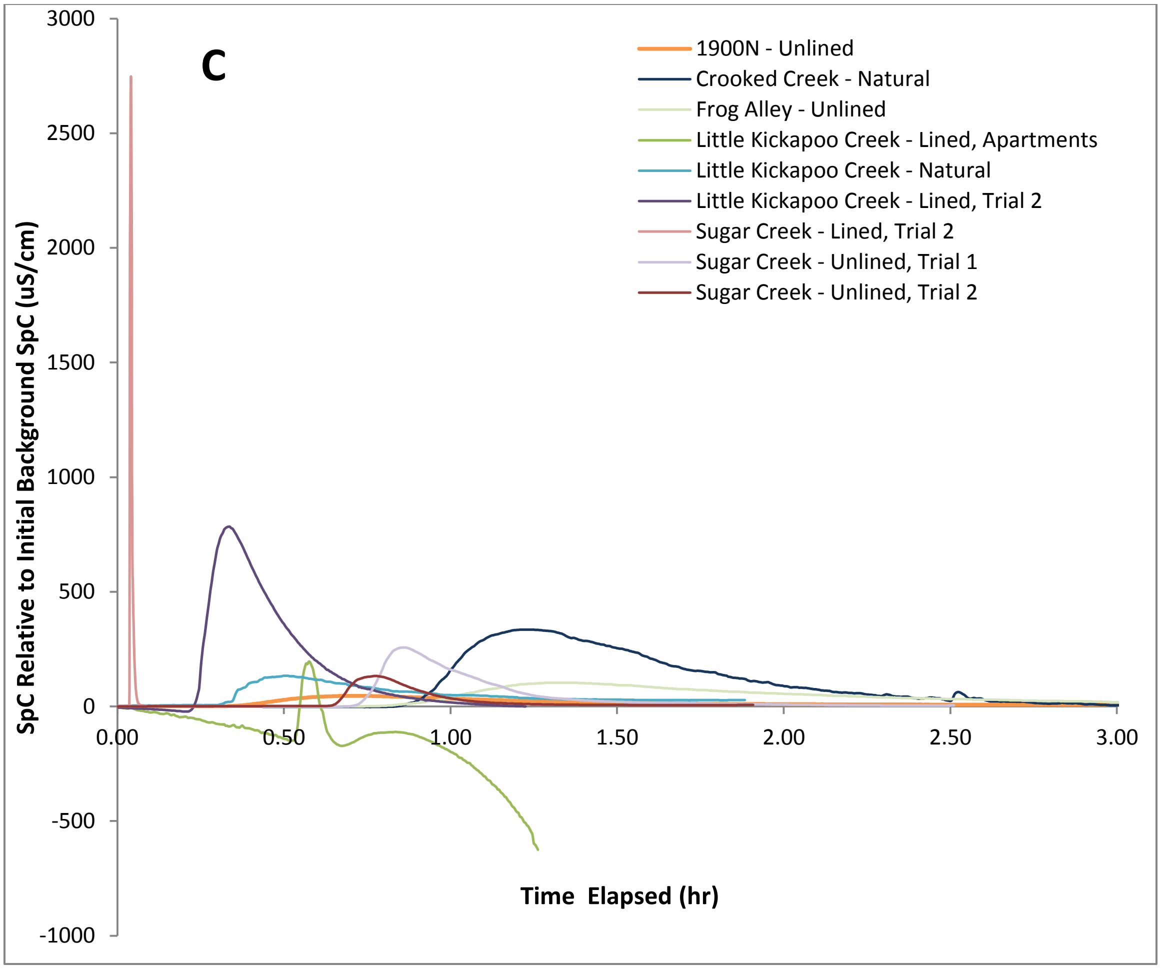


Figure 7. Cont'd

Field measurements were collected upstream and downstream prior to tracer tests. Average wetted width, AREA, and QSTART were collected along the length of each stream reach (Table 3). Modified lined stream reaches showed the least variation in wetted width and cross-sectional area measurements, followed by modified unlined and natural. Little Kickapoo Creek – Lined, Trial 2 had the smallest average wetted width of 1.056 ± 0.149 m while Sugar Creek – Unlined, Trial 2 had the largest average wetted with of 5.716 ± 0.908 m. Little Kickapoo Creek – Lined, Trial 2 also had the smallest cross-sectional area (0. 033 ± 0.004 m^2) and Frog Alley had the largest (1.528 ± 0.004 m^2). Modified lined streams showed, on average, the lowest discharge followed by natural, then modified unlined streams. However, both the lowest and highest discharges were from modified lined streams (Little Kickapoo Creek – Lined, Trial 1 - 0.001 ± 0.007 m^3/s and Sugar Creek – Lined, Trial 2- 0.103 ± 0.007 m^3/s).

Site	Morphology	Trial	Average Wetted Width	Average AREA	Average QSTART
--	--	--	*m*	*m2*	*m3*
1900N	Modified unlined	--	3.250	0.650	0.036
Crooked Creek	Natural	--	4.583	0.569	0.021
Frog Alley	Modified unlined	--	3.948	1.528	0.025
Little Kickapoo Creek	Modified lined	1	1.444	0.070	0.001
		2	1.056	0.033	0.002
	Modified lined	Apartments	4.157	0.122	0.006
	Natural	--	4.057	0.639	0.033
Sugar Creek	Modified lined	2	3.884	0.186	0.103
	Modified unlined	1	5.418	0.781	0.016
		2	5.716	0.802	0.040

Table 3. Parameters Calculated from Field Measurements.

OTIS Modeling and Calibration

General modeling began by using field measurements as input values and calibrating until a more accurate fit resulted (Appendix E). The better the fit, the more closely times and specific conductances generated by a model will match measured values. A perfect fit would exactly reproduce measured values. The majority of initial inputs produced poorly fitted models; for example, see Figure 8. Initial models generated large sources of error because of a perceived time delay between modeled and measured peak SpC. Final calibrations resulted in models that more closely mirrored measured values (Figure 9), and output provided data for RTS calculations. Average model NRMSE was lowest in modified unlined streams, followed by natural, and highest in modified lined streams (Figure 10). Values were 0.012, 0.028, and 0.068 respectively.

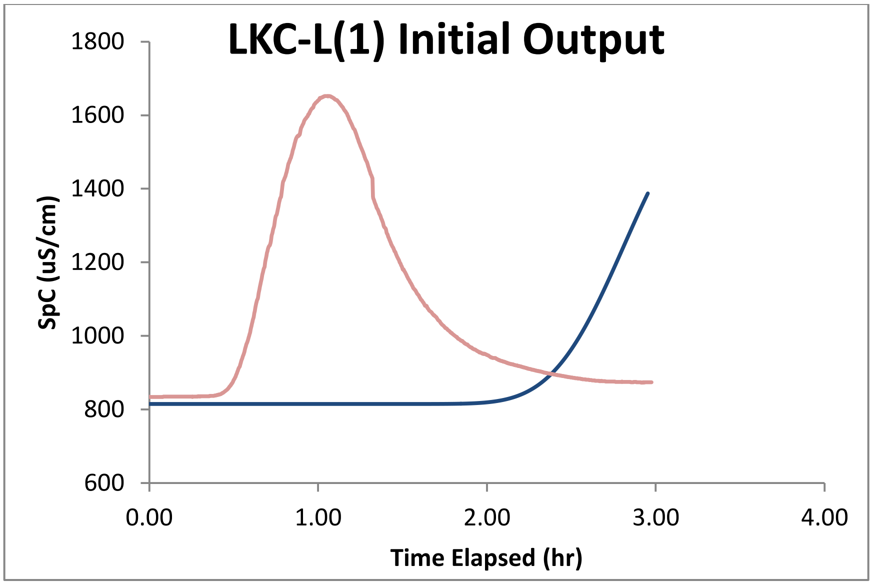


Figure 8. Initial OTIS Output.

The starting OTIS model (blue line) compared to measured values (red line) do not follow similar break-through-curve patterns as measured data, indicating the potential for a better fit.

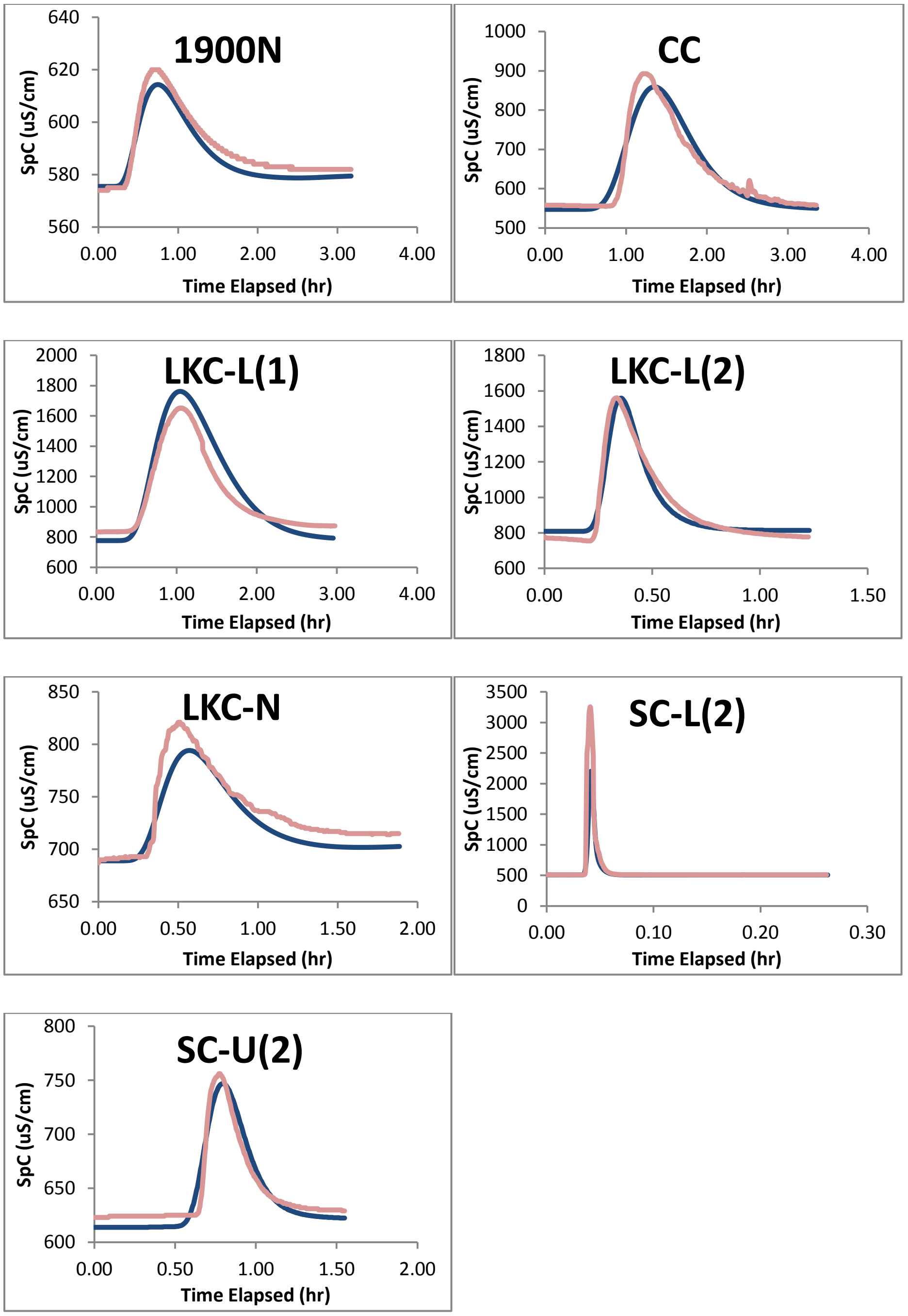


Figure 9. Final OTIS Output for Sites.
Measured, red, and corresponding OTIS modeled, blue, breakthrough curves for 1900N, Crooked Creek (CC), Little Kickapoo Creek – Lined, Trial 1 (LKC-L(1)), Little Kickapoo Creek – Lined, Trial 2 (LKC-L(2)), Little Kickapoo Creek – Natural (LKC-N), Sugar Creek – Lined, Trial 2 (SC-L(2)) and Sugar Creek – Lined, Trial 1 (SC-U (2)).

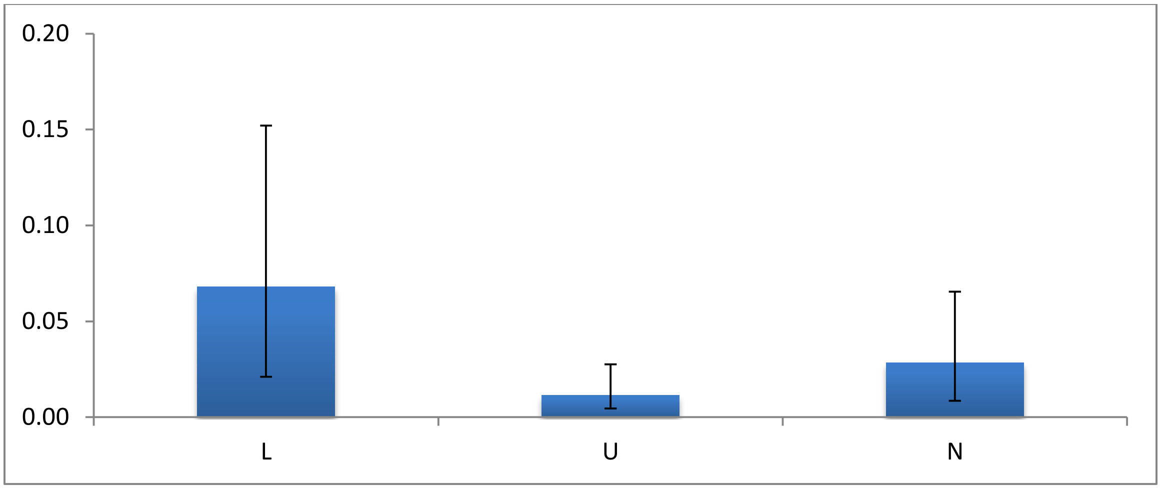


Figure 10. NRMSE Based on Stream Type.
Modified lined (L), modified unlined (U), or natural (N).

Measured versus final modeled parameter values for QSTART and AREA were compared (Figure 11). A line with slope (m)=1 represents where the modeled value is equal to the measured value. Points falling above this line have a modeled value greater than the measured value and points below this line have a modeled value less than measured value. Overall, there is a trend of measured QSTART being less than modeled QSTART ($m<1$). QSTART values lie more closely to the m=1 line. Little Kickapoo Creek – Lined, Trial 1 has the greatest difference between QSTART measured and QSTART modeled. Measured AREA has a trend of greater values than modeled AREA ($m>1$). AREA also shows a greater variation in measured values to modeled values, which is consistent with intra-stream variation of cross-sectional areas, than QSTART. Modified unlined and natural streams--1900N, Crooked Creek, Little Kickapoo Creek – Natural, and Sugar Creek – Unlined, Trial 2--show the greatest overall differences in AREA measured to AREA modeled.

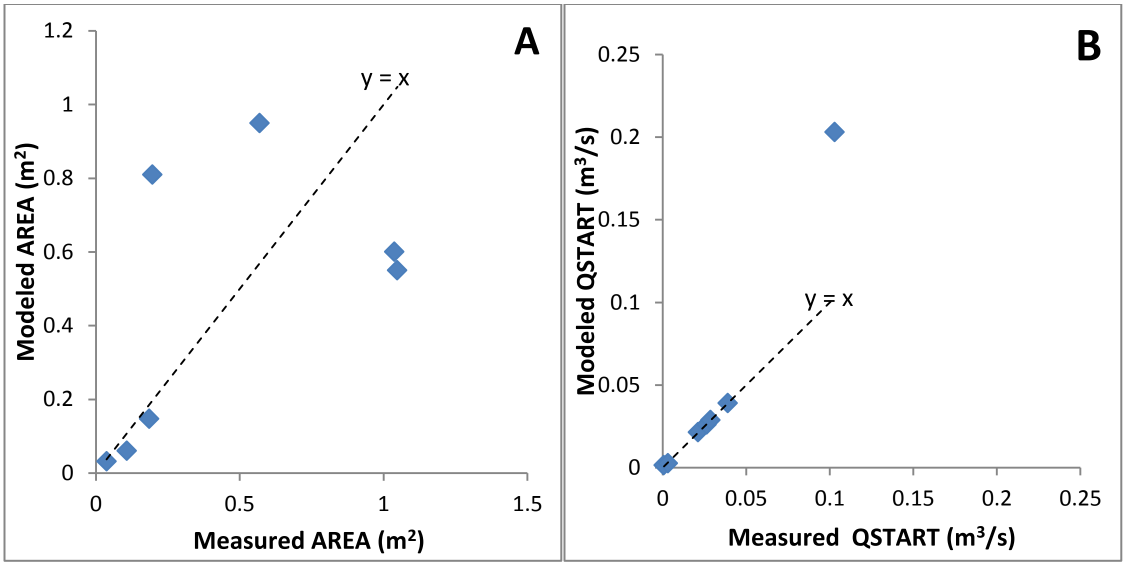


Figure 11. Measured v. Modeled Cross-Sectional Area and Discharge.
Comparisons of measured to modeled cross-sectional area (A) and discharge (B). Dashed line indicates slope=1, or an exact match between measured and modeled values.

Source of model error occurred mainly between values for peak SpC. Model error between peak SpC values is generally largest in the modified, lined locations. The largest discrepancy in peak SpC is more than 1000 uS/cm at Sugar Creek – Lined, Trial 2. Overall the smallest discrepancy in peak SpC is seen in modified unlined streams. The lowest error attributed to difference in peak SpC, however, is seen in Little Kickapoo Creek – Lined, Trial 2 (2 uS/cm). Little Kickapoo Creek – Lined, Trial 1 has the largest deviation between modeled and measured background value (≈80 uS/cm), contributing a substantial amount to its NRMSE. Yet, on average, modified lined streams had the least amount of error attributed to differences in background SpC.

Modified unlined streams had the highest RTS while modified lined streams had the lowest. OTIS models show that average RTS for modified lined streams is 0.131, for modified unlined streams RTS is 0.361, and for natural streams RTS is 0.137 (Figure 12). Modified lined streams experienced a small range of RTS values between 0.080 and 0.167. Natural streams had a slightly larger range between 0.085 and 0.190. The largest variation in RTS, 0.086 to 0.636, occurred in modified unlined streams.

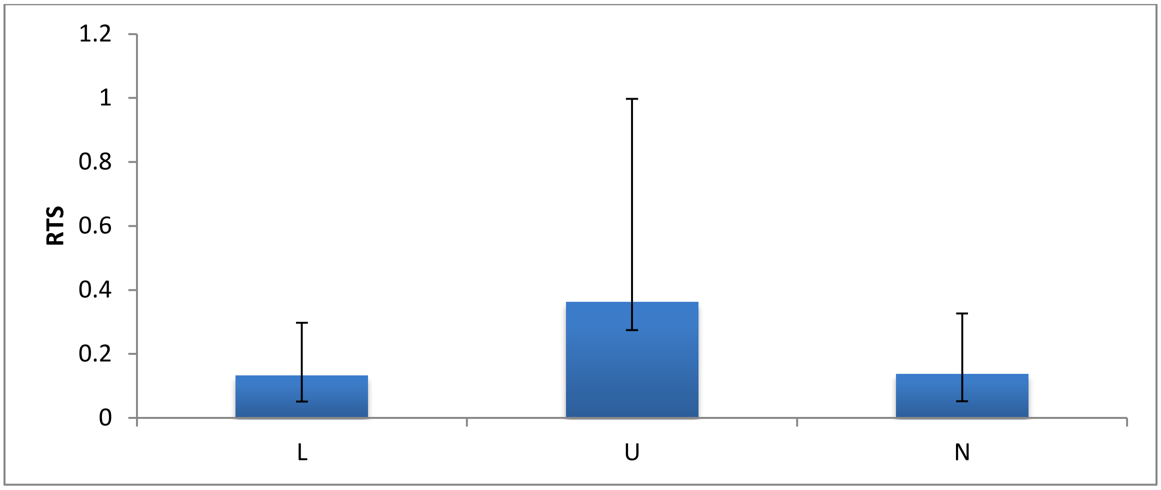
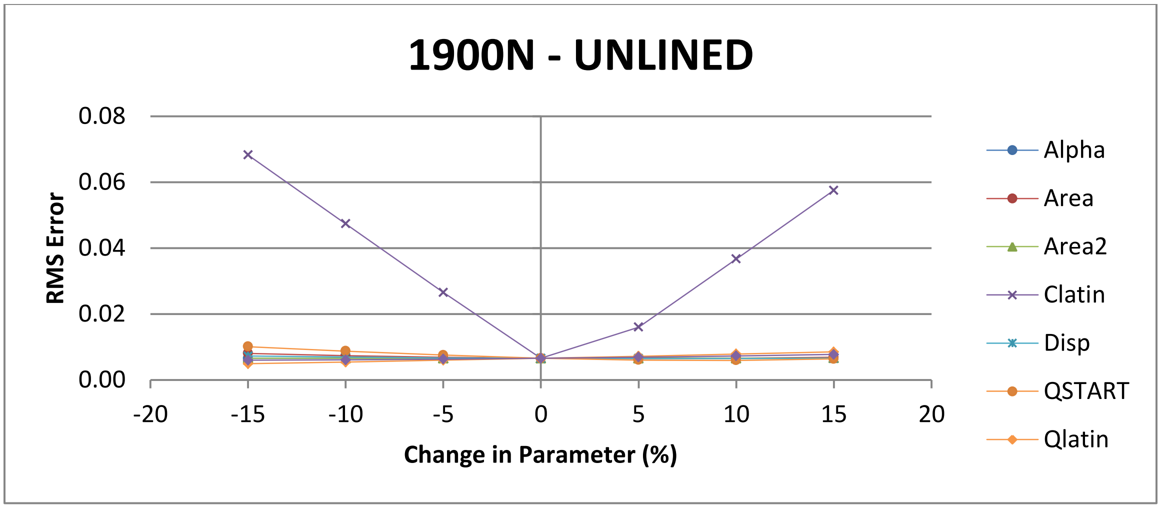


Figure 12. Average RTS Based on Stream Type.
Modified lined (L), modified unlined (U), or natural (N).

Sensitivity Analysis

Sensitivity analyses were used to determine model response to changes in parameters (±5%, ±10%, and ±15%), and verify calibration results. A best-fit corresponds to a minimum NRMSE at a 0% parameter change. Figure 13 shows sensitivity analyses to parameter changes for each site. All sites except 1900N exhibited primary sensitivities to QSTART and AREA. 1900N was most sensitive to CLATIN. Models are consistently more sensitive to QSTART at higher values and AREA at lower values. The only exception is Little Kickapoo Creek – Natural, which is more sensitive to AREA at higher values and QSTART at lower values. DISP sensitivity was only seen in Little Kickapoo Creek – Lined, Trial 1 at low DISP values. None of the models displayed high sensitivity to AREA2 or ALPHA transient storage parameters.



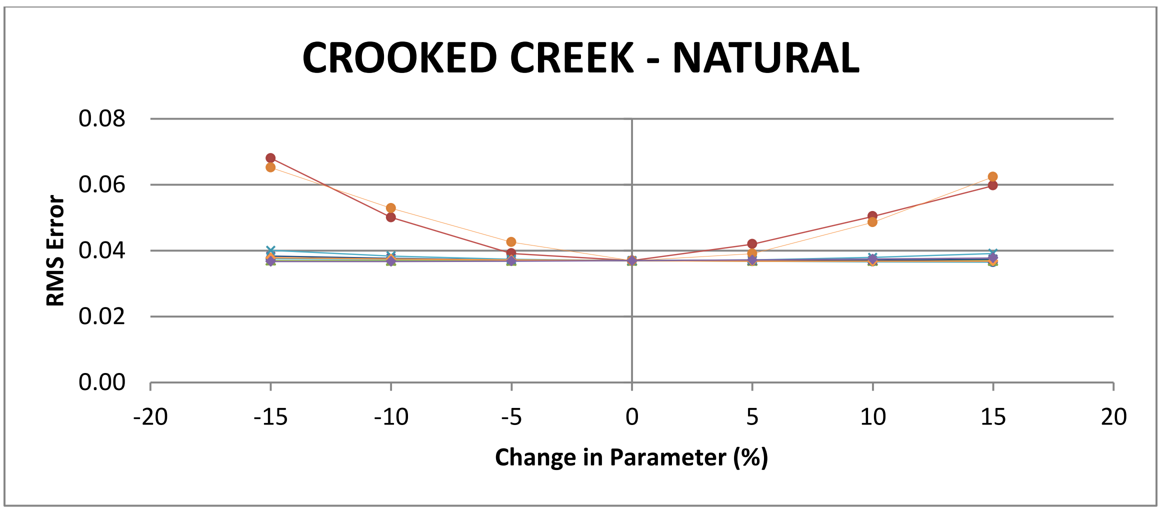
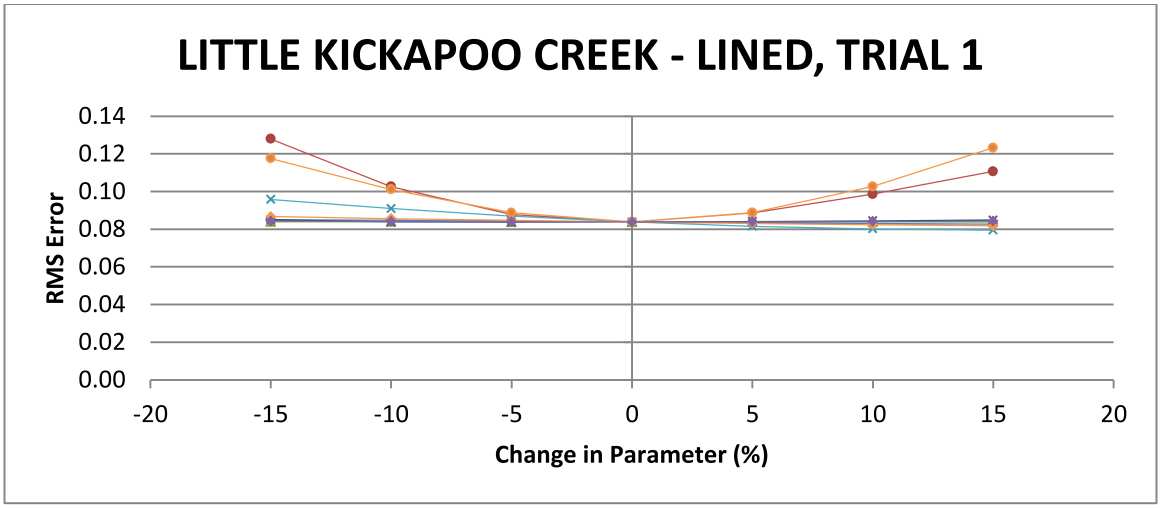
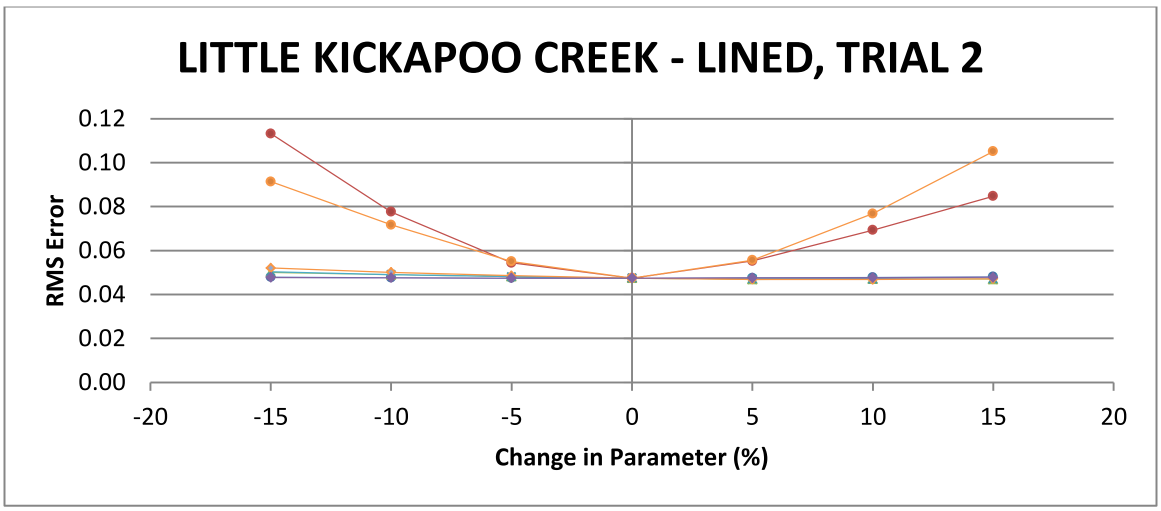
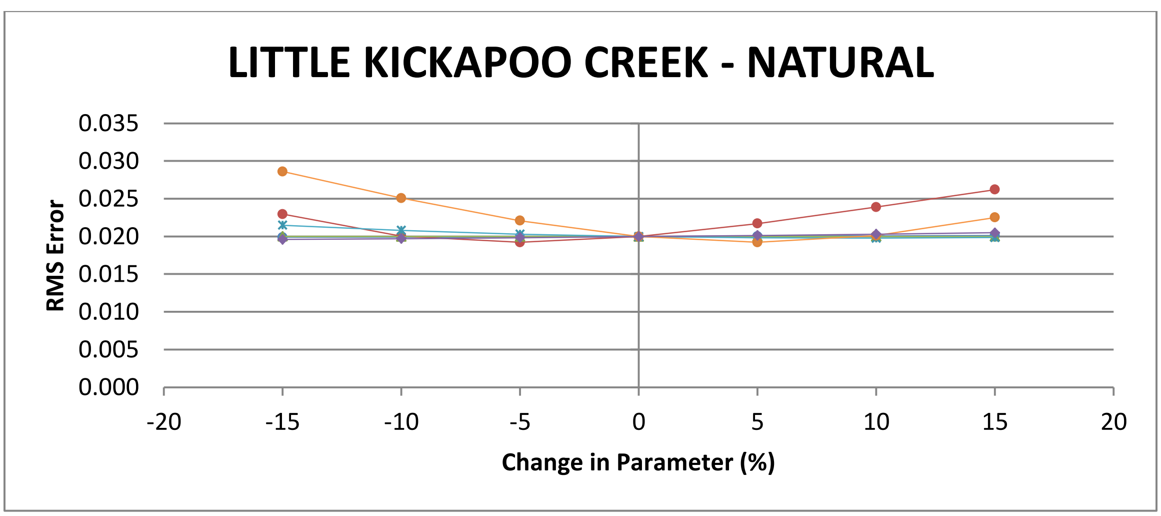


Figure 13. Sensitivity Analyses of OTIS Models.

Parameters for all sites are represented as seen in 1900N key: ALPHA = blue circle, AREA = red circle, AREA2 = green triangle, CLATIN = purple “x”, DISP = blue star, QSTART = orange circle, QLATIN = orange diamond, QLATOUT = purple diamond.







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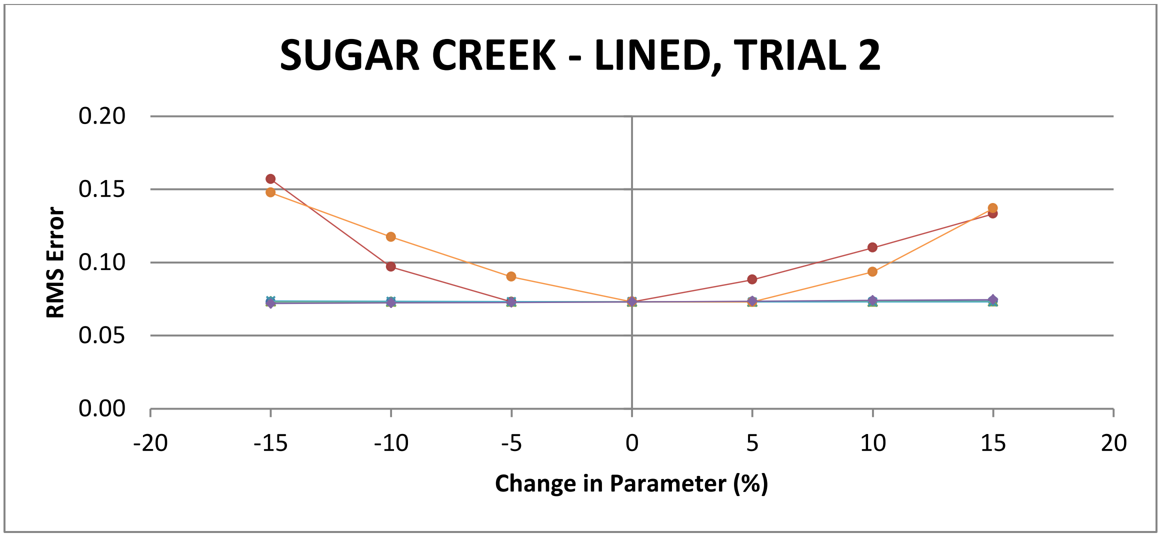

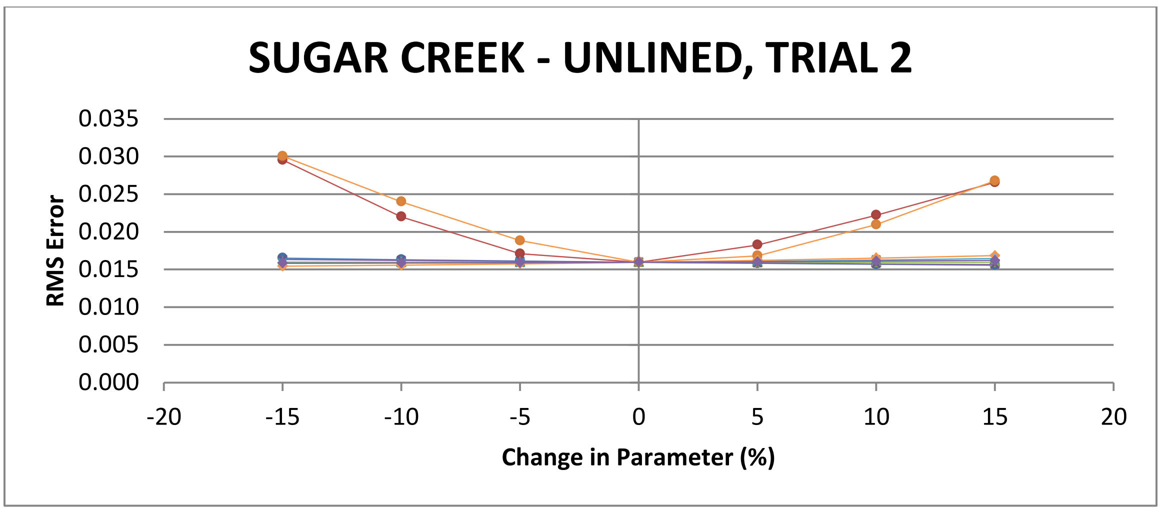

Figure 13. Cont'd

Solute Mass Balance

Average measurements of percent change in solute were calculated using both measured and modeled discharge values (Figure 14). Individual stream nutrient data are found in Table 4. A multivariate analysis was then run using Spearman's correlation coefficient. Measured Δ% Cl^- and modeled Δ% Cl^- have a strong, statistically significant correlation (r = 0.9429, p<0.005). Measured Δ% NO_3^--N and modeled Δ% NO_3^--N have a strong correlation, however, it is not statistically significant (r=0.7000, p>0.05). Measured change in Cl^- ranged from -93.34% in Crooked Creek to +247.43% in Sugar Creek – Lined, Trial 2 while change in NO_3^--N ranged from -64.81% in Little Kickapoo Creek – Natural to +254.84% in Sugar Creek – Lined, Trial 2. Modeled change in Cl^- ranged from -64.46% in Crooked Creek to +680.52% in Sugar Creek – Lined, Trial 2 while change in NO_3^--N ranged from -48.98% in Little Kickapoo Creek – Natural to +606.20% in Sugar Creek – Lined, Trial 2.

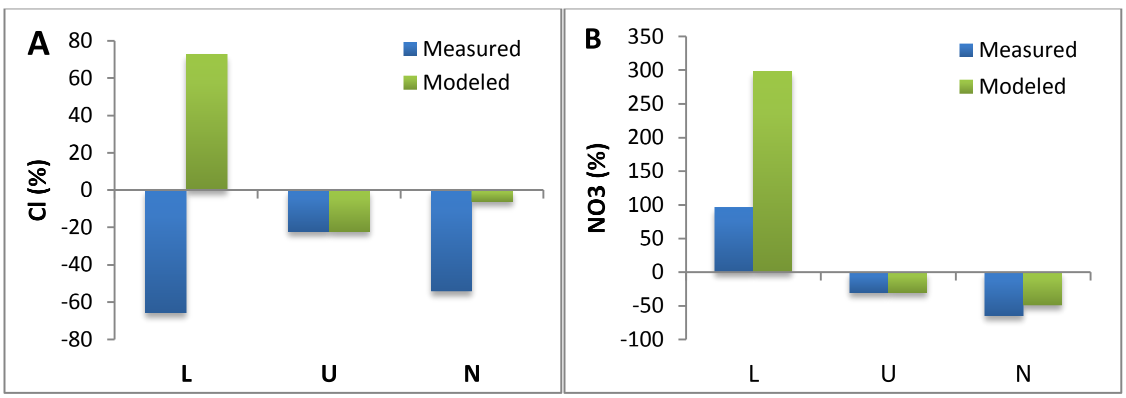

Figure 14. Solute Recovery by Stream Type.
Average percent (A) chloride and (B) nitrate as N change for measured and modeled discharges by stream type: modified lined (L), modified unlined (U), and natural (N).

Site	Morphology	Trial	RTS	NRMSE	Measured Average ΔCl	Modeled Average ΔCl	Measured Average ΔNO3--N	Modeled Average ΔNO3--N
--	--	--	--		%	%	%	%
1900N	Modified unlined	--	0.086	0.007	-39.977	-39.977	-16.166	-16.166
Crooked Creek	Natural	--	0.190	0.037	-93.337	-64.463	--	--
Frog Alley	Modified unlined	--	--	--	-0.382	--	--	--
Little Kickapoo Creek	Modified lined	1	0.167	0.084	--	--	--	--
		2	0.147	0.047	-29.141	73.283	-63.189	-9.979
	Modified lined	Apartments	--	--	--	--	--	--
	Natural	--	0.085	0.020	-14.238	24.355	-64.810	-48.975
Sugar Creek	Modified lined	2	0.080	0.073	247.431	680.519	254.839	606.200
	Modified unlined	1	--	--	0.237	--	--	--
		2	0.636	0.016	-37.121	-37.121	-44.587	-44.587

Table 4. Summary of Site RTS, NRMSE, and Solute Recovery.

Change in NO_3^--N/Cl^- throughout the sampling period is found in Figure 15. An unchanging ratio is indicative of nitrate acting as a conservative tracer, while an increasing or decreasing ratio indicates chemical changes. Substantially increasing ratios were seen at 1900N and Little Kickapoo Creek – Lined, Trial 2. While there is an overall increase in the NO_3^--N/Cl^- at 1900N, there is an initial decreasing trend in the data followed by a jump and subsequent increase in values. A noticeable decrease in NO_3^--N/Cl^- was seen at Sugar Creek – Lined, Trial 2. The remaining sites maintained a relatively stable tracer ratio.

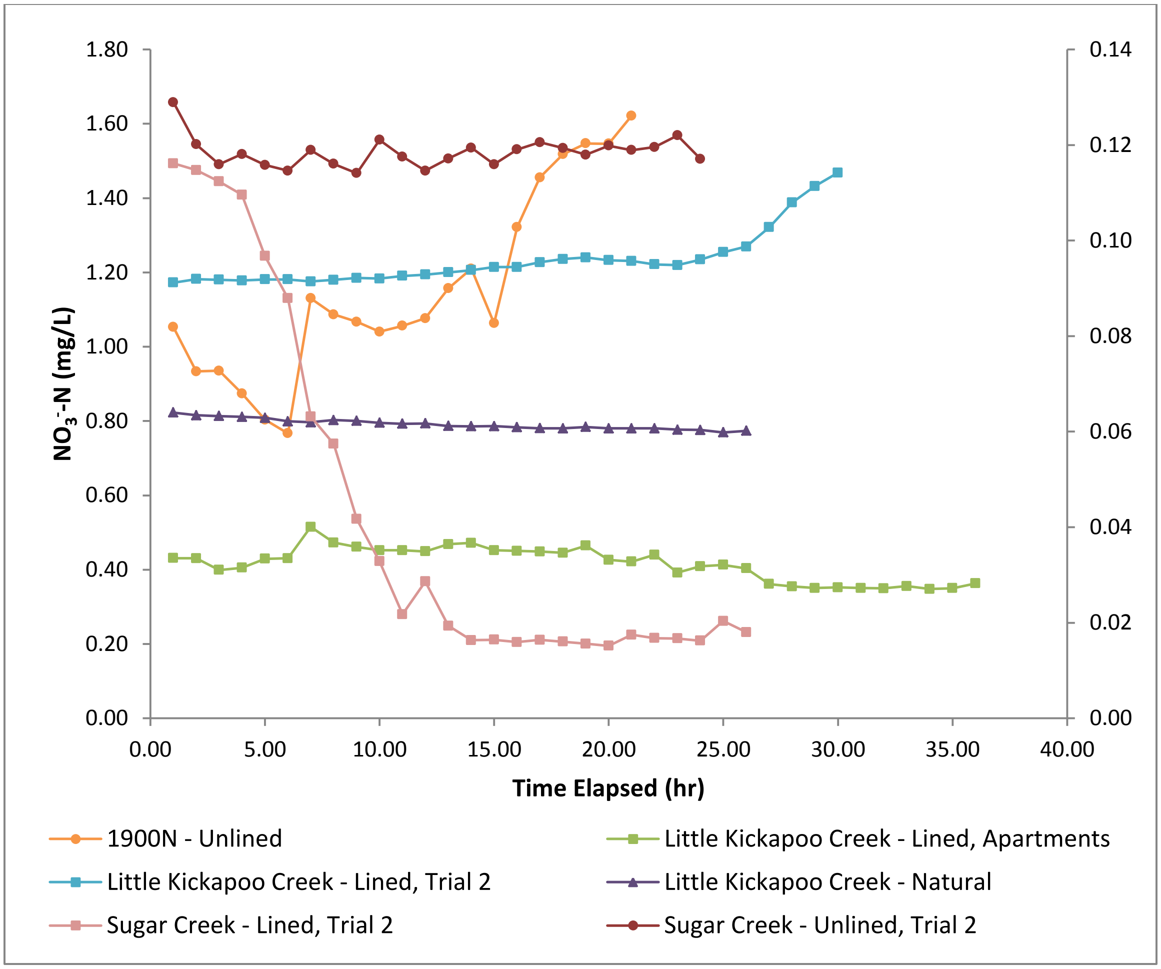

Figure 15. Nitrate-N to Chloride Ratios of Samples.

A consistent ratio is indicative of NO_3^--N acting as a conservative solute.

Solute recovery data were plotted against RTS (Figure 16). Streams show a decreasing trend in change in Cl^- with increasing RTS for measured (r^2=0.081, $p > 0.05$) and modeled (r^2=0.108, $p > 0.05$) values. A decreasing trend in NO_3^--N change was seen with increasing RTS for measured values (r^2=0.081, $p > 0.05$). Change in NO_3^--N for modeled values also displayed a decreasing trend with increasing RTS (r^2=0.095, $p > 0.05$). Overall, the relationship between RTS and Cl^- or NO_3^--N was not statistically significant.

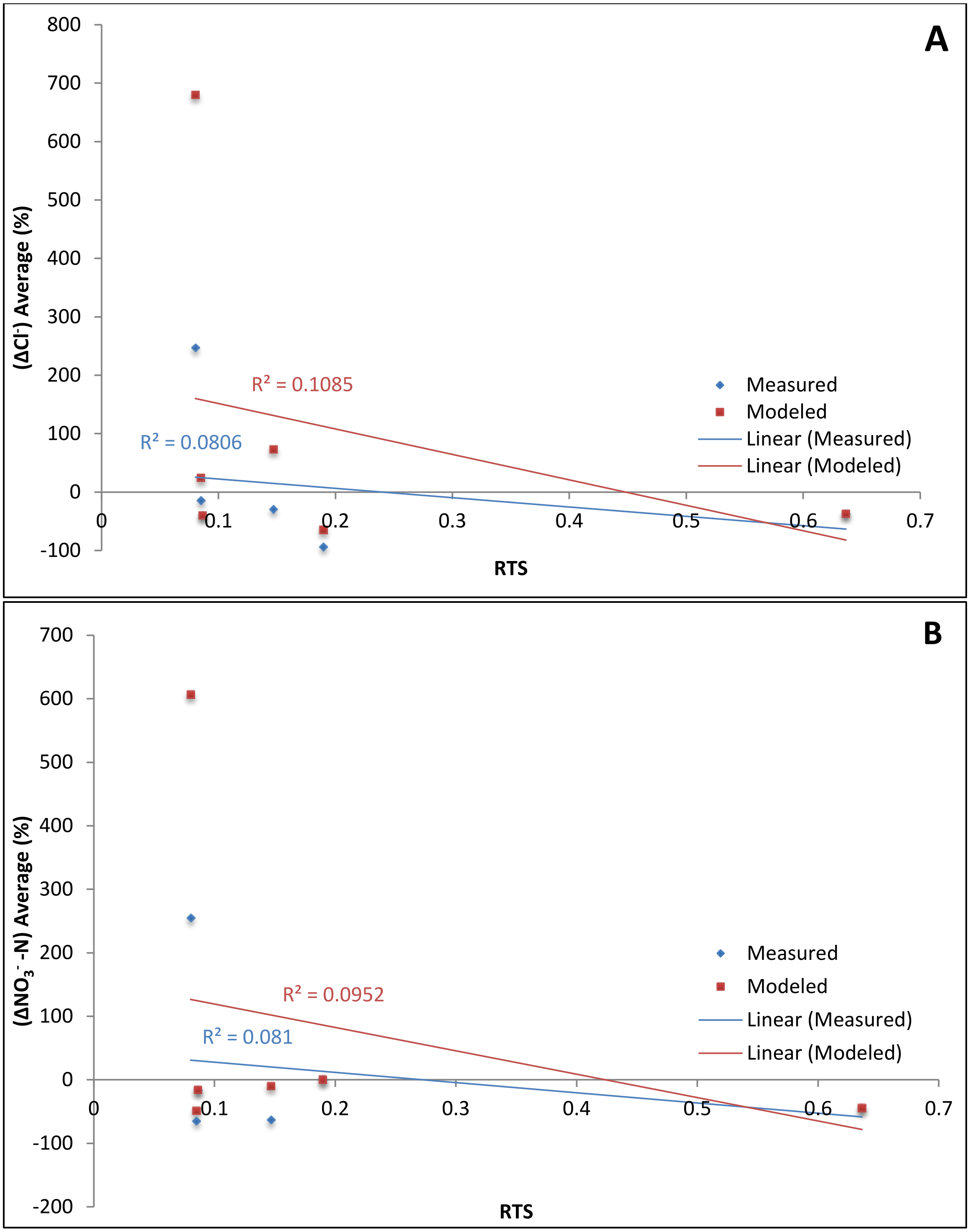

Figure 16. RTS v. Solute Recovered.
Changes in Cl^- (A) and NO_3^--N (B) as compared to RTS of each site. Blue indicates use of measured QSTART to calculate recovered percent and red indicates use of final modeled QSTART value in the calculation.

CHAPTER IV

DISCUSSION

Relative Transient Storage

RTS was predicted to be highest in natural streams, followed by modified unlined, and modified lined. Initial results do not support the hypothesized RTS of each stream type. Highest RTS was found in modified unlined streams, not natural as predicted. Modified lined streams supported the hypothesis that they would have the lowest RTS. Differences in stream sinuosity, vegetation, substrate, special variability, and temporal variability could all be contributing to the unpredicted RTS pattern.

Elimination of sinuosity variation in stream reaches potentially skewed results against natural stream having the highest RTS and NO_3^- loss. Reaches were controlled in an attempt to create more uniform conditions between sampling sites for comparison. As a result, stream RTS may have been skewed against natural streams. Research conducted by Peterson and Benning (2013) and Peterson and Sickbert (2006) emphasize the importance of stream meanders in creating additional hyporheic zone under bends and along banks. While meanders are not typical of modified lined streams, they are prevalent, and potentially more important, to the establishment of hyporheic zones in natural streams (Peterson and Sickbert, 2006). The hyporheic zone in sinuous reaches may also be more constant in its presence, further emphasizing the importance (Cardenas, 2009). Results from this study postulate that if a more representatively sinuous reach of natural stream were to be studied, RTS would be highest in natural streams, further supporting the criticality of meander reintroduction during stream restoration.

RTS may also be influenced by in-stream vegetation seen at sites. The importance of in-stream vegetation is two-fold; foliage density may itself retard the flow of water, or vegetative debris may accumulate and create pools where water is temporarily stored (Ensign and Doyle, 2005; Salehin et al., 2003). During a visual inspection of streams in this study, modified unlined streams were found to have a greater amount of vegetation growing in-stream and along banks. Natural sites, however, were fairly foliage free. In addition to differences seen between modified unlined and natural streams, tracer test Little Kickapoo Creek – Lined, Trial 1 was performed approximately two weeks prior to test Little Kickapoo Creek – Lined, Trial 2. As seen in Table 4, Little Kickapoo Creek – Lined, Trial 1 had an RTS of 0.167 while Little Kickapoo Creek – Lined, Trial 2 had an RTS of 0.147. Stream reach was the same, however, between the two testing periods a large quantity of algae was removed from within the reach. As a result, flow velocity and thereby discharge was increased (from 0.0008m^3/s (1) to 0.0021m^3/s). The discrepancy seen between Little Kickapoo Creek – Lined, Trial 1 and Little Kickapoo Creek – Lined, Trial 2 is consistent with findings by Salehin et al. (2003) showing in-stream vegetation impedes the flow of water. These results are consistent as well with a study by Ensign and Doyle (2005) where vegetation created a significant portion of the transient storage seen in-stream. This highlights the importance of reintroducing vegetation to create areas of transient storage.

Recharge and timing of sampling may have influenced outcome of RTS in stream reaches as well. Most sites experienced recharge between two (2) to five (5) days prior to sampling events. Recharge limits depth of interaction with the hyporheic zone and decrease hyporheic exchange rates (Harvey et al., 1996; Jones et al., 1995). Surface exchange rates increase during periods of high flow, further decreasing potential RTS by eliminating areas of surface storage. Wroblicky et al. (1998) showed lateral hyporheic zone to decrease by over half in Rio Calaveras and Aspen Creek following periods of recharge, in this case snowmelt introduction. Decreased RTS seen in this study further supports work by Hayden (2012) which saw decreased hyporheic zone depth during summer months compared to fall, when precipitation levels are greater.

Solute Recovery

A strong, significant correlation between measured Δ% Cl^- and modeled Δ% Cl^- was anticipated. Models were created using a proxy for chloride concentration, specifically because of the conservative nature of chloride. Any loss or gain of chloride could be approximated by the model using lateral inflow and outflow. While there was a strong correlation, no statistical significance was found between measured Δ% NO_3^--N and modeled Δ% NO_3^--N. This indicates that the model does not allow for an accurate prediction of nitrate recovery, since Δ% NO_3^-N is not occurring in a linear fashion. Differences in model sensitivities to inflow, outflow, or concentrations could be controlling this aspect. The analysis also indicated due to the small sample size, results are suspect. If a larger sample size could be analyzed, a stronger claim could be made regarding the relationship.

Nitrate conservation or loss was predicted to occur within transient storage zones, which would manifest as a steady N/Cl or decreasing N/Cl. The majority of sites followed this trend. Nitrate gain, increasing N/Cl, was not anticipated, but was seen in 1900N and Little Kickapoo Creek – Lined, Trial 2. There are several potential reasons for these unanticipated N/Cl results. Inflow or outflow can influence nitrate retention, even on a small scale (Bean, 2012). Short reaches experiencing inflow of groundwater controlled by nitrification processes, rather than denitrification processes due to anoxic conditions, can have an overall increase in N/Cl

(Bean, 2012; Duff et al., 2008). Either can dictate whether a stream has the capacity to retain nutrients in streambed sediments, or if groundwater occupying interstitial spaces it may increase nitrate loads (Duff et al., 2008).

Overall, natural and modified unlined streams experienced similar steady N/Cl during this study. While unexpected, similarities between the ability of natural or modified unlined streams to remove nitrate has been seen in a study by Herrman et al. (2008) where sites had similarly elevated nitrate concentrations. Most often the inability of a stream to process nitrate as effectively is attributed to the stream being at the saturation point (Bernot et al., 2006; Claessens et al., 2010; Covino et al, 2010; Kemp and Dodds, 2002). Nitrate saturation may be occurring at both natural and modified lined sites in this study, as both are located within agricultural watersheds.

Stream reach may also not have been of sufficient length to properly assess stream denitrification. In this study, reaches were limited to 100m, with an additional 20m allotted for mixing between the injection point and upstream probe location for a total reach length of 120m. While some studies used stream reaches comparable to those in this study to conduct transient storage modeling (Gooseff et al., 2005), others analyzed reach lengths in the 100s of meter and greater (Covino et al., 2010; Gooseff et al., 2013). Uptake was shown to decrease downstream, suggesting reaches of varying lengths may display different solute losses (Covino et al., 2010). Longer reaches were also shown to process solutes differently than short (Gooseff et al., 2013), likely due to long and short flow paths through the hyporheic zone (Poole et al., 2008).

RTS v. NO_3^--N

Previous studies have shown no correlation between RTS and NO_3^--N (Hall et al., 2002) as well as change in nitrate being controlled by RTS (Herrman et al., 2008). This study hypothesized that percent change in NO_3^--N would decreased (less nitrification occurring or denitrification occurring) as RTS increased. The data support an overall decreasing change in nitrate-N with increasing RTS, however, the results are not statistically significant. Differing states of microbial activity could be affecting the outcome of this analysis, as well as differences in background concentrations of NO_3^-N.

The addition of NO_3^--N rather than loss was seen in this study, which could have been the result of aerobic conditions rather than anaerobic. Aerobic conditions would cause the hyporheic zone to transition from denitrifying conditions to nitrifying conditions (Argerich et al., 2011; Haggard et al., 2001). This would cause the hyporheic zone to become a source, rather than sink, for nitrate. Other studies have also experienced increases in NO_3^--N rather than anticipated decreases (Argerich et al., 2011; Haggard et al., 2001).

CHAPTER V

CONCLUSION

Contrary to the hypothesis, RTS was highest in modified unlined streams. RTS was, however, lowest in modified lined streams as predicted. This discrepancy could be explained by the elimination of sinuosity, important characteristic of natural streams. It is expected that natural stream reaches allowing for sinuosity would display a larger RTS than modified unlined streams. Flow retardation due to vegetation could also account for inconsistencies in RTS. Elimination of vegetation in modified unlined streams, or additional vegetation in modified lined streams, is expected to increase the RTS in natural streams relative to modified unlined.

Change in percent of NO_3^--N decreased as RTS increased. While these results support the hypothesis, they were not statistically significant. Differences among individual stream features, as well as spatial and temporal variation in sampling may be influencing the outcome. Stream may also include alternating segments of nitrification and denitrification. Increasing the site sample size, and allowing for a longer study reach may provide further insight into these discrepancies.

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APPENDIX A

FIELD DATA

1900N – UNLINED Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
℃	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
9.7	88.2	10.01	628.8	446.3	8.38	742.2	n.a.

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
℃	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
9.74	n.a.	n.a.	573	406	n.a.	757.2	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	6.562	2.000
2	9.705	2.958
3	8.537	2.602
4	9.442	2.878
5	8.012	2.442
6	14.232	4.338
7	9.888	3.014
8	16.155	4.924
9	10.348	3.154
10	13.753	4.192
		3.250
		AVG Width

1900N – UNLINED Cont'd - Cross Sections

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
0.820	0.250	0.102	0.031	0.00	0.00	0.250	0.008	0.0000
1.640	0.500	0.302	0.092	0.12	0.04	0.250	0.023	0.0008
2.461	0.750	0.525	0.160	0.29	0.09	0.250	0.040	0.0035
3.281	1.000	0.623	0.190	1.40	0.43	0.250	0.048	0.0203
4.101	1.250	0.486	0.148	0.30	0.09	0.250	0.037	0.0034
4.921	1.500	0.328	0.100	0.08	0.02	0.250	0.025	0.0006
5.741	1.750	0.220	0.067	0.01	0.00	0.250	0.017	0.0001
6.562	2.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
					0.07		0.197	0.0287
					AVG Flow Velocity		TOT Area	TOT Discharge

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
0.820	0.250	0.630	0.192	0.04	0.01	0.250	0.048	0.0006
1.640	0.500	0.991	0.302	0.03	0.01	0.250	0.076	0.0007
2.461	0.750	1.070	0.326	-0.03	-0.01	0.250	0.082	-0.0007
3.281	1.000	1.194	0.364	-0.02	-0.01	0.250	0.091	-0.0006
4.101	1.250	1.319	0.402	-0.02	-0.01	0.250	0.101	-0.0006
4.921	1.500	1.470	0.448	0.09	0.03	0.250	0.112	0.0031
5.741	1.750	1.378	0.420	0.27	0.08	0.250	0.105	0.0086
6.562	2.000	1.312	0.400	0.00	0.00	0.250	0.100	0.0000
7.382	2.250	1.339	0.408	0.00	0.00	0.250	0.102	0.0000
8.202	2.500	1.227	0.374	0.00	0.00	0.250	0.094	0.0000
9.022	2.750	0.991	0.302	0.00	0.00	0.250	0.076	0.0000
9.843	3.000	0.899	0.274	0.00	0.00	0.250	0.069	0.0000
10.663	3.250	0.833	0.254	0.00	0.00	0.250	0.064	0.0000
11.483	3.500	0.774	0.236	0.00	0.00	0.250	0.059	0.0000
12.303	3.750	0.459	0.140	0.00	0.00	0.250	0.035	0.0000
13.123	4.000	0.341	0.104	0.00	0.00	0.221	0.023	0.0000
13.753	4.192	0.000	0.000	0.00	0.00	0.096	0.000	0.0000
					0.01		1.233	0.0111
					AVG Flow Velocity		TOT Area	TOT Discharge
							0.715	0.0199
							Avg. AREA	Avg. QSTART

CROOKED CREEK – NATURAL Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
18.6	81.3	7.53	608	534	8.49	746.8	0.3

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
18.64	31.4	2.9	558	491	8.8	763.6	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	11.400	3.47472
2	14.500	4.4196
3	18.070	5.50774
4	19.050	5.80644
5	18.650	5.68452
6	11.900	3.62712
7	17.900	5.45592
8	15.600	4.75488
9	12.150	3.70332
10	11.150	3.39852
		4.58328
		AVG Width

CROOKED CREEK – NATURAL Cont'd - Cross Sections

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.152	0.000	0.0000
1.000	0.305	0.150	0.046	0.00	0.00	0.305	0.014	0.0000
2.000	0.610	0.245	0.075	0.02	0.01	0.305	0.023	0.0001
3.000	0.914	0.320	0.098	0.10	0.03	0.229	0.022	0.0007
3.500	1.067	0.300	0.091	0.12	0.04	0.152	0.014	0.0005
4.000	1.219	0.315	0.096	0.14	0.04	0.152	0.015	0.0006
4.500	1.372	0.380	0.116	0.16	0.05	0.152	0.018	0.0009
5.000	1.524	0.475	0.145	0.15	0.05	0.152	0.022	0.0010
5.500	1.676	0.590	0.180	0.16	0.05	0.152	0.027	0.0013
6.000	1.829	0.560	0.171	0.15	0.05	0.152	0.026	0.0012
6.500	1.981	0.620	0.189	0.15	0.05	0.152	0.029	0.0013
7.000	2.134	0.740	0.226	0.13	0.04	0.152	0.034	0.0014
7.500	2.286	0.875	0.267	0.12	0.04	0.152	0.041	0.0015
8.000	2.438	0.875	0.267	0.13	0.04	0.152	0.041	0.0016
8.500	2.591	0.990	0.302	0.12	0.04	0.152	0.046	0.0017
9.000	2.743	1.200	0.366	0.14	0.04	0.229	0.084	0.0036
10.000	3.048	1.105	0.337	0.13	0.04	0.229	0.077	0.0031
10.500	3.200	0.800	0.244	0.08	0.02	0.152	0.037	0.0009
11.000	3.353	0.000	0.000	0.00	0.00	0.076	0.000	0.0000
					0.03		0.569	0.0213
					AVG Flow Velocity		TOT Area	TOT Discharge

FROG ALLEY – UNLINED Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
19.6	85.6	7.84	654	586	8.07	742	0.32

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
19.86	38.6	3.51	598	539	n.a.	760.3	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	6.810	2.07569
2	5.250	1.6002
3	14.625	4.4577
4	16.890	5.14807
5	15.880	4.84022
6	11.505	3.50672
7	14.690	4.47751
8	15.075	4.59486
9	14.220	4.33426
10	14.590	4.44703
		3.94823
		AVG Width

FROG ALLEY - UNLINED Cont'd - Cross Sections

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.152	0.000	0.0000
1.000	0.305	0.675	0.206	0.01	0.00	0.305	0.063	0.0002
2.000	0.610	1.340	0.408	0.04	0.01	0.305	0.124	0.0015
3.000	0.914	1.535	0.468	0.06	0.02	0.305	0.143	0.0026
4.000	1.219	1.580	0.482	0.10	0.03	0.229	0.110	0.0034
4.500	1.372	1.470	0.448	0.09	0.03	0.152	0.068	0.0019
5.000	1.524	1.470	0.448	0.07	0.02	0.152	0.068	0.0015
5.500	1.676	1.520	0.463	0.07	0.02	0.152	0.071	0.0015
6.000	1.829	1.580	0.482	0.07	0.02	0.152	0.073	0.0016
6.500	1.981	1.700	0.518	0.08	0.02	0.152	0.079	0.0019
7.000	2.134	1.540	0.469	0.10	0.03	0.152	0.072	0.0022
7.500	2.286	1.470	0.448	0.10	0.03	0.152	0.068	0.0021
8.000	2.438	1.510	0.460	0.07	0.02	0.152	0.070	0.0015
8.500	2.591	1.440	0.439	0.04	0.01	0.152	0.067	0.0008
9.000	2.743	1.335	0.407	0.04	0.01	0.152	0.062	0.0008
9.500	2.896	1.350	0.411	0.05	0.02	0.152	0.063	0.0010
10.000	3.048	1.230	0.375	0.05	0.02	0.152	0.057	0.0009
10.500	3.200	1.265	0.386	0.01	0.00	0.152	0.059	0.0002
11.000	3.353	1.110	0.338	0.01	0.00	0.152	0.052	0.0002
11.500	3.505	1.050	0.320	-0.01	0.00	0.229	0.073	-0.0002
12.500	3.810	0.700	0.213	0.00	0.00	0.305	0.065	0.0000
13.500	4.115	0.225	0.069	0.00	0.00	0.305	0.021	0.0000
14.500	4.420	0.000	0.000	0.00	0.00	0.152	0.000	0.0000
					0.01		1.528	0.0253
					AVG Flow Velocity		TOT Area	TOT Discharge

LITTLE KICKAPOO CREEK – LINED, TRIAL 1 Wetted Widths

Measure #	Width ft	m
1	4.163	1.269
2	5.315	1.620
		1.445
		AVG Width

Cross Sections

Width ft	m	Depth ft	m	Flow Velocity ft/s	m/s	Averaged Width m	Area m^2	Discharge m^3/s
0.000	0.000	0.000	0.000	0.00	0.00	0.200	0.000	0.0000
1.312	0.400	0.085	0.026	0.00	0.00	0.275	0.007	0.0000
1.804	0.550	0.138	0.042	0.22	0.07	0.200	0.008	0.0006
2.625	0.800	0.059	0.018	0.00	0.00	0.250	0.005	0.0000
3.445	1.050	0.131	0.040	0.04	0.01	0.200	0.008	0.0001
3.937	1.200	0.128	0.039	0.03	0.01	0.110	0.004	0.0000
4.163	1.269	0.000	0.000	0.00	0.00	0.035	0.000	0.0000
					0.01		0.032	0.0007
					AVG Flow Velocity		TOT Area	TOT Discharge

LITTLE KICKAPOO CREEK – LINED, TRIAL 1
Cont'd - Cross Sections

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.200	0.000	0.0000
1.312	0.400	0.269	0.082	0.00	0.00	0.400	0.033	0.0000
2.625	0.800	0.338	0.103	0.02	0.01	0.400	0.041	0.0003
3.937	1.200	0.282	0.086	0.06	0.02	0.400	0.034	0.0006
5.249	1.600	0.000	0.000	0.02	0.01	0.210	0.000	0.0000
5.315	1.620	0.000	0.000	0.00	0.00	0.010	0.000	0.0000
					0.01		0.108	0.0009
					AVG Flow Velocity		TOT Area	TOT Discharge

0.070	0.0008
Avg. AREA	Avg. QSTART

LITTLE KICKAPOO CREEK – LINED, TRIAL 2 Background

Ambient Up — YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
30.8	110.6	8.22	966	1083	8.96	737.8	0.4

Ambient Down — YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
31.99	223.5	16.31	768	877	n.a.	758.3	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	2.946	0.898
2	3.934	1.199
3	2.605	0.794
4	3.419	1.042
5	3.780	1.152
6	3.642	1.110
7	4.206	1.282
8	3.517	1.072
9	3.819	1.164
10	3.714	1.132
11	3.228	0.984
12	2.759	0.841
		1.056
		AVG Width

Cross Sections

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.050	0.000	0.0000
0.328	0.100	0.046	0.014	0.00	0.00	0.100	0.001	0.0000
0.656	0.200	0.098	0.030	0.00	0.00	0.100	0.003	0.0000
0.984	0.300	0.144	0.044	0.24	0.07	0.100	0.004	0.0003
1.312	0.400	0.148	0.045	0.26	0.08	0.100	0.005	0.0004
1.640	0.500	0.200	0.061	0.18	0.05	0.100	0.006	0.0003
1.969	0.600	0.184	0.056	1.27	0.39	0.100	0.006	0.0022
2.297	0.700	0.059	0.018	0.00	0.00	0.100	0.002	0.0000
2.625	0.800	0.052	0.016	0.00	0.00	0.099	0.002	0.0000
2.946	0.898	0.000	0.000	0.00	0.00	0.049	0.000	0.0000
					0.06		0.028	0.0032
					AVG Flow Velocity		TOT Area	TOT Discharge

LITTLE KICKAPOO CREEK – LINED, TRIAL 2
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.050	0.000	0.0000
0.328	0.100	0.039	0.012	0.00	0.00	0.100	0.001	0.0000
0.656	0.200	0.066	0.020	0.00	0.00	0.100	0.002	0.0000
0.984	0.300	0.112	0.034	0.26	0.08	0.100	0.003	0.0003
1.312	0.400	0.131	0.040	0.36	0.11	0.100	0.004	0.0004
1.640	0.500	0.164	0.050	0.17	0.05	0.100	0.005	0.0003
1.969	0.600	0.171	0.052	0.05	0.02	0.100	0.005	0.0001
2.297	0.700	0.151	0.046	0.04	0.01	0.100	0.005	0.0001
2.625	0.800	0.131	0.040	0.00	0.00	0.100	0.004	0.0000
2.953	0.900	0.125	0.038	0.00	0.00	0.100	0.004	0.0000
3.281	1.000	0.085	0.026	0.00	0.00	0.100	0.003	0.0000
3.609	1.100	0.052	0.016	0.00	0.00	0.100	0.002	0.0000
3.934	1.199	0.000	0.000	0.00	0.00	0.050	0.000	0.0000
					0.02		0.037	0.0011
					AVG Flow Velocity		TOT Area	TOT Discharge

0.033	0.0021
Avg. AREA	Avg. QSTART

LITTLE KICKAPOO CREEK – LINED, APARTMENTS Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
20.3	117.6	10.58	2571	2339	8.54	741.4	1.33

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
21.38	148.4	13.05	2530	2355	n.a.	759.3	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	10.974	3.345
2	16.680	5.084
3	10.623	3.238
4	10.676	3.254
5	11.732	3.576
6	14.377	4.382
7	14.573	4.442
8	14.600	4.450
9	15.997	4.876
10	16.142	4.920
		4.157
		AVG Width

LITTLE KICKAPOO CREEK – LINED, APARTMENTS Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
0.820	0.250	0.098	0.030	0.00	0.00	0.250	0.008	0.0000
1.640	0.500	0.112	0.034	0.00	0.00	0.250	0.009	0.0000
2.461	0.750	0.128	0.039	0.07	0.02	0.250	0.010	0.0002
3.281	1.000	0.157	0.048	0.14	0.04	0.250	0.012	0.0005
4.101	1.250	0.190	0.058	0.26	0.08	0.250	0.015	0.0011
4.921	1.500	0.194	0.059	0.29	0.09	0.250	0.015	0.0013
5.741	1.750	0.200	0.061	0.32	0.10	0.250	0.015	0.0015
6.562	2.000	0.171	0.052	0.18	0.05	0.250	0.013	0.0007
7.382	2.250	0.138	0.042	0.05	0.02	0.250	0.011	0.0002
8.202	2.500	0.102	0.031	0.00	0.00	0.250	0.008	0.0000
9.022	2.750	0.059	0.018	0.00	0.00	0.250	0.005	0.0000
9.843	3.000	0.046	0.014	0.00	0.00	0.250	0.004	0.0000
10.663	3.250	0.000	0.000	0.00	0.00	0.173	0.000	0.0000
10.974	3.345	0.000	0.000	0.00	0.00	0.048	0.000	0.0000
					0.03		0.122	0.0055
					AVG Flow Velocity		TOT Area	TOT Discharge

LITTLE KICKAPOO CREEK - NATURAL Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
19	99.20	9.18	770	682	8.22	740.2	0.38

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
18.78	n.a.	n.a.	684	603	n.a.	759.6	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	14.15	4.312
2	13.22	4.028
3	11.99	3.656
4	17.58	5.358
5	9.65	2.941
6	19.29	5.880
7	11.72	3.572
8	8.32	2.537
9	10.12	3.085
10	17.05	5.198
		4.057
		AVG Width

LITTLE KICKAPOO CREEK - NATURAL
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.00	0.000	0.000	0.00	0.00	0.100	0.000	0.0000
0.656	0.20	0.066	0.020	0.00	0.00	0.200	0.004	0.0000
1.312	0.40	0.125	0.038	0.33	0.10	0.200	0.008	0.0008
1.969	0.60	0.164	0.050	0.31	0.09	0.200	0.010	0.0009
2.625	0.80	0.171	0.052	0.39	0.12	0.200	0.010	0.0012
3.281	1.00	0.184	0.056	0.40	0.12	0.200	0.011	0.0014
3.937	1.20	0.236	0.072	0.51	0.16	0.200	0.014	0.0022
4.593	1.40	0.262	0.080	0.71	0.22	0.200	0.016	0.0035
5.249	1.60	0.381	0.116	0.74	0.23	0.200	0.023	0.0052
5.906	1.80	0.459	0.140	0.85	0.26	0.200	0.028	0.0073
6.562	2.00	0.427	0.130	0.74	0.23	0.200	0.026	0.0059
7.218	2.20	0.394	0.120	0.77	0.23	0.200	0.024	0.0056
7.874	2.40	0.279	0.085	0.60	0.18	0.200	0.017	0.0031
8.530	2.60	0.276	0.084	0.28	0.09	0.200	0.017	0.0014
9.186	2.80	0.177	0.054	0.06	0.02	0.200	0.011	0.0002
9.843	3.00	0.118	0.036	0.00	0.00	0.200	0.007	0.0000
10.499	3.20	0.079	0.024	0.00	0.00	0.200	0.005	0.0000
11.155	3.40	0.000	0.000	0.00	0.00	0.200	0.000	0.0000
11.811	3.60	0.000	0.000	0.00	0.00	0.200	0.000	0.0000
12.467	3.80	0.059	0.018	0.00	0.00	0.200	0.004	0.0000
13.123	4.00	0.072	0.022	0.00	0.00	0.200	0.004	0.0000
13.780	4.20	0.039	0.012	0.00	0.00	0.156	0.002	0.0000
14.147	4.31	0.000	0.000	0.00	0.00	0.056	0.000	0.0000
					0.09		0.241	0.0387
					AVG Flow Velocity		TOT Area	TOT Discharge

LITTLE KICKAPOO CREEK - NATURAL
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.00	0.000	0.000	0.00	0.00	0.100	0.000	0.0000
0.656	0.20	0.118	0.036	0.00	0.00	0.200	0.007	0.0000
1.312	0.40	0.157	0.048	0.04	0.01	0.200	0.010	0.0001
1.969	0.60	0.262	0.080	0.04	0.01	0.200	0.016	0.0002
2.625	0.80	0.407	0.124	0.08	0.02	0.200	0.025	0.0006
3.281	1.00	0.505	0.154	0.09	0.03	0.200	0.031	0.0008
3.937	1.20	0.682	0.208	0.10	0.03	0.200	0.042	0.0013
4.593	1.40	0.745	0.227	0.10	0.03	0.200	0.045	0.0014
5.249	1.60	0.879	0.268	0.10	0.03	0.200	0.054	0.0016
5.906	1.80	0.968	0.295	0.11	0.03	0.200	0.059	0.0020
6.562	2.00	1.043	0.318	0.12	0.04	0.200	0.064	0.0023
7.218	2.20	1.148	0.350	0.15	0.05	0.200	0.070	0.0032
7.874	2.40	1.129	0.344	0.11	0.03	0.200	0.069	0.0023
8.530	2.60	1.312	0.400	0.15	0.05	0.200	0.080	0.0037
9.186	2.80	1.306	0.398	0.07	0.02	0.200	0.080	0.0017
9.843	3.00	1.325	0.404	0.08	0.02	0.200	0.081	0.0020
10.499	3.20	1.142	0.348	0.05	0.02	0.200	0.070	0.0011
11.155	3.40	1.204	0.367	0.07	0.02	0.200	0.073	0.0016
11.811	3.60	1.319	0.402	0.03	0.01	0.200	0.080	0.0007
12.467	3.80	0.997	0.304	0.00	0.00	0.200	0.061	0.0000
13.123	4.00	0.650	0.198	-0.03	-0.01	0.114	0.023	-0.0002
13.215	4.03	0.000	0.000	0.00	0.00	0.014	0.000	0.0000
					0.02		1.038	0.0263
					AVG Flow Velocity		TOT Area	TOT Discharge

0.639	0.0325

SUGAR CREEK – UNLINED, TRIAL 2 Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
23.2	113.6	9.72	556	536	8.31	741.9	0.27

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
23.1	59	5.03	508	490	n.a.	766.8	n.a.

Wetted Widths

Measure	Width	
#	*ft*	*m*
1	11.873	3.619
2	14.731	4.490
3	13.438	4.096
4	11.870	3.618
5	13.025	3.970
6	14.193	4.326
7	12.808	3.904
8	11.155	3.400
9	12.080	3.682
10	12.257	3.736
		3.884
		AVG Width

Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
0.820	0.250	0.039	0.012	0.00	0.00	0.250	0.003	0.0000
1.640	0.500	0.082	0.025	0.00	0.00	0.250	0.006	0.0000
2.461	0.750	0.138	0.042	1.10	0.34	0.250	0.011	0.0035
3.281	1.000	0.135	0.041	1.62	0.49	0.250	0.010	0.0051
4.101	1.250	0.243	0.074	2.28	0.69	0.250	0.019	0.0129
4.921	1.500	0.354	0.108	2.25	0.69	0.250	0.027	0.0185
5.741	1.750	0.367	0.112	2.72	0.83	0.250	0.028	0.0232
6.562	2.000	0.341	0.104	2.63	0.80	0.250	0.026	0.0208
7.382	2.250	0.282	0.086	1.78	0.54	0.250	0.022	0.0117
8.202	2.500	0.203	0.062	1.14	0.35	0.250	0.016	0.0054
9.022	2.750	0.144	0.044	0.45	0.14	0.250	0.011	0.0015
9.843	3.000	0.069	0.021	0.00	0.00	0.250	0.005	0.0000
10.663	3.250	0.039	0.012	0.00	0.00	0.250	0.003	0.0000
11.483	3.500	0.013	0.004	0.00	0.00	0.185	0.001	0.0000
11.873	3.619	0.000	0.000	0.00	0.00	0.060	0.000	0.0000
					0.30		0.186	0.1026
					AVG Flow Velocity		TOT Area	TOT Discharge

SUGAR CREEK – UNLINED, TRIAL 2 Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
24.6	102.4	8062	1071	1064	8.51	740.6	0.53

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
23.71	43.8	3.69	960	936	n.a.	762	n.a.

WETTED WIDTHS

Measure	Width	
#	*ft*	*m*
1	12.675	3.863
2	16.835	5.131
3	19.320	5.889
4	19.690	6.002
5	14.210	4.331
6	13.270	4.045
7	16.170	4.929
8	20.800	6.340
9	21.960	6.693
10	22.815	6.954
		5.418
		AVG Width

SUGAR CREEK – UNLINED, TRIAL 1
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.076	0.000	0.0000
0.500	0.152	0.835	0.255	0.04	0.01	0.152	0.039	0.0005
1.000	0.305	1.110	0.338	0.06	0.02	0.152	0.052	0.0009
1.500	0.457	0.855	0.261	0.08	0.02	0.152	0.040	0.0010
2.000	0.610	0.970	0.296	0.10	0.03	0.152	0.045	0.0014
2.500	0.762	0.980	0.299	0.09	0.03	0.152	0.046	0.0012
3.000	0.914	0.885	0.270	0.10	0.03	0.152	0.041	0.0013
3.500	1.067	0.790	0.241	0.08	0.02	0.152	0.037	0.0009
4.000	1.219	0.625	0.191	0.09	0.03	0.152	0.029	0.0008
4.500	1.372	0.760	0.232	0.11	0.03	0.152	0.035	0.0012
5.000	1.524	0.800	0.244	0.12	0.04	0.152	0.037	0.0014
5.500	1.676	0.800	0.244	0.09	0.03	0.152	0.037	0.0010
6.000	1.829	0.885	0.270	0.10	0.03	0.152	0.041	0.0013
6.500	1.981	0.810	0.247	0.08	0.02	0.152	0.038	0.0009
7.000	2.134	0.820	0.250	0.04	0.01	0.152	0.038	0.0005
7.500	2.286	0.610	0.186	0.03	0.01	0.152	0.028	0.0003
8.000	2.438	0.590	0.180	0.01	0.00	0.152	0.027	0.0001
8.500	2.591	0.595	0.181	0.01	0.00	0.152	0.028	0.0001
9.000	2.743	0.605	0.184	0.02	0.01	0.152	0.028	0.0002
9.500	2.896	0.540	0.165	0.04	0.01	0.152	0.025	0.0003
10.000	3.048	0.555	0.169	0.04	0.01	0.152	0.026	0.0003
10.500	3.200	0.510	0.155	0.02	0.01	0.152	0.024	0.0001
11.000	3.353	0.435	0.133	0.02	0.01	0.152	0.020	0.0001
11.500	3.505	0.360	0.110	0.02	0.01	0.152	0.017	0.0001
12.000	3.658	0.075	0.023	0.00	0.00	0.152	0.003	0.0000
12.500	3.810	0.005	0.002	0.00	0.00	0.076	0.000	0.0000
					0.02		0.781	0.0157
					AVG Flow Velocity		TOT Area	TOT Discharge

SUGAR CREEK – UNLINED, TRIAL 2 Background

Ambient Up YSI ProPlus

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
9.9	96.8	10.93	680	483.7	5.9	741.5	0.33

Ambient Down YSI 556 MPS

T	DO		SpC	C	pH	mmHg	sal
°C	*%*	*mg/L*	*uS/cm*	*uS/cm*			*ppt*
9.29	n.a.	n.a.	620	434	n.a.	757.6	n.a.

WETTED WIDTHS

Measure	Width	
#	*ft*	*m*
1	14.045	4.281
2	16.667	5.080
3	16.778	5.114
4	19.068	5.812
5	20.669	6.300
6	15.292	4.661
7	19.547	5.958
8	20.407	6.220
9	21.526	6.561
10	23.517	7.168
		5.716
		AVG Width

SUGAR CREEK – UNLINED, TRIAL 2
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.125	0.000	0.0000
0.820	0.250	1.283	0.391	0.04	0.01	0.250	0.098	0.0012
1.640	0.500	1.266	0.386	0.15	0.05	0.250	0.097	0.0044
2.461	0.750	1.161	0.354	0.17	0.05	0.250	0.089	0.0046
3.281	1.000	1.115	0.340	0.23	0.07	0.250	0.085	0.0060
4.101	1.250	0.781	0.238	0.22	0.07	0.250	0.060	0.0040
4.921	1.500	0.945	0.288	0.24	0.07	0.250	0.072	0.0053
5.741	1.750	0.932	0.284	0.21	0.06	0.250	0.071	0.0045
6.562	2.000	0.807	0.246	0.12	0.04	0.250	0.062	0.0022
7.382	2.250	0.912	0.278	0.07	0.02	0.250	0.070	0.0015
8.202	2.500	0.833	0.254	0.08	0.02	0.250	0.064	0.0015
9.022	2.750	0.919	0.280	0.10	0.03	0.250	0.070	0.0021
9.843	3.000	0.932	0.284	0.05	0.02	0.250	0.071	0.0011
10.663	3.250	0.840	0.256	0.03	0.01	0.250	0.064	0.0006
11.483	3.500	0.568	0.173	0.00	0.00	0.250	0.043	0.0000
12.303	3.750	0.367	0.112	0.00	0.00	0.250	0.028	0.0000
13.123	4.000	0.098	0.030	0.00	0.00	0.250	0.008	0.0000
13.944	4.250	0.000	0.000	0.00	0.00	0.141	0.000	0.0000
14.045	4.281	0.000	0.000	0.00	0.00	0.015	0.000	0.0000
					0.03		1.049	0.0390
					AVG Flow Velocity		TOT Area	TOT Discharge

SUGAR CREEK – UNLINED, TRIAL 2
Cont'd - Cross Section

Width		Depth		Flow Velocity		Averaged Width	Area	Discharge
ft	*m*	*ft*	*m*	*ft/s*	*m/s*	*m*	*m^2*	*m^3/s*
0.000	0.000	0.000	0.000	0.00	0.00	0.250	0.000	0.0000
1.640	0.500	0.400	0.122	0.16	0.05	0.500	0.061	0.0030
3.281	1.000	0.289	0.088	0.33	0.10	0.500	0.044	0.0044
4.921	1.500	0.243	0.074	0.26	0.08	0.500	0.037	0.0029
6.562	2.000	0.236	0.072	0.16	0.05	0.500	0.036	0.0018
8.202	2.500	0.262	0.080	0.21	0.06	0.500	0.040	0.0026
9.843	3.000	0.266	0.081	0.23	0.07	0.500	0.041	0.0028
11.483	3.500	0.190	0.058	0.10	0.03	0.500	0.029	0.0009
13.123	4.000	0.282	0.086	0.33	0.10	0.500	0.043	0.0043
14.764	4.500	0.295	0.090	0.25	0.08	0.500	0.045	0.0034
16.404	5.000	0.328	0.100	0.06	0.02	0.500	0.050	0.0009
18.045	5.500	0.295	0.090	0.35	0.11	0.500	0.045	0.0048
19.685	6.000	0.262	0.080	0.37	0.11	0.500	0.040	0.0045
21.325	6.500	0.230	0.070	0.47	0.14	0.500	0.035	0.0050
22.966	7.000	0.079	0.024	0.00	0.00	0.463	0.011	0.0000
24.364	7.426	0.000	0.000	0.00	0.00	0.213	0.000	0.0000
					0.06		0.557	0.0414
					AVG Flow Velocity		TOT Area	TOT Discharge

0.803	0.0402
Avg. AREA	Avg. QSTART

APPENDIX B

SAMPLE TIMES AND SPECIFIC CONDUCTANCES

1900N – UNLINED

Injection Time						ProPlus SpC	556MPS SpC
Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	*uS/cm*	*uS/cm*
1	0	22	39.24	1359.24	0.37757	630	576
2	0	24	40.76	1480.76	0.41132	627	587
3	0	26	7.57	1567.57	0.43544	632	591
4	0	28	4.13	1684.13	0.46781	641	599
5	0	29	39.79	1779.79	0.49439	648	602
6	0	31	30.38	1890.38	0.52511	644	608
7	0	33	14.02	1994.02	0.55389	653	609
8	0	34	57.19	2097.19	0.58255	652	609
9	0	37	17.98	2237.98	0.62166	655	612
10	0	41	7.79	2467.79	0.68550	662	619
11	0	46	42.68	2802.68	0.77852	661	616
12	0	49	51.62	2991.62	0.83101	654	611
13	0	58	49.86	3529.86	0.98052	653	608
14	1	5	10.28	3910.28	1.08619	650	603
15	1	10	14.67	4214.67	1.17074	647	593
16	1	17	45.28	4665.28	1.29591	641	591
17	1	35	58.13	5758.13	1.59948	635	590
18	1	46	48.72	6408.72	1.78020	636	588
19	1	56	48.22	7008.22	1.94673	629	581
20	2	8	0.57	7680.57	2.13349	637	585
21	2	32	39.46	9159.46	2.54429	630	580
22	3	9	39.14	11379.14	3.16087	n.a.	n.a.
Amb U 1						641	569
Amb U 2						631	574

CROOKED CREEK – NATURAL

Injection Time						ProPlus SpC	556MPS SpC
Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	*uS/cm*	*uS/cm*
1	0	53	0.38	3180.38	0.88344	618	575
2	0	54	27.04	3267.04	0.90751	621	574
3	0	55	54.65	3354.65	0.93185	617	570
4	0	57	23.71	3443.71	0.95659	626	579
5	0	58	52.01	3532.01	0.98111	633	586
6	1	0	21.14	3621.14	1.00587	647	597
7	1	0	40.82	3640.82	1.01134	659	608
8	1	1	29.38	3689.38	1.02483	662	613
9	1	2	41.26	3761.26	1.04479	706	650
10	1	3	40.28	3820.28	1.06119	694	641
11	1	4	41.03	3881.03	1.07806	759	699
12	1	6	7.71	3967.71	1.10214	782	723
13	1	8	23.81	4103.81	1.13995	773	714
14	1	11	40.04	4300.04	1.19446	793	736
15	1	15	30.39	4530.39	1.25844	846	785
16	1	17	32.17	4652.17	1.29227	836	770
17	1	20	3.44	4803.44	1.33429	853	787
18	1	23	58.69	5038.69	1.39964	857	790
19	1	30	16.27	5416.27	1.50452	817	755
20	1	37	42.65	5862.65	1.62851	750	693
21	1	47	45.29	6465.29	1.79591	721	668
22	2	1	19.65	7279.65	2.02213	678	627
23	2	29	15.95	8955.95	2.48776	621	575
24	2	55	41.18	10541.18	2.92811	610	563
25	3	6	20.75	11180.75	3.10576	602	558
26	3	20	18.77	12018.77	3.33855	590	550
Amb U 1						607	561
Amb U 2						603	560
Amb U 3						609	559
Amb D 1						612	567
Amb D 2						611	566
Amb D 3						609	564
Slug Dil.						71	66

FROG ALLEY – UNLINED

Sample (#)	hr	min	sec	TOT sec elapsed	TOT hr elapsed	ProPlus SpC uS/cm	556MPS SpC uS/cm
1	0	47	22.91	2842.91	0.78970	649	599
2	0	53	32.63	3212.63	0.89240	659	609
3	0	57	33.30	3453.30	0.95925	672	620
4	1	0	38.77	3638.77	1.01077	687	633
5	1	3	3.71	3783.71	1.05103	697	646
6	1	5	30.04	3930.04	1.09168	711	656
7	1	7	59.45	4079.45	1.13318	725	668
8	1	10	52.04	4252.04	1.18112	737	678
9	1	14	38.75	4478.75	1.24410	753	693
10	1	18	27.06	4707.06	1.30752	757	699
11	1	21	56.04	4916.04	1.36557	762	701
12	1	24	15.77	5055.77	1.40438	761	701
13	1	28	35.60	5315.60	1.47656	n.a.	n.a.
14	1	32	10.40	5530.40	1.53622	751	693
15	1	41	52.13	6112.13	1.69781	736	677
16	1	51	47.83	6707.83	1.86329	721	664
17	1	57	31.68	7051.68	1.95880	708	654
18	2	13	11.85	7991.85	2.21996	693	643
19	2	21	27.92	8487.92	2.35776	689	636
20	2	30	58.75	9058.75	2.51632	687	625
21	2	47	16.83	10036.83	2.78801	675	622
22	3	0	12.50	10812.50	3.00347	668	617
23	3	10	51.33	11451.33	3.18093	665	613
24	3	38	31.66	13111.66	3.64213	663	608
25	4	42	30.42	16950.42	4.70845	653	603
26	6	22	13.68	22933.68	6.37047	631	584
Amb U 1						631	565
Amb U 2						653	597
Amb U 3						655	599
Amb D 1						648	584
Amb D 2						649	593
Amb D 3						647	596
Slug Dil.						75	67

LITTLE KICKAPOO CREEK – LINED, TRIAL 2

Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	ProPlus SpC *uS/cm*	556MPS SpC *uS/cm*
1	0	13	43.73	823.73	0.22881	905	844
2	0	13	47.21	827.21	0.22978	921	859
3	0	13	54.29	834.29	0.23175	937	877
4	0	14	8.35	848.35	0.23565	968	907
5	0	14	17.62	857.62	0.23823	988	921
6	0	14	26.86	866.86	0.24079	1019	951
7	0	14	38.19	878.19	0.24394	1037	971
8	0	14	52.40	892.40	0.24789	1080	1003
9	0	15	7.66	907.66	0.25213	1138	1059
10	0	15	18.32	918.32	0.25509	1151	1074
11	0	15	35.74	935.74	0.25993	1220	1137
12	0	15	49.70	949.70	0.26381	1271	1184
13	0	16	8.85	968.85	0.26913	1318	1225
14	0	16	26.82	986.82	0.27412	1392	1290
15	0	16	49.06	1009.06	0.28029	1457	1354
16	0	17	14.06	1034.06	0.28724	1539	1420
17	0	17	56.06	1076.06	0.29891	1592	1474
18	0	19	19.86	1159.86	0.32218	1673	1546
19	0	20	35.83	1235.83	0.34329	1666	1541
20	0	21	54.88	1314.88	0.36524	1591	1477
21	0	23	38.32	1418.32	0.39398	1493	1388
22	0	26	20.08	1580.08	0.43891	1356	1258
23	0	29	46.25	1786.25	0.49618	1217	1121
24	0	33	25.56	2005.56	0.55710	1103	1024
25	0	38	25.81	2305.81	0.64050	1001	950
26	0	39	59.61	2399.61	0.66656	983	930
27	0	46	39.60	2799.60	0.77767	972	902
28	0	57	4.59	3424.59	0.95128	916	824
29	1	4	9.08	3849.08	1.06919	860	793
30	1	10	32.23	4232.23	1.17562	842	784
Amb U 1						845	791
Amb U 2						890	828
Amb U 3						898	822
Slug Dil.						73	70

LITTLE KICKAPOO CREEK – LINED, APARTMENTS

						ProPlus SpC	556MPS SpC
Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	*uS/cm*	*uS/cm*
1	0	32	56.34	1976.34	0.54898	2559	2348
2	0	33	4.42	1984.42	0.55123	2669	2433
3	0	33	21.66	2001.66	0.55602	2656	2427
4	0	33	23.99	2003.99	0.55666	2698	2459
5	0	33	29.52	2009.52	0.55820	2700	2477
6	0	33	37.74	2017.74	0.56048	2751	2523
7	0	34	2.15	2042.15	0.56726	2760	2534
8	0	34	15.27	2055.27	0.57091	2816	2588
9	0	34	40.00	2080.00	0.57778	2881	2649
10	0	34	54.32	2094.32	0.58176	2833	2612
11	0	35	15.63	2115.63	0.58768	2874	2627
12	0	35	21.98	2121.98	0.58944	2863	2619
13	0	35	33.37	2133.37	0.59260	2809	2574
14	0	35	44.65	2144.65	0.59574	2847	2608
15	0	36	0.54	2160.54	0.60015	2773	2540
16	0	36	9.37	2169.37	0.60260	2720	2496
17	0	36	32.61	2192.61	0.60906	2717	2495
18	0	36	44.73	2204.73	0.61243	2664	2441
19	0	36	58.23	2218.23	0.61618	2662	2439
20	0	37	9.13	2229.13	0.61920	2638	2421
21	0	37	19.37	2239.37	0.62205	2590	2370
22	0	37	31.20	2251.20	0.62533	2587	2369
23	0	37	42.40	2262.40	0.62844	2562	2349
24	0	37	59.24	2279.24	0.63312	2554	2342
25	0	38	11.04	2291.04	0.63640	2530	2326
26	0	38	45.89	2325.89	0.64608	2524	2326
Amb U 1						2383	2070
Amb U 2						2461	2262
Slug Dil.						79	71

LITTLE KICKAPOO CREEK – NATURAL

Sample (#)	hr	min	sec	TOT sec elapsed	TOT hr elapsed	ProPlus SpC uS/cm	556MPS SpC uS/cm
1	0.00	11.00	2.63	662.63	0.18406	771	697
2	0.00	13.00	17.85	797.85	0.22163	776	698
3	0.00	18.00	23.16	1103.16	0.30643	803	717
4	0.00	19.00	6.52	1146.52	0.31848	808	722
5	0.00	20.00	25.28	1225.28	0.34036	801	718
6	0.00	20.00	58.91	1258.91	0.34970	865	776
7	0.00	21.00	16.05	1276.05	0.35446	876	787
8	0.00	21.00	32.35	1292.35	0.35899	864	775
9	0.00	21.00	49.97	1309.97	0.36388	850	764
10	0.00	22.00	22.13	1342.13	0.37281	889	793
11	0.00	23.00	19.42	1399.42	0.38873	891	797
12	0.00	24.00	6.93	1446.93	0.40193	876	781
13	0.00	26.00	29.59	1589.59	0.44155	927	824
14	0.00	28.00	23.80	1703.80	0.47328	935	838
15	0.00	30.00	53.33	1853.33	0.51481	910	811
16	0.00	32.00	43.61	1963.61	0.54545	910	812
17	0.00	34.00	37.44	2077.44	0.57707	902	799
18	0.00	39.00	22.94	2362.94	0.65637	890	791
19	0.00	43.00	17.24	2597.24	0.72146	869	775
20	0.00	45.00	39.61	2739.61	0.76100	857	765
21	0.00	48.00	36.01	2916.01	0.81000	831	744
22	0.00	57.00	12.03	3432.03	0.95334	820	736
23	1.00	6.00	5.10	3965.10	1.10142	816	728
24	1.00	13.00	6.56	4386.56	1.21849	804	723
25	1.00	26.00	53.05	5213.05	1.44807	801	719
26	1.00	47.00	34.66	6454.66	1.79296	800	716
Amb U 1						745	624
Amb U 2						770	693
Amb U 3						777	697
Slug Dil.						67	57

SUGAR CREEK – LINED, TRIAL 2

Injection Time						ProPlus SpC	556MPS SpC
Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	*uS/cm*	*uS/cm*
1	0	2	51.51	171.51	0.04764	5234	4887
2	0	2	55.44	175.44	0.04873	5123	4717
3	0	2	57.37	177.37	0.04927	3708	3413
4	0	2	59.60	179.60	0.04989	2518	2303
5	0	3	3.60	183.60	0.05100	1699	1574
6	0	3	8.96	188.96	0.05249	1094	991
7	0	3	12.60	192.60	0.05350	784	719
8	0	3	16.60	196.60	0.05461	726	671
9	0	3	20.71	200.71	0.05575	608	555
10	0	3	25.04	205.04	0.05696	589	539
11	0	3	29.37	209.37	0.05816	566	523
12	0	3	33.66	213.66	0.05935	566	518
13	0	3	41.58	221.58	0.06155	561	512
14	0	3	45.85	225.85	0.06274	559	513
15	0	3	50.18	230.18	0.06394	558	512
16	0	3	54.59	234.59	0.06516	558	510
17	0	4	0.42	240.42	0.06678	557	512
18	0	4	6.71	246.71	0.06853	556	511
19	0	4	11.06	251.06	0.06974	555	511
20	0	4	13.94	253.94	0.07054	555	511
21	0	4	18.79	258.79	0.07189	556	510
22	0	4	24.51	264.51	0.07348	559	512
23	0	4	33.26	273.26	0.07591	550	510
24	0	5	13.16	313.16	0.08699	547	511
25	0	5	26.35	326.35	0.09065	559	515
26	0	5	59.98	359.98	0.09999	545	498
Amb U 1						561	510
Amb U 2						548	503
Amb U 3						540	501
Amb D 1						551	506
Amb D 2						544	495
Amb D 3						547	500
Slug Dil.						75	65

SUGAR CREEK – UNLINED, TRIAL 1

Sample (#)	hr	min	sec	TOT sec elapsed	TOT hr elapsed	ProPlus SpC uS/cm	556MPS SpC uS/cm
1	1	16	12.28	4572.28	1.27008	1067	994
2	1	20	1.51	4801.51	1.33375	1092	1004
3	1	21	53.45	4913.45	1.36485	1101	1024
4	1	24	16.27	5056.27	1.40452	1124	1032
5	1	27	29.50	5249.50	1.45819	1161	1067
6	1	30	26.51	5426.51	1.50736	1217	1120
7	1	32	34.90	5554.90	1.54303	1218	1122
8	1	34	44.01	5684.01	1.57889	1283	1185
9	1	37	28.81	5848.81	1.62467	1319	1214
10	1	40	3.23	6003.23	1.66756	1337	1234
11	1	42	38.99	6158.99	1.71083	1339	1237
12	1	45	28.38	6328.38	1.75788	1337	1235
13	1	49	24.31	6564.31	1.82342	1316	1222
14	1	52	53.39	6773.39	1.88150	1313	1204
15	1	55	59.31	6959.31	1.93314	1292	1183
16	1	59	25.09	7165.09	1.99030	1278	1173
17	2	4	16.37	7456.37	2.07121	1255	1155
18	2	9	18.93	7758.93	2.15526	1234	1136
19	2	17	0.78	8220.78	2.28355	1208	1049
20	2	24	25.63	8665.63	2.40712	1186	1092
21	2	30	45.73	9045.73	2.51270	1166	1070
22	2	39	18.05	9558.05	2.65501	1155	1051
23	2	46	59.23	10019.23	2.78312	1123	1035
24	3	0	4.68	10804.68	3.00130	1103	1015
25	3	35	52.49	12952.49	3.59791	1076	995
26	5	42	15.65	20535.65	5.70435	1070	1003
Amb U 1						1048	960
Amb U 2						1058	964
Amb U 3						1049	965
Amb D 1						1064	973
Amb D 2						1061	971
Amb D 3						1062	963
Slug Dil.						68	60

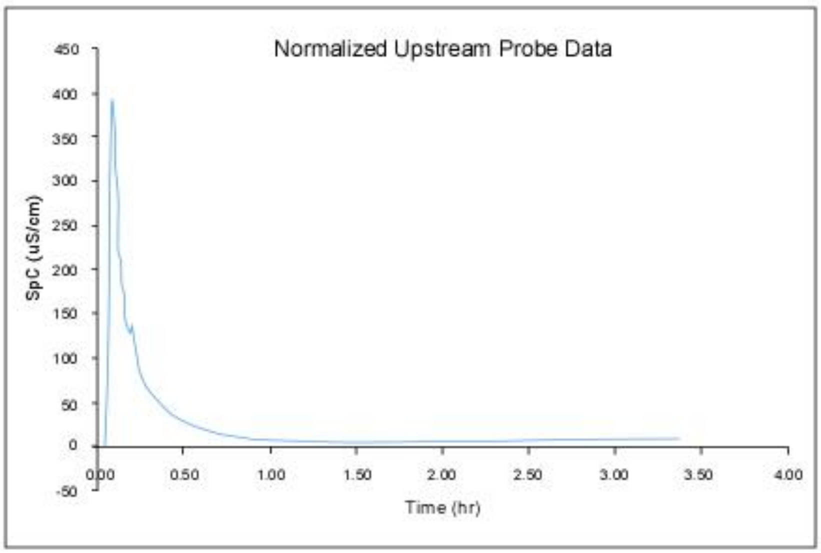
SUGAR CREEK – UNLINED, TRIAL 2

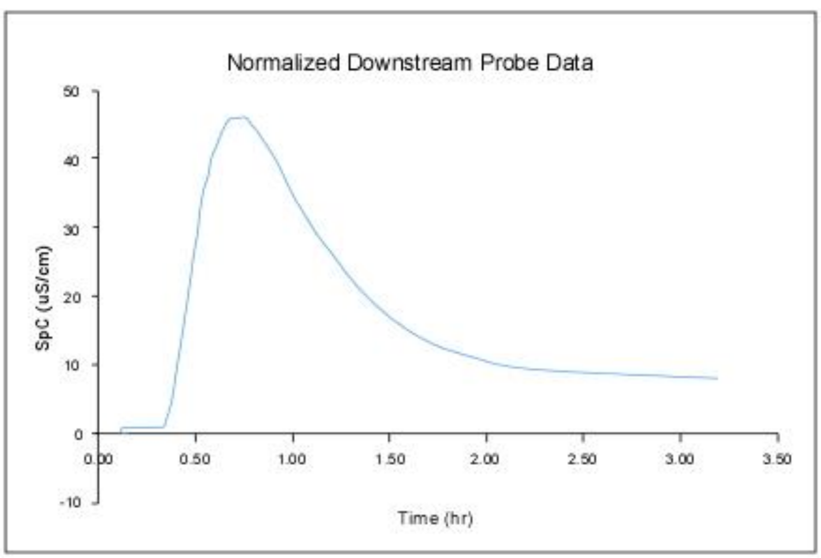
Sample (#)	*hr*	*min*	*sec*	*TOT sec elapsed*	*TOT hr elapsed*	ProPlus SpC *uS/cm*	556MPS SpC *uS/cm*
1	0	40	57.69	2457.69	0.68269	732	669
2	0	41	5.31	2465.31	0.68481	729	670
3	0	41	14.66	2474.66	0.68741	727	668
4	0	41	30.40	2490.40	0.69178	735	673
5	0	41	41.22	2501.22	0.69478	738	676
6	0	41	54.87	2514.87	0.69858	742	679
7	0	42	4.30	2524.30	0.70119	745	688
8	0	42	23.44	2543.44	0.70651	745	694
9	0	42	48.28	2568.28	0.71341	762	709
10	0	43	19.62	2599.62	0.72212	764	713
11	0	43	49.00	2629.00	0.73028	769	712
12	0	44	51.74	2691.74	0.74771	783	721
13	0	46	28.70	2788.70	0.77464	793	731
14	0	49	7.57	2947.57	0.81877	782	718
15	0	0	0.00	0.00	0.00000	n.a.	n.a.
16	0	51	17.38	3077.38	0.85483	770	715
17	0	54	44.09	3284.09	0.91225	743	676
18	0	56	32.51	3392.51	0.94236	728	670
19	0	59	13.41	3553.41	0.98706	715	664
20	1	3	19.94	3799.94	1.05554	704	647
21	1	7	30.64	4050.64	1.12518	691	637
22	1	13	5.95	4385.95	1.21832	684	630
23	1	15	45.35	4545.35	1.26260	682	625
24	1	25	27.56	5127.56	1.42432	681	625
25	1	39	10.15	5950.15	1.65282	684	628
26	1	54	11.22	6851.22	1.90312	683	623
Amb 1						667	614
Amb 2						675	618
Amb 3						669	612

APPENDIX C

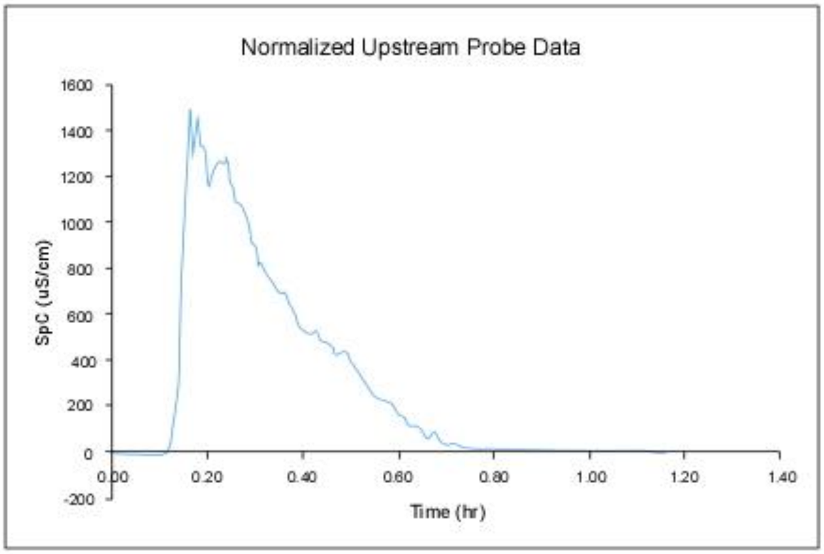
PROBE DATA

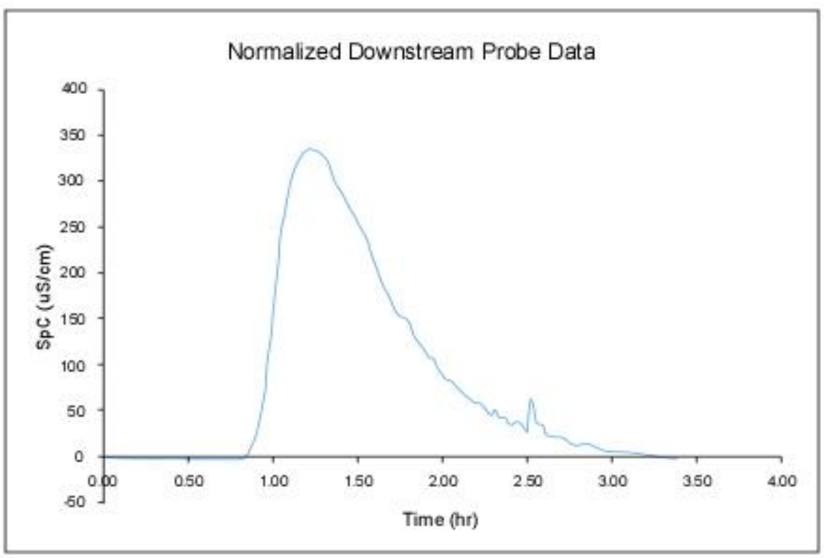
1900N – UNLINED



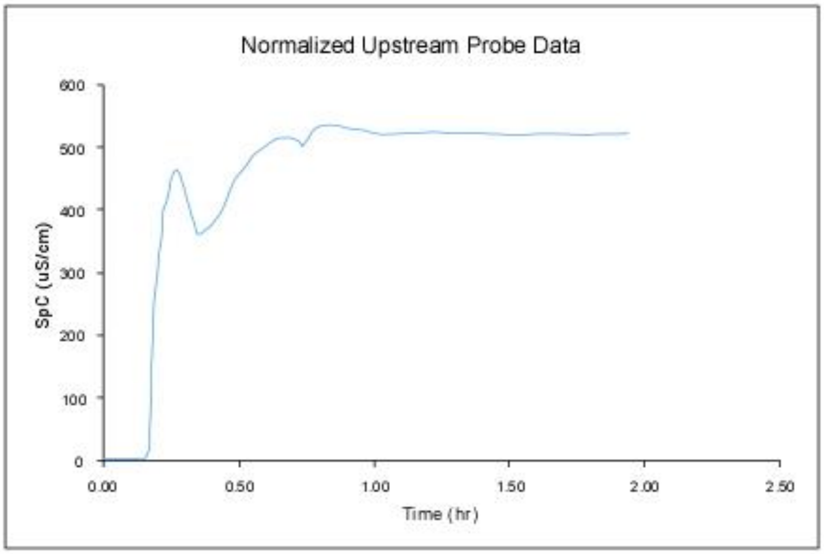


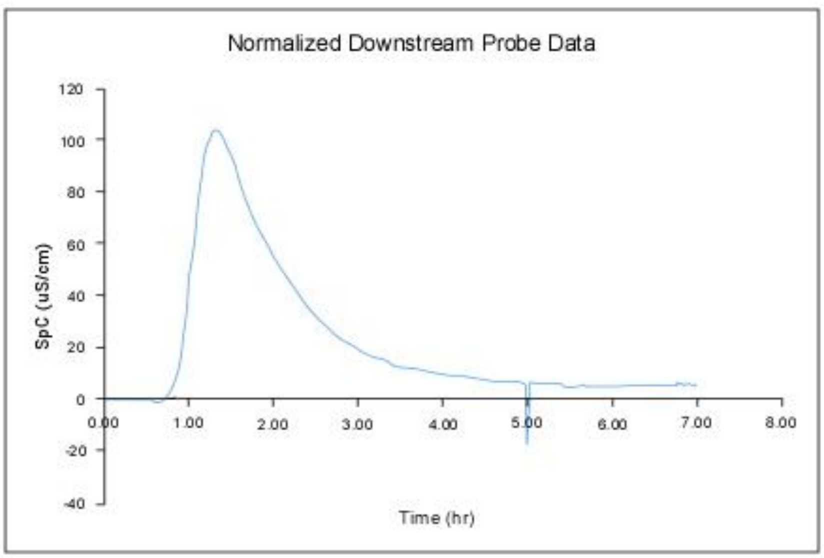
CROOKED CREEK – NATURAL



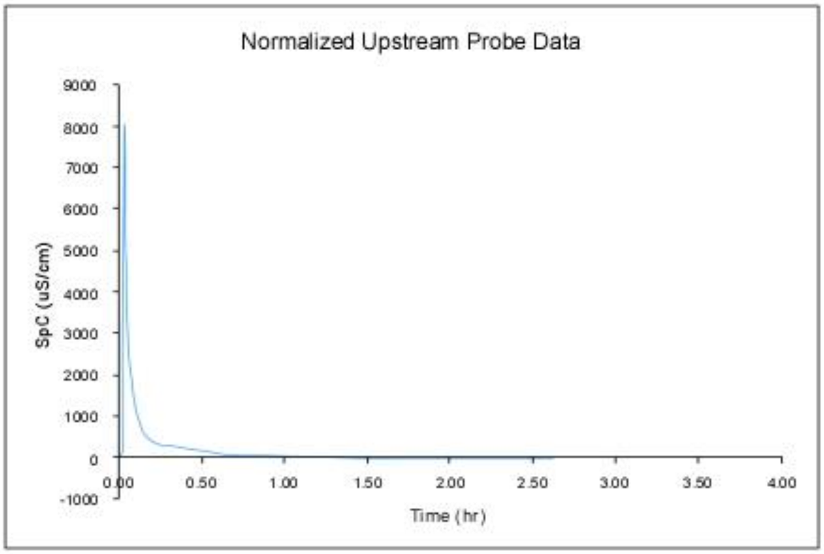


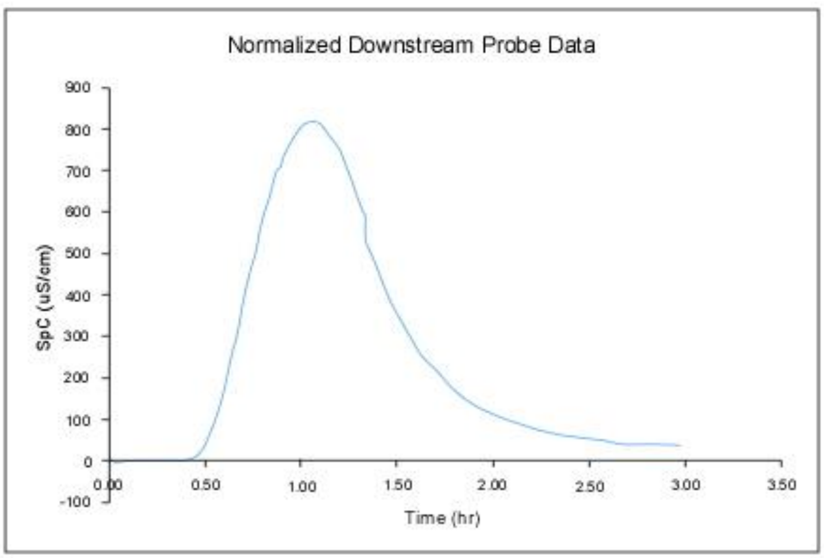
FROG ALLEY – UNLINED



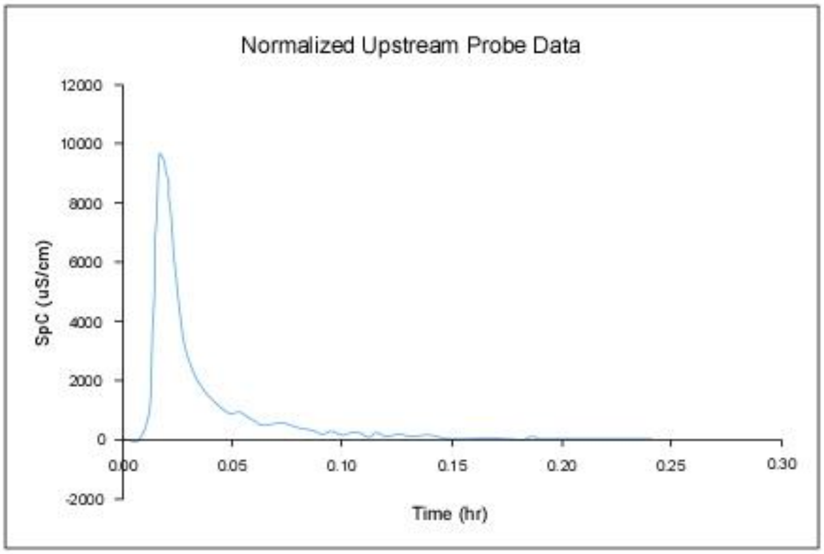


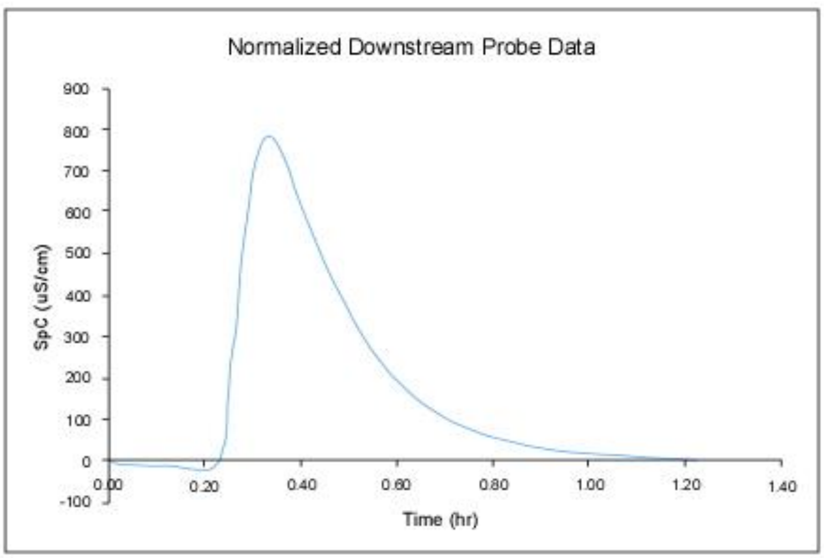
LITTLE KICKAPOO CREEK – LINED, TRIAL 2



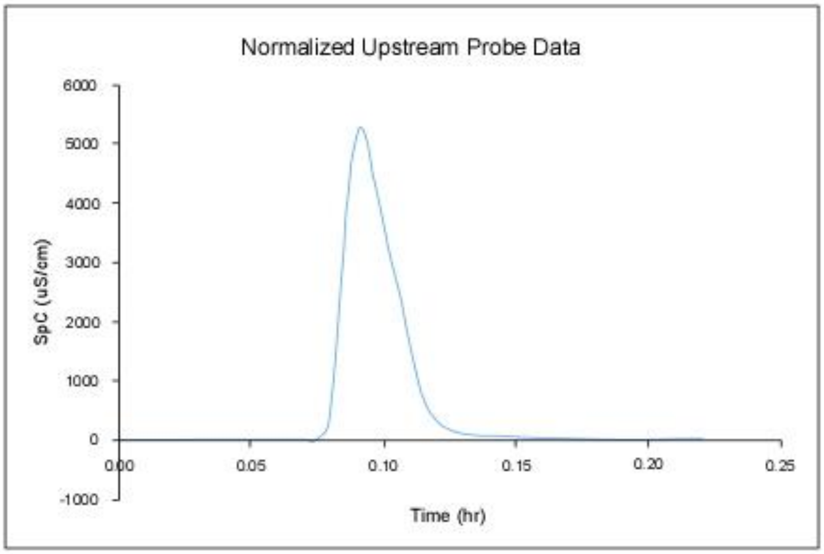


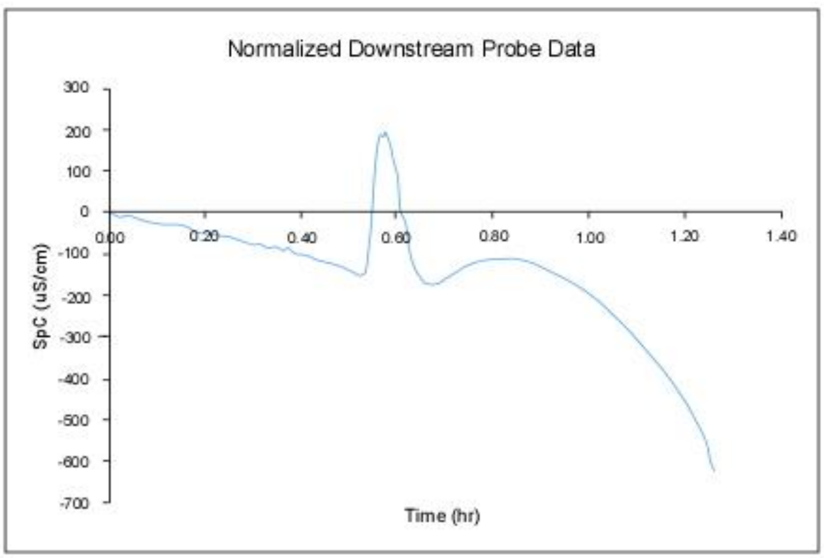
LITTLE KICKAPOO CREEK – LINED TRIAL 2



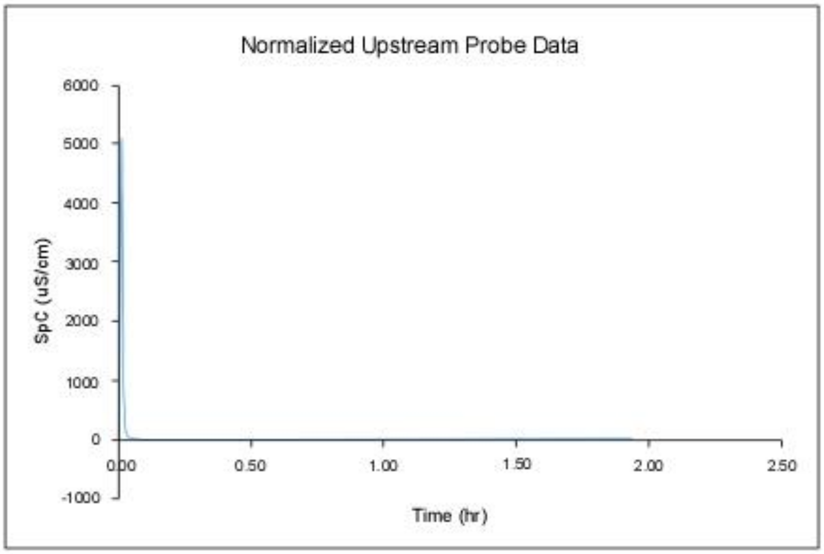


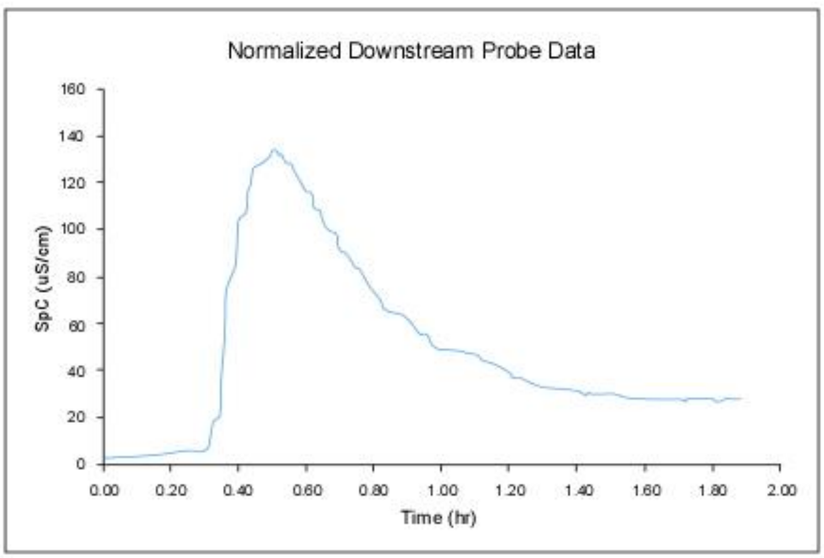
LITTLE KICKAPOO CREEK – LINED, APARTMENTS



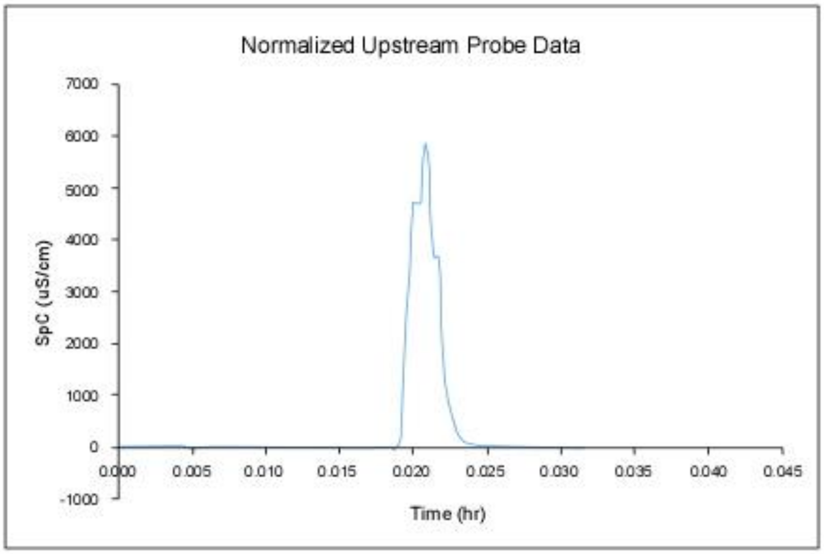


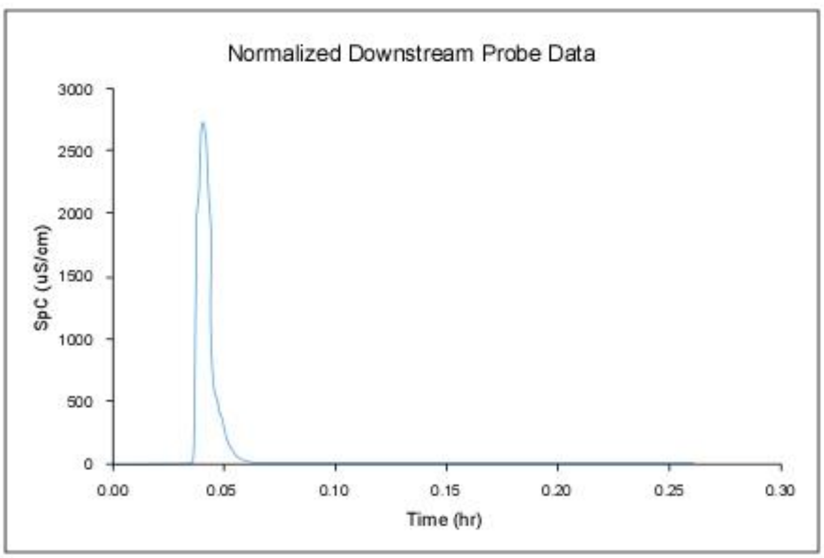
LITTLE KICKAPOO CREEK - NATURAL



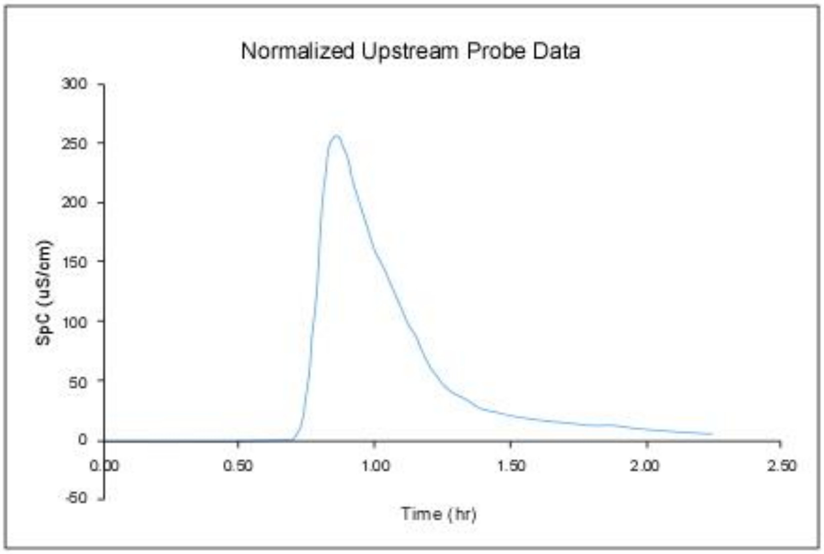


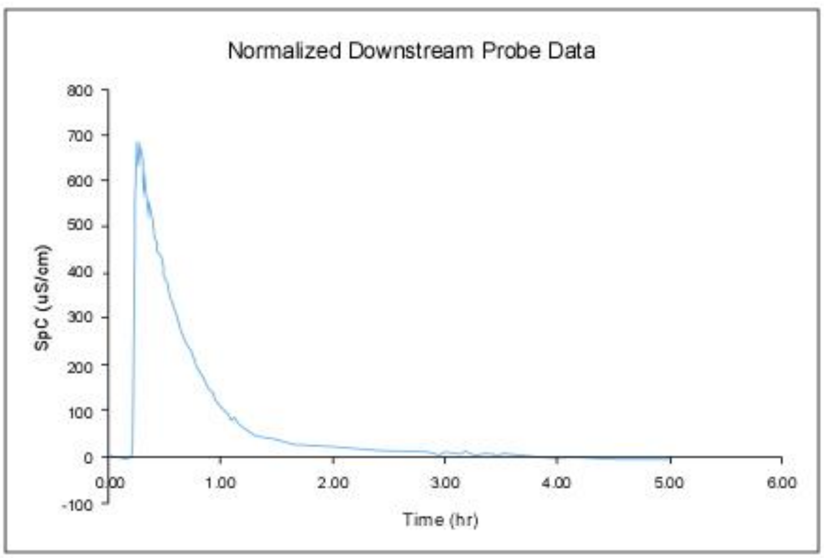
SUGAR CREEK – LINED, TRIAL 2



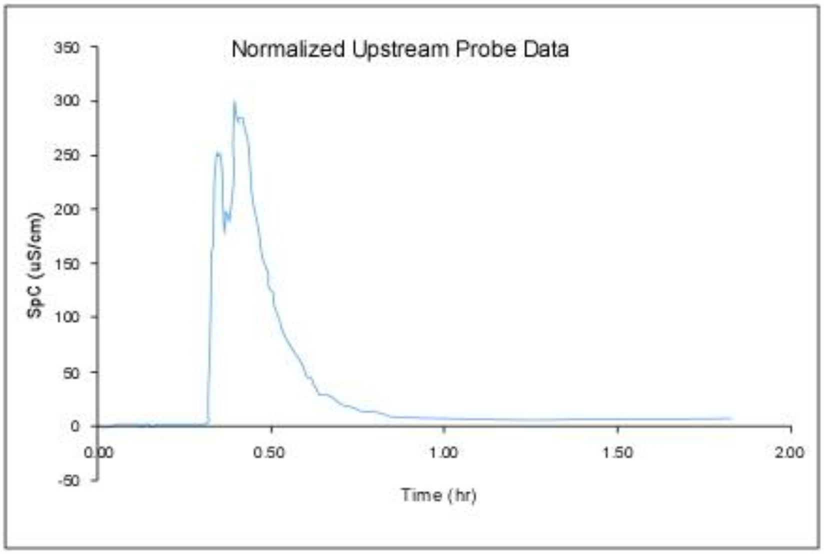


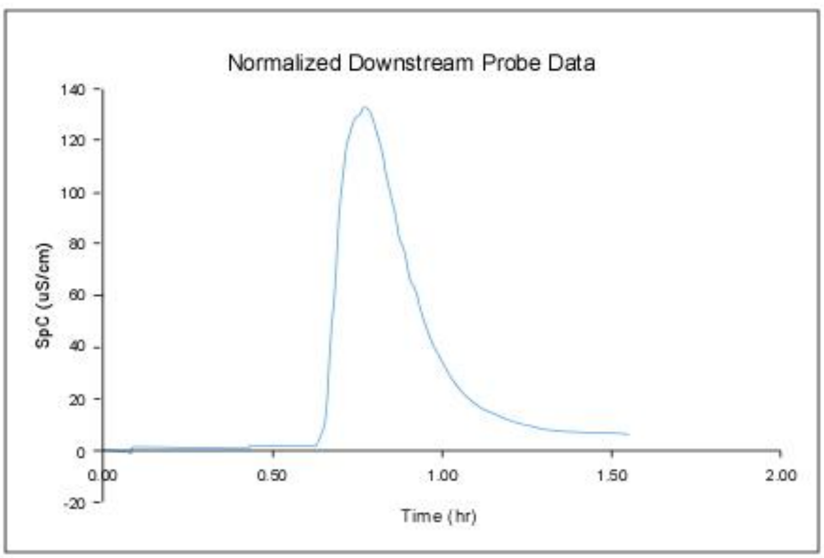
SUGAR CREEK – UNLINED, TRIAL 1





SUGAR CREEK – UNLINED, TRIAL 2





APPENDIX D

NUTRIENT CONCENTRATIONS OF SAMPLES

1900N - UNLINED

Sample	**Cl- (mg/L)**	**NO3--N (mg/L)**
1	16.57	3.94
2	18.76	3.95
3	19.02	4.02
4	20.55	4.05
5	22.60	4.10
6	23.84	4.13
7	16.08	4.10
8	16.82	4.13
9	17.24	4.15
10	17.59	4.13
11	17.31	4.13
12	17.09	4.15
13	15.76	4.12
14	15.04	4.11
15	16.90	4.06
16	13.79	4.11
17	12.26	4.03
18	11.69	4.01
19	11.50	4.02
20	11.66	4.07
21	10.96	4.01
Ambient 1	11.12	3.97
Ambient 2	13.80	3.95

CROOKED CREEK - NATURAL

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	27.85	n.a.
2	27.94	n.a.
3	25.43	n.a.
4	29.59	n.a.
5	30.41	n.a.
6	35.15	n.a.
7	38.30	n.a.
8	40.06	n.a.
9	53.55	n.a.
10	49.02	n.a.
11	70.28	n.a.
12	77.02	n.a.
13	72.01	n.a.
14	80.52	n.a.
15	99.40	n.a.
16	93.01	n.a.
17	98.90	n.a.
18	101.73	n.a.
19	89.77	n.a.
20	68.65	n.a.
21	59.00	n.a.
22	45.92	n.a.
23	28.24	n.a.
24	24.80	n.a.
25	23.03	n.a.
26	23.25	n.a.
Ambient 1	22.34	n.a.
Ambient 2	21.80	n.a.
Ambient 3	23.06	n.a.
Ambient 4	21.86	n.a.
Ambient 5	21.90	n.a.
Ambient 6	22.10	n.a.

FROG ALLEY - UNLINED

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	24.85	n.a.
2	27.44	n.a.
3	31.62	n.a.
4	36.25	n.a.
5	39.33	n.a.
6	43.35	n.a.
7	47.59	n.a.
8	50.15	n.a.
9	55.57	n.a.
10	57.80	n.a.
11	57.78	n.a.
12	58.38	n.a.
13	54.78	n.a.
14	49.49	n.a.
15	45.19	n.a.
16	n.a.	n.a.
17	43.18	n.a.
18	38.57	n.a.
19	36.35	n.a.
20	34.98	n.a.
21	32.33	n.a.
22	30.67	n.a.
23	29.47	n.a.
24	28.28	n.a.
25	26.05	n.a.
26	24.73	n.a.
Ambient 1	26.17	n.a.
Ambient 2	24.37	n.a.
Ambient 3	24.31	n.a.
Ambient 4	23.51	n.a.
Ambient 5	23.67	n.a.
Ambient 6	23.46	n.a.

LITTLE KICKAPOO CREEK – LINED, TRIAL 2

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	146.70	3.02
2	151.24	3.14
3	156.74	3.25
4	167.02	3.45
5	174.46	3.62
6	184.27	3.82
7	193.36	3.99
8	207.10	4.29
9	225.88	4.70
10	229.86	4.78
11	255.39	5.34
12	271.64	5.69
13	289.40	6.10
14	314.34	6.66
15	335.99	7.16
16	357.67	7.62
17	379.04	8.17
18	403.93	8.77
19	404.44	8.81
20	381.26	8.25
21	347.03	7.50
22	297.73	6.39
23	248.95	5.33
24	207.81	4.50
25	171.92	3.79
26	162.18	3.61
27	138.22	3.21
28	123.25	3.00
29	118.00	2.97
30	114.50	2.95
Ambient 1	133.54	2.80
Ambient 2	136.68	2.84
Ambient 3	127.77	2.76

LITTLE KICKAPOO CREEK – LINED, APARTMENTS

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	331.56	2.51
2	318.72	2.41
3	351.41	2.46
4	362.03	2.58
5	331.73	2.50
6	366.53	2.77
7	259.76	2.35
8	332.56	2.76
9	384.17	3.11
10	365.33	2.90
11	379.91	3.02
12	383.55	3.02
13	370.83	3.05
14	375.27	3.11
15	364.88	2.90
16	355.88	2.81
17	334.96	2.64
18	336.30	2.63
19	311.74	2.54
20	345.43	2.59
21	328.67	2.43
22	311.86	2.41
23	333.61	2.30
24	331.13	2.38
25	328.44	2.38
26	323.28	2.29
Ambient 1	308.56	2.29
Ambient 2	317.87	2.31

LITTLE KICKAPOO CREEK - NATURAL

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	139.07	2.01
2	139.67	2.00
3	144.54	2.06
4	149.19	2.12
5	147.58	2.09
6	172.00	2.41
7	173.96	2.43
8	169.52	2.39
9	166.55	2.34
10	178.49	2.49
11	179.01	2.49
12	172.90	2.41
13	192.46	2.66
14	193.59	2.67
15	186.10	2.57
16	186.47	2.56
17	183.57	2.52
18	179.01	2.45
19	172.47	2.37
20	166.84	2.28
21	162.32	2.22
22	158.21	2.17
23	156.56	2.14
24	153.32	2.09
25	151.47	2.05
26	149.72	2.03
Ambient 1	142.42	2.01
Ambient 2	143.22	2.00
Ambient 3	144.31	2.00

SUGAR CREEK – LINED, TRIAL 2

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	1289.97	33.82
2	1252.69	32.45
3	836.50	21.22
4	463.33	11.46
5	463.20	10.12
6	124.65	2.47
7	162.29	2.31
8	132.87	1.72
9	84.66	0.80
10	98.72	0.73
11	174.72	0.86
12	95.79	0.62
13	148.45	0.65
14	195.02	0.72
15	187.93	0.70
16	96.67	0.70
17	95.57	0.35
18	89.82	0.33
19	95.68	0.34
20	95.83	0.33
21	79.29	0.31
22	88.37	0.33
23	89.84	0.34
24	94.33	0.35
25	72.63	0.33
26	97.14	0.39
Ambient 1	80.66	0.34
Ambient 2	92.48	0.35
Ambient 3	92.60	0.34
Ambient 4	92.27	0.34
Ambient 5	72.88	0.32
Ambient 6	93.08	0.35

SUGAR CREEK – UNLINED, TRIAL 1

Sample	Cl- (mg/L)	NO3--N (mg/L)
1	233.43	n.a.
2	241.00	n.a.
3	245.99	n.a.
4	252.80	n.a.
5	264.43	n.a.
6	282.54	n.a.
7	284.54	n.a.
8	309.03	n.a.
9	320.90	n.a.
10	325.60	n.a.
11	327.75	n.a.
12	326.66	n.a.
13	322.50	n.a.
14	317.21	n.a.
15	310.80	n.a.
16	306.17	n.a.
17	299.74	n.a.
18	292.47	n.a.
19	285.02	n.a.
20	278.03	n.a.
21	270.69	n.a.
22	262.67	n.a.
23	257.25	n.a.
24	250.11	n.a.
25	242.44	n.a.
26	232.20	n.a.
Ambient 1	225.97	n.a.
Ambient 2	225.37	n.a.
Ambient 3	219.39	n.a.
Ambient 4	230.56	n.a.
Ambient 5	233.62	n.a.
Ambient 6	232.45	n.a.

SUGAR CREEK – UNLINED, TRIAL 2

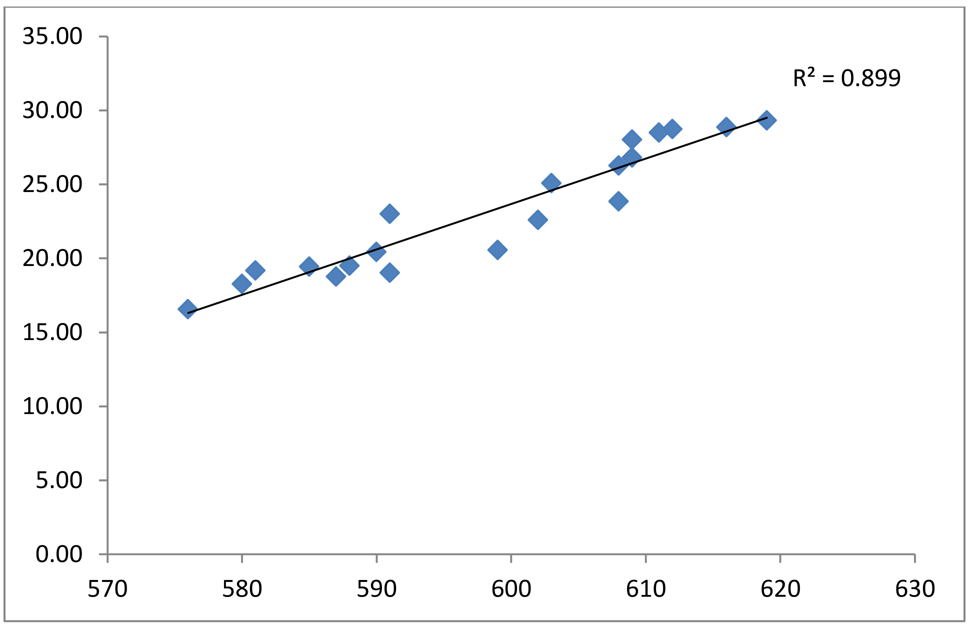
Sample	Cl- (mg/L)	NO3--N (mg/L)
1	110.35	3.21
2	119.99	3.25
3	126.08	3.30
4	126.48	3.37
5	129.42	3.38
6	128.94	3.34
7	131.29	3.52
8	n.a.	n.a.
9	135.10	3.54
10	137.36	3.54
11	132.94	3.63
12	136.22	3.62
13	143.23	3.71
14	139.95	3.70
15	n.a.	n.a.
16	135.94	3.67
17	128.54	3.36
18	124.07	3.33
19	122.86	3.34
20	116.70	3.14
21	116.75	3.11
22	111.13	3.01
23	111.25	2.99
24	111.44	3.01
25	108.82	3.00
26	112.65	2.98
Ambient 1	107.54	3.14
Ambient 2	108.79	3.16
Ambient 3	107.10	3.14

APPENDIX E

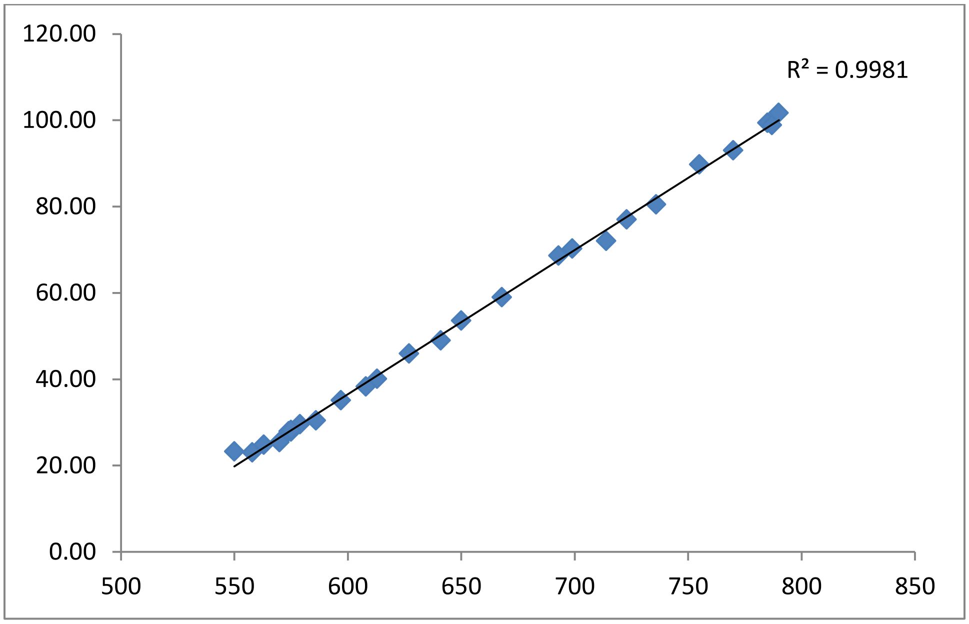
PROXY RELATIONSHIP

**Note: For all sites, relationship is displayed as SpC v. Cl^- (mg/L).*

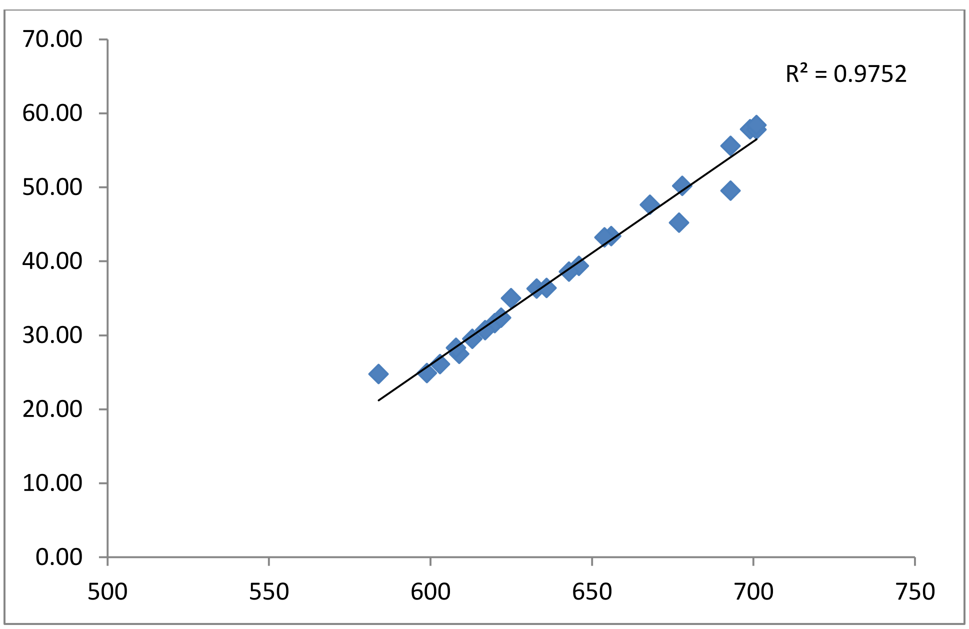
1900N – UNLINED



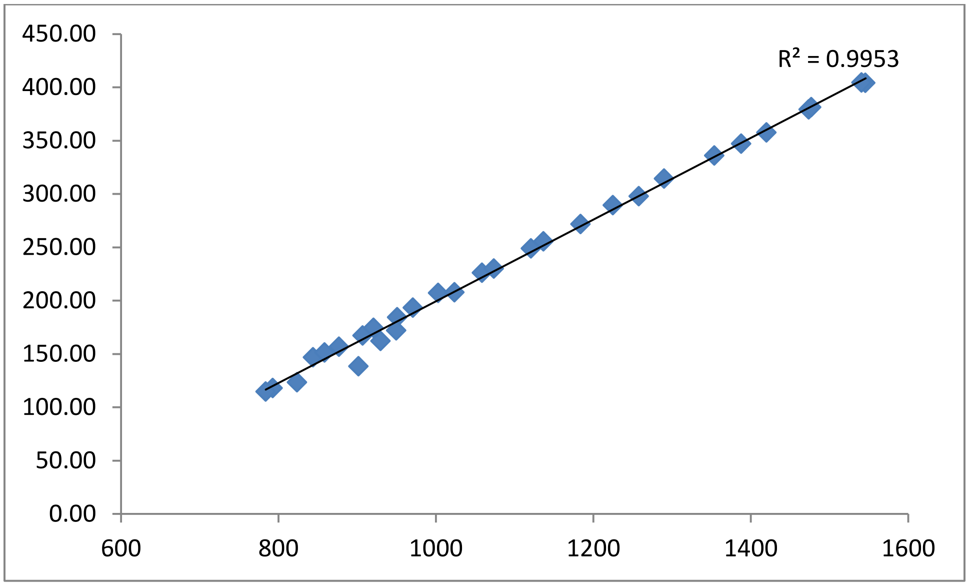
CROOKED CREEK – NATURAL



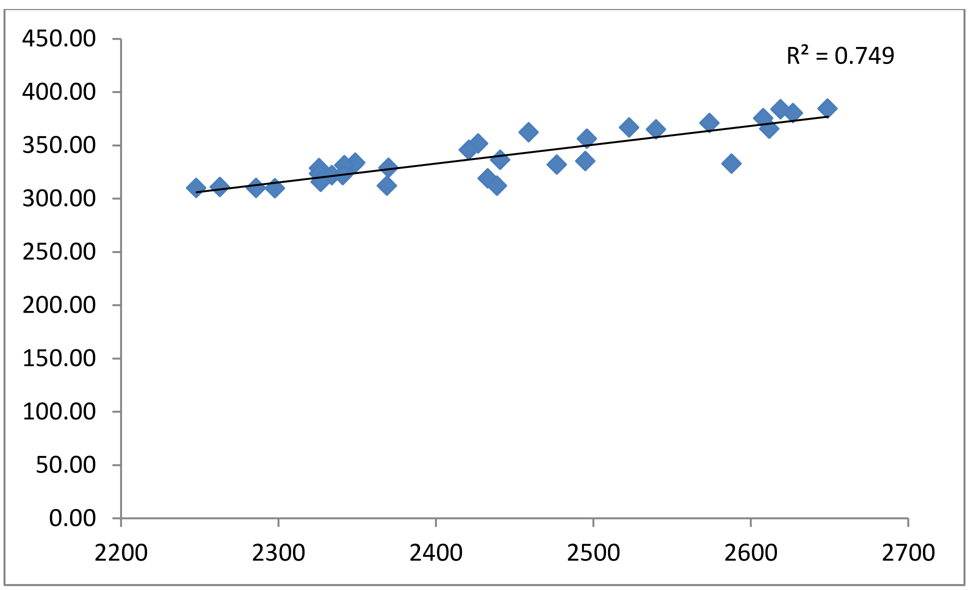
FROG ALLEY – UNLINED



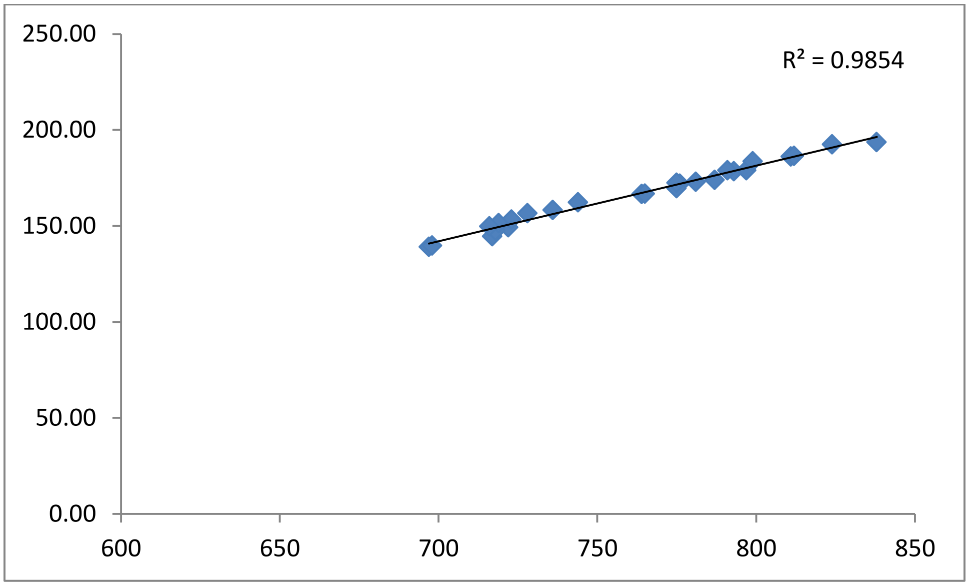
LITTLE KICKAPOO CREEK – LINED, TRIAL 2



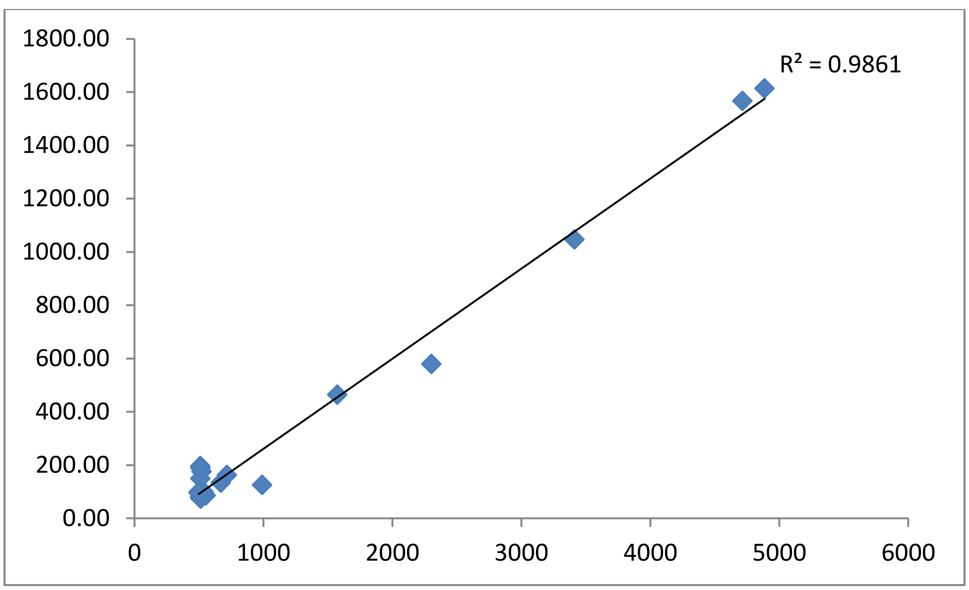
LITTLE KICKAPOO CREEK – NATURAL



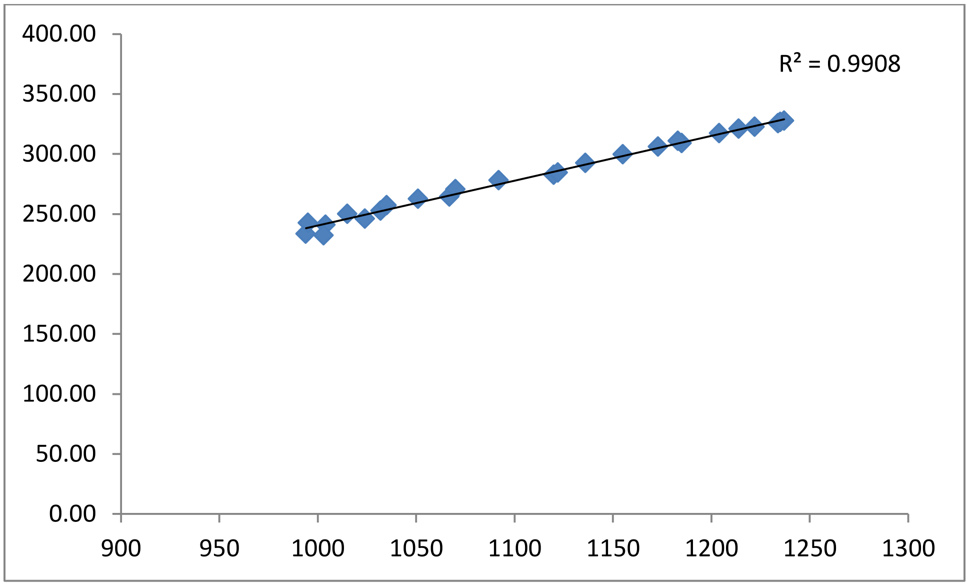
LITTLE KICKAPOO CREEK – LINED, APARTMENTS



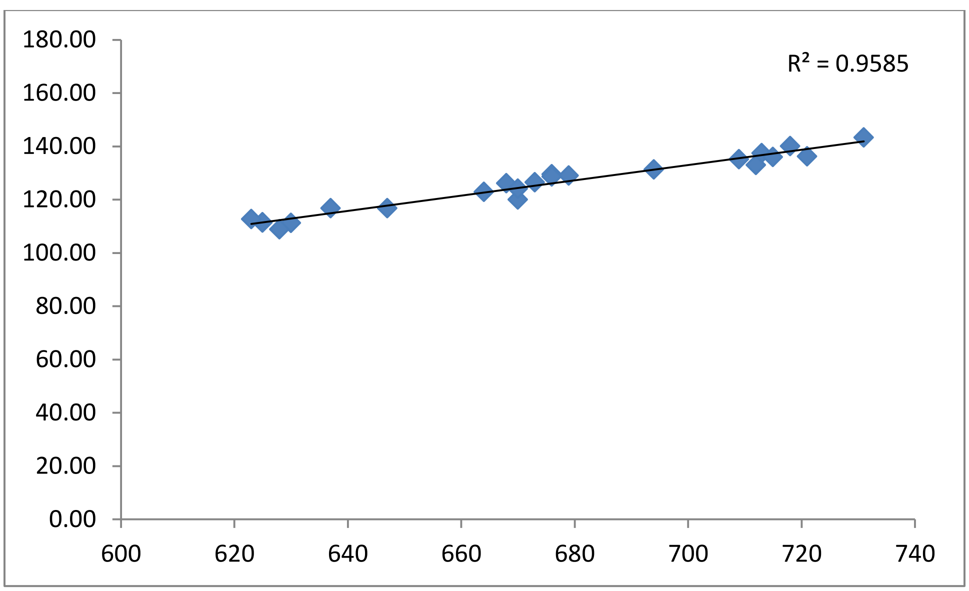
SUGAR CREEK – LINED, TRIAL 2



SUGAR CREEK – UNLINED, TRIAL 1



SUGAR CREEK – UNLINED, TRIAL 2



APPENDIX F

OTIS PARAMETER VALUES

1900N – UNLINED

Site	Parameter	Initial Value	Final Value
1900N	*DISP*	0.1	0.43
	AREA2	0.02	0.07
	ALPHA	0	0.003
	QSTART	0.0287	0.0287
	QLATIN	0	2.E-04
	QLATOUT	0	2.E-04
	AREA	0.197	0.81
	CLATIN	583	566

CROOKED CREEK – NATURAL

Site	Parameter	Initial Value	Final Value
CC	*DISP*	0.1	0.12
	AREA2	0.06	0.18
	ALPHA	0	2.E-05
	QSTART	0.0213	0.0213
	QLATIN	0	2.E-05
	QLATOUT	0	4.E-05
	AREA	0.569	0.949
	CLATIN	558	410

LITTLE KICKAPOO CREEK – LINED, TRIAL 1

Site	Parameter	Initial Value	Final Value
LKC-L(1)	*DISP*	0.01	0.16
	AREA2	0.001	0.01
	ALPHA	0	9.E-06
	QSTART	0.00088	0.0015
	QLATIN	0	8.E-07
	QLATOUT	0	3.E-06
	AREA	0.108	0.06
	CLATIN	1100	1090

LITTLE KICKAPOO CREEK – LINED, TRIAL 2

Site	Parameter	Initial Value	Final Value
LKC-L(2)	*DISP*	0.01	0.13
	AREA2	0.00374	0.0047
	ALPHA	0	6.E-04
	QSTART	0.00318	0.00269
	QLATIN	0	3.E-06
	QLATOUT	0	4.E-06
	AREA	0.0374	0.032
	CLATIN	768	0

LITTLE KICKAPOO CREEK - NATURAL

Site	Parameter	Initial Value	Final Value
LKC-N	*DISP*	0.1	0.25
	AREA2	0.1	0.051
	ALPHA	0	1.E-04
	QSTART	0.0263	0.0261
	QLATIN	0	0
	QLATOUT	0	5.E-05
	AREA	1.038	0.6
	CLATIN	689	689

SUGAR CREEK – LINED, TRIAL 2

Site	Parameter	Initial Value	Final Value
SC-L(2)	*DISP*	0.1	0.66
	AREA2	0.0186	0.0118
	ALPHA	0	0.0057
	QSTART	0.103	0.203
	QLATIN	0	0
	QLATOUT	0	2.E-04
	AREA	0.186	0.147
	CLATIN	508	508

SUGAR CREEK – UNLINED, TRIAL 2

Site	Parameter	Initial Value	Final Value
SC-U(2)	*DISP*	0.1	0.19
	AREA2	0.1	0.35
	ALPHA	0	1.E-04
	QSTART	0.039	0.039
	QLATIN	0	9.E-06
	QLATOUT	0	4.E-05
	AREA	1.048	0.550
	CLATIN	630	180