The Ozarks Environmental and Water Resources Institute (OEWRI)

PRE-CONSTRUCTION REPORT FOR THE WARD BRANCH STREAM RESTORATION PROJECT

Prepared By:
Marc R. Owen, M.S., Research Specialist
Mark A. Gossard, Graduate Assistant
Robert T. Pavlowsky, Ph.D., Director

Completed for: Greene County, Missouri

"U.S. Environmental Protection Agency Region VII,
through the Missouri Department of Natural Resources,
has provided partial funding for this project under
Section 319 of the Clean Water Act."

Missouri Department
of Natural Resources

November 14, 2007

Missouri State University

Missouri State University
OEWRI
Ozarks Environmental and Water Resources Institute

OEWRI EDR-07-004

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SCOPE AND OBJECTIVES

Urbanization can cause changes in hydrologic conditions that result in increased flooding and erosion in local streams. The Ward Branch (11 sq. mi) of the James River located in southern Springfield, Greene County, Missouri is an urban stream that has experienced excessive flooding and erosion from increased flow and frequency of stormwater. In July 2000, a 100-year flood event occurred in the Ward Branch. The flood hit the Shadowood Subdivision and destroyed homes bordering the stream that were later bought out by Greene County. While the land was converted into a greenway trail, the eroded channel, which the county owned, offered an opportunity to demonstrate bioengineering practices that previously have not been widely used in the Ozarks.

Fine-grain sediment eroded from stream banks is considered a nonpoint source of pollution because it can supply and transport nutrients and other pollutants such as heavy metals to receiving waters. Streams conveying water with high suspended sediment loads are also poor habitat for fish and other aquatic life. Coarse-grain sediment originating from eroding channel banks and beds can also affect streams by becoming clogged in the channel and forcing flows against the banks causing the erosion process to start over again. Coarse-grain sediment also fills in bridges and culverts decreasing the capacity for these structures to convey floods. Therefore, identification of sediment sources through stream assessment and channel stabilization using bioengineering practices can create more habitat, improve water quality, reduce flooding, and be an aesthetic asset to the community.

Few if any geomorphic based stream channel stabilization and restoration projects have been implemented in the Ozarks. A lack of understanding of these concepts in terms of design and construction in the region prompted Greene County to apply for and receive 319 funding in September, 2004 from the Missouri Department of Natural Resources to address these issues with a demonstration project in the Ward Branch. The primary goal of this funding is to improve water quality through the reduction of sediment entering the stream through erosion with sustainable solutions appropriate for the area. Along with a nationally recognized consultant as a project partner, various local agencies formed a multi-disciplined project team to address these issues.

OEWRI is responsible for initial data collection and pre/post implementation monitoring of water quality and sediment transport. This report organizes and summarizes data collected during the pre-construction portion of this study from the winter of 2004 to the spring of 2006. This report is organized into four separate sections. These sections detail methods and results for the initial geomorphic assessment, water quality monitoring, bank erosion monitoring, and bedload transport monitoring. Maps, figures, tables and photos corresponding to these sections will be at the end of these sections. Appendices of all data collected can be found at the end of this report.

STUDY AREA

The Ward Branch is a tributary of the James River located in the Ozark Plateaus region of southwest Missouri in southern Greene County (Figure 1). The underlying geology is Mississippian age limestone within which is formed a karst landscape with sinkholes, losing streams, and springs. Ward Branch is a typical Ozarks stream with bedrock at or near the surface of the streambed, gravel bed load, cohesive banks, low slope, and low sinuosity. The study reach is a 3,000 foot section of stream south of Republic Road located in the upper portion of the watershed (Figure 2). This reach is located on two properties, the Twin Oaks Golf Course and the Greene County owned property in the Shadowood subdivision. The upstream drainage area is approximately 2.5 square miles and contains a combination of high intensity development from commercial land use and lower intensity housing developments for a total urban land use of 83% with approximately 47% impervious area.

EXECUTIVE SUMMARY

The following section summarizes this report into the following eight sections:

1. Channel Survey and Evaluation
2. Bank Stability Assessment
3. Bank Material Evaluation
4. Bank Erosion Monitoring
5. Bedload Material Evaluation
6. Bedload Transport Monitoring
7. Nutrient Concentrations and Loads
8. Non-point Source Contributions

1. CHANNEL SURVEY AND EVALUATION. A detailed channel survey was needed for both design purposes and to make geomorphic interpretations of the study reach. The study reach was split into three reaches and nine sub-reaches based on these data and field observations. The 3,000 foot long channel survey included both a longitudinal profile and cross-sectional profiles of the stream. Longitudinal profiles are valuable for identifying bedform characteristics and evaluating channel slope. Average slope for the study reach is 1.1%. There are 50 riffles in the study reach with an average spacing of 67 ft. The 50 pools found in the study reach have an average residual pool depth of 0.8 ft. Geometry of the bankfull channel provides critical information on channel forming flows used to characterize channel shape. Average bankfull width is 18.3 ft with an average bankfull depth of 1.7 ft in the study reach.

2. BANK STABILTY ASSESSMENT. The stability of the streambanks in the study reach were evaluated for both the design purposes as well as erosion monitoring for interpretation of nonpoint load reduction. Bank stability was evaluated by measuring both the bank height and upper bank angle. High bank heights and high upper bank angles have a higher potential for erosion then relatively lower banks with lower bank

angles. Average bank heights ranged from 2.5 ft to 6.3 ft and average bank angles ranged from 10 degrees to 70 degrees for each of the nine subreaches.

3. BANK MATERIAL EVALUATION. Bank material was evaluated at 6 exposed cutbank locations along the study reach. At each site, morphologically different soil layers were identified and sampled. The physical and chemical characteristics of these layers were analyzed. Banks consisted of alluvium, colluvium and fill material. In general, fine-grain material ($\leq$ 2 mm) made up 75% of the bank material with an average grain size distribution of 31% clay, 43% silt, and 26% sand. The bulk density of the fine grain material in the banks is about 87 lbs/ft^3. Of the other 25% of the material making up the banks, the majority is coarse gravel between 16 and 32 mm in size. Chemical analysis of the bank material shows the mean phosphorus (P) concentration of the fine grain fraction is around 400 ug/g.

4. BANK EROSION MONITORING. Bank erosion monitoring is necessary to estimate the amount of sediment entering the stream prior to construction.   Erosion pins were placed at 12 locations in the study reach at actively eroding areas identified in the channel survey in the lower half of the golf course reach and the disturbance reach. This 1,000 foot section of channel was monitored after each significant storm event for an eight month period. The average erosion rate for the monitoring period is around 0.4 feet in 8 months. This translates into 77 tons of fine grain material lost over that timeframe. With a mean P concentration of 400 ug/g, it is estimated that 62 lbs of P entered the stream in 8 months. Extrapolating that out to 12 months, 116 tons of fine-grain material and 93 lbs of P enters the stream annually from this reach.

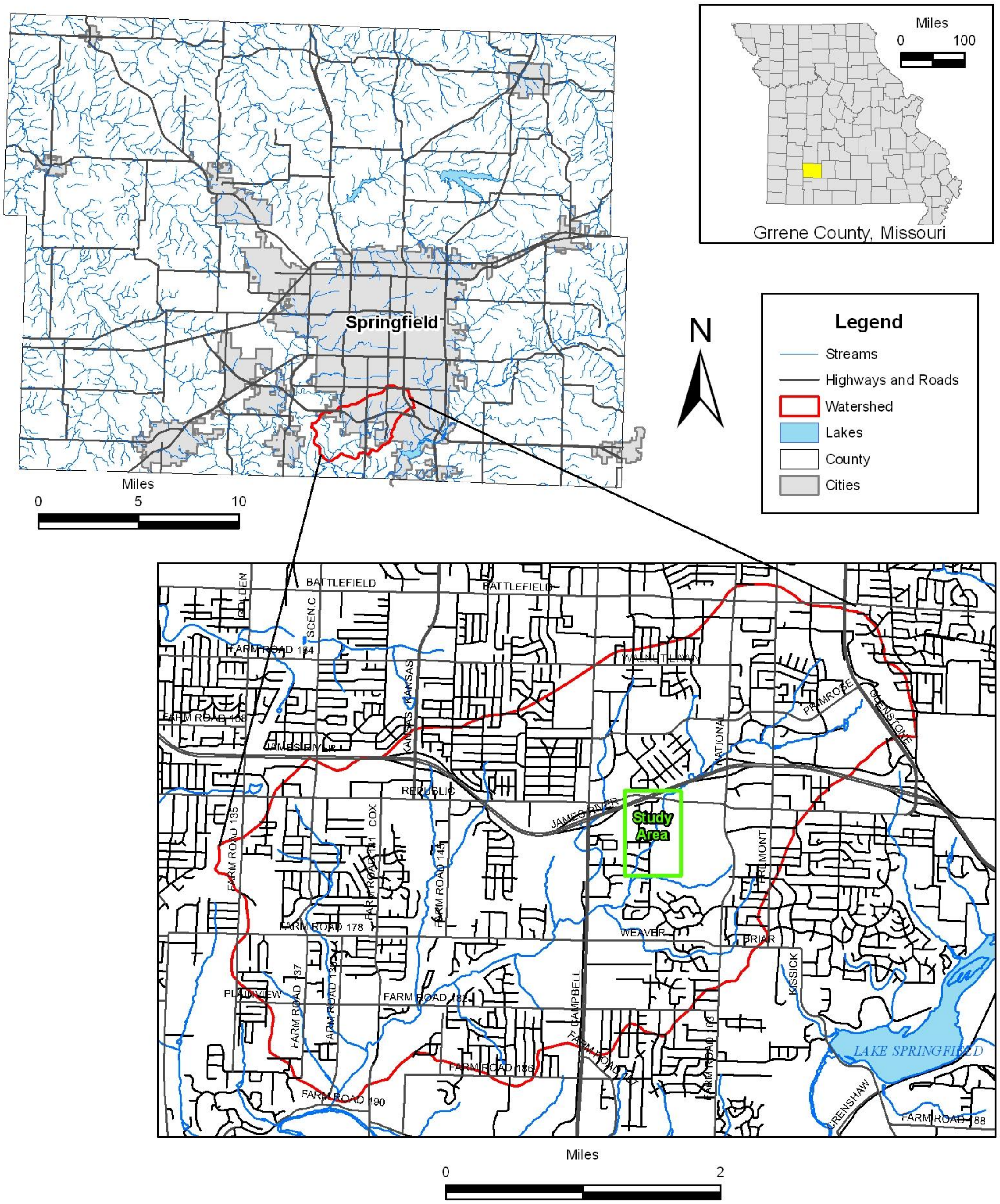
5. BEDLOAD MATERIAL EVALUATION. The size of bed material in the channel is an indication of the streams ability to transport bed material. The size of sediment found in the channel is directly related to the shear stress exerted on the bed. For this study, over 1,000 pieces of sediment were collected and measured through the study reach at 103 transects. The average D50 ranges from 23 mm to 50 mm for each of the subreaches. The average D84 ranges from 66 mm to 110 mm for each of the subreaches. Finally, the average maximum sediment size for each of the subreaches ranged from 140 mm to 235 mm and represents the largest size material the stream can transport.

6. BEDLOAD TRANSPORT MONITORING. The ability of the stream to transport bedload at bankfull discharge is key to understanding stream morphology. While field identification of bankfull indicators is an important component of geomorphic assessments, the streams sediment transport capability during these flows is less understood. The bedload transport capability for the Ward Branch was estimated using bedload tracer experiments. Painted sediment representing the size range of material typically found on the bed was released prior to three near bankfull storm events and the distance traveled was measured. Results suggest even these frequent, in-channel discharges typically less than 18 inches deep have the ability to transport the D84 in this stream. These results also provide evidence that the field identified bankfull estimates

are related to actual bed mobility and helps validate the morphological interpretations used for this study.

7. NUTRIENT CONCENTRATIONS AND LOADS. In order to evaluate the effect of the restoration measures on non-point reduction, nutrient loads need to be determined for Ward Branch and compared to loads and supplied from bank and bed erosion. Nutrient concentrations were monitored and loads calculated using load-discharge rating equations at five sites along the Ward Branch. In general, base flow concentrations ranged from 1 to 3 mg/L TN and < 5 to 30 ug/L TP. Storm runoff concentrations were as high as 7 mg/L TN and 80 ug/L TP. At mean annual discharge, annual TN loadings ranged from 198 to 696 lbs/day and annual TP loadings ranged from 3.9 to 6.8 lbs/day.

8. NON-POINT SOURCE CONTRIBUTIONS. The purpose of this project is to use stream stabilization and restoration practices to reduce non-point source pollution in streams. If bed and bank erosion can be reduced, then associated non-point P and metals sources to the channel are also reduced. The pre-construction impact of bank erosion can be determined by comparing results of the water quality monitoring and bank erosion monitoring sections of this report. The bank erosion monitoring indicates that approximately 93 lbs/yr of P enters the stream by sediment erosion annually. Results of the water quality monitoring study shows annual loading at the site downstream of the study reach is around 173 lbs/yr at site 3. While these are estimates, these results show that restoration reach bank erosion has the potential to contribute over 50% of the annual P load at this site. Furthermore, data from these studies can be used to estimate impacts of bank erosion in other areas in the James River Basin and also provides valuable water quality information for urban areas around Springfield as well. Efforts to stabilize eroding banks have the potential to significantly decrease local non-point pollutant loads in Ward Branch.



Location of Ward Branch Watershed in Greene County, Missouri

Figure 1. Study Area Map. Watershed area of the entire Ward Branch is 11 sq. miles. Drainage area above the restoration reach is 2.5 sq. miles.

GEOMORPHIC ASSESSMENT

Graduate students Gopala Borchelt and Ron Miller perform a sediment survey in December 2004

GEOMORPHIC ASSESSMENT METHODS

The objective of the geomorphic assessment is to provide the morphological data necessary to complete a channel stabilization design for the Ward Branch. This will be accomplished by providing a channel survey, bed and bank material evaluation, and a bank stability assessment. Reaches will be identified based on geomorphologic characteristics of data gathered for this assessment along with interpretation.

Channel Survey

Two types of topographic surveys are used in this study to evaluate the geomorphology of the study reach: longitudinal surveys and cross-section surveys. A longitudinal survey involves downstream measurements of channel bed elevation at its deepest point along the thalweg. Survey points were collected at every riffle and pool location with additional points in between as needed. Longitudinal trends are useful for defining channel slope, riffle spacing, and residual pool depths. Riffle spacing is the distance between the riffle crests. Residual pool depths are the elevation difference between the bottom of the pool and the top of the downstream riffle crest. The survey notes places in the channel where bedrock or concrete was visible. A planform map shows the station locations in Figure 2.

Cross-section surveys were completed by measuring elevation changes across the channel by identifying slope-breaks along the bank and bed. Cross-sections were taken at points of interest determined in the field, typically at riffles and pool locations, less than 200 feet apart. Geomorphic data collected at these locations best describe channel size and shape for hydraulic analysis. In addition, elevations of alluvial surfaces or deposits indicative of historical and recent channel behavior were also measured.

Two channels are identified for analysis in this study: bankfull and total channel. The top stage of the “bankfull” channel is identified as the highest elevation of bed load or gravel transport in the channel and indicates the minimum elevation of the active floodplain surface which in a natural equilibrium state typically conveys the 1 to 2 year flood. Active bankfull width is the width of the stream from bank to bank at the bankfull stage. Using bankfull stage, or depth in combination with bankfull width give an idea of sediment transport potential through a particular reach. Deep, narrow channels have a higher sediment transport capability versus a shallow, wide channel. The “total” channel represents the stage at which the channel will overflow its high banks and spread out over the valley floor. In this area the valley floor near the channel is referred to as the low terrace. This detailed survey data was integrated into an existing HEC-RAS hydraulics model by the City of Springfield used to estimate velocity and shear stresses along the study reach at various stages.

Bed Material Evaluation

Bed sediment data was collected by measuring material along the bed at 103 transects spaced ≈30 feet apart along the entire study reach. Individual sediment particles were identified by blind touch at 10 equal increments along each transect. Bed sediment size was determined by measuring the B-axis with a ruler, which the second longest axis perpendicular to the longest axis or A-axis. This axis approximates the size of sieve the individual sediment particle would pass through. Bed material sand size or smaller was designated as “fine”. When the bed was on residual material “cut earth” is described in the data. If bedrock was found along the bed it was noted as well.

From the individual transects changes in sediment size through the reach was related to bedform (pool or riffle) to understand the competency of the stream to transport sediment through different sections of the study reach. Sediment size is usually positively related to velocity and can be used in conjunction with channel geometry and slope to understand the stream processes throughout the reach. The bed sediment analysis was used to determine velocities and shear stress in the hydraulics model used in the design process.

Bank Material and Stability

Bank height, bank angle, and tree root exposure was measured at each 30 foot transect throughout the study reach. Bank height (feet) and bank angle (degrees) can be related to susceptibility to erosion of the bank at that location. These measurements were used to calculate a bank erosion index (BCI) that is simply the product of height and angle so these indicators can be evaluated as one number. High bank angle and high bank height would be the highest potential to erosion. Low bank angle and low bank height would be the lowest potential for erosion. A combination of relatively high and low numbers would fall in between. Combining BCI with exposed root data, which indicates the presence of woody vegetation, can give a comparative picture of bank conditions through the reach.

Bank material composition was also evaluated at six locations along the study reach where significant bank heights allowed for material analysis between stations 880 and 1,500 feet. Distinct sedimentary units were identified at each bank profile and a sample was collected from each layer. Field data collected for each horizon included depth, structure, and Munsell color.

Samples from each horizon were analyzed for grain size of both the fine grained (≤2 mm) and the coarse fraction (>2 mm). Each sample was dried in a 60ºC oven, disaggregated with mortar and pestle, and passed through a 2 mm sieve. The coarse fraction was passed through a series of sieves to separate the particles into size classes based on the Wentworth Scale. The fine grain fraction was analyzed for sand, silt and clay by use of the hydrometer method. The sand fraction was wet sieved for comparison purposes. One gram of the fine-grain sediment sampled was sent to ALS Chemex for chemical analysis of 34 elements including phosphorus. A 3:1 Hydrochloric:Nitric acid extraction method was used to extract total phosphorus and metals from the sediment for ICP analysis.

Organic matter was analyzed using the loss on ignition method. A 5-gram sample is placed in a porcelain crucible and the pre-burn weight is recorded. These samples are then placed in a 600ºC muffle furnace for 6 hours to incinerate the organic matter. After 6 hours the samples are re-weighed and the difference is recorded.

Soil pH is analyzed by placing an electronic pH meter into a solution of 1:2 ratio of soil to de-ionized water (DI). This mixture is allowed to set for 1 hour and then is mixed again, with a settling time of 10 minutes.

RESULTS AND DISCUSSION

Channel Survey

The channel survey begins (0 feet) at the downstream face of the Republic Road culvert at a pool. A riffle crest at approximately 300 feet marks the beginning of a relatively steep reach that extends to 500 feet (Figure 3 and Photos 1 and 2). The slope exceeds 2% through this section and bank heights are relatively low. Bedrock does begin to appear in the channel at 500 feet along the profile suggesting bedrock may be controlling the headcut elevation along this section. Downstream of 500 feet station, bank heights and pool depths begin to rise indicating either a headcut moved through this reach due to bedrock elevation change or the channel was able to cut through fill material or colluvium increasing the bank height due to increased flooding from urban runoff or historical land clearing and row cropping activities. Downstream bedrock appears at a lower elevation along the high right bank between 800 and 1,200 feet along the profile limiting further downcutting. This 400 foot long vertical right bank along the west side of the stream is approximately 6 foot in height (Photo 3).

A plane bed section with little contrast between pool and riffle topography occurs between 1,200 and 1,600 feet and has low to moderately high banks. This indicates excess bed sediment loading into the reach due to upstream bank erosion releasing gravel to the channel. Downstream of 1,600 feet the profile remains relatively consistent until 2,000 feet at the first subdivision bridge. Immediately downstream of the bridge a scour hole has formed and increased the slope locally (almost 3%) (Photo 4). The vertical adjustment of the stream below the bridge is also limited due to bedrock that is again visible along the bed at the scour hole location. A reality consistent riffle/pool sequence alternating from the right to left low terrace bank in the section between the bridges indicates a quasi equilibrium through this reach. Downstream of the second subdivision bridge the stream is pinned up against a high right bank that is eroding, but vertical adjustment is again controlled by bedrock that is visible along the bed throughout the remainder of the study reach. Appendix A shows the longitudinal profile data collected.

The mean bankfull active width for the entire study reach is 17.7 feet (Figure 4). Higher active bankfull widths are found below the Republic Road culvert from 0-200 feet and in the meander sections of the disturbance reach at stations 1,300-1,500 feet. High widths found below the culvert are probably due to construction of the culvert, but the high widths in the disturbance reach are probably due to a geomorphic response. In this section, sediment transport potential should be low and sediment accumulation would be expected causing flow to spread against the banks and widening the channel. Channel bend increases shear against the steep high banks.

The average bankfull depth of this reach is 1.8 feet (Figure 4). High bankfull depths are found in the reach at stations 1,000 and 1,500 feet. High bankfull depths indicate areas where the channel is constricted and sediment transport potential is relatively high. Typically, areas with high bankfull depths will have low active widths such as station 1,000. However, station 1,500 has both a high bankfull depth and high active width. This suggests this is an area of both erosion and deposition, depending on when the last flood occured. During a flood, large amounts gravel can get deposited in this area and subsequent flows not large enough to move all of the gravel start to take away the bank material causing a high active width. These subsequent flows also start to remove gravel and over time transport this material away leaving a relatively high bankfull depth. This phenomenon is typical in Ozarks streams as gravel waves move through the system. Data collected for active width and bankfull depth can be found in Appendix B.

Fifty riffles and fifty pools were noted through the reach with an average riffle spacing of around 59 feet and an average maximum residual pool depth of 0.73 feet (Figure 5). Relatively short riffle spacing and low maximum residual pool depths are found together through the steep reach between 300 and 500 feet, upstream of the first bridge at Holland Ave, and below the Camino Bridge in the bedrock controlled reaches. High riffle spacing and high pool depths are found below the steep reach between 800 and 1,100 feet on the longitudinal profile. Since the distribution of these bedforms does not appear to follow a discernable pattern, the elevation of bedrock in the stream seems to be the chief factor influencing the variability of riffle spacing and pool depths. Therefore, these data are not recommended to be used in the design. Appendix C is an inventory of pools and riffles along the reach.

Bank Material

Much of the bank materials exposed at cutbanks along the reach were of mixed origin consisting of alluvium, colluvium and fill material (Photo 5). In general, bank material analysis shows fine grain material ($\leq$ 2 mm) made up around 75% of the bank material while coarse grained material accounted for approximately 25%. However, in some horizons coarse materials accounted for as high as 85% of the bank material. The majority of the coarse grain fraction is coarse gravel size material between 16 and 32 mm in size. On average, fine grained bank material through the reach on average consisted of 31% clay, 43% silt and 26% sand. Individual horizons with higher clay content (>40%) were found in the lower part of the profile at stations 888 and 938 feet where limestone residuum is exposed due to channel incision. More specific bank material is discussed in the bank erosion section of this report.

Bank Conditions

Relatively high BCI numbers for right banks are found at stations 800-1,200 and 2,600-2,800 feet on the longitudinal profile (Figure 6 and Photo 6). These two areas were also identified above in the channel survey section, but the BCI highlights these areas as significantly higher potential for erosion compared to the rest of the reach. Moderately high banks are found between 600-800 and 1,400-1,700 feet on the profile. Moderately high banks are also found directly below the first bridge at 2,100 feet along the profile, but seem to be a localized problem due to the bridge. Alternating high and low BCI scores indicate the lower floodplain and point bar formation on the inside of a bend with the thalweg and high lateral bank on the outside. High BCI scores for both banks indicate downcutting of the bed.

Both sides of the stream above 800 feet have no exposed roots in the bank indicating poor riparian conditions (Photo 7). This section goes through the golf course where trees have been removed and replaced by turf grasses, with poor rooting depths. Sporadic, low density exposed roots are found between 800-1,300 feet through the golf course. Below 1,300 feet exposed root density increases with a few holes along both banks as seen in Figure 6. Data collected for the bank condition analysis can be found in Appendices E and F.

Bed Material Inventory

Over 1,000 pieces of sediment at 103 transects were measured along the study reach (Photo 8). Overall, the largest Dmax sediment sizes tend to be found in the upper 2,000 feet of the stream, which is above the first bridge in the subdivision (Figure 7). From station 2,000-3,500 the overall Dmax seems to be lower. This suggests sediment transport potential is higher in the upstream sections. The D50 however is relatively consistent through both the upper and lower section with the exception of the portion of the stream immediately upstream of the first bridge where slopes increase due to the scour hole formed at around station 2,000. The mean D50 was 40 mm (very coarse gravel) and the reach mean Dmax was 176 mm (large cobble). Data collected for bed material evaluation can be found in Appendix G.

RESULTS BY REACH

The study area was classified into three separate reaches based on the findings. These reaches are the <u>golf course reach</u> (0 – 1,290 feet), <u>disturbance reach</u> (1,290 – 1,960 feet), and <u>subdivision reach</u> (1,960 – 3,000 feet). Each reach exhibited different geomorphic characteristics that need to be identified and addressed in the restoration design process. Two characteristics are common to the entire study reach. First, bedrock is at or near the surface, so vertical adjustment is limited. Second, bank material is made of gravel and silty clay that is fairly resistant to erosion. Banks erode, but are relatively resistant to erosion and with roots helping to hold vertical banks in some places. To summarize the results of the pre-installation survey three sub-reaches within each section are discussed below. See Table 2 for summary data.

Golf Course Reach

<u>Bridge-Pool Sub-Reach (0-310)</u>

A pool has formed at the downstream face of west barrel at the Republic Road culvert causing the bottom of the east barrel to fill with sediment. However, flows are able to keep the west barrel open. Some localized bank erosion occurs below the culvert causing a high average bankfull width (24.2 feet), but the banks seem to have adjusted and have remained in fairly good condition with low average bank angle (10 and 11 degrees).

Steep Sub-Reach (310-550)

The relatively high 2.1% slope found in this reach marks the point in the study area where a headcut is currently located. Historical photo analysis suggests this headcut has been in the same location since the 1930s and exactly when the channel started incising is unclear. Historical records do indicate this area was heavily farmed with row crops as early as the 1870s and could have started the process. While bedrock is not visible at the surface at this location, it probably serves has a natural grade check halting further incision upstream. This reach displays all the geomorphic characteristics of a steep reach including low bank heights, low bankfull width, short riffle spacing, low pool depths, and the largest Dmax grain size in the study area. These characteristics would be expected as a result of higher velocities from a bed slope of 2.1%, but would not be considered typical for a stream of this size in the Ozarks which have average stream bed slopes of near 1%.

Eroding Sub-Reach (550-1,290)

The channel adjustments to both land use changes and the manipulation of the channel during golf course construction has lead to highly erodable banks found along this reach. As discussed in the section above, channel incision probably originating from initial land clearing began the process. Incision was probably exacerbated by golf course construction where the channel was straightened, floodplain raised, and removal of riparian vegetation in the 1950s that can been seen in historical aerial photos. Evidence of fill materials in the exposed banks along the channel also suggest raising the of floodplain surface might have occurred in some places along the channel causing the banks to be higher and more unstable when the vegetation was replaced with turf grasses. Urban development starting in the mid 1980s increasing the frequency and magnitude of storm flows affected this channel again. Small, frequent events occur more often in urban systems attacking the lower bank causing bank collapses. All of these factors probably led to the highly erosive banks found downstream of the steep reach. This section has been identified as a major source of sediment for the study reach.

Disturbance Reach

Plane Bed (1,290-1,610)

This section serves as a transport reach moving sediment generated from bank erosion in the upstream steep reach to downstream areas. While the high bankfull widths, high banks, and steep bank angles suggest instability, this reach is helped out by a relatively good riparian corridor.

Meandering (1,610-1,770)

Accumulations of gravel in this reach have caused lateral bank migration resulting in relatively high average bank heights (5.2 feet -5.4 feet) with moderately high average bank angles (45-59 degrees). Average reach slope is very low at 0.25%, but bankfull geometry is similar to the other sub reaches in this study. The channel seems to maintain the bankfull geometry by taking out the banks as more gravel is moved in. High average riffle spacing and high average residual pool depths are also found in this sub reach.

Grade Check (1,770-1,960)

A sanitary sewer crossing at station 1,850 feet provides the relief for this mostly bedrock controlled bed that has an average slope of 0.91%. The low average bank heights with the controlled bed elevation probably suggests this is or is near the original low terrace elevation before development of the golf course and subdivision further south. The average bankfull width is similar to other sub-reaches and the moderate bank angles (40-42 degrees) suggest a fair amount of stability. Short riffle spacing and truncated average bankfull depths and average residual pool depths are typical of bedrock controlled streams in the Ozarks.

Subdivision Reach

Scour Hole (1,960-2,130)

The channel characteristics of the scour hole that has formed directly below the Holland bridge are the most extreme in the study reach. Due to the depth of the pool, the local slope is almost 3% which helps generate the kind of velocities needed to maintain the scour hole at station 2,100 feet. The depth of the scour hole is maintained by difference in elevation of the bedrock near the bridge and the bedrock elevation that can be seen in the bottom of the pool. High average bank heights and relatively high average bank angles indicate these banks have a higher than normal erosion risk. Average bankfull widths, average bankfull depths, and riffle spacing are maintained through this sub-reach.

Riffle-Pool (2,130-2,430)

Of all of the sub-reaches this section has the most consistent riffle-pool sequence. All geomorphic characteristics are near the study reach average which is probably due to its position between two bridges that is not affected by the localized scour and erosion. Bank in this sub-reach have moderate average bank heights and low average bank angles suggesting bank stability. This area does have moderately poor riparian conditions.

Bedrock (2,430-3,000)

A bedrock bed dominates this reach and helps maintain the 0.81% slope. The bankfull geometry through this reach is comparable to the other relatively stable reaches upstream with an average bankfull width of 16.4 feet and average bankfull depth of 1.7 feet. Banks in this sub-reach are relatively high (5.5-6 feet) but average bank angles suggest low erosion potential. This average is misleading since this sub-reach has a 150 foot section of nearly vertical bank as documented above. Riffle spacing and pool depths are low which is typical of bedrock controlled streams in the Ozarks.

These data were presented at a design team meeting held on August 8th – 9th, 2005 that included officials from Greene County and the project consultants. Data from this assessment was used in the development of the approved restoration plan completed March 8th 2006.

Table 1. Channel Assessment Methods used for the Ward Branch Study

Channel Morphology	**Reference**
Bankfull stage indicators	Harrelson et al. (1994), Rosgen (1996)
Cross-section survey (width and depth)	Harrelson et al. (1994), Rosgen (1996)
Historical aerial photo analysis	Legleiter (1999), Martin (2005)
Channel Type	Bisson et al. (2006)
Longitudinal Profile	**Reference**
Riffle and pool identification	Panfil and Jacobson (2001)
Longitudinal survey	Harrelson et al. (1994)
Channel slope	Rosgen (1996)
Residual pool depth	Lisle (1987), Panfil and Jacobson (2001)
Bed Material	**Reference**
Pebble counts for gravel to boulder sizes	Wolman (1954); Rosgen (1996)
Presence of bedrock, cut earth, and fines	Kaufman and Robison (1998)
Bank Conditions	**Reference**
Bank height and angle	Rosgen (1996); Fitzpatrick et al. (1998)
Root protection and exposure	Developed for this study; after Simon and Downs (1995) and Rosgen (1996)
Bank Material	**Reference**
Stratigraphic evaluation (field descriptions)	Boulding (1994)
Sediment size analysis (hydrometer)	Sheldrick and Wang (1993)
Sediment organic matter content	Dean (1974)

Table 2. Summary of Geomorphic Data by Subreach

Geomorphic Variable	**Golf Course Reach**			**Disturbance Reach**			**Subdivision Reach**		
	Bridge Pool	**Steep**	**Eroding**	**Plane Bed**	**Meandering**	**Grade Check**	**Scour Hole**	**Riffle-Pool**	**Bedrock**
	0-310	*310-550*	*550-1,290*	*1,290-1,610*	*1,610-1,770*	*1,770-1,960*	*1,960-2,130*	*2,130-2,430*	*2,430-3,000*
Length (ft)	310	240	740	320	160	190	170	300	570
Avg. Reach Slope (%)	0.69	2.1	0.78	1	0.25	0.91	2.96	0.57	0.81
Avg. Rt bank height (ft)	4	2.5	4.8	5.3	5.4	3.7	6	4.4	6
Avg. Lt. bank height (ft)	3.5	3	3.6	4.8	5.2	3.6	6.3	4.2	5.5
Avg. Rt. Bank Angle	11	38	66	39	45	40	55	34	47
Avg. Lt. Bank Angle	10	52	57	70	59	42	66	45	32
Avg. Bankfull Width (ft)	24.2	13.9	15	22.7	18.4	16.7	18.5	18.8	16.4
Avg. Bankfull Max Depth (ft)	1.7	1.7	1.9	2.1	1.8	1.1	1.7	1.8	1.7
Avg. Total Channel Max Depth (ft)	3.5	2.5	3.3	4.3	4.6	3.1	6.0	4	4.7
Avg. Riffle Spacing (ft)	76.5	22.6	74.4	73.8	97.4	56.4	72.7	80	48
Avg. Residual Pool Max Depth (ft)	0.7	0.4	1	0.8	1.2	0.6	1.4	0.6	0.6
Avg. D50	40	50	42	37	23	34	30	30	30
Avg. D84	75	87	82	76	78	80	66	110	78
Avg. Dmax	219	235	168	173	200	196	140	144	163

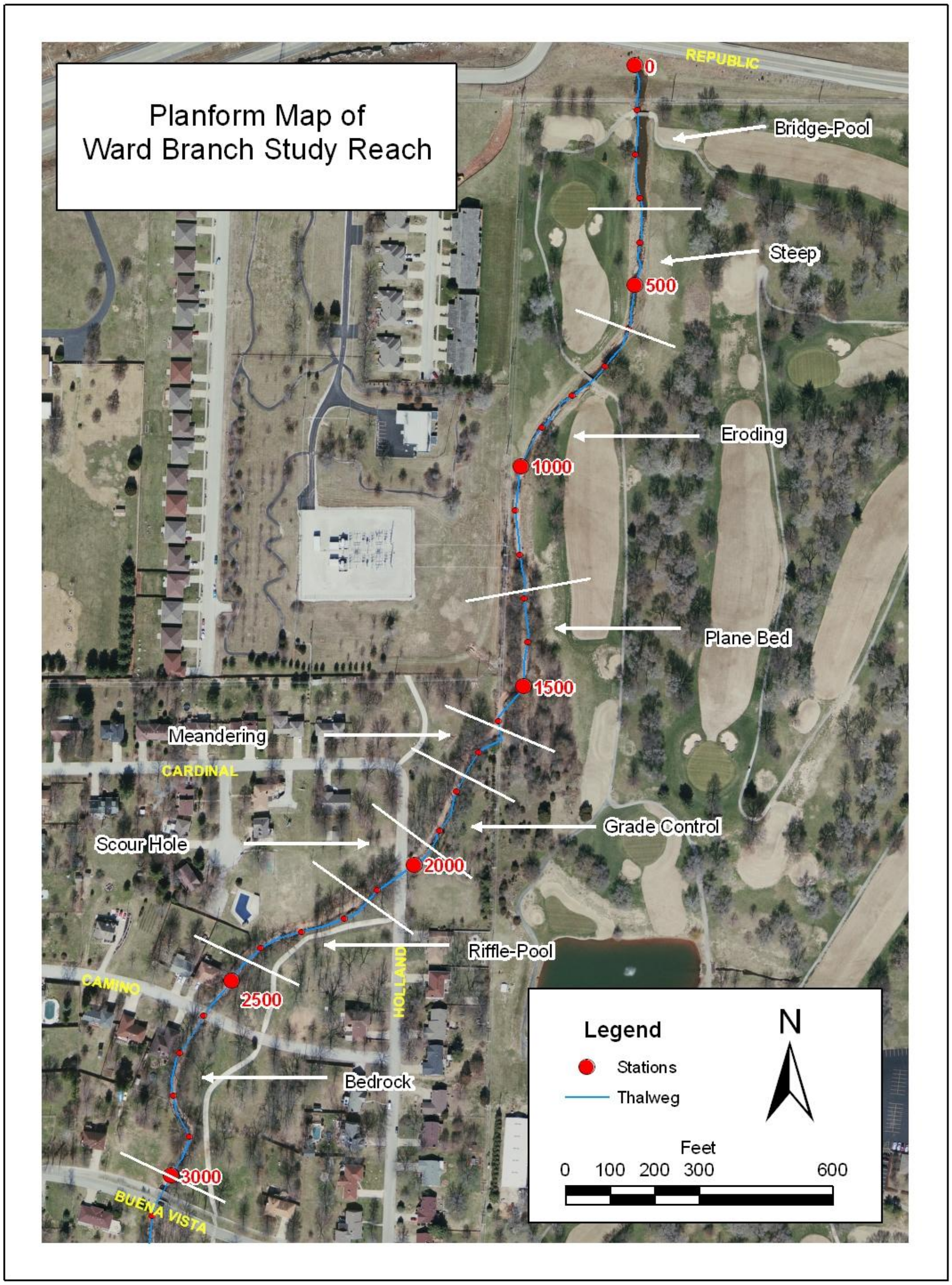


Figure 2. Planform Map of Study Reach with Stations

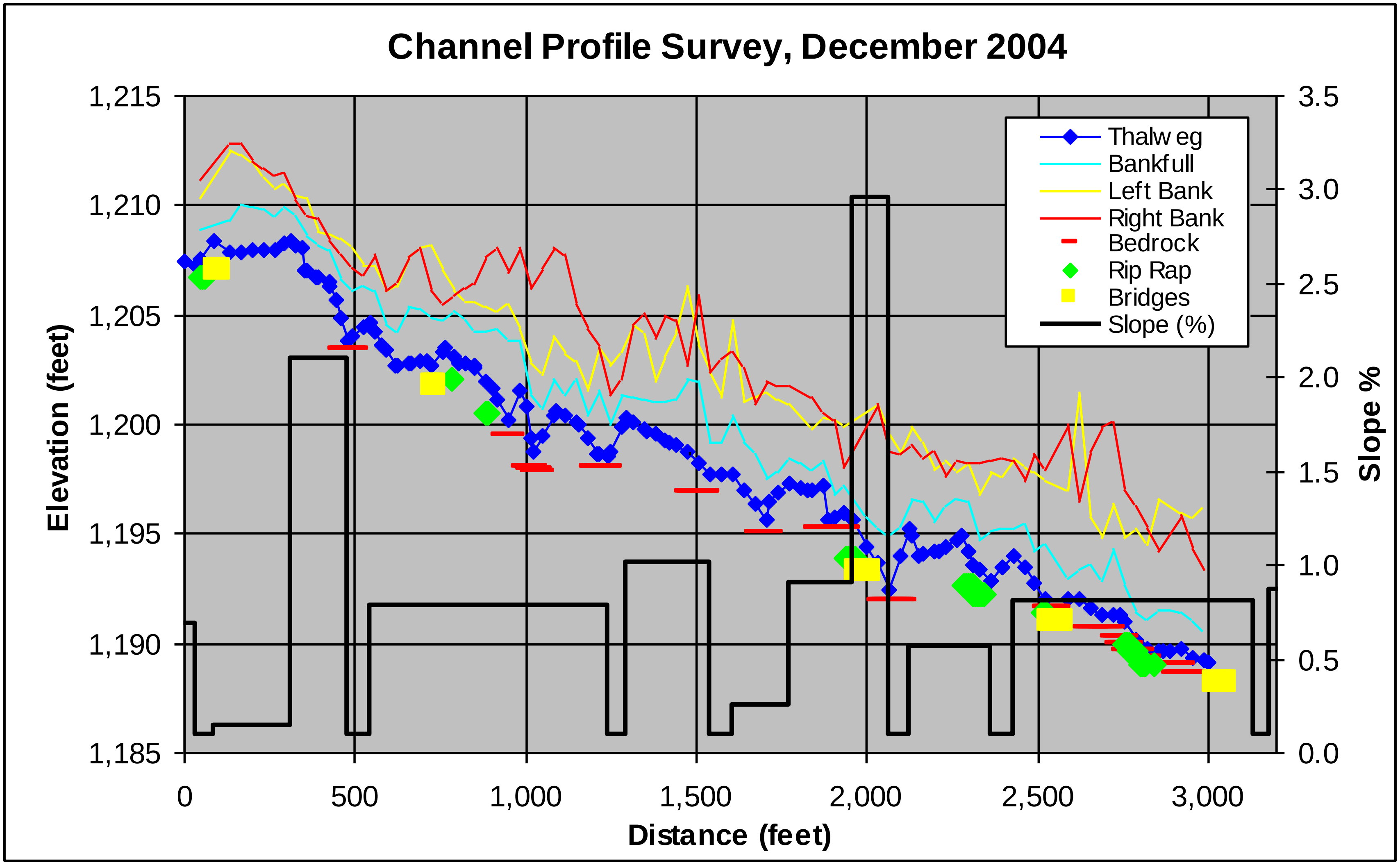


Figure 3. Longitudinal Profile

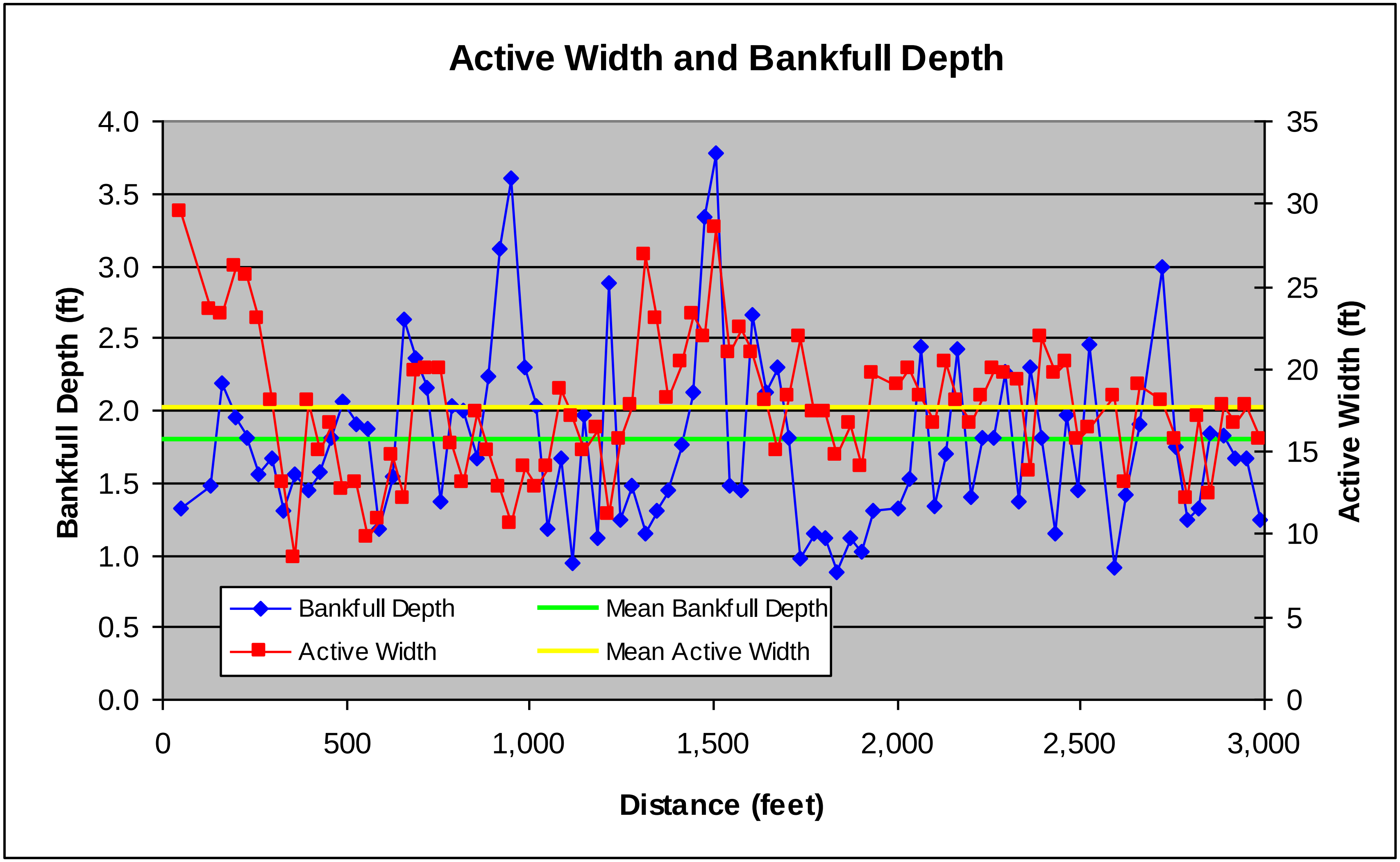


Figure 4. Bankfull Depth and Active Width

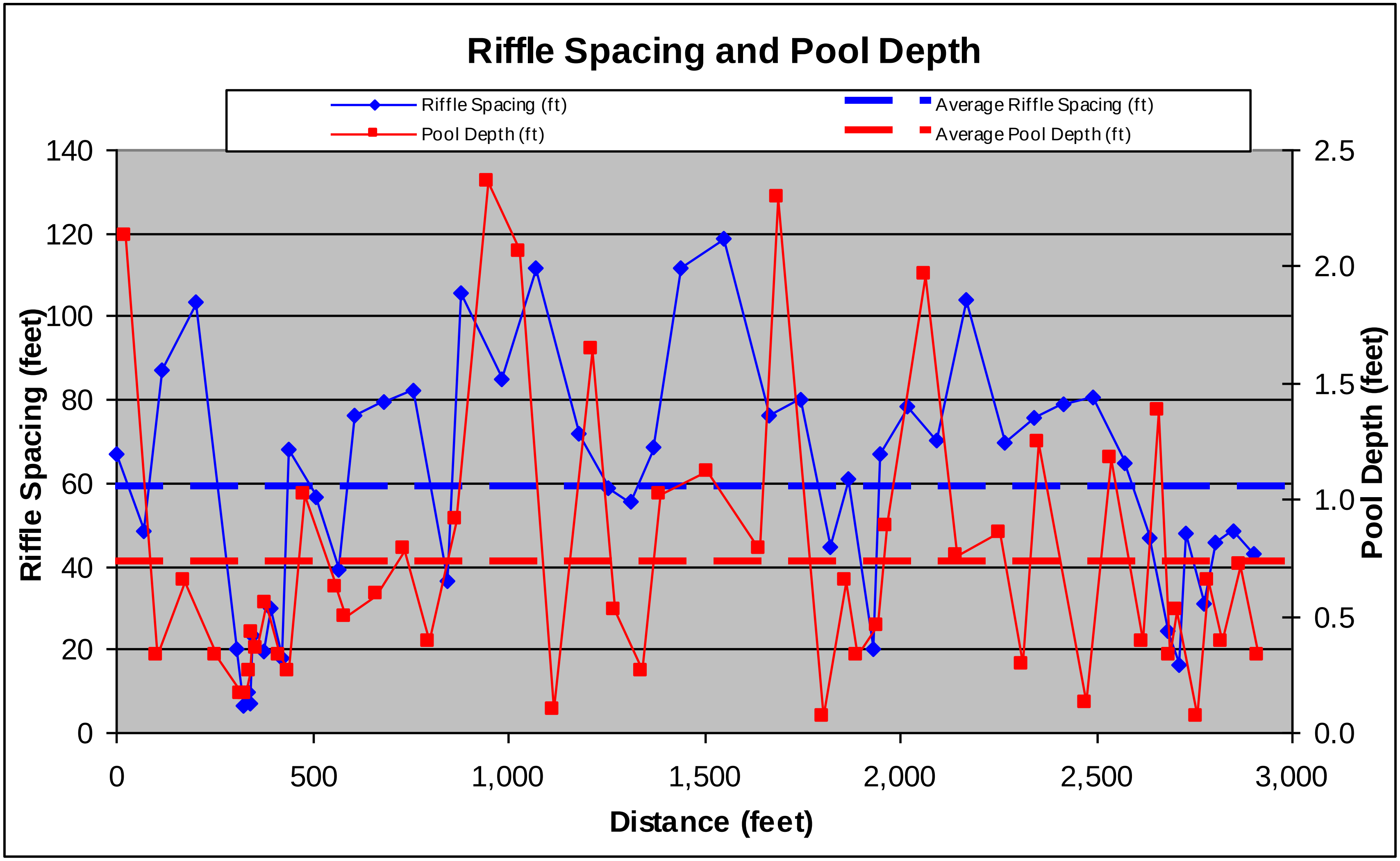


Figure 5. Riffle Spacing and Pool Depth

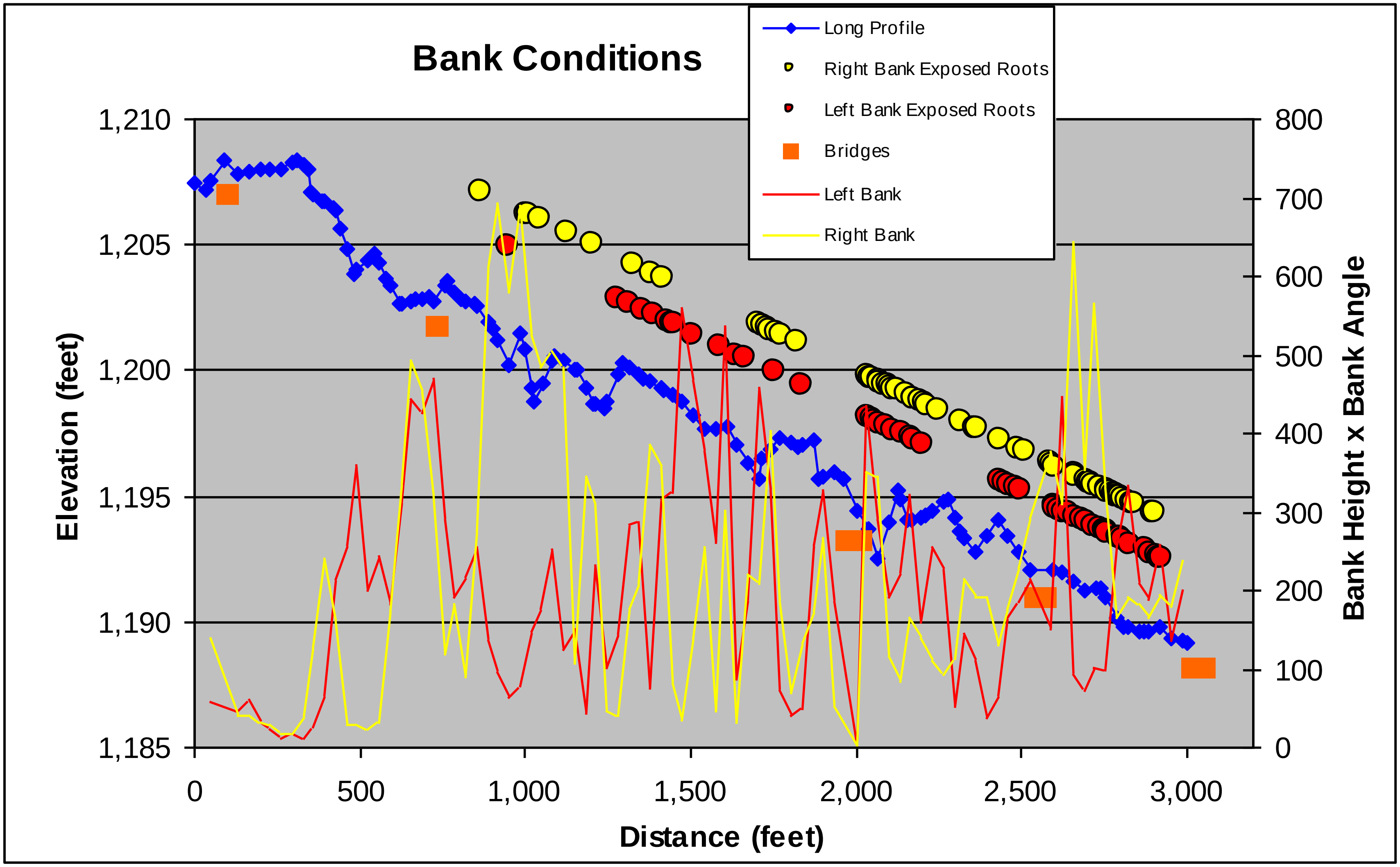


Figure 6. Bank Conditions

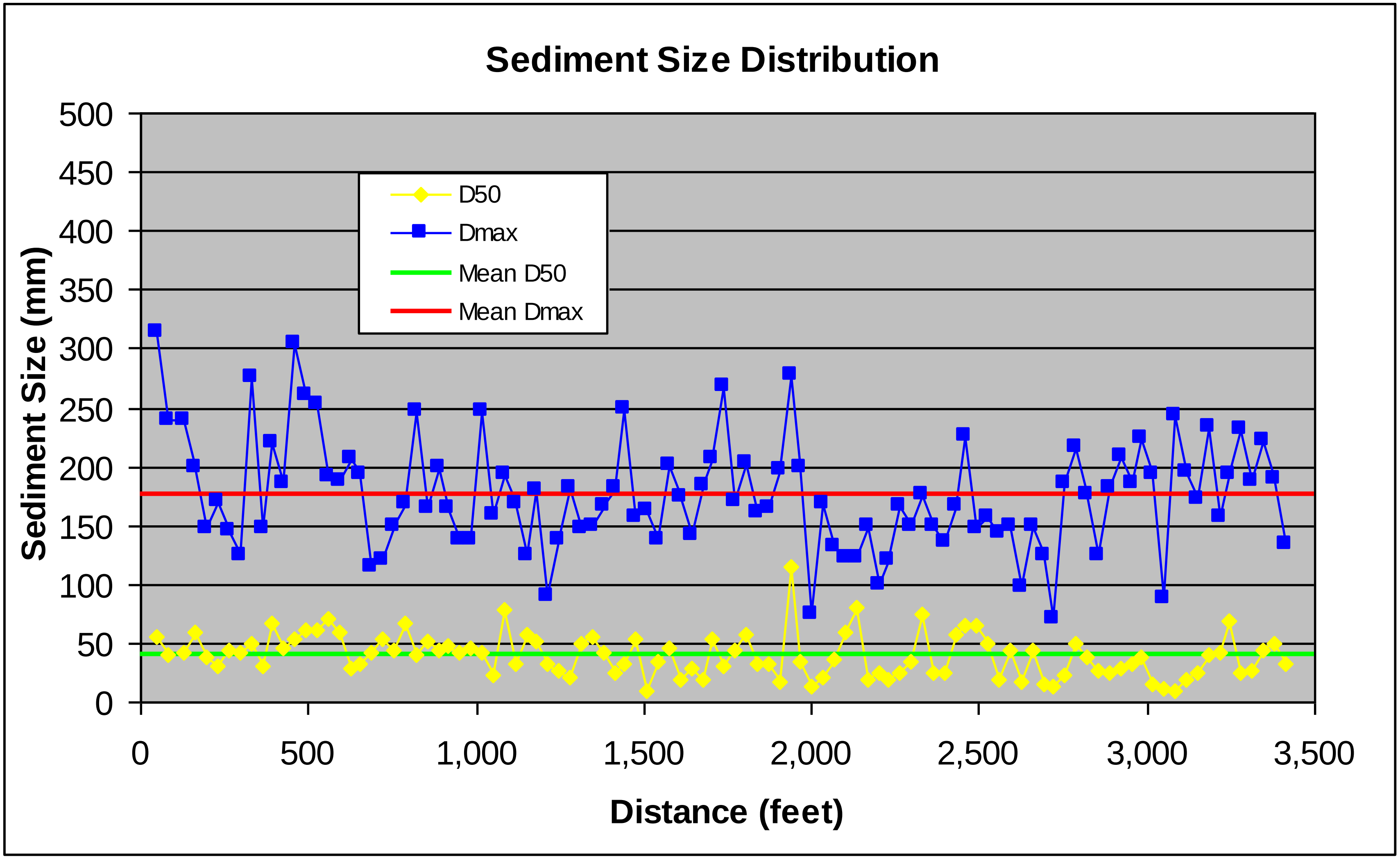


Figure 7. Bed Sediment and Slope

GEOMORPHIC ASSESSMENT PHOTOS

Photo 1. Looking south at Republic Road

Photo 2. Bottom of steep reach at station 800 feet

Photo 3. High bank at station 1,000 feet

Photo 4. Scour hole at station 2,100 feet

Photo 5. Typical bank material through reach

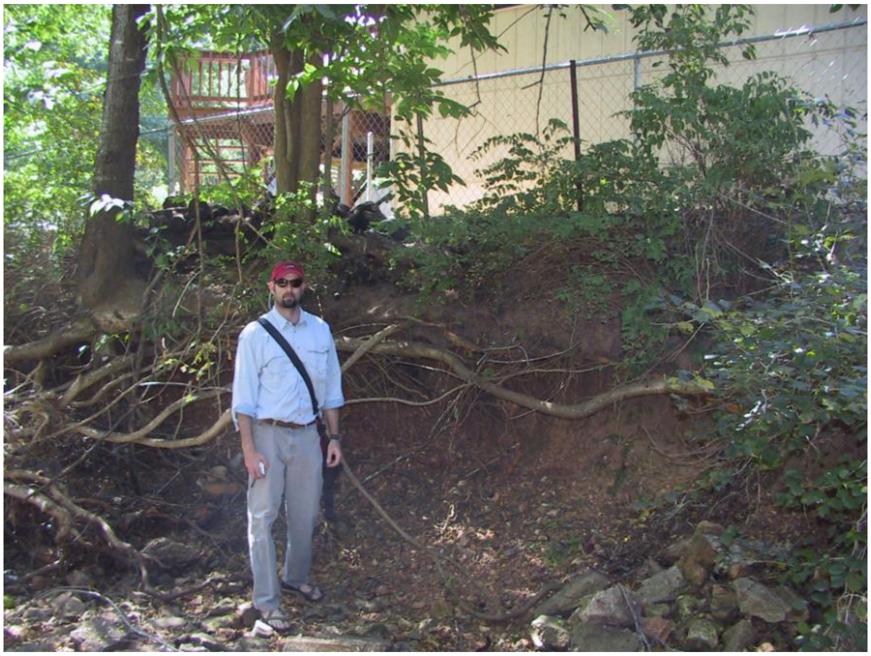


Photo 6. High right bank at station 2,700 feet

Photo 7. Bank failure due to poor riparian conditions in golf course reach

Photo 8. Gravel accumulation in disturbance reach

WATER QUALITY MONITORING

Graduate student Maya Hirsch takes velocity measurements at Camino Ave.

WATER QUALITY MONITORING METHODS

The objective of the water quality monitoring section of this report is to measure pre-construction water quality conditions of the study reach. This will be accomplished by collecting water samples throughout the reach at varying flows and analyzing these samples for nutrient concentrations and water chemistry. These data will be used to estimate nutrient loading to quantify non-point pollution contributions from this section of stream.

This section describes methods used for water quality sample collection and water quality analysis. For more details on these methods the Standard Operating Procedures (SOPs) used for this project are available on our website at http://www.oewri.missouristate.edu .

Sample Collection

A total of 5 sites were chosen along the study reach to assess water quality before implementation of the restoration efforts. Sites were selected based on access, cross-section stability, and geographic relationship to the restoration reach. These sites were located at Republic Road, Holland Ave., Camino St., Buena Vista St., and Campbell Ave. A map showing the locations of the sample sites can be found in Figure 8.

At each of the 5 sites, water samples were collected during 10 storm events between November 2004 and March of 2006 and analyzed for both nutrients and water chemistry. Loosing sections of the stream caused some areas to be dry when other areas had flow after smaller rain events. Consequently, 10 samples were not able to be collected at all 5 sites. The total number of water samples collected for this project was 42. Water chemistry was measured at each site by a Horbia U22 multi-probe meter. Water chemistry parameters measured include dissolved oxygen, turbidity, conductivity, pH, and temperature. Grab samples were collected at each site in 500mL containers, preserved and cooled in the field.

Nutrient Analysis

Samples were analyzed at Missouri State University Chemistry Laboratory. Total nitrogen (TN) was analyzed by a Hitachi UV-2001 Spectrophotometer and total phosphorus (TP) was analyzed by a Spectronic Genesys 20 Spectrophotometer. Average detection limits were 0.2 mg/L TN and 3 ug/L TP with accuracy within the range of + or – 20%.

Discharge, Loading, and Yields

Discharge (Q) during sample events was estimated by establishing a stage gage at each site at the bridge. The bridge was chosen because it would have a stable cross section throughout the sampling period. A cross-sectional survey was completed for each site to calculate channel geometry at each stage. During the sample collection, a mean velocity was collected using a flow meter and the stage was recorded. The continuity equation was used to estimate Q (ft^3/s). Stage relationship curves were created for each site showing how velocity (v), cross-sectional area (CSA), and Q change with water depth based on measurements taken during sampling.

Nutrient rating curves were created to show how nutrient concentrations change with Q at each site. These data can be used to estimate concentrations of TP or TN based on Q that can either be measured or estimated from hydrologic models. From these estimates a nutrient load rating curve was established converting concentration and Q into a daily output of TP and TN in unit mass. From these data annual loads can be calculated from annual mean Q estimates.

Annual Q for each sample site was estimated using the mean Q recorded from 39 USGS gaging stations found throughout the Ozarks region. Since these data include records for days with no flow, estimated runoff days were determined using rainfall records. For this project the mean annual Q from the region regression equation was divided by the percentage of days it rained over 0.25 inches over the 17 months sampling period. This more accurately reflects hydrologic conditions in this intermittent stream. These data combined with mean P and N concentrations at each of the sampling sites were used to calculate annual load.

RESULTS AND DISCUSSION

Hydrologic Conditions and Discharge

Of the approximately 511 days of the study period, rainfall of over 0.25 inches was recorded at the Springfield-Branson Regional Airport for 45 days or 8.8% of the study period (Table 3). Rainfall totals and rainfall intensity varied throughout the study period. Total rainfall produced by storms sampled ranged from as low as 0.1 inches on 3-22-05 to 2.4 inches on 10-31-05 (Table 4). The maximum rainfall intensity for a storm event sampled for this project was 0.69 inches per hour. These are typical low frequency rainfall intensities for this area that are important for water quality. In contrast, a rainfall intensity of 1.8 inches per hour is expected to produce a 2-year flood (Greene County, 1999).

Stage relationships to discharge (Q), velocity (v), and cross-sectional area (CSA) were developed for each site. All sites were located at box-culvert style bridges which allowed for a good stage versus CSA relationship. The stage relationships for site 1 are good despite being influenced by a wet detention pond located upstream (Figures 9-11, Photo 1). The stage versus velocity relationship was poor for site 2 that could be attributed to fluctuations in bedload during different storm events that can change local bed roughness or slope that affect velocity (Figures 12-14, Photo 2). The stage relationships for site 3 were very good with very high and consistent correlations between water level and discharge throughout the study period (Figures 15-17, Photo 3). Site 4 had good stage versus Q and v relationships, but the CSA relationship was not as good as the other sites due to a nearly 1 foot difference between the channel bottom and the base of the gage located on top of the bridge footing (Figures 18-20, Photo 4). The stage relationships were good at site 5 as well (Figures 21-23, Photo 5).

Site 1 and 5 are both spring fed, and samples were collected here during the full 10 events (Table 5). Sites 2, 3, and 4 however, were dry during smaller events sampled in late spring and summer of 2005. This flow discontinuity is probably due to the losing and gaining sections found in this section of stream that is typical during low flow conditions in the Ozarks. Consequently, the full 10 sampling events were not gathered at these three locations.

Nutrients

By Site

Total nitrogen (TN) concentrations at each site showed poor relationships with Q for the study period (Figures 24-28). Nitrogen concentrations would be expected to have a negative relationship with discharge because it tends to be in its dissolved form in an aquatic environment. During low flows, with a low suspended load, nitrogen becomes concentrated. In contrast, as the suspended load increases during a storm flow nitrogen concentrations become diluted. Data collected for this study suggest the variability of nitrogen concentrations in this system are not due to changes in Q, perhaps with the exception of site 1. These data suggest the average concentration accurately reflects total nitrogen conditions at these sites.

Total phosphorus (TP) concentrations at each site also showed poor relationships with Q over the study period (Figures 29-33). In contrast to nitrogen, phosphorus tends to be bound to sediment in an aquatic environment. In theory, as the suspended sediment load increases during a storm event, so does a TP concentration. These data suggest the average concentration accurately reflects total phosphorus conditions at these sites again with the exception of site 1 which has an R^2 value of 0.68.

Between Sites

Mean TN concentrations for all 5 sites range from 2 to 3 mg/L (Figure 34). These concentrations are higher than the recommended concentration from the TMDL for the James River of 1.5 mg/L (MDNR, 2001). Median concentrations are similar suggesting extremes are not influencing the average concentrations. Maximum TN concentrations were as high as 7 mg/L and minimum concentrations came in near 1 mg/L TN. No downstream pattern exists when looking at mean concentration, but single high concentrations more than twice the mean were found at sites 3 and 4. Sites 3 and 4 are draining the subdivision property and both spikes occurred on October 31st of 2005.

Mean TP concentrations for all 5 sites are between 30 and 40 ug/L (Figure 35). These concentrations are below the recommended concentration of 75 ug/L in the James River TMDL (MDNR, 2001). Median concentrations come in consistently lower suggesting extremes are influencing the average concentrations. Maximum TP concentrations were as high as 80 ug/L and minimum concentrations came in less than detection limit. Gradual increase in mean concentration downstream exists from site 1 to 3. This gradually decreases downstream from site 3 to 5. These spikes do not occur in the same event

Water Chemistry

By Site

Fairly good relationships between specific conductivity (SC) and Q occur at all sites except for Site 2 (Figures 36-40). Generally, SC decreases with increasing discharge as dissolved ions are concentrated at baseflow. However, this linear trend does not necessarily hold true during first flush when SC can be high from initial runoff across the landscape. Since grab samples were used for this project, detailed analysis of SC across the hydrograph cannot be accomplished but may explain the inconstancy of SC at the flows that were sampled like at site 2.

Turbidity is a measure of water clarity. This indicator does not however give an indication of what is causing the water clarity to change. Turbidity could be high due to suspended sediment or algae. Turbidity will typically increase with Q as suspended sediments are transported in storm flows. The relationship between turbidity and Q was weak for most of the sites in this study (Figures 41-45). Turbidity values range from 10 to 100 NTUs for most sites with the exception of site 1 which has values as high as 1,000 NTUs. Again, turbidity values can change for the same amount of flow based on where the sample was taken in relationship to the hydrograph. Without continuous flow data these issues cannot be identified in the data set.

Between Sites

Turbidity

Mean turbidity concentrations are <100 NTU for all of the sites except Site 1 (Figure 46). Median concentrations are near 50 NTU for all of the sites which means high readings in the data set are raising the mean concentrations. A very high concentration of 999 NTU was collected at site 1 which is >3 times higher than any of the other sites. Generally, maximum concentrations fall between 200 and 300 NTU for the other sites. The October 31, 2005 sampling shows high turbidity at all sampling locations, indicating high suspended sediment associated with this event. Minimum concentrations were below 12 NTU for all sites. The extreme values collected for site 1 make it unclear if there is any downstream pattern in turbidity.

pH

Mean and median pH values range from 7.1 to 7.5 with the highest maximum value being 7.6, which is to be expected in this area (Figure 47). Minimum pH values for the sampling period were 6.6 to 6.7 during the October 31, 2005 sampling.

Dissolved Oxygen

The mean dissolved oxygen (DO) concentrations through the reach were between 8 and 10 mg/L (Figure 48). Mean and median DO data are similar suggesting the average concentration has not been influenced by extreme values. The maximum concentrations were >12 mg/L and minimum concentrations came in below 7 mg/L, with Site 2 being as low as 4 mg/L during one sample collection. No downstream pattern exists when looking at mean concentration. All maximum concentrations recorded occurred during the October 31st of 2005 sampling.

Conductivity

Mean conductivity readings for all 5 sites are between 0.3 and 0.4 uS/cm (Figure 49). Median readings are similar suggesting extremes are not influencing the average concentrations. Maximum readings were slightly higher coming in between 0.4-0.5 uS/cm. Minimum values for all of the sites ranged from 0.2-0.3 uS/cm and all but one was recorded during the October 31, 2005 sampling. No downstream pattern in conductivity exists in this dataset.

Temperature

Mean, median, and minimum temperature values for all 5 sites are between 52-59 ^oF (Figure 50). Maximum temperature readings were near 70 ^oF on the September 15, 2005 sampling.

Nutrient Loading

Daily nutrient load rating equations developed for this project provided better relationships for TP than TN over the study period (Figures 51-55). All TP load rating curves had R^2 values over 0.6. For TN, good relationships were developed for Sites 1, 3, and 5. Relationships for sites 2 and 4 were fairly poor with R^2 values of 0.47 and 0.491. Again flow discontinuity at low flow conditions in this karst stream can complicate trends. A summary of these equations can be seen in Table 6.

The mean annual Q for each of these sites was estimated using the regression equation developed from 39 USGS gaging stations in the western Ozarks (Figure 56 and Table 6). Mean Q ranged from 24.5 – 51 ft^3/s for these sites. The daily Q was multiplied by 32 days, which is the estimated days of stream flow, to get the annual Q. Since the difference in drainage area between sites 2, 3, and 4 ranges from 2.44 to 2.48 square miles and is so small it is useless to compare these sites. For comparison purposes the average of these three sites is a better representation of the data.

The average annual TP load of sites 2, 3, and 4 is around 175 lb/year which is about a 30% increase over site 1 at 123 lbs of TP per year. From sites 2, 3, and 4 to site 5 there is a 20% increase in TP loading from 175 lbs/year to around 219 lbs/year. The annual TN load was calculated in tons per year. The average annual load of sites 2, 3, and 4 is around 4.3 T/year, which is only slightly higher than site 1 at 4.1 T/year. The load at site 5, however more than doubled 11.1 T/year from the upstream site.

SUMMARY

Forty-two samples were collected over 10 rainfall events during the 17 month pre-installation monitoring period. Construction commenced in April 2006 ending the pre-installation monitoring period. Extreme values for most parameters occurred during the October 31st 2005 sampling, suggesting the sampling occurred at a significantly different time period on the hydrograph then the other samples. This sample set could represent an example of a first flush or rising limb concentration. No downstream trend detected during this study for nutrient concentrations. Mean TP concentrations (30-40 ug/L) are well below the concentration threshold (75 ug/L) specified in the James River

TMDL. Mean concentrations of TN (≈ 2 mg/L) however are at or slightly above the specified level (1.5 mg/L) set forth in the TMDL. Nutrient loading increases between 20% to 30% downstream for TP and TN loading is similar at the upstream sites (4.1-4.3 T) and more than doubles (11.1 T) at site 5 along Campbell Ave.

Table 3. Rainfall Totals and Intensity for Storm Events

Date	Total Rainfall (in)	Duration (hrs)	Mean Intensity (in/hr)	Max Intensity (in/hr)
11/29/2004	1.0	14	0.07	0.22
12/7/2004	0.9	8	0.11	0.27
1/12/2005	1.5	7	0.21	0.45
3/22/2005	0.1	8	0.01	0.03
9/15/2005	1.7	6	0.29	0.66
10/31/2005	2.4	14	0.17	0.58
11/15/2005	1.9	10	0.19	0.69
3/9/2006	1.0	7	0.14	0.34

Table 4. Discharge Statistics over Sampling Period ($Q_1 \approx 470$ ft^3/s*)

Site #	Location	Ad (mi^2)	Storm Events Sampled n	Mean Storm Q (ft^3/s)	Median Storm Q (ft^3/s)	Min Storm Q (ft^3/s)	Max Storm Q (ft^3/s)
Site 1	Republic Road	2.38	10	47.4	21.8	2.1	196.8
Site 2	Holland St.	2.69	7	19.5	13	9.4	60.6
Site 3	Camino St.	2.71	8	49.1	50.3	0.1	93.8
Site 4	Buena Vista St.	2.74	7	27.8	19.3	9.2	89.9
Site 5	Campbell Ave.	4.97	10	113.2	103.7	10.3	252

* Based on City of Springfield hydrology models.

Table 5. Nutrient Load Rating Curve Equations

Equation - Nutrient Load (lbs/day) = b_0*Q(ft^3/s)^b_1

Site	TN (lbs/day)			TP (lbs/day)		
	b_0	b_1	R^2	b_0	b_1	R^2
1	19.599	0.800	0.931	0.0360	1.461	0.956
2	29.201	0.576	0.470	0.0279	1.634	0.692
3	11.912	0.995	0.943	0.1758	1.028	0.966
4	17.736	0.834	0.491	0.1838	0.966	0.600
5	27.848	0.818	0.857	0.0312	1.370	0.878

Table 6. Daily and Annual Nutrient Loading Estimates by Site

Site	Ad (mi^2)	Mean Q (ft^3/s)*	TP lbs/day	TP lbs/yr	TN lbs/day	TN lbs/yr
1	2.15	24.5	3.85	123.23	253.3	8,106
2	2.44	27.7	6.35	203.26	197.9	6,332
3	2.46	27.9	5.39	172.59	327.5	10,481
4	2.48	28.2	4.62	147.88	287.2	9,191
5	4.5	51.1	6.84	218.92	695.9	22,269

* Mean Q (ft^3/s) from regional curve (Figure 56) and rainfall records where 8.8% (32 days) of the year rainfall of > 0.25 inches occurred.

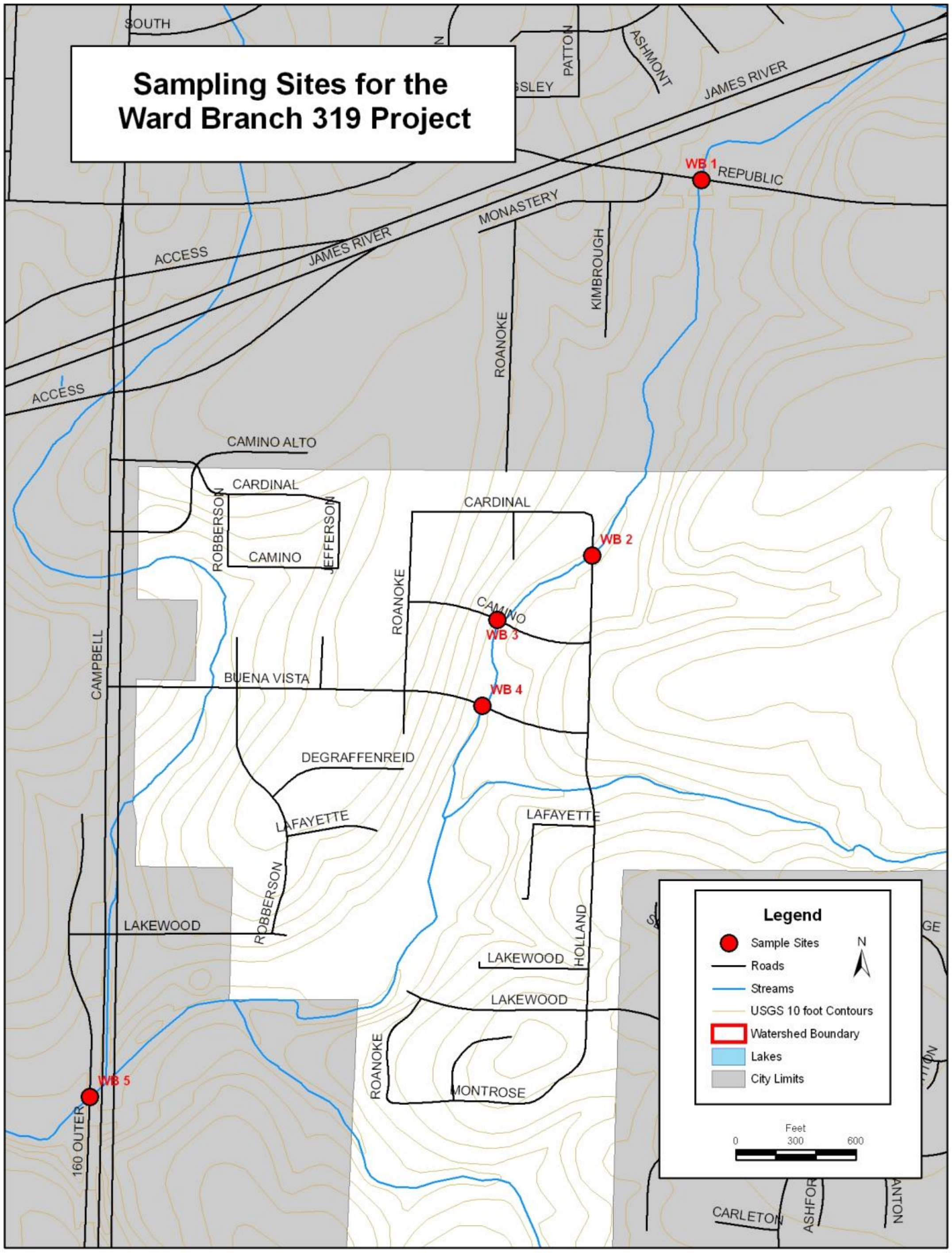


Figure 8. Location of Ward Branch Sampling Sites

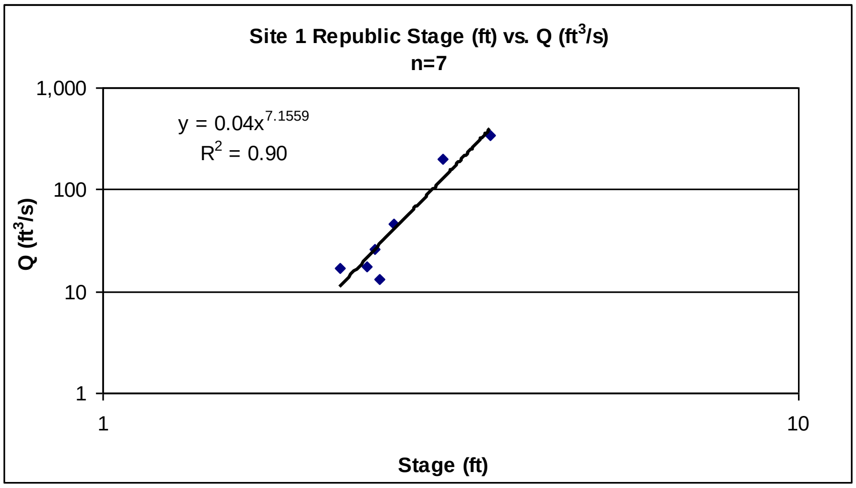


Figure 9. Site 1 Republic Rd. Stage (ft) vs. Q (ft^3/s)

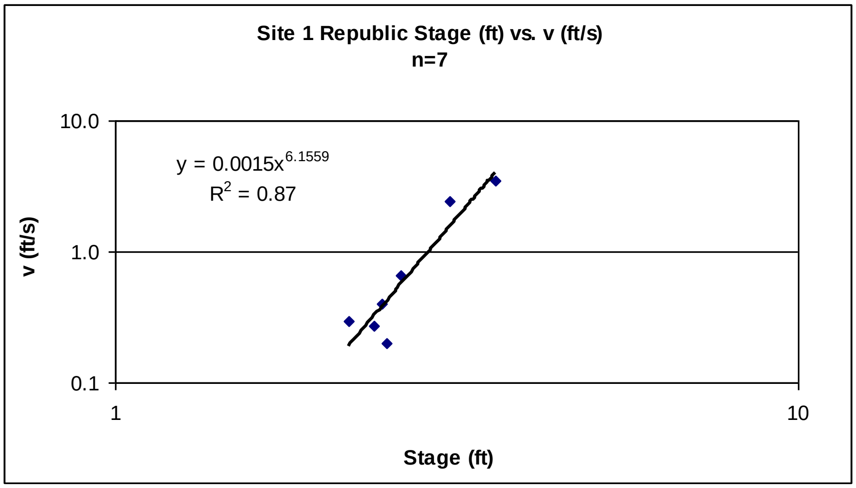


Figure 10. Site 1 Republic Rd. Stage (ft) vs. v (ft/s)

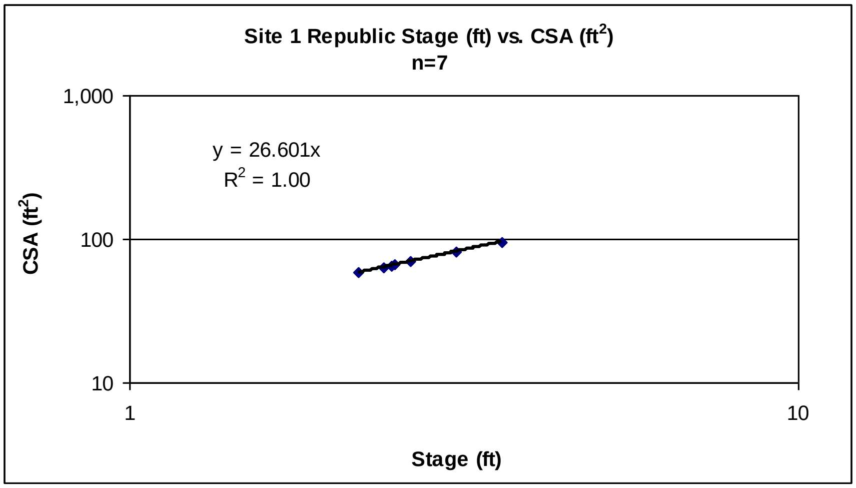


Figure 11. Site 1 Republic Rd. Stage (ft) vs. CSA (ft^2)

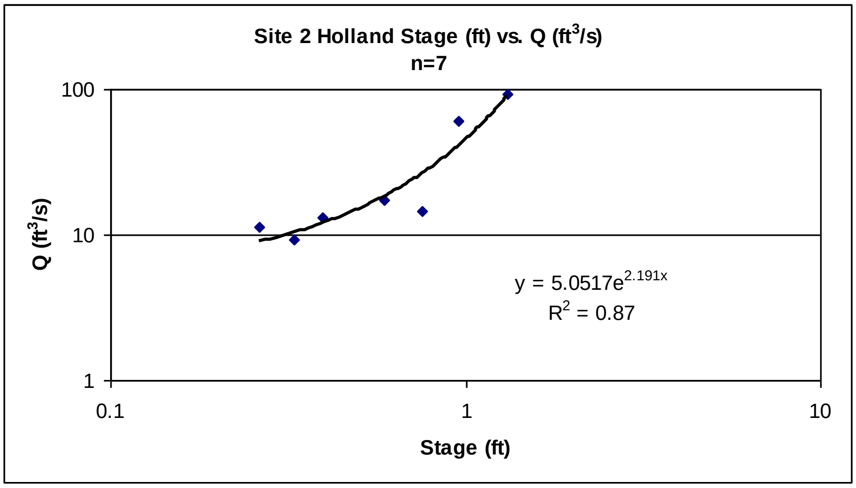


Figure 12. Site 2 Holland Ave. Stage (ft) vs. Q (ft^3/s)

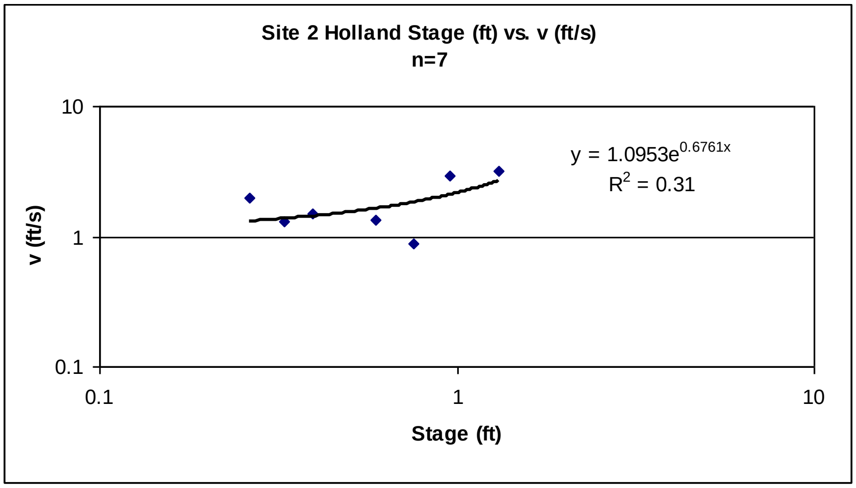


Figure 13. Site 2 Holland Ave. Stage (ft) vs. v (ft/s)

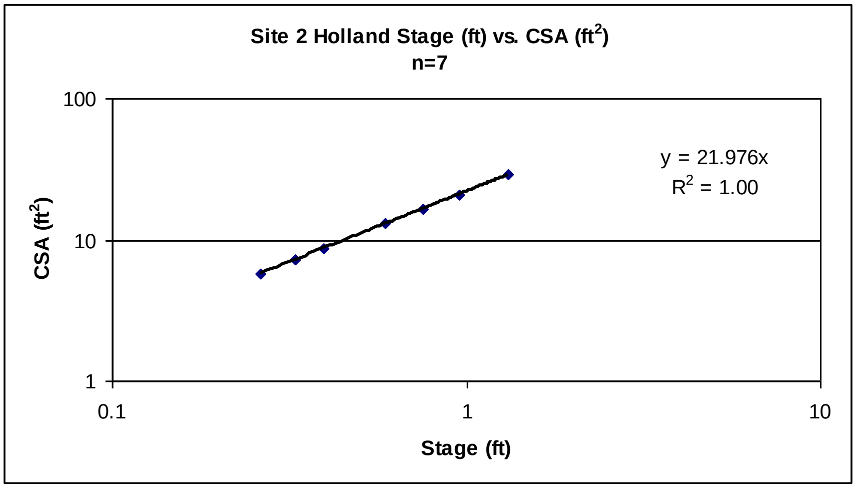


Figure 14. Site 2 Holland Ave. Stage (ft) vs. CSA (ft^2)

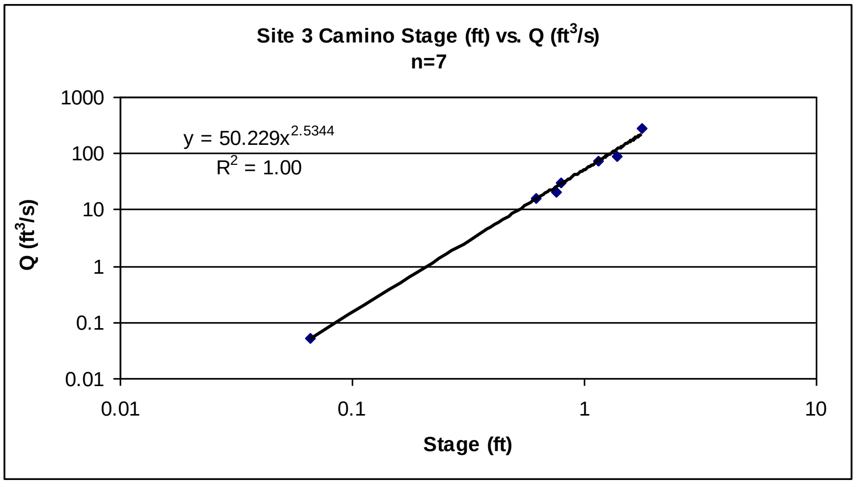


Figure 15. Site 3 Camino St. Stage (ft) vs. Q (ft^3/s)

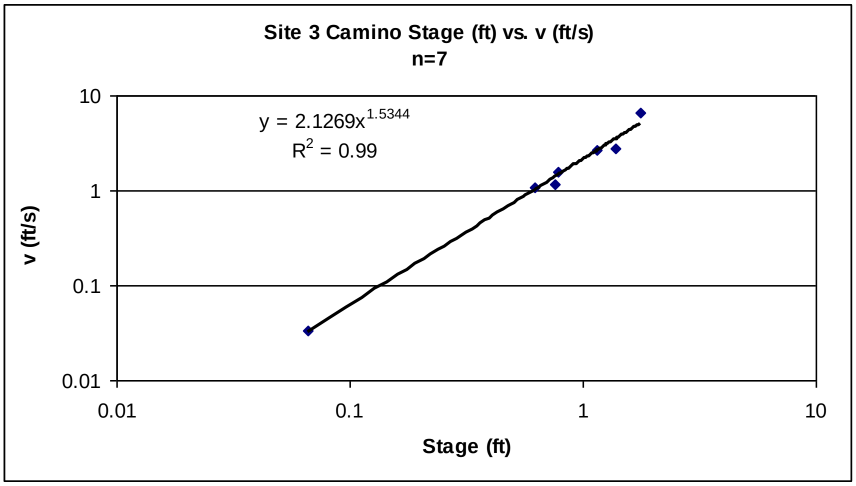


Figure 16. Site 3 Camino St. Stage (ft) vs. v (ft/s)

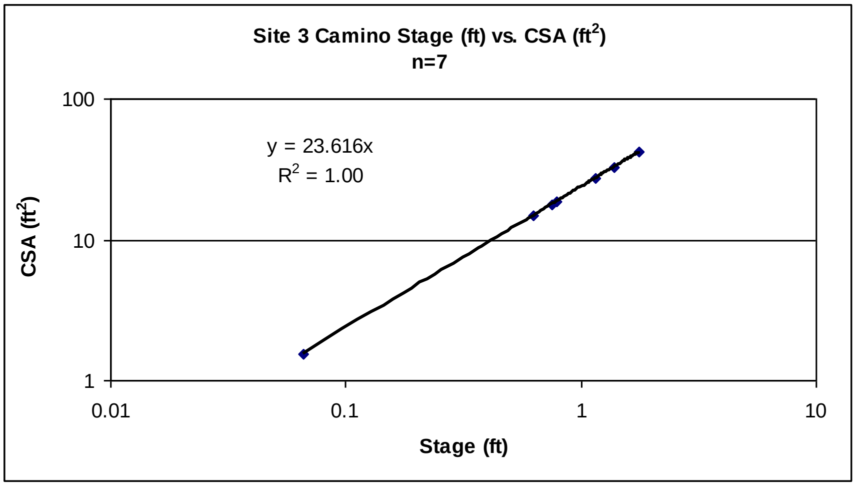


Figure 17. Site 3 Camino St. Stage (ft) vs. CSA (ft^2)

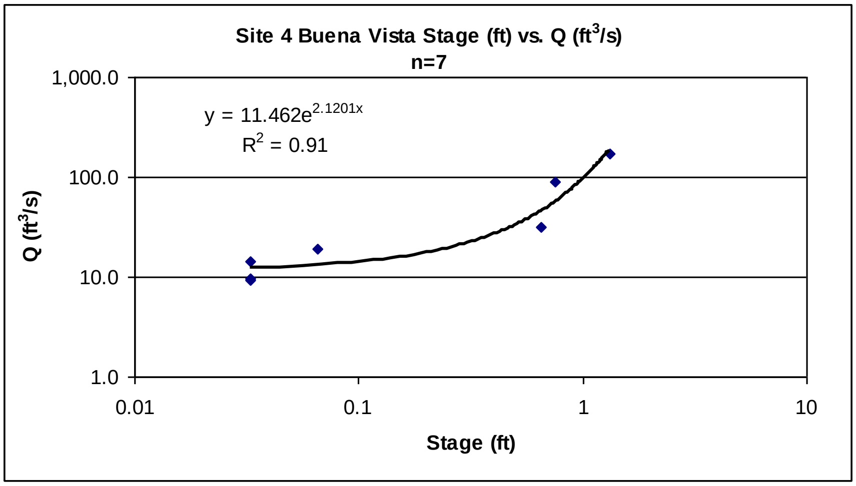


Figure 18. Site 4 Buena Vista St. Stage (ft) vs. Q (ft^3/s)

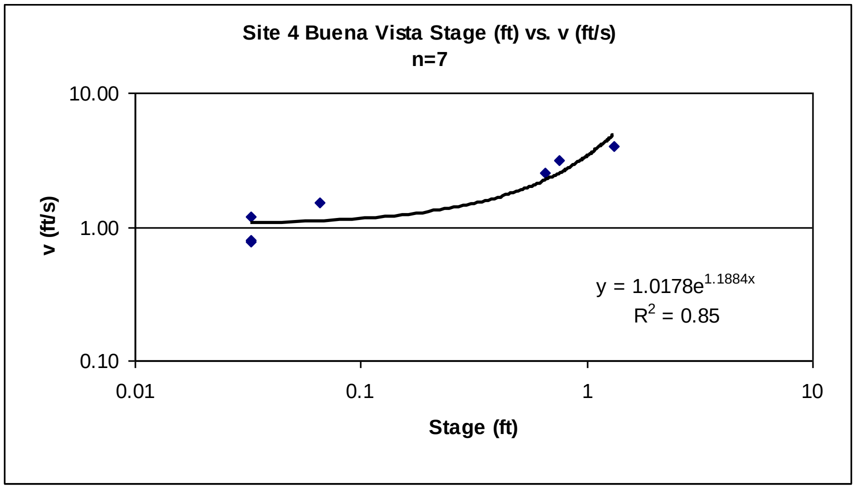


Figure 19. Site 4 Buena Vista St. Stage (ft) vs. v (ft/s)

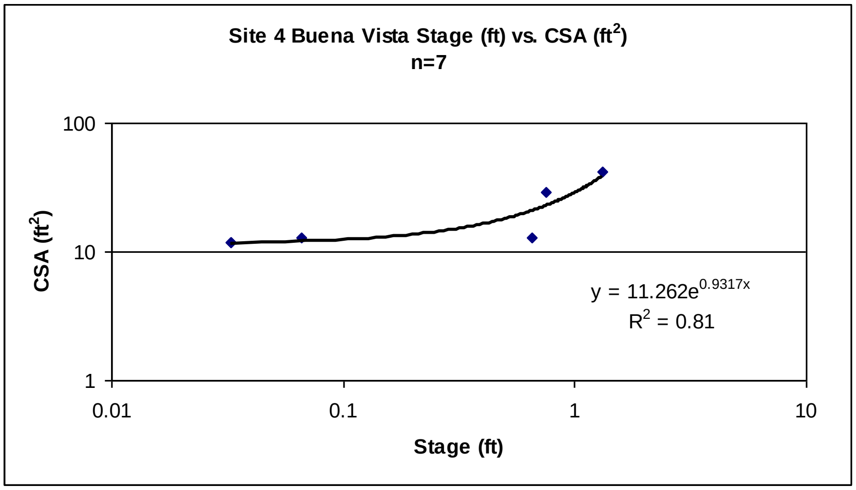


Figure 20. Site 4 Buena Vista St. Stage (ft) vs. CSA (ft^2)

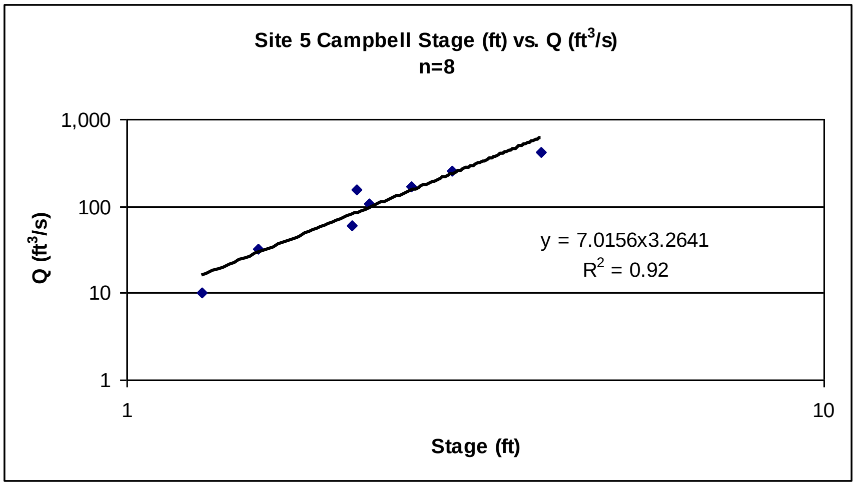


Figure 21. Site 5 Campbell Ave. Stage (ft) vs. Q (ft^3/s)

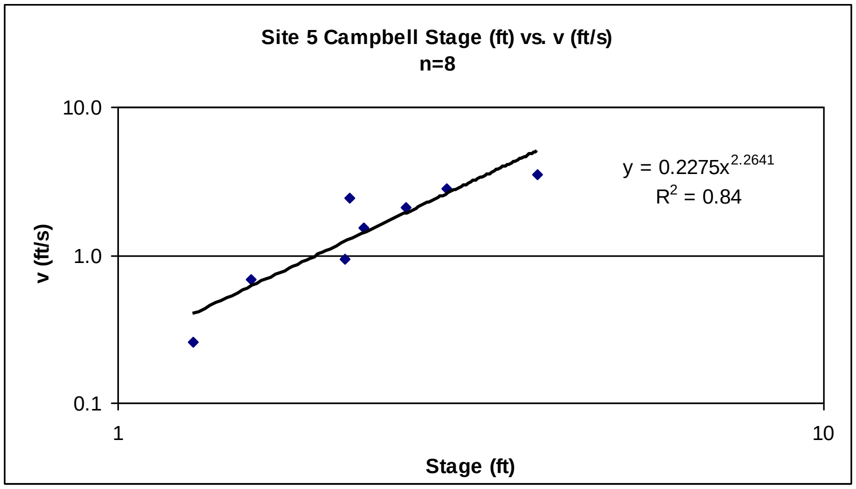


Figure 22. Site 5 Campbell Ave. Stage (ft) vs. v (ft/s)

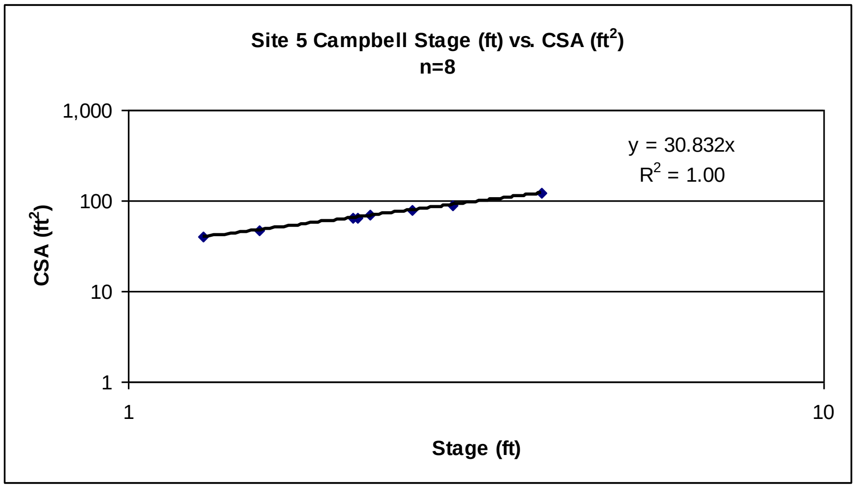


Figure 23. Site 5 Campbell Ave. Stage (ft) vs. CSA (ft^2)

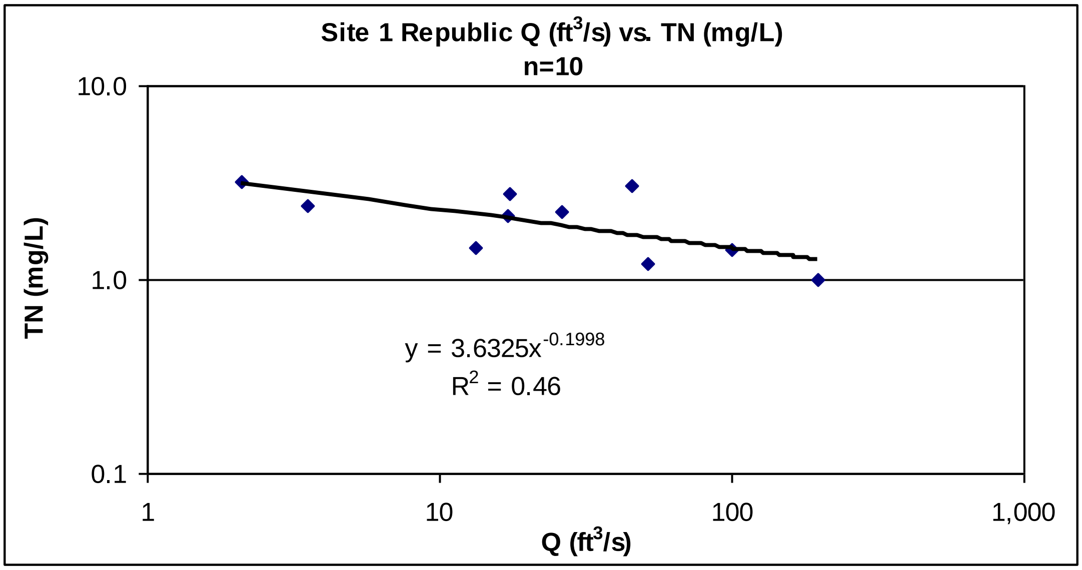


Figure 24. Site 1 Republic Rd. Q (ft^3/s) vs. Total Nitrogen (mg/L)

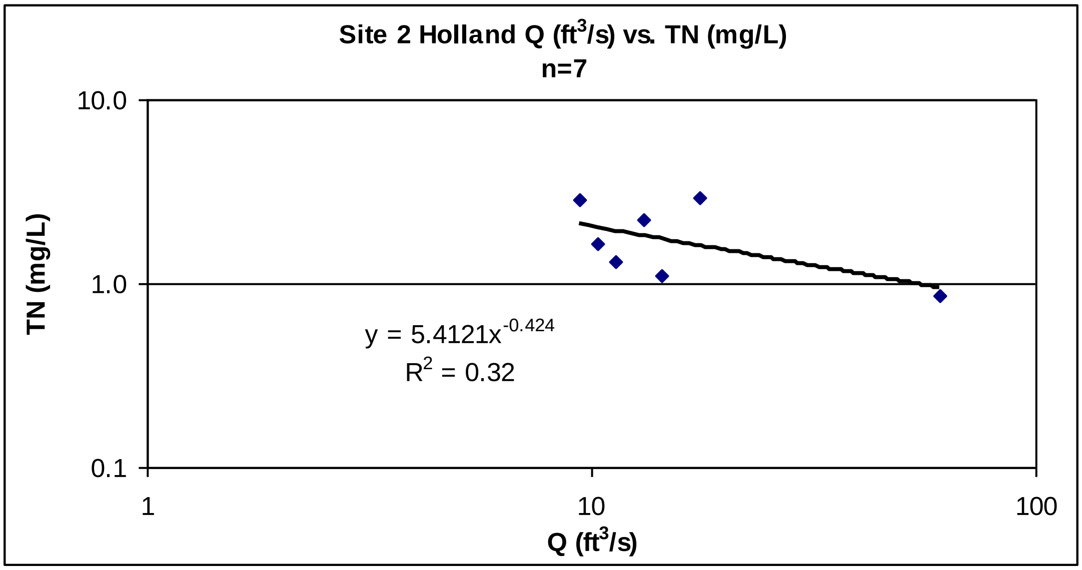


Figure 25. Site 2 Holland Ave. Q (ft^3/s) vs. Total Nitrogen (mg/L)

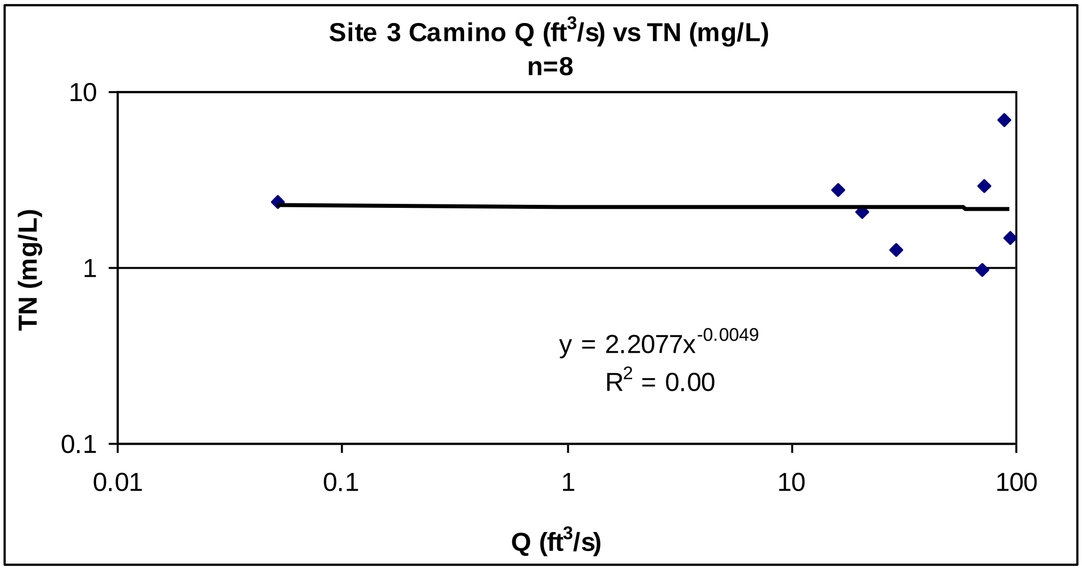


Figure 26. Site 3 Camino St. Q (ft^3/s) vs. Total Nitrogen (mg/L)

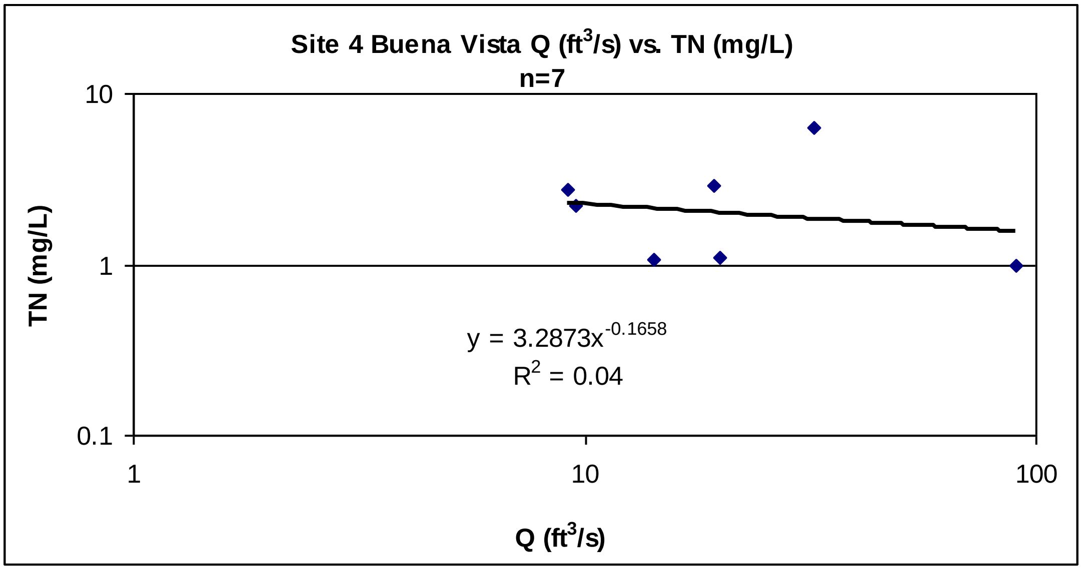


Figure 27. Site 4 Buena Vista St. Q (ft3/s) vs. Total Nitrogen (mg/L)

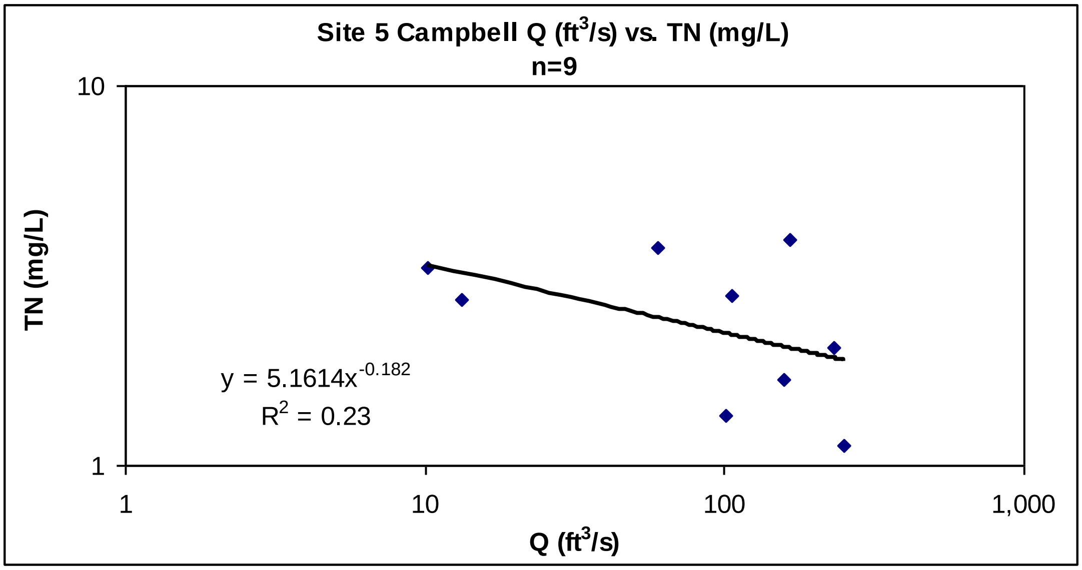


Figure 28. Site 5 Campbell Ave. Q (ft^3/s) vs. Total Nitrogen (mg/L)

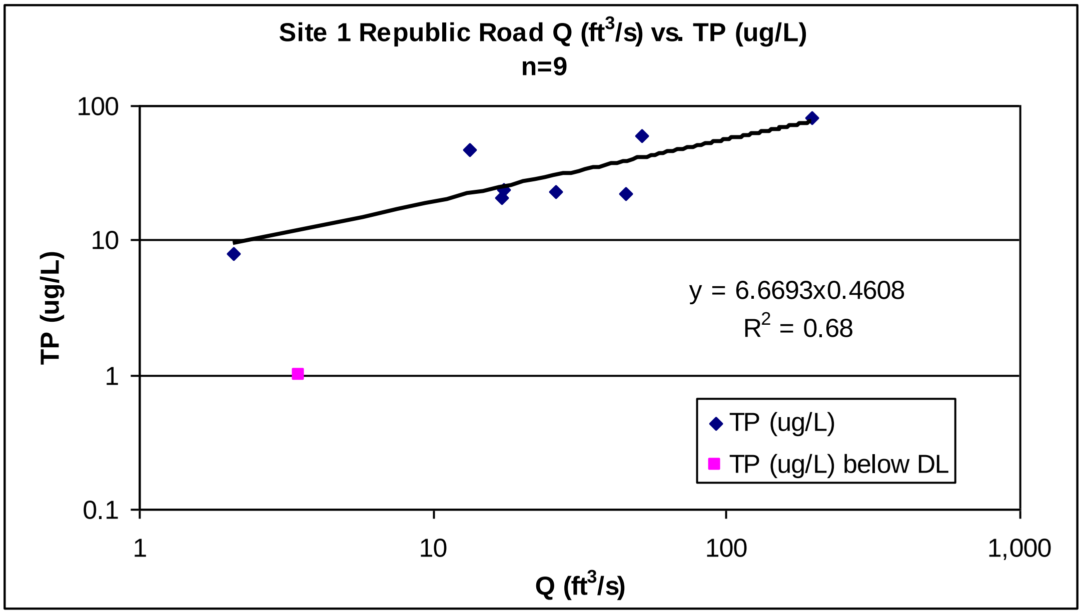


Figure 29. Site 1 Republic Rd. Q (ft^3/s) vs. Total Phosphorus (ug/L)

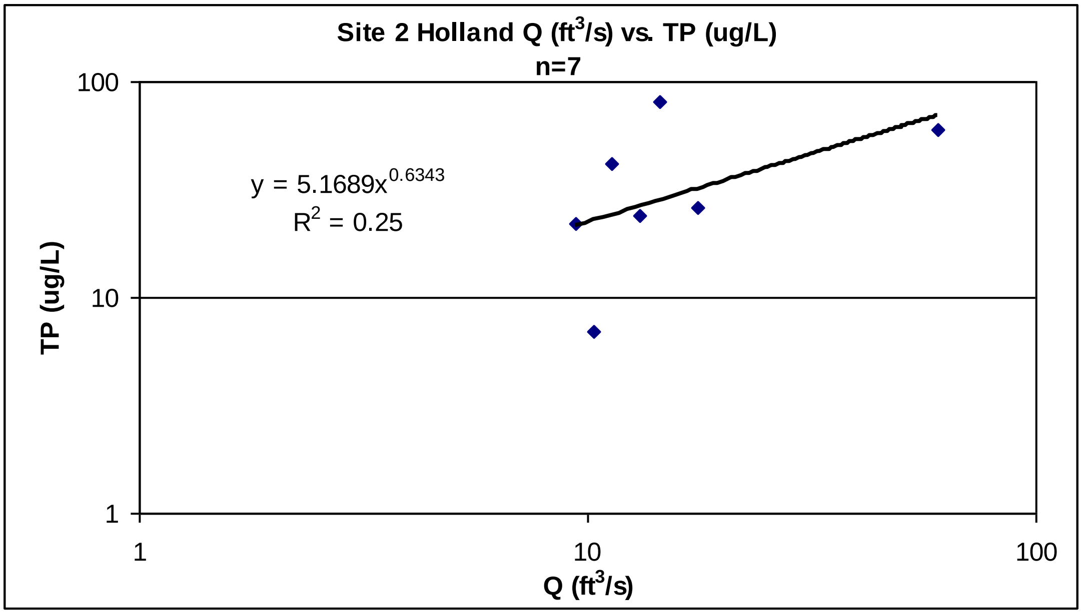


Figure 30. Site 2 Holland Ave. Q (ft^3/s) vs. Total Phosphorus (ug/L)

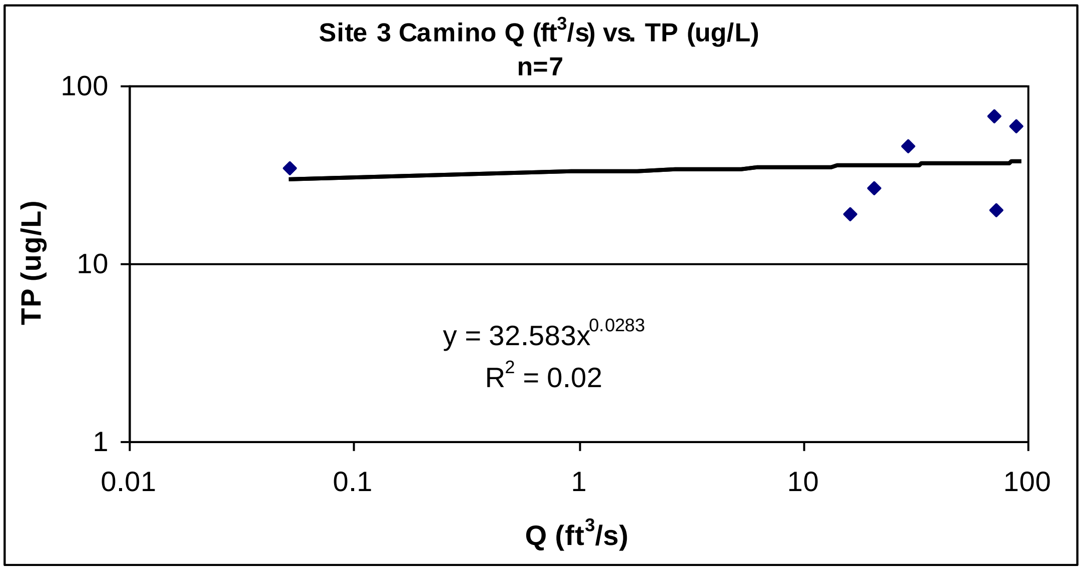


Figure 31. Site 3 Camino St. Q (ft^3/s) vs. Total Phosphorus (ug/L)

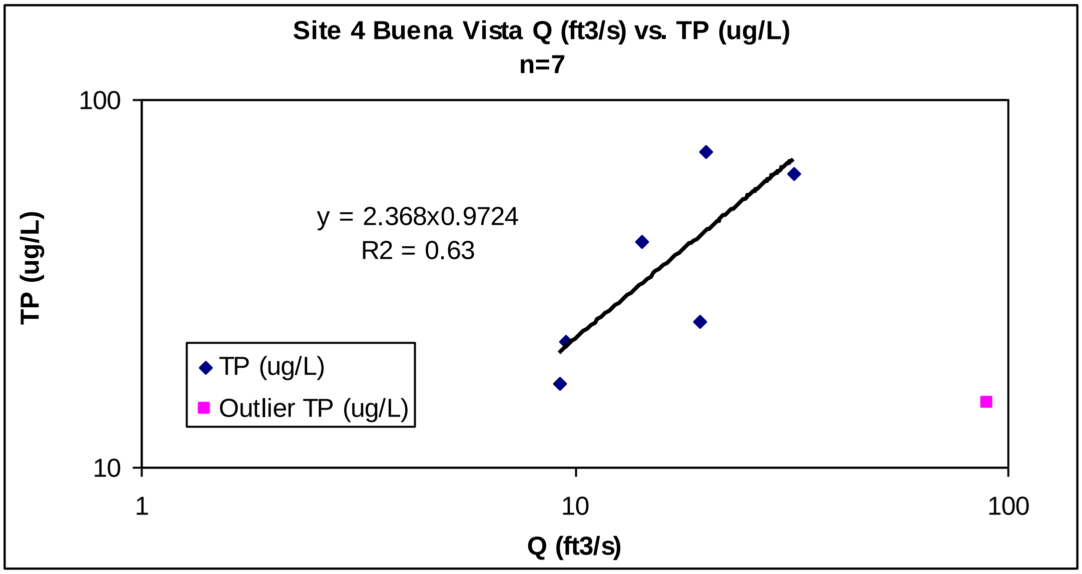


Figure 32. Site 4 Buena Vista St. Q (ft^3/s) vs. Total Phosphorus (ug/L)

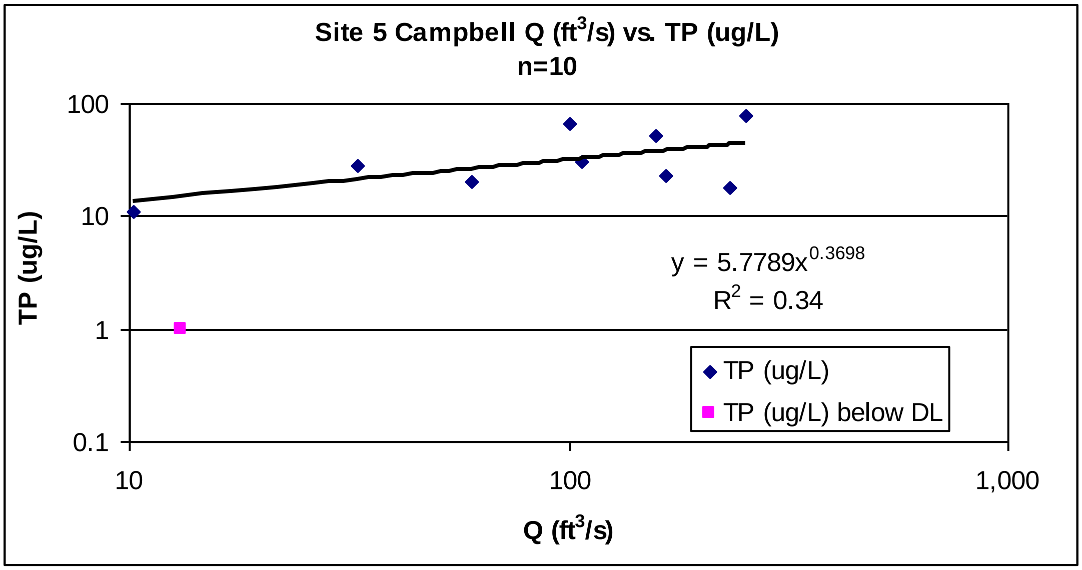


Figure 33. Site 5 Campbell Ave. Q (ft^3/s) vs. Total Phosphorus (ug/L)

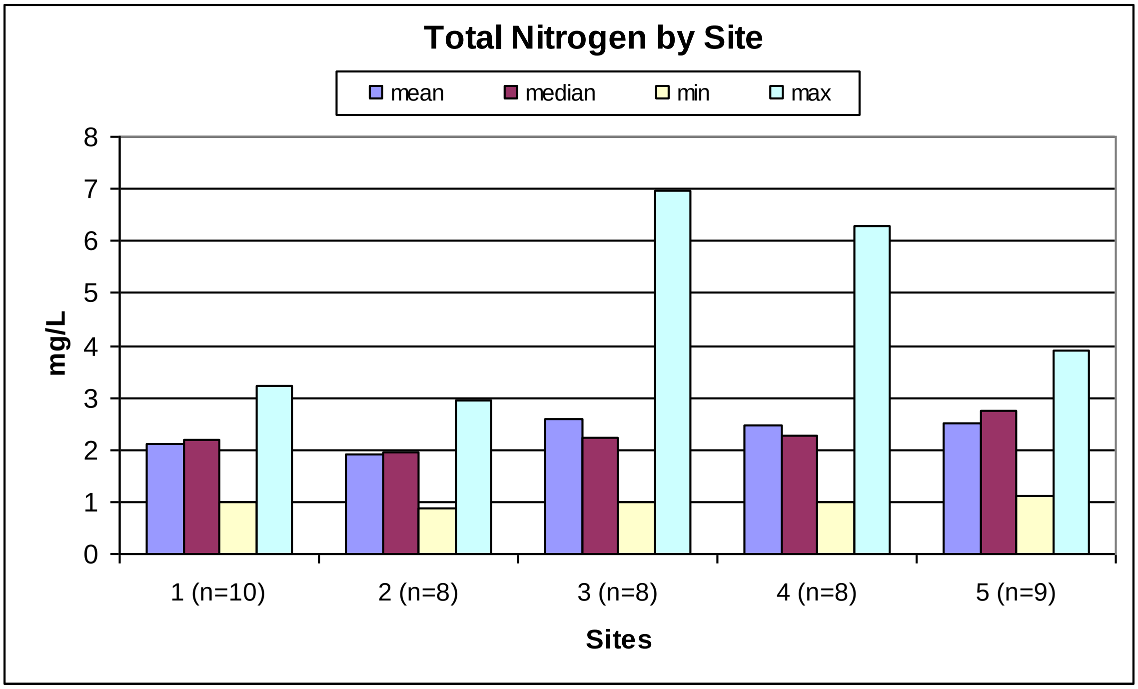


Figure 34. Total Nitrogen Data by Site

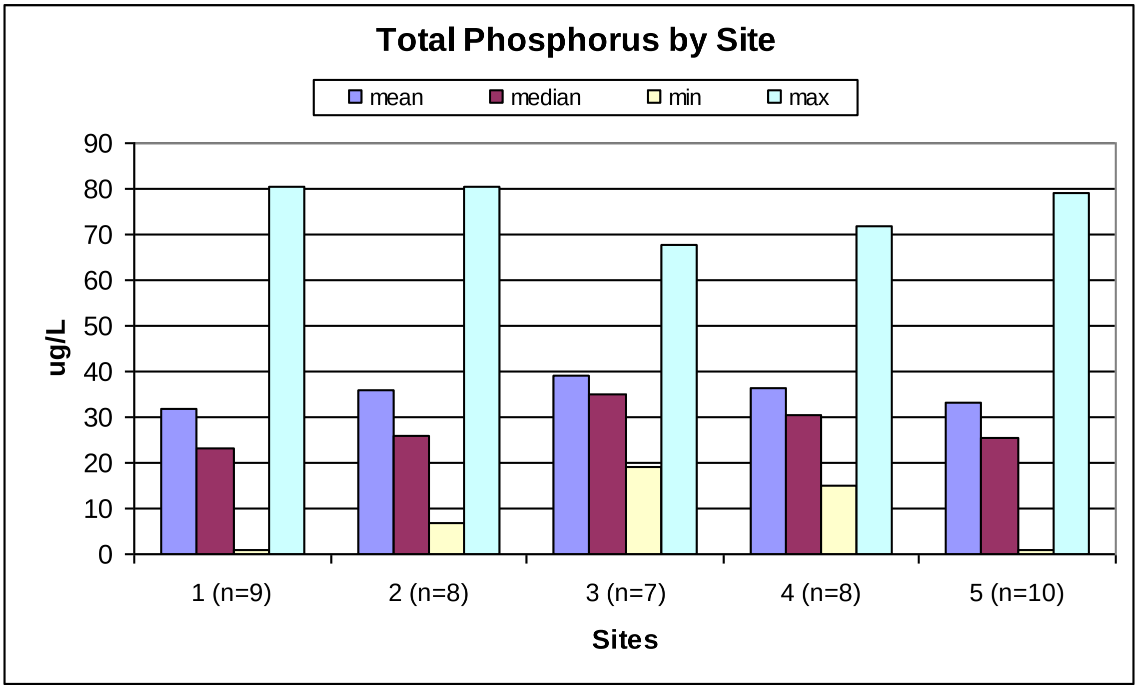


Figure 35. Total Phosphorus Data by Site

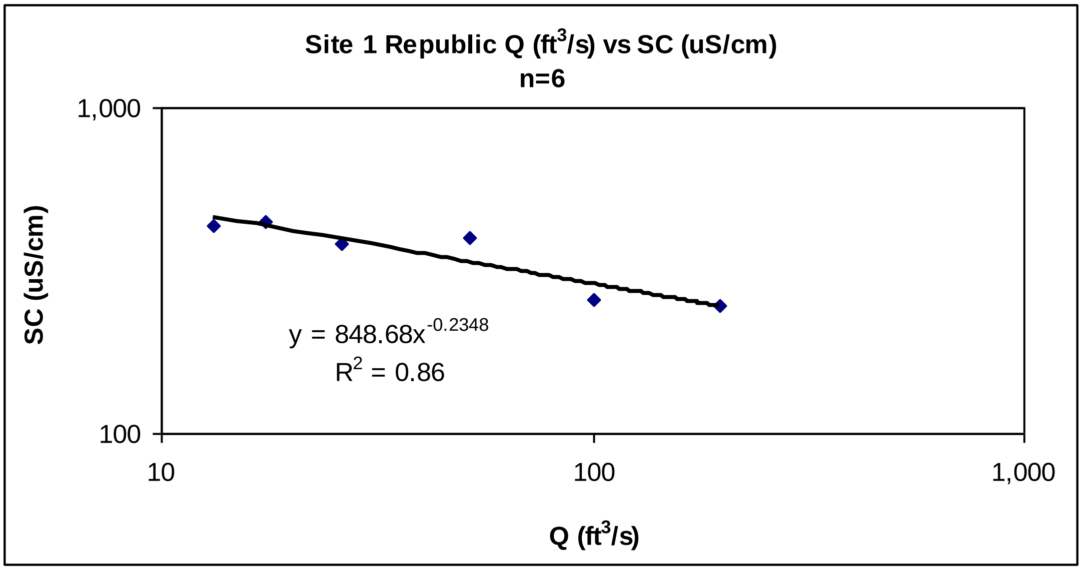


Figure 36. Site 1 Republic Rd. Q (ft^3/s) vs. Specific Conductivity (uS/cm)

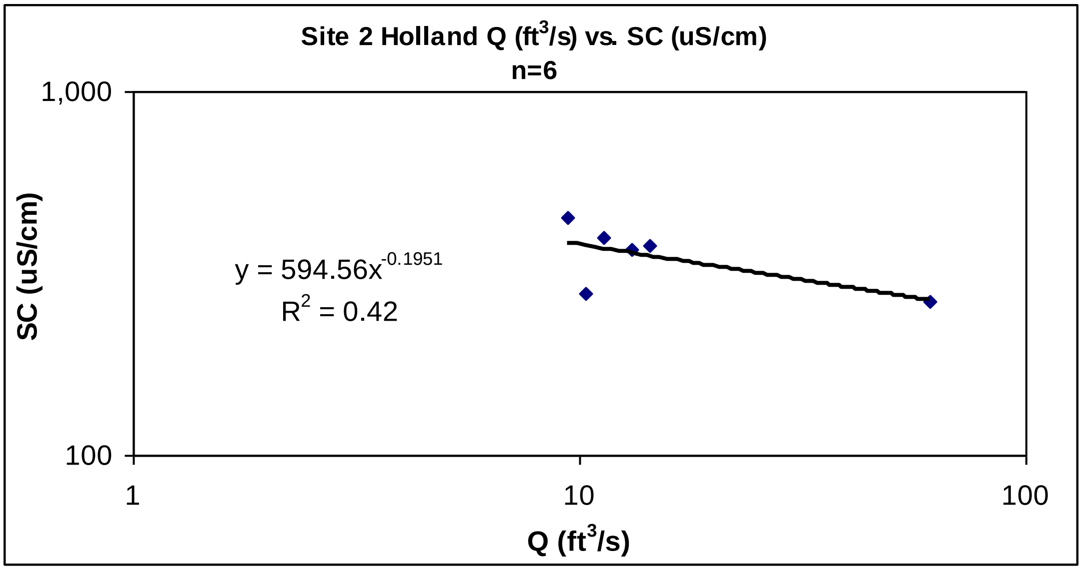


Figure 37. Site 2 Holland Ave. Q (ft^3/s) vs. Specific Conductivity (uS/cm)

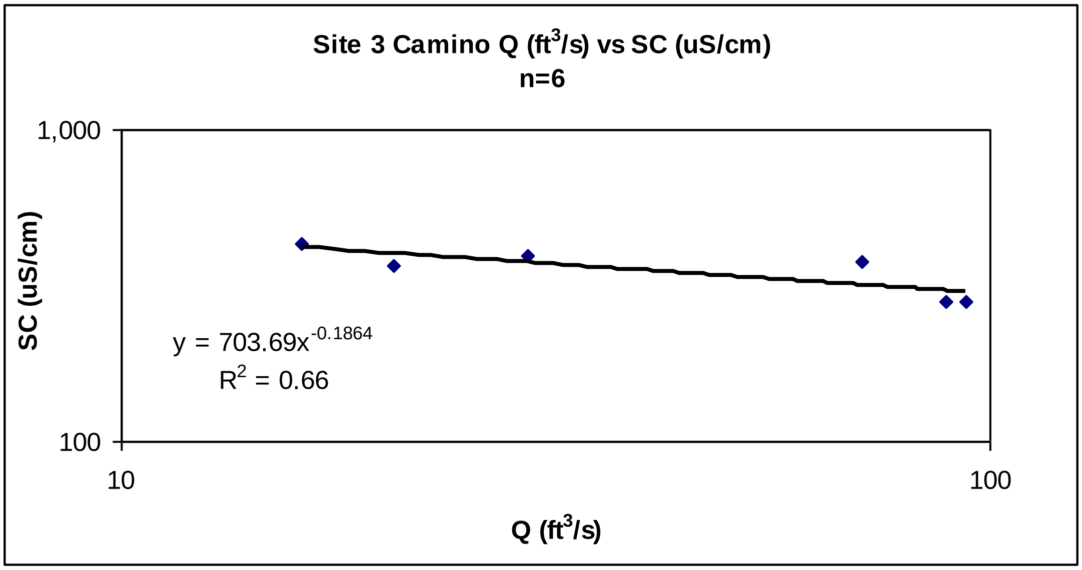


Figure 38. Site 3 Camino St. Q (ft^3/s) vs. Specific Conductivity (uS/cm)

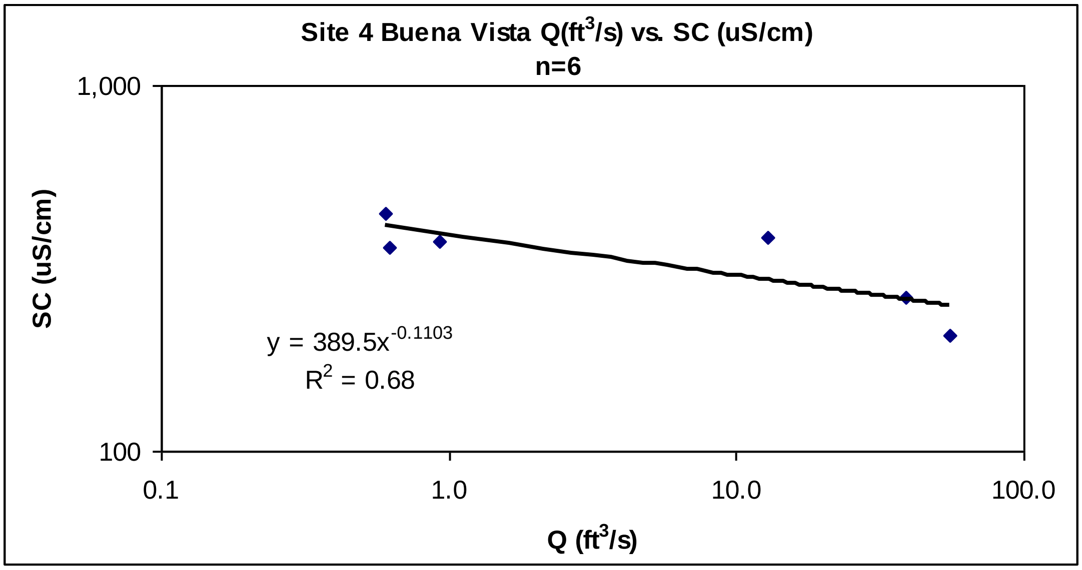


Figure 39. Site 4 Buena Vista St. Q (ft^3/s) vs. Specific Conductivity (uS/cm)

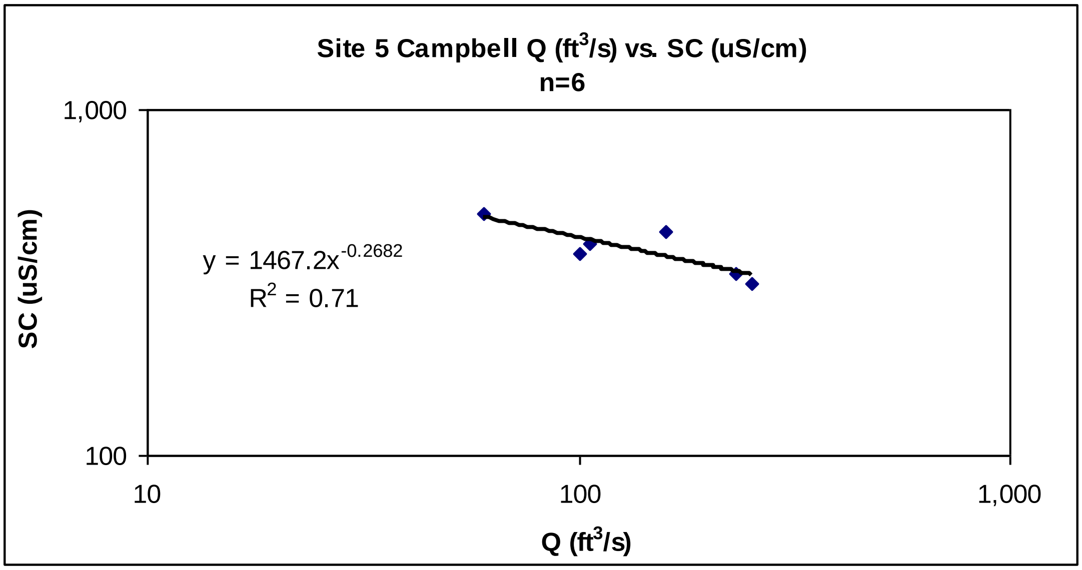


Figure 40. Site 5 Campbell Ave. Q (ft^3/s) vs. Specific Conductivity (uS/cm)

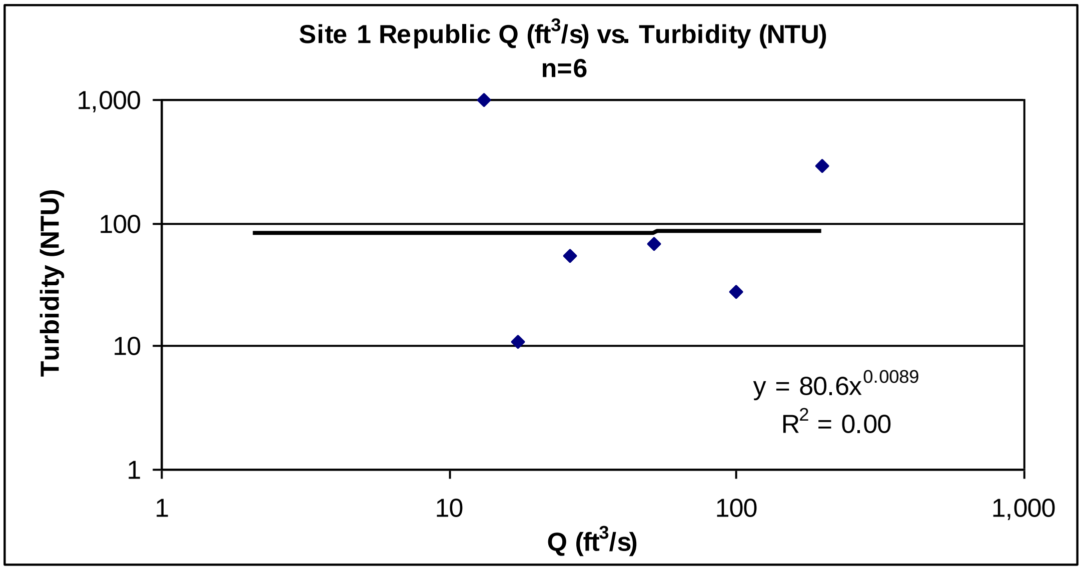


Figure 41. Site 1 Republic Rd. Q (ft^3/s) vs. Turbidity (NTU)

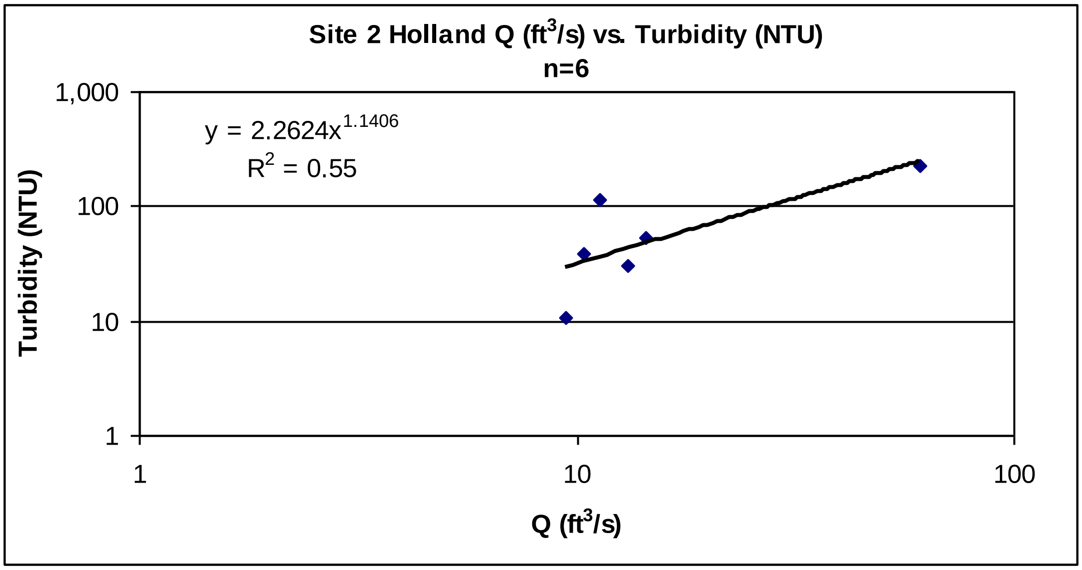


Figure 42. Site 2 Holland Ave. Q (ft^3/s) vs. Turbidity (NTU)

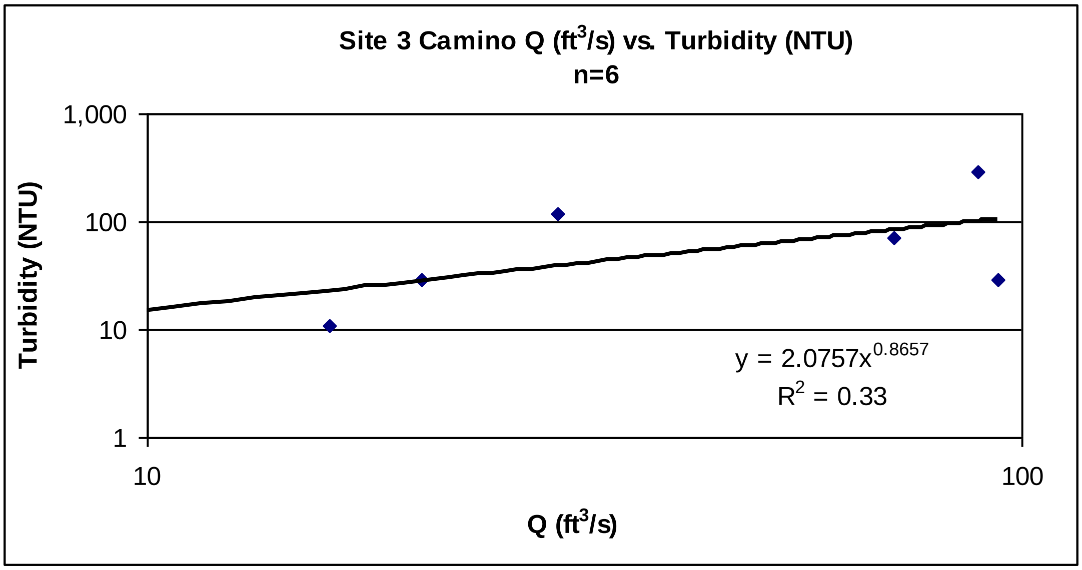


Figure 43. Site 3 Camino St. Q (ft^3/s) vs. Turbidity (NTU)

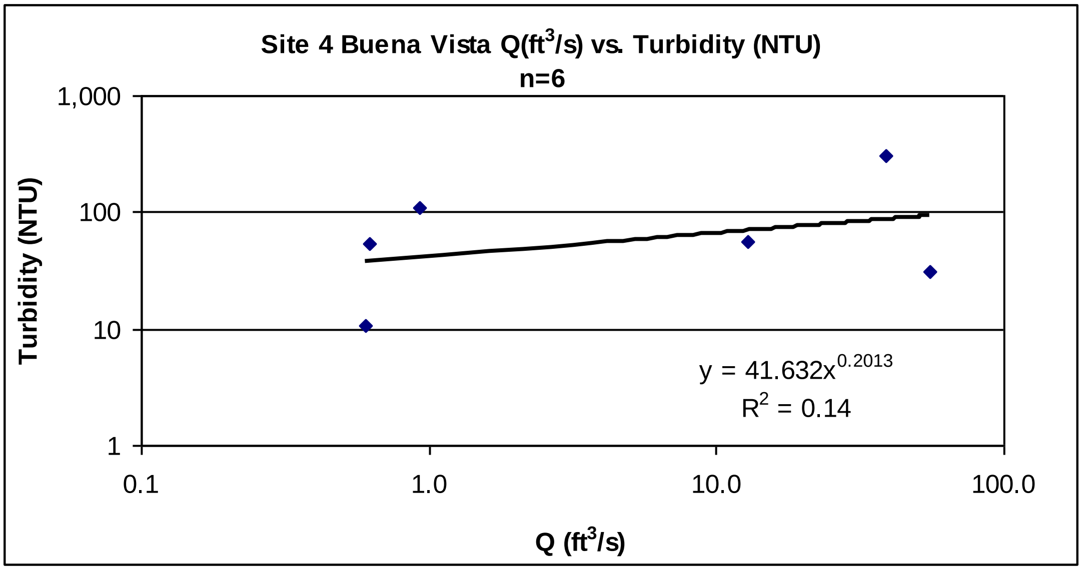


Figure 44. Site 4 Buena Vista St. Q (ft3/s) vs. Turbidity (NTU)

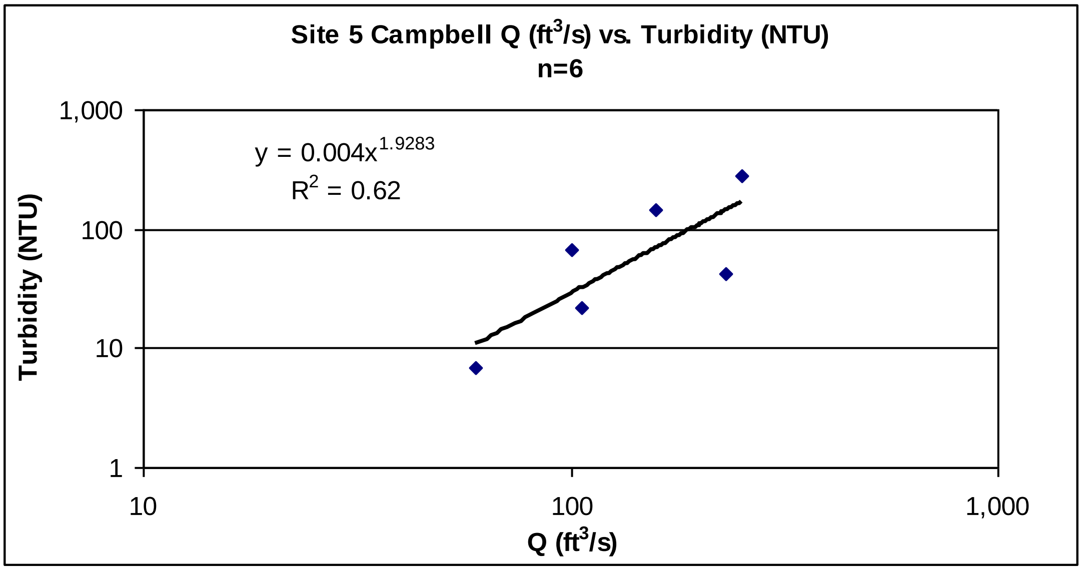


Figure 45. Site 5 Campbell Ave. Q (ft3/s) vs. Turbidity (NTU)

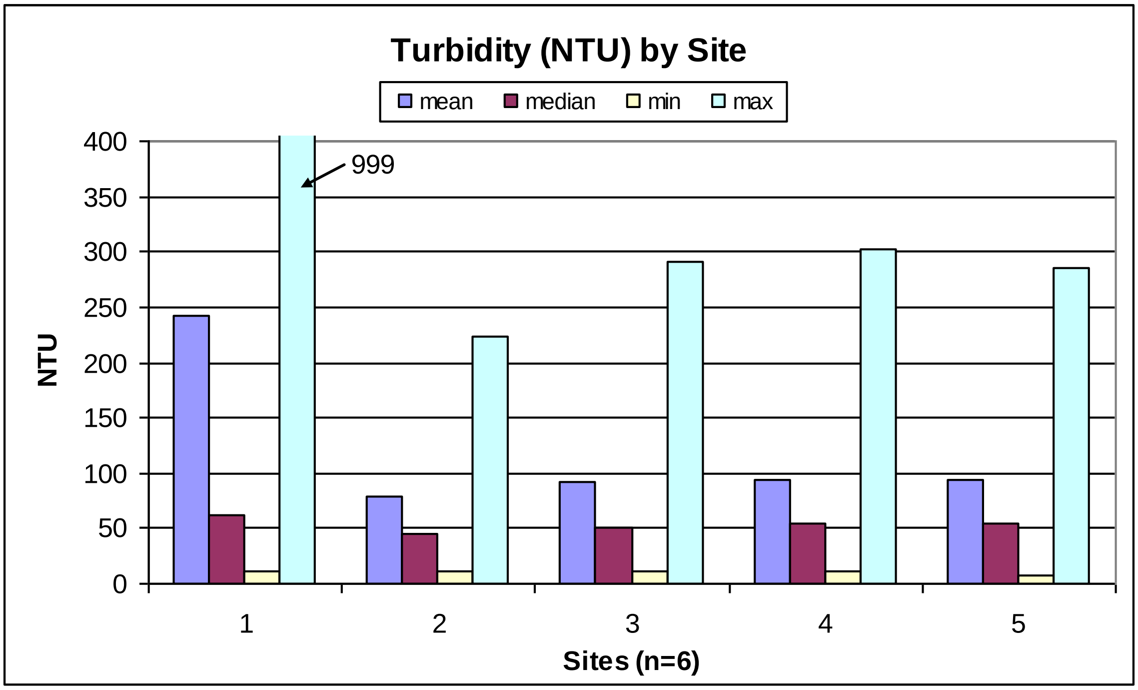


Figure 46. Turbidity Data by Site

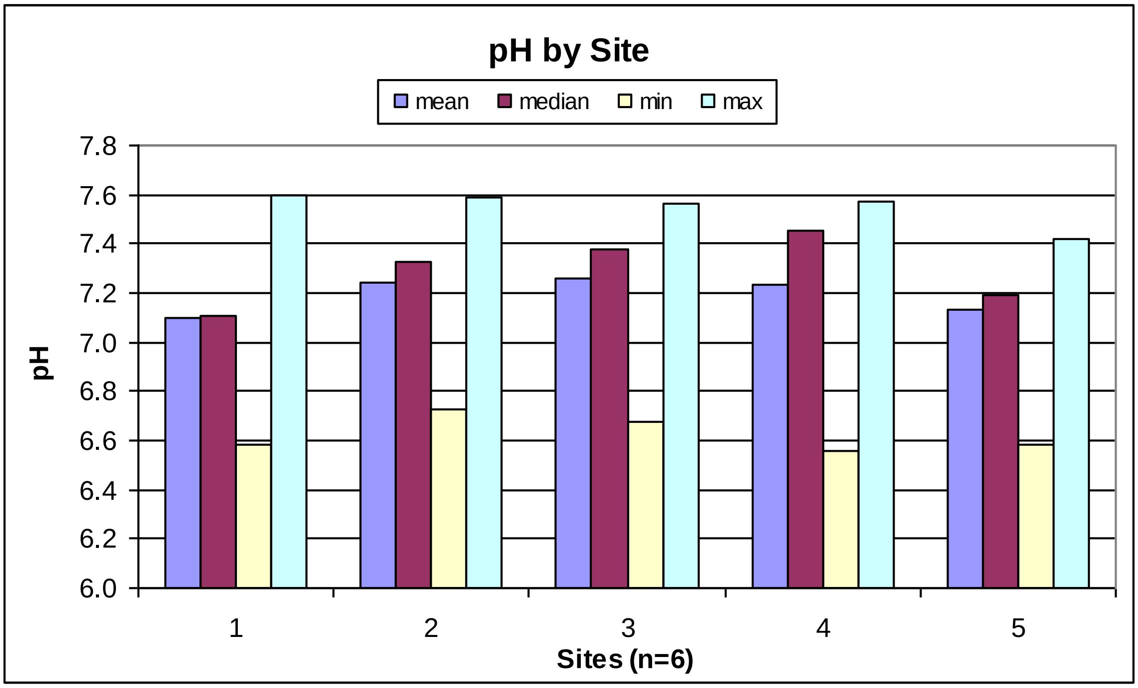


Figure 47. pH Data by Site

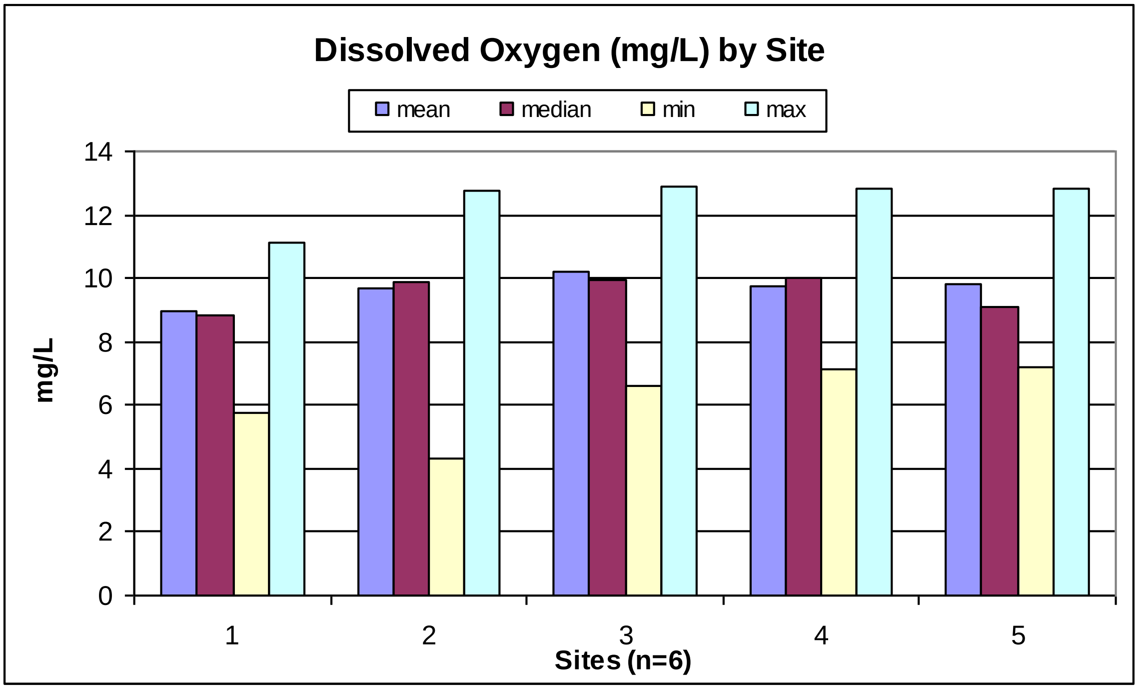


Figure 48. Dissolved Oxygen Data by Site

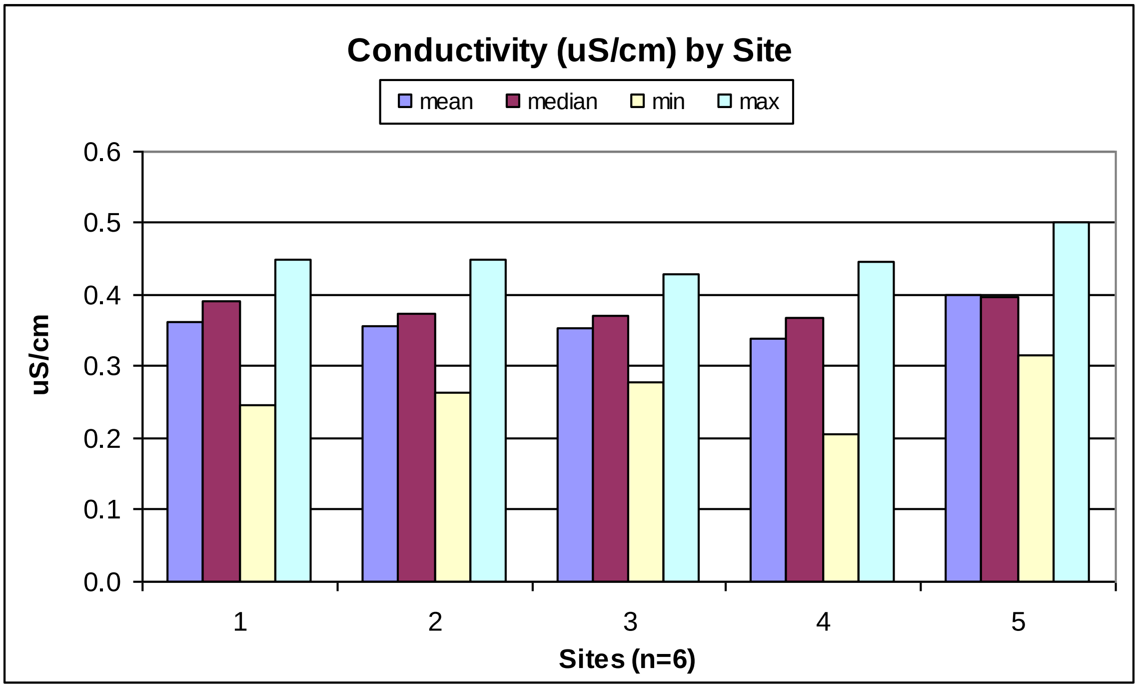


Figure 49. Specific Conductivity Data by Site

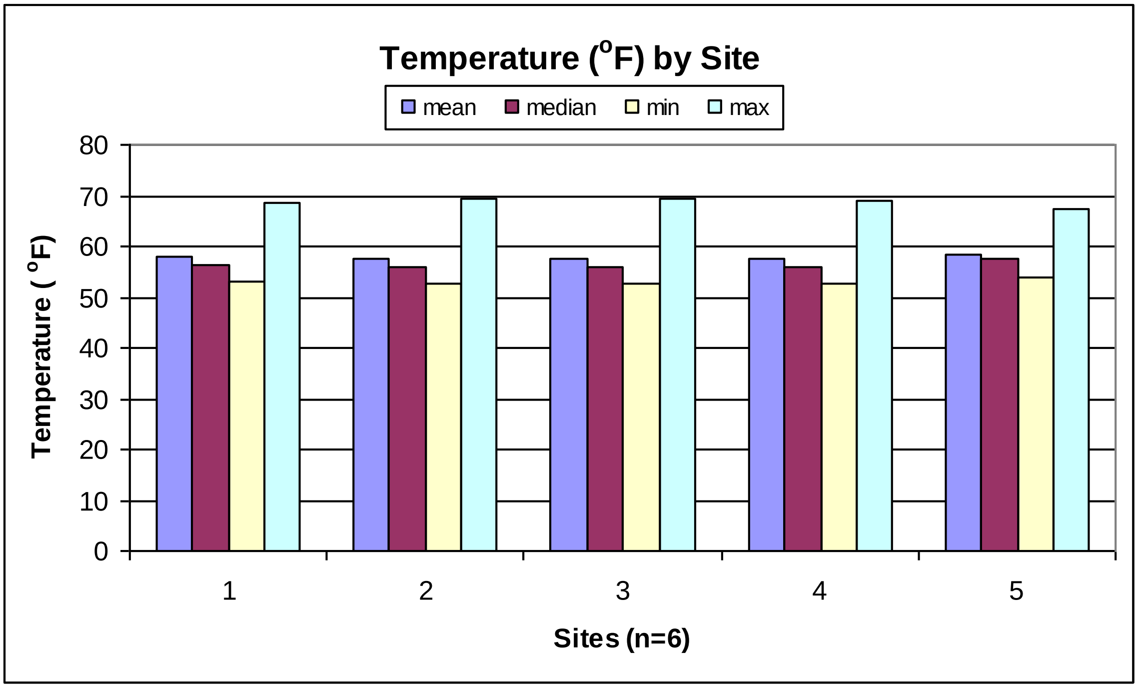


Figure 50. Temperature Data by Site

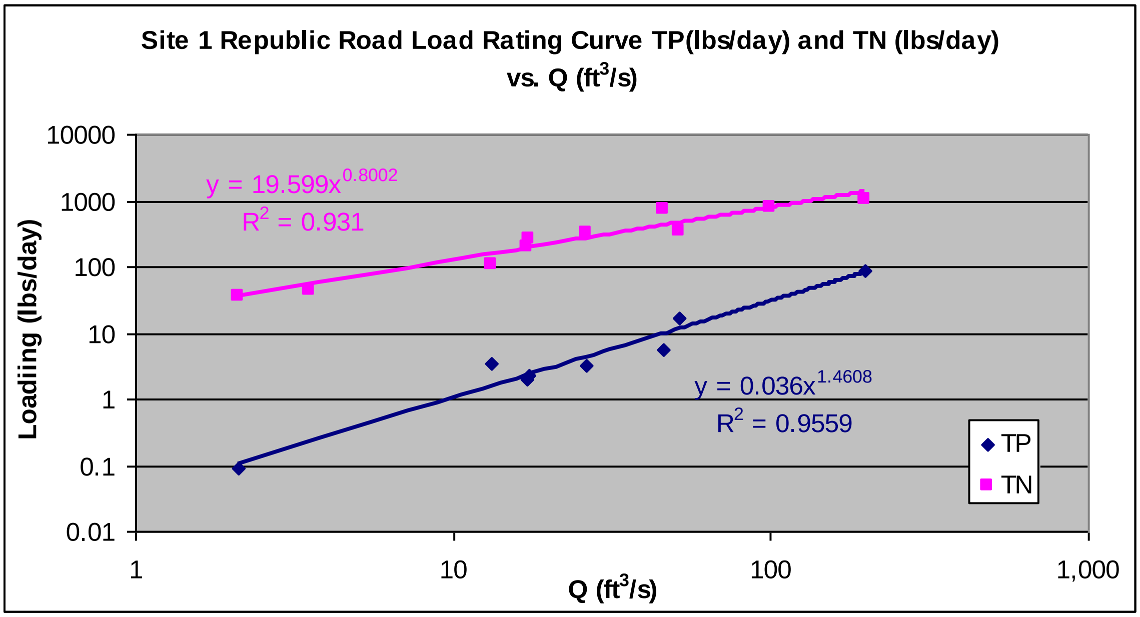


Figure 51. Site 1 Republic Road Load Rating Curves

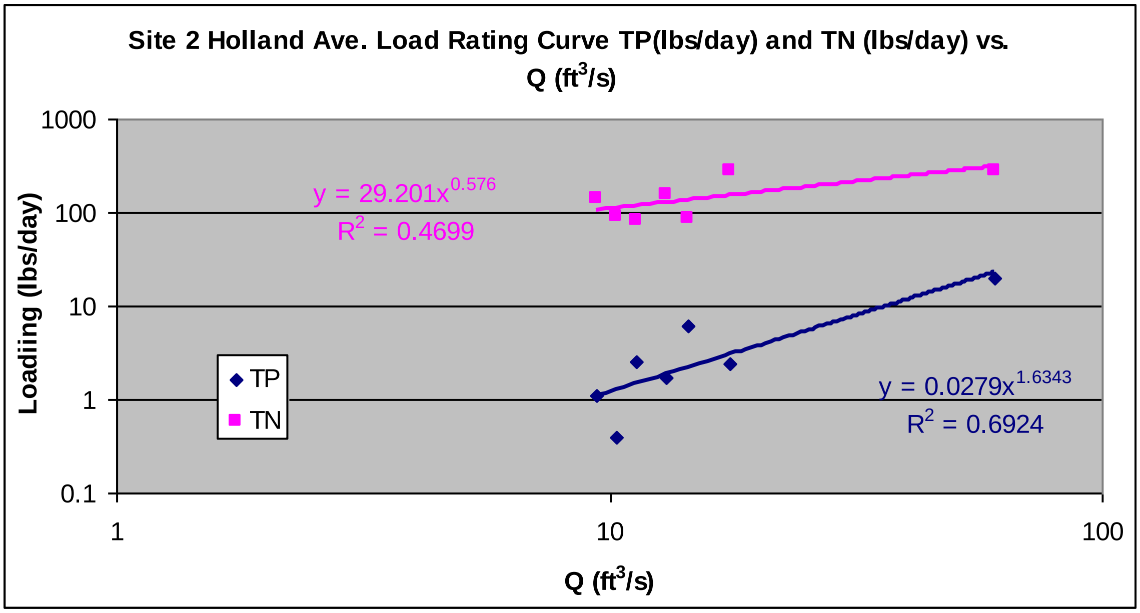


Figure 52. Site 2 Holland Ave. Load Rating Curves

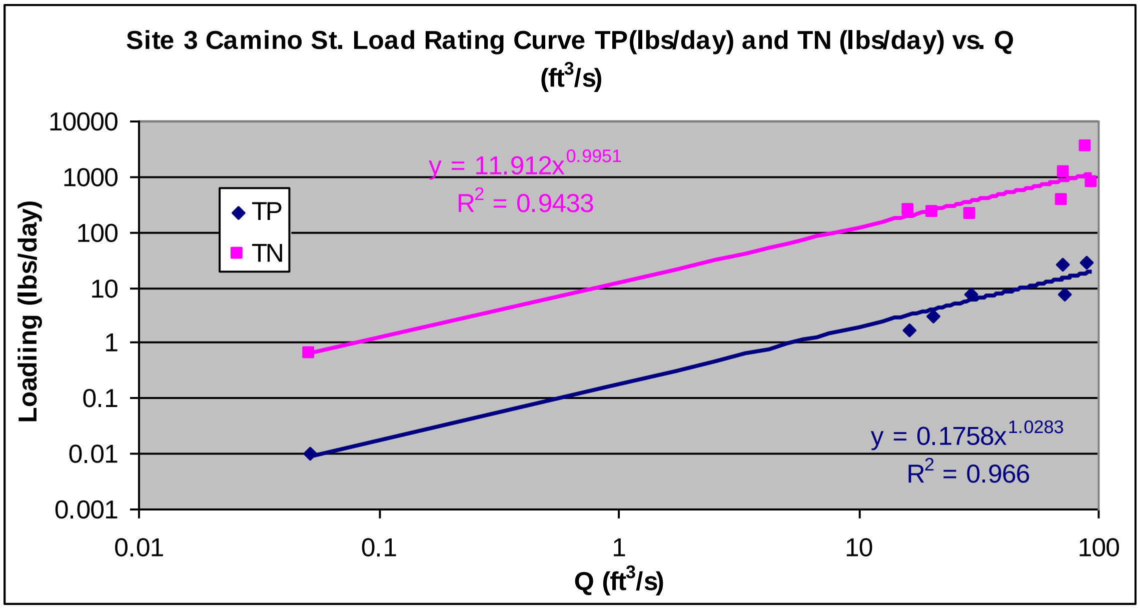
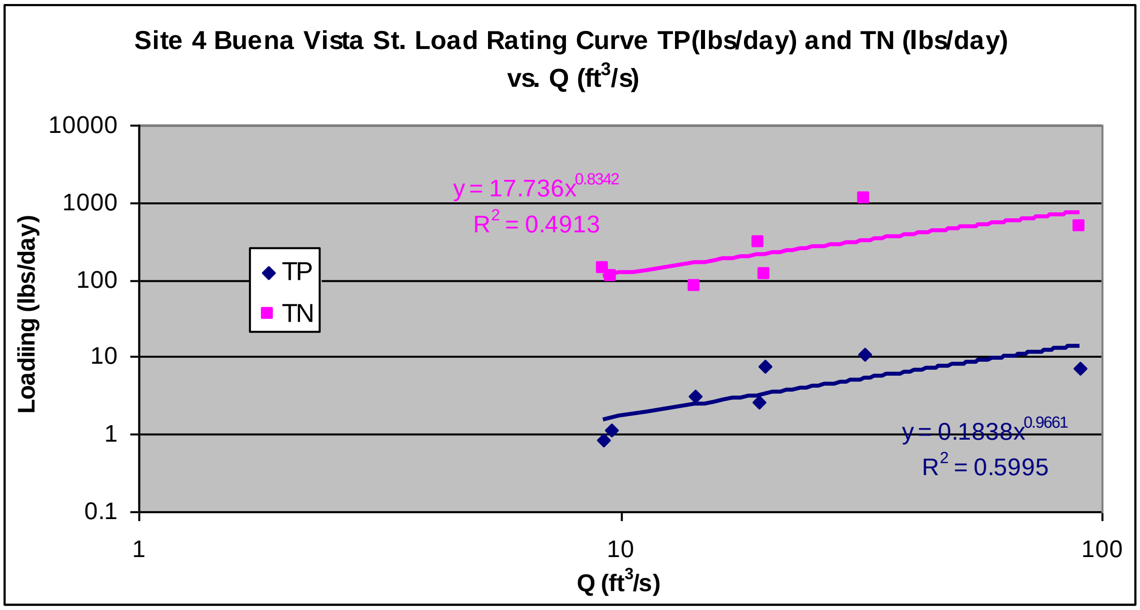
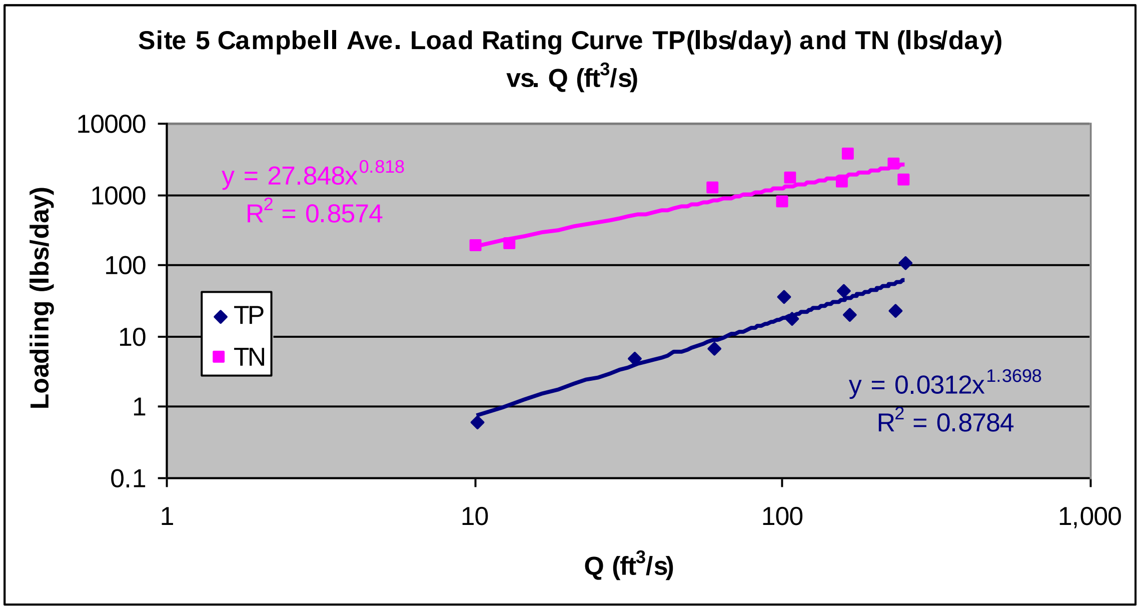


Figure 53. Site 3 Camino St. Load Rating Curves



Site 4 Buena Vista St. Load Rating Curve TP(lbs/day) and TN (lbs/day) vs. Q (ft^3/s)

Figure 54. Site 4 Buena Vista St. Load Rating Curves



Site 5 Campbell Ave. Load Rating Curve TP(lbs/day) and TN (lbs/day) vs. Q (ft^3/s)

Figure 55. Site 5 Campbell Ave. Load Rating Curves

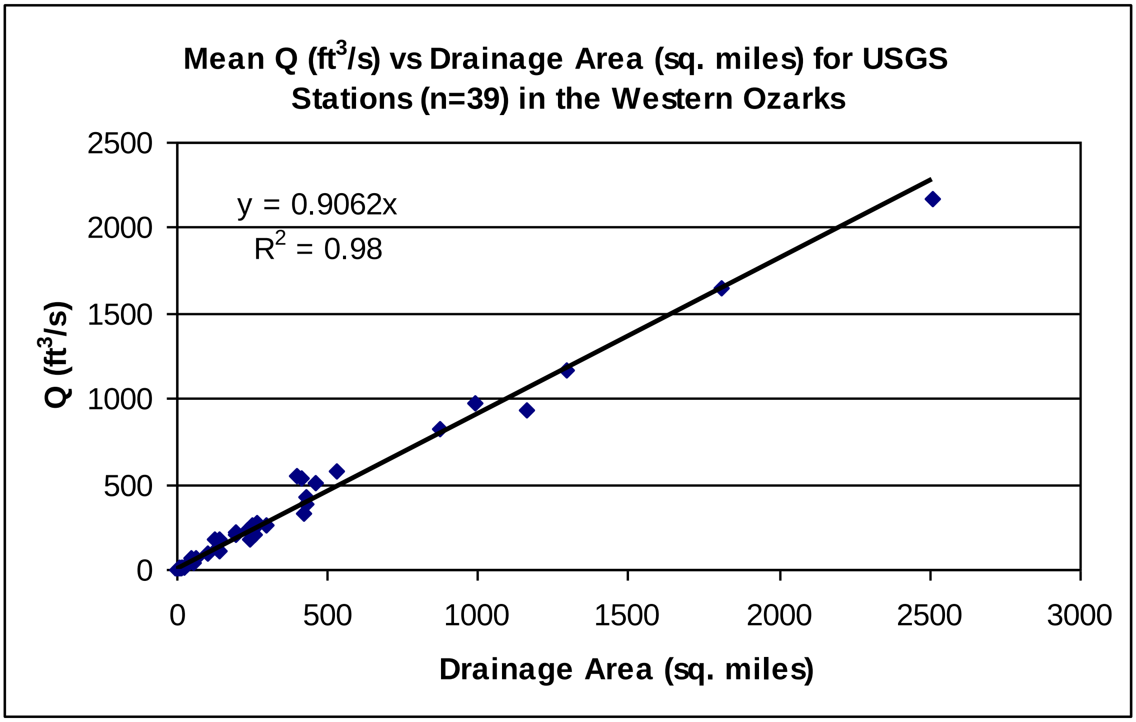


Figure 56. Mean Discharge Regional Regression Curve

Water Quality Monitoring Photos

Photo 1. Site 1 below the Republic Road culvert

Photo 2. Site 2 downstream of bridge at Holland

Photo 3. Site 3 downstream of bridge at Camino

Photo 4. Site 4 downstream of Buena Vista

Photo 5. Site 5 upstream of bridge at Campbell

Photo 6. Flow meter measurements

BANK EROSION MONITORING

Graduate student Mark Gossard inspects erosion pins after a storm event in September 2005

BANK EROSION MONITORING

METHODS

The objectives of the bank erosion monitoring portion of this study is to estimate the amount of sediment being eroded from the banks throughout the study reach, to assess the physical characteristics of this material, and measure P concentrations in this material. This will be accomplished by performing a bank material evaluation at several locations along the reach and placing erosion pins at actively eroding areas.

Bank material composition was also evaluated at six locations along the study reach where significant bank heights allowed for material analysis between stations 880 and 1,500 feet. Distinct sedimentary units were identified at each bank profile and a sample was collected from each layer. Samples from each horizon were analyzed for grain size of both the fine grained (≤2 mm) and the coarse fraction (>2 mm). Each sample was dried in a 60ºC oven, disaggregated with mortar and pestle, and passed through a 2 mm sieve. The coarse fraction was passed through a series of sieves to separate the particles into size classes based on the Wentworth Scale. The fine grain fraction was analyzed for sand, silt and clay by use of the hydrometer method. The sand fraction was wet sieved for comparison purposes. One gram of the fine-grain sediment sampled was sent to ALS Chemex in Sparks, Nevada for chemical analysis of 34 elements including phosphorus. A 3:1 Hydrochloric:Nitric acid extraction method was used to extract total phosphorus and metals from the sediment for ICP analysis.

Arrays of ½ inch rebar, 18 inches long were driven into the stream banks at 12 locations between stations 685.5 and 1597.4 in areas that showed signs of erosion along one bank of the stream (Figure 2). Arrays consisted of groups of 3 to 5 pins located in a vertical line in the banks (Photo 1). The spacing of the vertical aligned pins was determined by bank stratigraphy, with each pin being placed in significantly different horizons. Sources of parent material in these horizons included alluvium, colluvium, residuum, and fill material. Each pin was driven flush to the stream bank and after each storm event, pins were measured for erosion (Photo 2) and re-installed. Banks were monitored from September, 2005 to May, 2006.

Total bank material lost was estimated by taking the mean total erosion of each pin at each location and multiplying that by the mean bank height over the length of the eroding reach (550-1,290) and the plane bed reach (1,290-1,610) identified in the Geomorphic Assessment Section of this report. This gives an estimated total volume of material eroded for each section. Using the bank material survey data described above, the total amount of fine grain martial, coarse grain material and total phosphorus eroded is estimated.

RESULTS AND DISCUSSION

Bank erosion along streams occurs in a series of steps. The first step is that the toe of the bank is removed during low frequent events where shear stresses are high along the bank, such as along a meander bend. Over time, the angle and the weight of the upper bank overcomes the cohesiveness of the bank material and large blocks of bank material fall to the channel. This material is removed in subsequent flows and the process starts over again.

Over the course of the bank erosion monitoring period each of the 12 erosion pin locations displayed the different stages of bank erosion. Stations 846, 925, 958 and 984 in the golf course and stations 1,440 and 1,492 in the disturbance reach had total bank failures during the monitoring period (Table 7). Total bank failure would be the entire height of the bank eroded. This suggests a high erosion rate in these areas since the entire bank erosion cycle was measured in less than 12 months. It was in these sections that the majority of the erosion took place over the course of the monitoring period.

Stations 686 and 886, which are in the golf course reach, showed toe erosion, while stations 1,407 and 1,597, in the disturbance reach, had upper bank erosion (Table 7). Toe erosion measured would be the first step in the bank erosion cycle and upper bank erosion would be anticipated in the future. A station with upper bank erosion only suggests that toe erosion had taken place prior to pin installation. Data collected at these stations reflect moderate erosion that may become more substantial as the more aggressive erosion above and below these areas could migrate. In contrast, Stations 1,066 and 1,145 did not experience any erosion over the monitoring period (Table 7). These stations are located on the lower end of the golf course reach just before the plane bed section of the disturbance reach.

The assumption that one bank is eroding along the entire reach is problematic for a couple of reasons. First, both banks could be eroding or neither bank is eroding at one particular location. This could make the erosion estimate too high or too low. Another problem with this method is pin placement. Pins were only placed in areas that appeared to be eroding. This would tend to make the erosion estimates too high. It is obviously impractical to place pins over every square foot of bank in the reach, so concessions have to be made. As long as the sources of error are understood, these estimates can be used for general comparisons. However, even using these data conservatively helps in understanding the impact bank erosion has on streams.

Total bank material lost for the 1,060 feet of bank measured for this project is 2,369 ft^3 of bank material (Table 8). The eroding sub reach comprises approximately 70% of the reach measured and contributes 84% of the total material lost over the 8 month study period. Of the nearly 2,000 ft^3 of material lost from the eroding reach about 1,500 ft^3 is fine grain material and 278 ft^3 of fine grain material was lost from the plane bed reach. The average bulk density of the fine grain bank material is 1.4 g/cm^3 which is about 87 lbs/ft^3 (Hughes, 1982). This translates to 65 T (0.13 T/ft/yr) of fine grain material lost in the eroding reach and 12 T (0.06 T/ft/yr) of material being eroded from the plane bed reach.

Chemical analysis of the sediment shows the average concentration of phosphorus (P) was approximately 400 ug/g. This is around 0.035 lbs of P per cubic foot of bank material which turns out to be around 52 lbs of sediment bound phosphorus from the eroding reach and 10 lbs from the plane bed reach. These results show that bank erosion in the study reach supplied an equivalent of nearly half (93 lbs) of the estimated annual TP load (≈ 175 lbs/year from WQ section) to the stream extrapolated to a full year. While excessive P loading may not be a problem in this stream, results here emphasize the relative importance of the role bank erosion has on water quality in an urban setting.

Table 7. Changes in Banks as Measured by Erosion Pin Monitoring

Station (ft) and Pin Position		Total Erosion (in)	Station (ft) and Pin Position		Total Erosion (in)
686	top	0.0	**1,066**	top	0.0
	middle	0.0		middle	0.0
	bottom	2.3		bottom	0.0
846	top	2.8	**1,145**	top	0.0
	middle	0.0		middle	0.0
	bottom	9.0		bottom	0.0
886	top	0.0	**1,407**	top	2.4
	middle 2	2.2		middle	0.0
	middle 1	5.1		bottom	0.0
	bottom	12.1			
925	top	14.2	**1,440**	top	3.1
	middle 3	19.3		middle	0.0
	middle 2	15.5		bottom	2.9
	middle 1	17.9			
	bottom	33.8			
958	top	8.0	**1,492**	top	4.5
	middle	21.8		middle	3.8
	bottom	40.0		bottom	10.4
984	top	5.1	**1,597**	top	7.9
	middle	5.7		middle	0.0
	bottom	5.7		bottom	0.0

Table 8. Bank Erosion Estimates

	Eroding Reach	Plane Bed Reach	Total
Average Bank Erosion for Reach (feet)	0.5	0.2	0.4
Average Bank Height (feet)	5.4	5.8	5.5
Length (feet)	740	320	1,060
Total Loss for Reach (ft^3)	1,998	371	2,369
% of Total Loss	84%	16%	100%
Coarse Material (ft^3)	500	93	593
Fine Grain Material (ft^3)	1,499	278	1,777
Fine Grain Material Mass (T)	65	12	77
Annual Fine Grain Material Loss (T)	98	18	116
Fine Grain Material Erosion Rate (T/ft/yr)	0.13	0.06	0.11
Total Phosphorus Eroded (lbs)	52	10	62
Annual Phosphorus Eroded (lbs)	78	15	93

Bank Erosion Photos

Photo 1. Erosion pin array

Photo 2. Bank erosion monitoring through golf course reach

Photo 3. Bank material lying in the stream after collapse

Photo 4. Measuring bank erosion at a pin

BEDLOAD TRANSPORT MONITORING

Graduate students Tim Davis and Mark Gossard collect sediment for bedload transport study

BEDLOAD TRANSPORT MONITORING METHODS

The proposed method for determining the sediment transport rate for this project was to use a Helly-Smith sampler during storm events. Attempts to use the sampler failed due to high velocities that made it difficult to hold the sampler in the flow and the bedload transported during storm events was too large to fit into the mouth of the sampler. Alternatively, a sediment tracer study was used to determine bedload transport rates. Specific methods used for each task required to perform the study are detailed here.

Bed Material Evaluation

Bed sediment data was collected by measuring material along the bed at 103 transects spaced ≈30 feet apart along the entire study reach. Individual sediment particles were identified by blind touch at 10 equal increments along each transect. Bed sediment size was determined by measuring the B-axis, which is the second longest axis perpendicular to the longest axis or A-axis (Photo 1). This axis represents the size of sieve the individual sediment particle would pass through. Bed material sand size or smaller was designated as “fine” and bedrock found along the bed was also noted.

Grain size data is measured and recorded in millimeters (mm) which is a standard method in geomorphology regardless of the units of the survey data. Grain size data is presented statistically by percentile size distribution. The 25th percentile diameter would be labeled the D25, meaning 75% of the sediment is larger then that number. Data collected during the 2004 survey can be found in Appendix E of the Geomorphic Conditions Report.

Bedload Tracers

Using data collected during the sediment surveys in 2004, grain size statistics were calculated for the study reach. Bed sediment was then collected along the reach and measured in the laboratory and classified based on bed material survey statistics outlined above (Photo 2). Approximately 100 pieces of sediment representing the range of sizes found in the channel were numbered and painted. Each group of sediment was released prior to a storm event at 3 different bed locations; riffle, run, and glide (Photo 3). Tracers were released at stations 885.6, 984, and 1325.1 (Figure 18). After each storm event the painted sediment was recovered and the distance it traveled from its original location was recorded (Photo 4-6).

Bedload Transport Estimates

Peak discharge (Q) was estimated after each storm event based on the high water mark as measured in the field after each storm event. Velocity (v) was estimated from the application of the Darcy-Weisbach Equation (Equation 1) using an empirical estimation of channel roughness based on the friction factor (f) equation published by Hey in 1979 (Equation 2). The friction factor equation uses Bathurst’s (1982) estimation of “a” and the D84 sediment size, an empirical statistic based on field measurements. The D84 for each station was calculated based on the sediment measurements from the 5 transects above and the 5 transects below the release point. Bathursts “a” is based on the maximum depth of the channel (dm) (Equation 3).

Equation 1: Darcy-Weisbach Equation

$v = (8gRS/f)^{0.5}$

Where:
v=mean velocity (ft/s)
g = acceleration due to gravity = 32.18 ft/s^2
R = hydraulic radius (ft)
S = slope (ft/ft)
f = friction factor (figured by Hey 1979)

Equation 2: Friction Factor (Hey, 1979)

$f = \{1/ [2.03 \log ((a R)/ (3.5 D84))]\}^{2}$

Where:
a = is figured by the Bathurst (1982)
R = hydraulic radius (ft)
D84 = 84th percentile bed sediment (ft)

Equation 3: “a” Estimation (Bathurst, 1982)

$a = 11.1 (R/d_m)^{-0.314}$

Where:
R = hydraulic radius (ft)
d_m=maximum depth (ft)

For each storm event, sediment transport analyses are based on the bed shear stress equation (Equation 5). Shear stress values were used to estimate the critical size of sediment that can be transported by the channel using empirical models (Rosgen, 2005; Leopold, Wolman, and Miller, 1964). These values were compared to bed material sample statistics (i.e. D50 and D84) collected over the study period to evaluate the applicability of these models to this stream.

Equation 5: Mean Bed Shear Stress

$T_o = Y_w RS$

Where:
$T_{o=}$ Mean Bed Shear Stress (lbs/ft^2)
Y_w = specific weight of sediment-free water = 62.4 lbs/ft^3
R = hydraulic radius (ft)
S = slope (ft/ft)

Equation 6: Leopold, Wolman & Miller (1964) Critical Sediment Size

$D_C = 77.966\tau_C^{1.042}$

Where:
$D_C =$ Critical Sediment Size (mm)
$T_C =$ Critical Shear Stress (lbs/ft^2)

Equation 7: Wildland Hydrology (2005) Critical Sediment Size

$D_c = 152.02\tau_C^{0.7355}$

Where:
$D_C =$ Critical Sediment Size (mm)
$T_C =$ Critical Shear Stress (lbs/ft^2)

RESULTS

Over the course of this study in April and May of 2006, three storm events occurred and data was recovered. A fourth larger storm event occurred at the end of May that caused most of the tracers to be lost and the data proved to be inconclusive for the few that were recovered. Results of the tracer experiments are presented here by storm event.

Storm Events

April 23-25, 2006 Event

The first storm event between April 23rd and 25th, 2006 produced 1.6 inches of rainfall over the three day period. Of the 100 tracers placed at station 984, 57 were recovered (Table 6). The depth of the flow was estimated at 1.6 feet based on highwater marks noted in the field (Table 5). Using the mean local slope of the field observed bankfull stage as a surrogate for water surface slope (1.34%), the velocity was estimated at 1.6 ft/s with a Q of 32 ft^3/s (Table 5).

Mean boundary shear stress at this discharge was estimated at 0.62 lbs/ft^2 (Table 7). The storm event moved all sizes of sediment placed in the channel. The flow moved the D95 an average of 4 feet and the D50 an average of 9.7 feet (Table 6). Sediment was left in the channel to be measured again after the next storm event.

April 28 - May 3, 2006 Event

The storm event on May 3, 2006 produced around 4 inches of rainfall according to the National Weather Service. Prior to the storm event 100 tracers were placed at both station 885.6 and 1,325.1. The distances traveled of tracers placed at 984 were measured again. On average 52% of the sediment released was recovered (Table 6). Depth of the flow was estimated at 2.2 ft at 885.6, 1.9 ft at 984, and 2 ft at 1,325.1 (Table 5). Corresponding velocity and discharge estimates were 2.6 ft/s - 57.2 ft^3/s at 885.6, 2 ft/s – 62.5 ft^3/s at 984, and 1.9 ft/s – 56.2 ft^3/s at 1325.1 (Table 5).

Shear stress estimates at these water depths were 1.26 lbs/ft^2 at 885.6, 0.62 lbs/ft^2 at 984, and 0.65 lbs/ft^2 at 1,325.1 (Table 7). This storm event also moved the entire range of sediment sizes, moving the D95 an average of 11.4 feet at 1,325.1, 4.1 feet at 984, and 20 feet at 885.6 (Table 6). The D50 traveled an average of 24.7 feet at 1,325.1, 42.8 feet at 984, and 126 feet at 885.6 (Table 6). Sediment was left in the channel to be measured again after the next storm event.

May 4 - 6, 2006 Event

The storm event from May 4-6, 2006 produced 0.9 in of rainfall. Tracers were re-measured at all three locations. Recovery rates were around 36% (Table 6). Depth of the flow was estimated at 2.4 feet at 885.6, 2 at 984, and 2.1 at 1,325.1 (Table 5). Corresponding velocity and discharge estimates were 2.8 ft/s – 68.4 ft^3/s at 885.6, 2.1 – 70.6 ft^3/s at 984, and 2 ft/s and 40 ft^3/s at 1325.1 (Table 5).

Shear stress estimates at these water depths were 1.32 lbs/ft^2 at 885, 0.86 lbs/ft^2 at 964, and 0.69 lbs/ft^2 at 1,325.1 (Table 7). This storm event also moved the entire range of sediment sizes, moving the D95 an average of 17.5 feet at 885.6, 4.9 at 984, and 17.5 feet at 1,325.1 (Table 6). The D50 traveled an average distance of 54.4 feet at 885.6, 42.8 at 984, and 7.3 feet at 1,325.1 (Table 6).

May 7-10, 2006 Event

The storm event on May 30, 2006 was only produced 0.44 inches of rainfall at the Springfield/Branson Regional Airport which is 4 miles away to the Northeast of the study site. However, the rainfall intensity was apparently heavy over the Ward branch watershed with highwater marks. This coincides with the 10-year reoccurrence interval. Recovery rates were very low at only 7% (Table 10).

DISCUSSION

Bankfull Discharge

Defining the bankfull discharge for a stream is the key to understanding stream morphology. The bankfull discharge, or more appropriately the channel forming discharge, is the discharge that has a high enough frequency to transport the largest total amount of sediment over a significant period of time (Rosgen, 1996). For natural stream conditions, this frequency has been estimated at between the 1-year and the 1.5-year reoccurrence interval (Leopold, 1994). Bankfull stage is typically estimated in the field based on the average elevation of the active floodplain.

The field estimated bankfull stage for the study reach was reported in the Geomorphic Conditions Report. The City of Springfield Stormwater Section estimated the bankfull discharge based on the field observed elevations. Hydraulic modeling results estimated the bankfull discharge through the reach at around 60 ft^3/s, with a very short reoccurrence interval of < 1-year.

The stage recorded during the initial assessment compares favorably to the high water marks documented for this bedload transport study noted between 4-25-2006 and 5-8-2006 at stations 885.6 and 984 (Table 5 and Appendix B). Highwater marks for these two stations ranged from 1.6 to 2.4 feet deep, which is at or just below the field identified bankfull stage that is estimated at 2.2 and 2.3 feet deep for these stations. However, at station 1,325.1, in the plane bed stretch, field observed bankfull (1.1-1.2 feet) was much lower than the highwater marks (2 – 2.1) noted after the rain events.

Techniques used estimate discharge for the highwater marks seem to coincide well with the City's models. Discharge estimates using the Darcy-Weisbach Equation for the highwater marks ranged from 32 – 71 ft^3/s compared to 60 ft^3/s from the models. At 1,325.1 specifically discharge for the highwater marks at around 2 feet deep were estimated at 56 and 63 ft^3/s suggesting the field observed bankfull estimate from the initial survey are too low.

For the purposes of this study comparing models to field observations provides evidence that the discharge responsible for forming the channel has been correctly identified. The frequency of this discharge illustrates two important points about urban streams in the Ozarks. One point to make is how this study provides evidence on how development can cause small, frequent storm events to have an impact on streams. Data provided by hydrological models suggests that the bankfull discharge is more frequent then in a "natural" stream when comparing the reoccurrence intervals. The second point being that Ozarks streams are very resistant to change. The fact that this stream has avoided catastrophic equilibrium shifts when impacted by seemingly significant hydrologic changes is a testament to the inherent stability of this Ozark stream.

Bedload Transport Field Measurements

Modeling sediment transport is complicated due to the interrelated aspects of bedform, flow depth, and water surface slope of a single storm event (Hey, 1995, Knighton, 1998). As the depth of flow changes over the hydrograph; moving from relatively shallow, to relatively deep, back to shallow, bedform elevation controls water surface slopes. The two factors controlling shear stress, the amount of force exerted on the bed, are water depth and water surface slope.

At the beginning of the storm, flow depths are shallow and the riffle slope controls water surface slope. For instance the riffle slope at station 984 is around 4%. While the mean depth is low, water surface slope is relatively high and shear stress at the riffle is highest at this lower flow rate. At the same time pools have low slope and shear stress when the riffle controls the water surface slope. Thus, the pool cannot scour at these depths and they become sediment deposition zones.

During the peak of the storm event, maximum shear stresses switch from the riffle to the pool. When the water depth is high enough, riffle slopes no longer control the water surface slope. The slope from riffle crest to riffle crest starts to control the water surface slope. At this point pools, which are now relatively deep, have the highest water surface slope and will scour during this portion of the hydrograph. Riffles have limited sediment transport capability because the water surface slope has been drastically reduced.

When the hydrograph is in recession, the riffle again has the highest sediment transport capability and the pools become deposition zones. The changing water surface slope over a storm hydrograph illustrates how sediment is moved through streams in a series of pulses. The exact stage at which the water surface slopes change during the storm is unclear. However, understanding how bedload is transported downstream is significant in the interpretation of the tracer results.

Understanding how sediment is transported in the stream helps analyzing the tracer results. For the purposes of this interpretation, sediment must be able to be moved out of the pool to be considered “transported” at a given discharge even though movement might be initiated when riffle slopes are controlling water surface elevations. Results for each of the three sediment tracer releases are discussed here:

Station 885.6 - Riffle-Run
Data collected for this study shows that the riffle run at 885.6 has the ability to move the largest grain size the furthest of the three bedforms studied here (Table 6). Shear stresses generated at near bankfull stage can move at least the D84 according to Wolman’s critical shear stress equation (Table 7). This estimate holds true for field observations, as the D84 on average moved beyond the downstream pool and was deposited near the crest of the next riffle (Figure 19). The D95 was moved, but never made it to the bottom of the pool.

Data for the maximum distance traveled for each class from this release location shows all sediment classes traveled beyond the downstream pool suggesting velocities at the field identified bankfull stage can transport the largest sediment sizes found in the channel at this location. This is significant because it occurred in only two bankfull storm events. The pool at 950 feet however is relatively shallow compared to the other pools in the study reach. Consequently, relatively less shear stress is required to move bedload beyond this pool. The sediment transport rate for the D50 at this location is estimated at 8.2 feet/day (Table 8). This is the highest transport rate calculated for this study.

Station 984 - Riffle Crest
Estimated shear stresses at the riffle-crest at 984 for the near bankfull stage can move at least the D50 according to Wolman’s critical shear stress equation (Table 7). This estimate again coincides with field observations, as the D50 on average moved beyond the downstream pool and was deposited near the crest of the next riffle (Figure 19). Both the D84 and D95 moved, but did not reach the bottom of the downstream pool.

From this release location the maximum travel distance of the D84 sediment size class went beyond the downstream pool at 1,025 feet to the next riffle at 1,180 feet. The D95 however did not go beyond the pool at 1,025 even after 3 bankfull storm events. Again the pool at 1,025 is relatively deep compared to the rest of the study reach and higher shear stresses are required to transport sediment beyond it. The sediment transport rate for the D50 at this location is estimated at 2 feet/day (Table 8).

Station 1,325.1 - Plane Bed

For the plane bed section, shear stress estimates for the near bankfull stage could move at least the D50 using Wolman’s critical shear stress equation (Table 7). At this location, sediment transport seems less clear due to the nature of the bedform, which is nearly 200 feet in length. While all of the sediment was moved during the study, no sediment traveled far enough to be moved through the next downstream pool (Figure 19). For comparison, the D50 moved around 1.5 feet/day which is a slightly lower rate than the riffle-crest location (Table 8).

The maximum travel distance by class also does not travel past the next downstream pool after the two bankfull events that occurred after the tracers were released at this site. This site may reflect stable sediment transport conditions where sediment inputs equal sediment outputs, at least under current hydrologic conditions.

Table 9. Bankfull Hydraulics for each Event

Station	Bedform	Storm Event Date	Bankfull Stage*	Flow Depth	Mean Bankfull Slope	CSA	Wp	Top Width	R	Mean Depth (d)	v	Q
			ft	ft	ft/ft	ft^2	ft	ft	ft	ft	ft/s	ft^3/s
885.6	riffle run	5/3/2006	2.2	2.2	0.0134	21.8	15.9	14.7	1.4	1.5	2.6	57.2
885.6	riffle run	5/8/2006		2.4	0.0134	24.8	17	15.7	1.5	1.6	2.8	68.4
984	riffle crest	4/25/2006	2.3	1.6	0.0134	19.4	26.9	25.9	0.7	0.8	1.6	32.0
984	riffle crest	5/3/2006		1.9	0.0134	30.5	31.6	30.7	1	1	2.0	62.5
984	riffle crest	5/8/2006		2	0.0134	33.7	33.9	32.9	1	1	2.1	70.6
1325.1	plane bed	5/3/2006	1.1-1.2	2	0.008	29.1	23.8	22.3	1.2	1.3	1.9	56.2
1325.1	plane bed	5/8/2006		2.1	0.008	31.4	24.2	22.7	1.3	1.4	2.0	63.1

Table 10. Sediment Tracer Recovery Data

Storm Dates	Rainfall	Recovery Dates	Recovery Rate	Station	Average Distance Traveled (feet) by Class per Event				Maximum Distance Traveled (feet) by Class per Event			
	in		%	feet	D25	D50	D84	D95	D25	D50	D84	D95
4/23/2006 - 4/25/2006	1.6	4/25/2006	57	984	5.8	9.7	5.8	4	20.0	16.1	17.4	6.6
5/3/2006	0.9	5/3/2006	52	885.6	87.5	126	53.5	20	178.1	223.0	178.1	32.8
				984	13	42.8	12	4.1	23.0	23.0	110.9	13.8
				1325.1	37.7	24.7	22.8	11.4	107.6	93.8	102.3	39.7
5/4/2006 - 5/6/2006	0.4	5/8/2006	36	885.6	6.6	54.4	26.8	17.5	6.6	108.9	58.7	109.6
				984	72.3	42.8	2.3	4.9	90.2	84.3	5.9	25.9
				1325.1	13.2	7.3	8.4	1.8	37.1	13.8	61.0	5.2

Table 11. Sediment Transport Estimates Compared to Sediment Survey

Station	Bedform	Storm Event	Shear Stress	Wolman	Rosgen	D25	D50	D84	D95	Dmax
		Date	lbs/ft^2	mm	mm	mm	mm	mm	mm	mm
885.6	run	5/3/2006	1.24	98	178	28	46	85	118	177
885.6	run	5/8/2006	1.32	104	187					
984	riffle	4/25/2006	0.62	48	108	29	42	86	110	181
984	riffle	5/3/2006	0.83	64	133					
984	riffle	5/8/2006	0.86	66	136					
1325.1	plane bed	5/3/2006	0.65	50	111	20	37	75	105	164
1325.1	plane bed	5/8/2006	0.69	53	116					

Table 12. Bedload Transport Rate of the D50 Grain Size (feet/day)

Bedform	Station	Days	D50	
			Avg. Dist (ft)	Rate (ft/day)
riffle-crest	964	16	32	2.0
riffle-run	885.6	11	90	8.2
plane bed	1,325.1	11	16	1.5

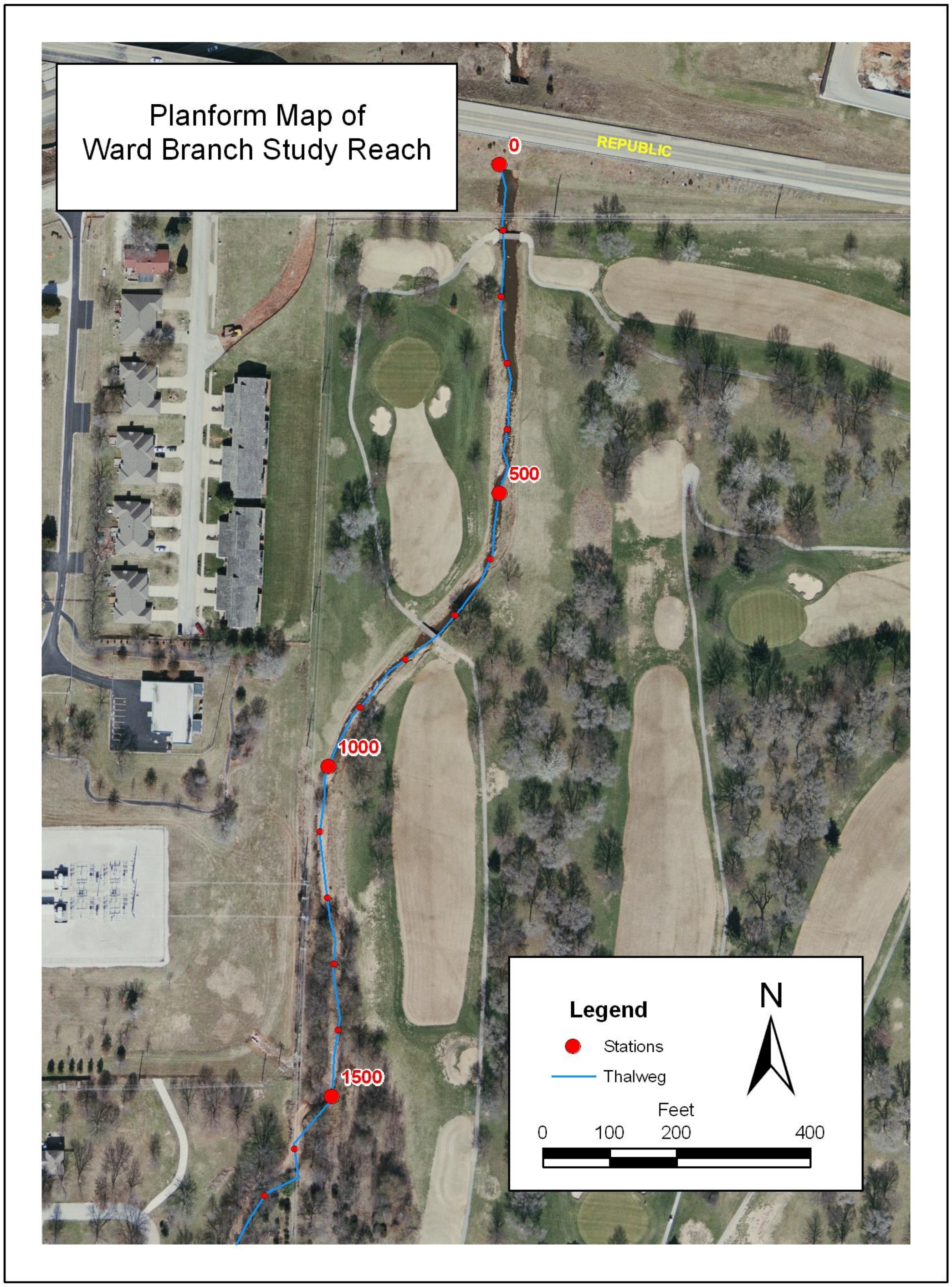


Figure 57. Study Reach

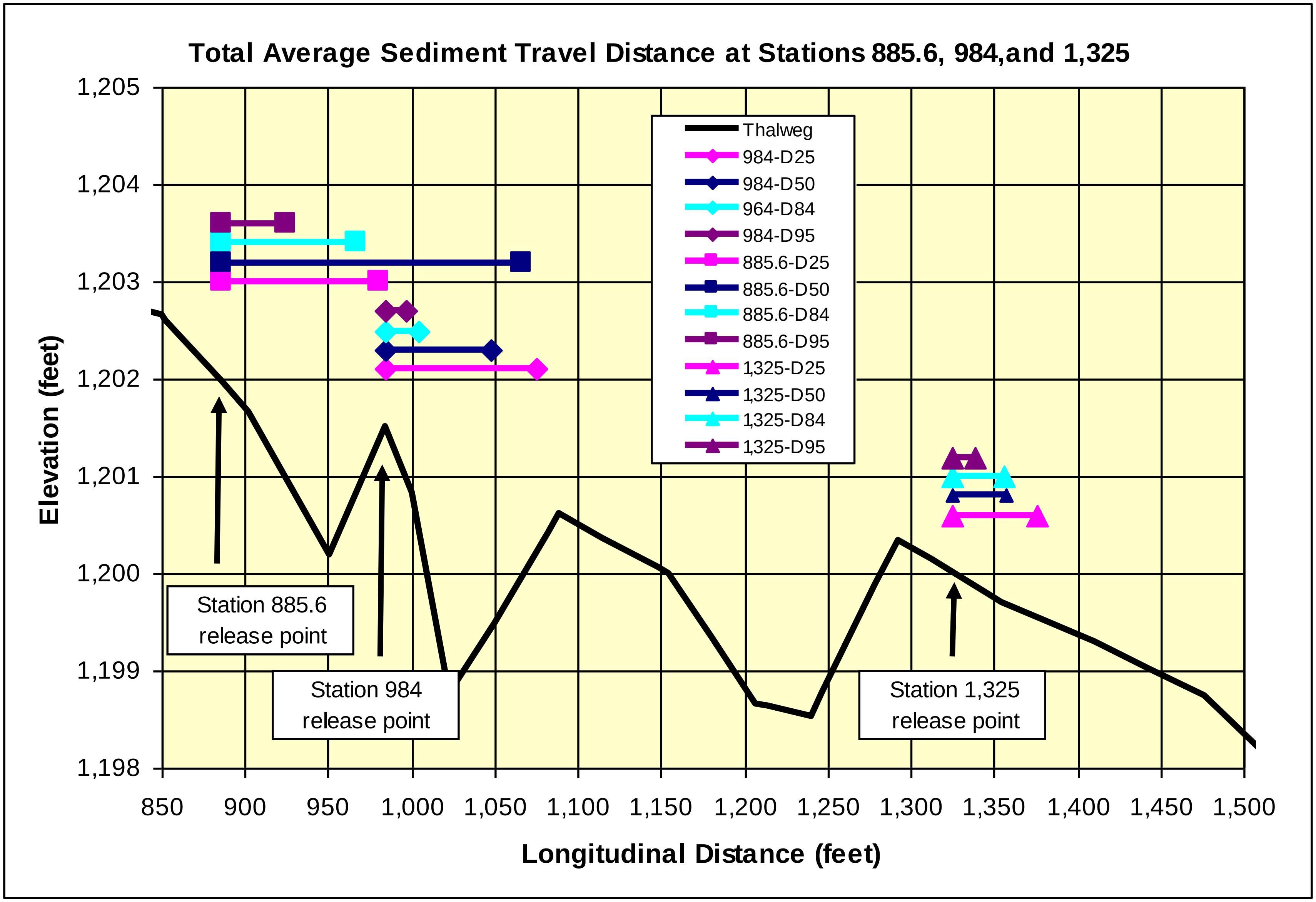


Figure 58. Total Average Travel Distance of Sediment Tracers by Class at each Release Location

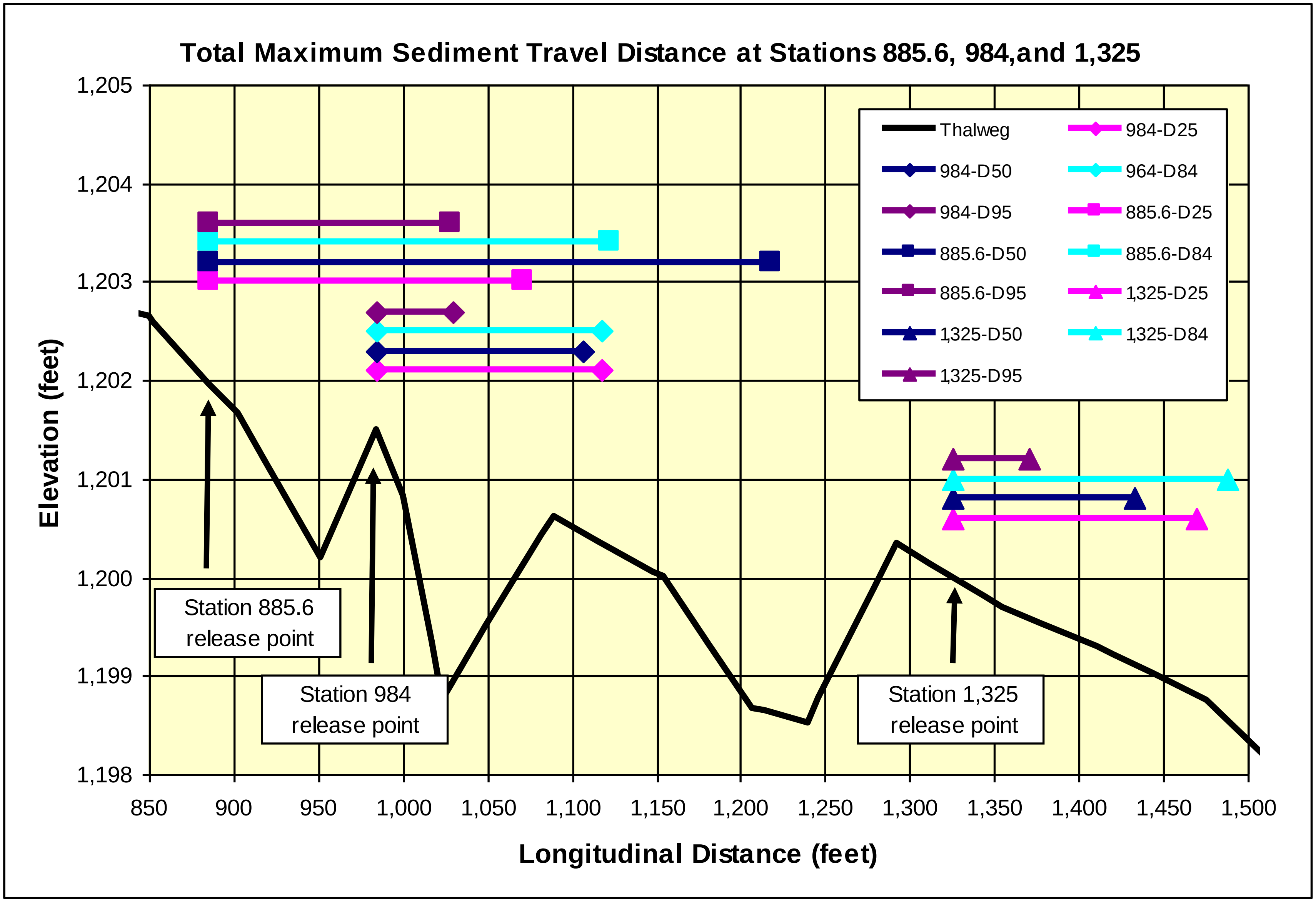


Figure 59. Total Maximum Distance Traveled of Sediment Tracers by Class at each Release Location

PHOTOS

Photo 1: Measuring the B axis of a piece of sediment.

Photo 2: Sediment being collected for tracer experiment

Photo 3: Sediment tracers released at 1,325.1 in plane bed reach

Photo 4: Recovering tracers after a storm event and measuring distance traveled

Picture 5: Sediment tracer recovery

Picture 6: Showing identification number of sediment tracer

LITERATURE CITED

Bisson, P.A., D.R. Montgomery, and J.M. Buffington, 2006. Valley segments, stream reaches, and channel units-chapter 2. In, F.R. Hauer and G.A. Lamberti (eds.), Methods in Stream Ecology, 2nd Edition, Elsevier, Amsterdam, 877 p.

Boulding, J.R., 1994. Description and Sampling of Contaminated Soil: A Field Guide (2nd Ed.), Boca Raton: Lewis Publishers.

Dean, W.E., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. Journal of Sedimentary Petrology 44:242-248.

Fitzpatrick, F.A., I.R. Waite, P.J. D'Arconte, M.R. Meador, M.A. Maupin, and M.E. Gurtz, 1998. Revised methods for characterizing stream habitat in the National Water-Quality As sessment Program. Water-Resources Investigations Report 98-4052, United States Geological Survey.

Greene County, Missouri, 1999. Greene County Storm Water Design Standards. Greene County Resources Management Department.

Hey, R and D. Rosgen, 2004. A Geomorphic Approach to Natural Channel Design in River Restoration. Lecture notes from Self-Sustaining Solutions for Streams, Wetlands, and Watersheds workshop, September 12, 2004.

Legleiter, K.J., 1999. GIS Analysis of channel changes due to a small dam on the James River, SW Missouri. Unpublished MS Thesis in Resource Planning, Missouri State Univerity, Springfield, Missouri.

Leopold, L.B., 1994. A View of the River. Harvard University Pres, Cambridge, Massachusetts. 298 pp.

Lisle, T.E., 1987. Using "residual depths" to monitor pool depths independently of discharge. Research Note PSW-394. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experimental Station, 4 pp.

Kaufmann, P.R., and E.G. Robison, 1998. Physical habitat characterization-chapter 7. In: J.M. Lazorchak, D.J. Klemm, and D.V. Peck (Eds), Environmental Monitoring and Assessment Program- Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Wadeable Streams. EPA/620/R-94/004F. U.S. Environmental Protection Agency, Washington, D.C., 42 pp.

Knighton, D., 1998. Fluvial Forms and Processes. Oxford University Press, New York, New York. 383 pp.

Martin, D.J., 2005. Geospatial analysis of gravel bar deposition and channel migration within the Ozark National Scenic Riverways, Missouri (1955-2003). Unpublished MS thesis in Geospatial Science MS Program, Department of Geography, Geology, and Planning, Missouri State University, 109 pp.

MDNR, 2001. Total Maximum Daily Load (TMDL) for James River, Webster, Greene, Christian and Stone Counties, Missouri. Missouri Department of Natural Resources, 31 pp.

NOAA, 2007. National Climate Data Center. http://www.ncdc.noaa.gov/oa/ncdc.html

Panfil, M.S., and R.B. Jacobson, 2001. Relations among geology, physiography, land use, and stream habitat conditions in the Buffalo and Current River systems, Missouri and Arkansas. United States Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2001-0005.

Rosgen, Dave, 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Sheldrick and Wang, 1993. Particle size distribution-chapter 47. In M.R. Carter (Ed.), Soil Sampling Methods of Analysis, Canadian Society of Soil Science. Boca Raton, Florida: Lewis Publishers, p. 499-511.

Simon, A., and P.W. Downs, 1995. An interdisciplinary approach to evaluation of potential instability in alluvial channels. Geomorphology 12(3):215-232.

Wolman, M.G., 1954. A method of sampling coarse river-bed material. Transactions American Geophysical Union 35:951-956.

APPENDIX A: LONGITUDINAL SURVEY DATA

Longitudinal Distance (ft)	Thalweg Elev. (ft)
0	1,207.4
32.8	1,207.2
49.2	1,207.6
88.6	1,208.4
131.2	1,207.8
164	1,207.9
196.8	1,208
229.6	1,208
262.4	1,208
295.2	1,208.2
311.6	1,208.4
328	1,208.2
344.4	1,208
354.2	1,207.1
360.8	1,207
383.8	1,206.8
393.6	1,206.7
423.1	1,206.5
426.4	1,206.3
442.8	1,205.7
459.2	1,204.9
478.9	1,203.9
492	1,204
524.8	1,204.4
544.5	1,204.6
557.6	1,204.3
580.6	1,203.6
590.4	1,203.4
619.9	1,202.7
623.2	1,202.7
656	1,202.8
665.8	1,202.8
688.8	1,202.9
708.5	1,202.9
721.6	1,202.7
754.4	1,203.4
764.2	1,203.5
787.2	1,203.1
803.6	1,202.8
820	1,202.8
849.5	1,202.7
852.8	1,202.6
885.6	1,202
902	1,201.7
918.4	1,201.2
951.2	1,200.2
984	1,201.5
1,000.4	1,200.8
1,016.8	1,199.4
1,023.4	1,198.8
1,049.6	1,199.5
1,082.4	1,200.4
1,089	1,200.6
1,115.2	1,200.4
1,148	1,200.1
1,154.6	1,200
1,180.8	1,199.3
1,207	1,198.7
1,213.6	1,198.6
1,239.8	1,198.5
1,246.4	1,198.8
1,279.2	1,199.9
1,292.3	1,200.3
1,312	1,200.1
1,344.8	1,199.8
1,354.6	1,199.7
1,377.6	1,199.5
1,410.4	1,199.3
1,420.2	1,199.2
1,443.2	1,199
1,476	1,198.7
1,508.8	1,198.2
1,541.6	1,197.7
1,574.4	1,197.7
1,607.2	1,197.7
1,640	1,197.1
1,672.8	1,196.4
1,705.6	1,195.7
1,712.2	1,196.5
1,738.4	1,196.9
1,771.2	1,197.3
1,804	1,197.1
1,827	1,197
1,836.8	1,197
1,869.6	1,197.2
1,872.9	1,197.2
1,882.7	1,195.7
1,902.4	1,195.8
1,931.9	1,196
1,935.2	1,195.9
1,958.2	1,195.7
2,000.8	1,194.5
2,033.6	1,193.7
2,066.4	1,192.5
2,099.2	1,194
2,125.4	1,195.2
2,132	1,194.9
2,151.7	1,194
2,164.8	1,194.1
2,197.6	1,194.2
2,210.7	1,194.2
2,230.4	1,194.4
2,263.2	1,194.8
2,276.3	1,194.9
2,296	1,194.2
2,312.4	1,193.6
2,328.8	1,193.4
2,361.6	1,192.8
2,394.4	1,193.4
2,427.2	1,194
2,460	1,193.4
2,492.8	1,192.8
2,525.6	1,192.1
2,591.2	1,192
2,624	1,192
2,656.8	1,191.6
2,689.6	1,191.3
2,722.4	1,191.3
2,738.8	1,191.3
2,755.2	1,191
2,788	1,190.2
2,804.4	1,189.8
2,820.8	1,189.8
2,853.6	1,189.7
2,870	1,189.6
2,886.4	1,189.7
2,919.2	1,189.8
2,952	1,189.4
2,984.8	1,189.2
3,001.2	1,189.2

APPENDIX B: CHANNEL GEOMETRY

Longitudinal Distance (ft)	Bankfull Elev. (ft)	Left Bank Elev. (ft)	Right Bank Elev. (ft)	Active Width (ft)	Bankfull Depth (ft)
49.2	1,208.9	1,210.4	1,211.2	29.5	1.3
131.2	1,209.3	1,212.5	1,212.9	23.6	1.5
164	1,210.1	1,212.3	1,212.8	23.3	2.2
196.8	1,209.9	1,212	1,212	26.2	2.0
229.6	1,209.8	1,211.2	1,211.7	25.6	1.8
262.4	1,209.5	1,210.8	1,211.4	23.0	1.6
295.2	1,209.9	1,210.9	1,211.5	18.0	1.7
328	1,209.5	1,210.5	1,210.2	13.1	1.3
360.8	1,208.6	1,210.4	1,209.6	8.5	1.6
393.6	1,208.1	1,208.8	1,209.4	18.0	1.4
426.4	1,207.9	1,208.7	1,208.3	15.1	1.6
459.2	1,206.7	1,208.5	1,207.7	16.7	1.8
492	1,206.1	1,208.1	1,207.2	12.6	2.1
524.8	1,206.3	1,207.2	1,206.8	13.1	1.9
557.6	1,206.1	1,207.3	1,207.7	9.8	1.9
590.4	1,204.6	1,206.1	1,206.1	10.8	1.2
623.2	1,204.2	1,206.3	1,206.5	14.8	1.5
656	1,205.4	1,207.7	1,207.7	12.1	2.6
688.8	1,205.2	1,208	1,208	19.8	2.4
721.6	1,204.9	1,208.1	1,206.1	20.0	2.2
754.4	1,204.7	1,207	1,205.5	20.0	1.4
787.2	1,205.2	1,206.1	1,205.9	15.4	2.0
820	1,204.8	1,205.6	1,206.2	13.1	2.0
852.8	1,204.3	1,205.6	1,206.4	17.4	1.7
885.6	1,204.2	1,205.3	1,207.7	15.1	2.2
918.4	1,204.3	1,205.1	1,208.1	12.8	3.1
951.2	1,203.8	1,205.4	1,206.9	10.7	3.6
984	1,203.8	1,204.3	1,208.1	14.1	2.3
1,016.8	1,201.4	1,202.8	1,206.2	12.8	2.0
1,049.6	1,200.7	1,202.3	1,207.2	14.1	1.2
1,082.4	1,202.1	1,204	1,208.1	18.7	1.7
1,115.2	1,201.3	1,203.2	1,207.7	17.1	1.0
1,148	1,202	1,202.8	1,205.5	15.1	2.0
1,180.8	1,200.4	1,201.6	1,204.4	16.4	1.1
1,213.6	1,201.5	1,203.5	1,203.5	11.2	2.9
1,246.4	1,200.0	1,202.7	1,201.4	15.7	1.2
1,279.2	1,201.4	1,203.3	1,202	17.7	1.5
1,312	1,201.3	1,204.6	1,204.6	26.9	1.1
1,344.8	1,201.1	1,204.1	1,205.1	23.0	1.3
1,377.6	1,201	1,202	1,203.9	18.2	1.4
1,410.4	1,201.1	1,203.1	1,204.9	20.3	1.8
1,443.2	1,201.2	1,204.2	1,204.8	23.3	2.1
1,476	1,202.1	1,206.3	1,202.7	22.0	3.3
1,508.8	1,202	1,203.6	1,205.9	28.5	3.8
1,541.6	1,199.2	1,202.3	1,202.3	21.0	1.5
1,574.4	1,199.2	1,201.3	1,203	22.5	1.4

Longitudinal Distance (ft)	Bankfull Elev. (ft)	Left Bank Elev. (ft)	Right Bank Elev. (ft)	Active Width (ft)	Bankfull Depth (ft)
1,607.2	1,200.4	1,204.8	1,203.3	21.0	2.7
1,640	1,199.2	1,201	1,202.6	18.0	2.1
1,672.8	1,198.7	1,201.3	1,201	15.1	2.3
1,705.6	1,197.5	1,201.4	1,202	18.4	1.8
1,738.4	1,197.8	1,201.1	1,201.8	22.0	1.0
1,771.2	1,198.5	1,200.9	1,201.7	17.4	1.1
1,804	1,198.2			17.4	1.1
1,836.8	1,197.9	1,199.8	1,201.3	14.8	0.9
1,869.6	1,198.3	1,200.3	1,200.5	16.7	1.1
1,902.4	1,196.8	1,200.2	1,200.2	14.1	1.0
1,935.2	1,197.3	1,199.9	1,198.1	19.7	1.3
2,000.8	1,195.8			19.0	1.3
2,033.6	1,195.3	1,200.9	1,200.9	20.0	1.5
2,066.4	1,194.9	1,199.5	1,198.8	18.4	2.4
2,099.2	1,195.4	1,198.7	1,198.6	16.7	1.3
2,13	1,196.6	1,199.9	1,199.1	20.3	1.7
2,164.8	1,196.5	1,199.2	1,198.4	18.0	2.4
2,197.6	1,195.6	1,198	1,198.7	16.7	1.4
2,230.4	1,196.2	1,198.3	1,197.6	18.4	1.8
2,263.2	1,196.6	1,197.9	1,198.3	20.0	1.8
2,296	1,196.5	1,198.2	1,198.2	19.7	2.3
2,328.8	1,194.7	1,196.8	1,198.2	19.4	1.4
2,361.6	1,195.1	1,197.8	1,198.3	13.8	2.3
2,394.4	1,195.2	1,197.6	1,198.5	22.0	1.8
2,427.2	1,195.2	1,198.4	1,198.4	19.7	1.1
2,460	1,195.4	1,198	1,197.4	20.3	2.0
2,492.8	1,194.2	1,197.8	1,198.7	15.7	1.4
2,525.6	1,194.5	1,197.5	1,197.9	16.4	2.5
2,591.2	1,192.9	1,197	1,200	18.4	0.9
2,624	1,193.4	1,201.5	1,196.5	13.1	1.4
2,656.8	1,193.5	1,195.8	1,198.8	19.0	1.9
2,689.6	1,192.9	1,194.9	1,199.9		
2,722.4	1,194.3	1,196.4	1,200.1	18.0	3.0
2,755.2	1,192.7	1,194.8	1,196.9	15.7	1.7
2,788	1,191.4	1,195.3	1,196.3	12.1	1.2
2,820.8	1,191.1	1,194.5	1,195.3	17.1	1.3
2,853.6	1,191.5	1,196.6	1,194.2	12.5	1.8
2,886.4	1,191.5	1,195.9		17.7	1.8
2,919.2	1,191.4	1,195.8	1,195.9	16.7	1.7
2,952	1,191	1,196.2	1,194.4	17.7	1.7
2,984.8	1,190.5	1,200.9	1,193.2	15.7	1.2

APPENDIX C: POOL-RIFFLE INVENTORY

Riffle Location on Tape (ft)	Riffle Spacing (ft)	Pool Location on Tape (ft)	Max Residual Pool Depth (ft)
66.9	66.9	21.3	2.1
115.1	48.2	103.6	0.3
202.4	87.2	171.2	0.7
306	103.6	255.8	0.3
326.4	20.3	320.1	0.2
332.9	6.6	329	0.2
342.8	9.8	340.1	0.3
349.6	6.9	347.4	0.4
373.3	23.6	360.8	0.4
392.9	19.7	381.1	0.6
423.1	30.2	414.9	0.3
441.2	18	436.9	0.3
509.1	67.9	478.9	1
565.5	56.4	560.9	0.6
604.5	39	585.8	0.5
680.6	76.1	665.8	0.6
760	79.4	734.7	0.8
842	82	796.1	0.4
878.4	36.4	868.5	0.9
984	105.6	947.9	2.4
1,069	85.0	1,026.6	2.1
1,180.8	111.8	1,115.2	0.1
1,253	72.2	1,215.6	1.6
1,312	59	1,269.4	0.5
1,367.8	55.8	1,338.2	0.3
1,436.6	68.9	1,386.1	1
1,548.2	111.5	1,507.5	1.1
1,666.9	118.7	1,640	0.8
1,743	76.1	1,685.3	2.3
1,823	80	1,805.3	0.1
1,868	44.9	1,863	0.7
1,929	61	1,892.6	0.3
1,949	20	1,941.8	0.5
2,015.9	66.9	1,964.7	0.9
2,094.3	78.4	2,062.1	2
2,164.8	70.5	2,145.1	0.8
2,268.8	104	2,252.7	0.9
2,338.3	69.5	2,313.1	0.3
2,414.1	75.8	2,354.1	1.2
2,492.8	78.7	2,475.7	0.1
2,573.2	80.4	2,536.1	1.2
2,638.1	64.9	2,618.8	0.4
2,684.7	46.6	2,659.1	1.4
2,709.3	24.6	2,686.3	0.3
2,725.7	16.4	2,707.6	0.5
2,773.6	47.9	2,759.5	0.1
2,804.7	31.2	2,783.7	0.7
2,850.6	45.9	2,823.1	0.4
2,899.2	48.5	2,869.3	0.7
2,942.5	43.3	2,914.9	0.3

APPENDIX D: BANK SEDIMENT DATA

Tapeline	Sample Location			Sedimentary Unit	Soil Horizon (A, B, C)	OM% (LOI)	pH (1:1 water/sed)	Munsell Color			**Description**
	#	Depth upper	Depth lower					Hue	Value	Chroma	
888	1	0	39	Fill	A	5.2	6.1	10YR	3	3	dark brown
	2	39	82	Y-Br	Bt	6	6.2	7.5YR	3	4	dark brown
	3	82	113	Y-Br	Bt1	5.4	6.2	7.5YR	3	4	dark brown
	4	113	123	Y-Br	Bt2	5.6	6.4	7.5YR	4	3	brown
	5	123	164	R-Br	Bt3	5	6.5	2.5YR	3	4	dusky red
	6	164	181	R-Br	2Bt4	6.4	6.9	2.5YR	3	4	dusky red
938	1	0	26	Fill	A	6	6.7	10YR	2	1	dark brown
	2	26	49	Y-Br	B1	5	6.3	7.5YR	3	3	dark brown
	3	49	89	Y-Br	Bt2	4.8	6.2	7.5YR	3	3	dark brown
	4	89	116	Y-Br	Bt3	4.5	5.8	7.5YR	3	4	dark brown
	5	116	142	Y-Br	Bt4	4.6	6	7.5YR	4	4	brown
	6	142	212	R-Br	2Bt5	5.8	6.4	2.5YR	3	4	dusky red
1,312	1	0	19	?	A	4	7.1	7.5yr	3	2	dark brown
	2	19	38	?	Ab?	6	7.4	10yr	3	2	very dark grayish brown
	3	38	79	?	B?	5.5	6.4	7.5yr	3	2	dark brown
	4	79	121	?	B?	5.7	7	10yr	3	4	dark yellowish brown
	5	121	179	?	Bt2?	5.8	7.2	7.5yr	4	4	reddish brown
1,443	1	0	22	Fill	A	7.2	7.1	7.5yr	3	2	dark brown
	2	22	51	Fill	A	5.5	7	5yr	3	2	dark reddish brown
	3	51	84	lacustrine/pond?	A	5.6	7.2	7.5yr	3	2	dark brown
	4	84	116	lacustrine/pond?	B	5.9	6.7	7.5yr	3	4	dark brown
	5	116	153	lacustrine/pond?	B	5.9	7.1	10yr	3	3	yellowish dark brown
1,476	1	0	34	Fill	A	1.9	7.4	7.5YR	3	2	Dark Brown
	2	34	45	Overbank	2Ab	1.8	6.7	10YR	2	2	Very Dark Brown
	3	45	103	Overbank		1.5	5.9	10YR	3	4	Dark Yellowish Brown
	4	103	162	Channel		1.9	6.5	7.5YR	3	4	Dark Brown
	5	162	176	Residuum	3C	3.7	7	7.5YR	3	4	Dark Brown
1,564	1	0	10	Fill	A	9	7.4	7.5YR	3	4	Dark Brown
	2	10	24	Overbank	Ab	6.8	7.4	5YR	3	2	Dark Reddish Brown
	3	24	45	Channel Bar	Bt	5.7	7.3	5YR	3	2	Dark Reddish Brown
	4	45	67	Lag Gravel	Bt	6	7.1	5YR	3	2	Dark Reddish Brown
	5	67	134	Lag Gravel	Bt	6.9	6.9	5YR	3	3	Dark Reddish Brown
	6	134	139	Residuum	Bt2	6.4	7.1	7.5YR	3	4	Dark Brown

		Soil Texture	Texture of fines			Percent size fraction (%) by sieve size (mm)					Chemical Data				
Tapeline	**#**	**USDA**	**clay%**	**silt%**	**sand%**	**<2 mm fines**	**2-4 vfg**	**4-8 fg**	**8-16 mg**	**16-32 cg**	**Al %**	**Ca %**	**Fe %**	**Mn ppm**	**P ppm**
888	1	grSicl	32.6	58.8	8.6	77.6	0	10.4	12	0	1.54	0.40	3.44	10,300	470
	2	vgrSic	45.2	46.1	8.7	43.4	0	0	1.6	55	1.85	0.26	2.66	3,290	440
	3	vgrSic	42.6	50.1	7.3	51.5	0	0	7.7	40.8	2.31	0.22	3.41	5,290	350
	4	vgrSic	41.4	44	14.6	61.4	0	0	19.5	19.1	2.21	0.24	2.81	2,090	240
	5	grCl	39	33.3	27.7	64.8	18.7	16.5	0	0	3.01	0.27	4.08	10,700	310
	6	grC	56.5	36.5	7	79.2	0.6	1.9	0	18.3	3.73	0.34	5.06	5,370	410
938	1	vgrSil	25.1	61.5	13.4	44	4.9	10.7	28.1	12.3	1.91	0.26	3.00	5,320	440
	2	xgrSicl	27.5	57.6	14.9	34.5	7.8	9.4	19.5	28.8	2.67	0.29	2.94	2,920	390
	3	vgrSicl	38.6	45.4	16	48.3	5.2	15.7	11.6	19.1	3.01	0.30	3.01	3,760	340
	4	grSicl	37.6	56.8	5.6	80.4	3.4	3.1	3.1	10.1	3.03	0.31	3.46	5,750	320
	5	xgrSic	43.9	47.2	8.9	14.6	3.2	3.2	6.2	72.9	3.18	0.37	4.80	6,890	350
	6	vgrC	45.2	35.5	19.3	63.5	7.8	18.5	10.1	0	3.88	0.47	4.08	4,440	290
1,312	1	Loam	12.8	38.5	48.6	94.9	2	1.5	1.6	0	0.76	0.53	1.08	971	270
	2	Silty Clay	23.5	54.8	21.8	89.1	3.4	2.9	0	0	1.45	0.37	2.13	2,670	410
	3	Silty Clay	26.1	54.9	19	99.9	0.1	0.1	0	0	1.49	0.25	1.84	2,020	330
	4	Clay Loam	27.3	30	42.7	42.1	5.8	10.7	10.9	30.6	1.94	0.26	3.12	7,190	420
	5	Clay	39.3	39.3	21.4	49.6	27.5	9.6	7.9	5.5	2.63	0.33	3.29	4,280	480
1,443	1	Silt Loam	29.4	41.6	29.0	99.9	0.1	0	0	0	1.81	1.04	2.26	2,640	470
	2	Silt Loam	20.4	68.9	10.7	99.9	0.1	0	0	0	1.14	0.29	1.50	1,275	340
	3	Sicl	27.8	58.2	14	98.7	0.3	0.3	0.7	0	1.49	0.21	1.87	1,580	360
	4	Silt Loam	25.4	60.9	13.8	100	0	0	0	0	1.45	0.24	1.72	1,510	400
	5	Sicl	33.1	40.7	26.3	91.5	6.3	2.2	0	0	1.80	0.29	2.21	3,040	460
1,476	1	Silty	21	28	51	99.3	0.1	1	0.5	0	1.63	0.50	1.94	1,940	410
	2	Loamy	15	35	50	90.3	6	1.4	2.4	0	1.46	0.27	1.82	1,970	510
	3	Clay	15	36	48	95.2	2.7	0.9	1.2	0	1.99	0.20	2.34	2,220	380
	4	Clay-	30	37	33	37.6	2.7	5.4	15.7	38.7	2.94	0.30	3.53	4,200	470
	5	Sand	38	47	15	81.9	13.1	4.5	0.5	0	4.31	0.56	9.55	14,050	660
1,564	1	Silt	35	35	30	95	4.8	0.2	0	0	2.19	1.65	3.24	5,770	560
	2	Clay	36	24	50	85.5	2	0.3	1.1	11.3	1.37	0.46	1.92	2,620	390
	3	Clay	16	24	60	93.7	2.8	0.6	1.2	1.7	1.11	0.30	1.55	1,875	390
	4	Clay	25	27	48	92	4.9	1.4	1.7	0	1.79	0.30	2.75	4,920	420
	5	Silt	19	35	45	68.3	10.5	7.6	5.9	7.8	1.98	0.31	2.66	3,250	410
	6	Gravel	46	34	19	41.1	13.2	15.0	19.9	10.9	2.64	0.33	4.42	4,840	400

APPENDIX E: BANK CONDITIONS

Tape Distance feet	**Left Bank Height** feet	**Right Bank Height** feet	**Upper Left Bank Angle** (degrees)	**Upper Right Bank Angle** (degrees)	**BCI** Left Bank	**BCI** Right Bank
49.2	2.8	3.7	21	38	59	140
131.2	4.7	5.1	10	8	47	40
164.0	4.4	5	14	8	62	40
196.7	4.0	4	8	8	32	32
229.5	3.3	3.7	7	8	23	30
262.3	2.8	3.4	4	5	11	17
295.1	2.7	3.3	7	5	19	16
327.9	2.3	2.1	5	19	12	39
360.7	3.4	2.6	8	50	27	128
393.5	2.1	2.7	31	88	66	240
426.3	2.4	2	89	79	213	158
459.1	3.6	2.9	71	10	258	29
491.9	4.1	3.2	88	9	361	28
524.7	2.8	2.4	71	10	200	24
557.5	3.0	3.4	81	9	244	31
590.2	2.7	2.7	67	65	182	175
623.0	3.6	3.8	87	88	314	335
655.8	4.9	4.9	90	100	443	492
688.6	5.2	5.2	83	88	427	453
721.4	5.4	3.4	87	95	471	318
754.2	3.7	2.2	79	55	290	119
787.0	3	2.7	64	67	191	182
819.8	2.9	3.4	76	26	217	89
852.6	3	3.8	86	72	254	276
885.4	3.4	5.7	40	107	135	611
918.2	4	6.9	24	100	95	692
951.0	5.3	6.7	12	86	63	578
983.7	2.8	6.6	28	105	78	689
1,016.5	3.4	6.9	43	76	148	523
1,049.3	2.8	7.7	63	63	176	484
1,082.1	3.6	7.6	70	66	253	504
1,114.9	2.8	7.4	45	66	125	485
1,147.7	2.8	5.4	54	20	151	108
1,180.5	2.3	5.1	19	68	43	343
1,213.3	4.9	4.9	48	63	233	306
1,246.1	3.9	2.6	26	18	101	47
1,278.9	3.4	2.1	42	19	145	41
1,311.7	4.4	4.4	64	40	283	177
1,344.5	4.3	5.3	67	40	288	210
1,377.2	2.4	4.4	31	88	75	387
1,410.0	3.8	5.6	82	63	315	355
1,442.8	5.2	5.	62	14	323	80
1,475.6	7.5	3.9	74	9	558	35
1,508.4	5.4	7.7	86	18	465	139
1,541.2	4.7	4.7	81	55	377	256

Tape Distance feet	Left Bank Height feet	Right Bank Height feet	Upper Left Bank Angle (degrees)	Upper Right Bank Angle (degrees)	BCI Left Bank	BCI Right Bank
1,574.0	3.5	5.3	74	9	262	48
1,606.8	7.1	5.6	76	54	536	301
1,639.6	3.9	5.5	22	6	87	33
1,672.4	4.9	4.6	38	48	187	220
1,705.2	5.7	6.3	80	33	459	209
1,738.0	4.3	4.9	77	82	328	403
1,770.7	3.6	4.4	20	42	72	186
1,803.5	2.6	4.4	16	16	41	70
1,836.3	2.8	4.3	18	31	50	132
1,869.1	3.1	3.3	83	53	259	174
1,901.9	4.4	4.4	74	60	328	266
1,934.7	3.9	2.1	47	25	185	53
2,000.3			90	90	0	0
2,033.1	7.2	7.2	61	49	436	352
2,065.9	7	6.3	41	55	289	346
2,098.7	4.7	4.6	41	25	191	116
2,131.5	5	4.2	45	20	223	84
2,164.2	5.1	4.3	63	38	320	165
2,197.0	3.8	4.5	42	31	158	140
2,229.8	3.9	3.2	66	34	255	109
2,262.6	3.1	3.5	73	26	227	92
2,295.4	4.0	4	13	28	52	113
2,328.2	3.4	4.9	42	44	145	214
2,361.0	5	5.5	22	35	110	192
2,393.8	4.2	5	9	38	38	191
2,426.6	4.4	4.3	15	30	66	130
2,459.4	4.6	3.9	36	45	165	177
2,492.2	5	5.9	37	39	186	229
2,525.0	5.4	5.8	40	50	215	292
2,590.5	5	8.	30	47	150	376
2,623.3	9.5	4.5	47	69	446	310
2,656.1	4.2	7.2	22	90	91	644
2,688.9	3.6	8.7	20	41	72	355
2,721.7	5.1	8.8	20	64	102	566
2,754.5	3.8	6	26	55	100	330
2,787.3	5.1	6.1	50	27	254	164
2,820.1	4.8	5.5	70	35	332	192
2,852.9	6.9	4.6	30	40	208	184
2,885.7	6.1	4.3	31	38	188	164
2,918.5	6.2	6.1	42	32	259	195
2,951.2	6.4	5	21	36	135	180
2,984.0	7	4	29	60	203	240

APPENDIX E: BED SEDIMENT DATA

Tape Distance	**Bed Sediment Size (B-axis) (mm)**									
(feet)	B = bedrock, C = cut earth, F = fines, TD = too deep, RR = riprap									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
49.2	F	80	50	10	70	60	80	30	10	F
82	20	15	80	40	45	15	75	35	40	F
131.2	20	50	40	35	110	B	45	95	5	F
164	F	80	35	20	130	20	60	110	240	5
196.8	F	60	50	75	35	30	20	35	40	F
229.6	F	4	15	30	35	30	70	35	10	F
262.4	F	30	75	25	60	45	35	50	60	5
295.2	F	45	20	95	25	45	30	50	40	F
328	F	35	55	80	40	80	130	50	15	3
360.8	2	3	30	100	25	35	40	F	30	15
393.6	F	F	25	50	85	160	100	20	90	30
426.4	17	75	28	32	66	47	143	44	55	8
459.2	F	C	58	73	35	87	25	60	27	50
492	C	C	73	107	87	62	60	43	27	F
524.8	F	29	60	10	58	123	128	62	75	F
557.6	C	C	70	31	65	54	70	97	187	C
590.4	C	C	52	77	65	90	48	33	F	F
623.2	C	C	C	85	34	28	8	5	F	C
656	C	C	B	TD	TD	TD	TD	32	C	C
688.8	C	C	63	79	TD	25	30	54	17	C
721.6	C	C	C	82	75	56	53	12	28	C
754.4	C	64	11	50	51	39	72	20	25	C
787.2	C	14	148	105	93	82	52	8	28	C
820	C	9	84	66	34	33	57	40	C	C
852.8	C	49	53	24	80	31	83	95	19	C
885.6	36	38	46	88	42	103	86	30	C	C
918.4	18	33	48	58	145	46	93	C	C	C
951.2	F	37	65	32	47	TD	TD	TD	TD	C
984	34	46	53	71	48	19	35	C	C	C
1,016.8	C	20	40	210	21	60	130	40	45	C
1,049.6	C	110	73	27	7	20	18	25	9	C
1,082.4	C	110	96	79	24	92	42	15	F	C
1,115.2	C	C	50	7	34	32	11	25	36	C
1,148	C	77	56	65	60	117	18	53	5	C
1,180.8	C	23	34	78	75	64	39	64	8	C
1,213.6	C	C	38	34	22	32	45	20	14	F
1,246.4	C	18	27	B	B	8	26	32	105	C
1,279.2	C	43	14	11	23	90	64	17	19	C
1,312	C	C	37	42	70	84	49	55	37	C
1,344.8	C	65	20	73	54	100	40	56	21	C
1,377.6	C	80	8	34	52	44	81	39	29	C
1,410.4	C	107	34	17	49	34	16	12	6	C
1,443.2	F	32	16	127	16	22	105	34	44	C
1,476	6	14	53	19	62	39	119	93	72	C

1,508.8	F	7	F	5	F	37	12	B	B	C
1,541.6	C	F	F	21	51	80	49	14	15	C
1,574.4	C	C	9	58	30	175	69	35	46	C
1,607.2	C	17	23	36	14	17	90	31	12	C
1,640	F	F	11	39	21	95	34	22	C	C
1,672.8	C	32	18	21	15	78	22	18	9	F
1,705.6	C	109	B	54	23	C	C	23	85	C
1,738.4	C	14	16	109	21	36	44	30	C	C
1,771.2	C	55	12	17	31	34	61	170	87	C
1,804	C	67	58	23	52	96	15	70	C	C
1,836.8	C	33	10	53	34	68	70	16	20	C
1,869.6	C	111	52	25	8	32	53	30	C	C
1,902.4	C	15	17	49	B	B	13	16	26	C
1,935.2	C		20	137		114	17	235	C	C
1,968	F	16	C	34	38	29	82	B	B	C
2,000.8	F	6	F	15	6	5	30	36	21	11
2,033.6	F	10	82	60	9	60	22	65	20	12
2,066.4	F	37	F	F	80	42	25	11	F	F
2,099.2	10	6	62	17	30	60	60	105	70	80
2,132	20	60	80	70	110	30	140	140	430	F
2,164.8	8	10	15	20	20	25	20	140	70	45
2,197.6	F	60	30	25	12	30	35	25	20	20
2,230.4	F	20	10	20	60	40	20	50	15	30
2,263.2	25	25	15	15	20	40	40	50	40	F
2,296	10	30	30	60	210	15	40	50	40	20
2,328.8	F	90	170	110	250	60	12	20	15	F
2,361.6	25	240	230	10	F	30	25	10	20	F
2,394.4	15	110	60	50	25	15	25	15	15	F
2,427.2	20	900	430	300	30	35	80	140	35	25
2,460	F	60	60	70	70	60	40	120	80	F
2,492.8	F	40	120	70	40	70	100	50	60	RR
2,525.6	280	90	25	50	30	30	60	50	70	RR
2,558.4	20	15	40	15	25	30	30	20	15	10
2,591.2	20	68	45	65	44	31	80	30	17	F
2,624	F	F	35	10	45	15	18	12	15	20
2,656.8	14	65	110	580	580	240	9	13	13	24
2,689.6	3	29	14	7	15	38	8	39	F	40
2,722.4	F	7	15	35	4	7	20	10	F	82
2,755.2	17	F	78	37	16	23	20	29	31	13
2,788	10	360	590	95	25	490	60	38	18	14
2,820.8	F	15	118	F	45	60	120	14	30	14
2,853.6	11	90	24	75	14	30	19	25	37	250
2,886.4	F	78	29	7	15	B	B	19	B	460
2,919.2	F	78	7	17	24	8	36	B	206	32
2,952	13	38	B	58	B	160	9	29	50	16
2,984.8	F	38	52	19	25	21	61	19	60	53
3,017.6	F	F	B	15	7	23	F	31	13	F
3,050.4	F	32	12	12	9	40	44	48	8	11
3,083.2	F	17	8	9	16	10	B	B	142	9
3,116	F	140	23	B	B	B	B	B	10	14

3,148.8	F	182	23	13	25	7	28	39	F	17
3,181.6	F	F	F	41	16	9	39	174	157	558
3,214.4	F	F	346	112	63	14	22	12	F	F
3,247.2	F	48	12	79	F	264	58	188	93	11
3,280	F	176	104	244	23	24	B	B	9	14
3,312.8	F	F	14	26	19	8	164	366	31	26
3,345.6	F	74	40	20	49	37	40	259	245	F
3,378.4	F	54	52	147	391	48	19	20	F	9
3,411.2	44	B	B	B	B	B	114	F	22	20

APPENDIX F: WATER QUALITY DATA SHEETS

Sample Discharge Estimates

Q (ft^3/s)

Site	11/30/2004	12/7/2004	1/13/2005	3/22/2005	6/3/2005	8/3/2005	9/15/2005	10/31/2005	11/15/2005	3/9/2006	5/9/2006
1	17.4	26.2	45.6	17.1	2.1	3.5	166.2	196.8	13.3	100.3	335.9
2	9.4	13	17.6	0	0	0	9.4	60.6	11.3	14.4	92.3
3	16.1	20.6	72.4	0.1	0	0	122.1	89.1	29.4	102.9	271.9
4	0.6	0.6	2.3	0	0	0	55.4	38.7	0.9	1.9	123.9
5	60.2	106.6	165.9	33	10.3	13.2	244.3	252	158.4	139.6	424.7

All Water Quality Data by Parameter

Total Nitrogen (mg/L)

Site #	Location	11/30/04	12/7/04	1/13/05	3/22/05	6/3/05	8/3/05	9/15/05	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
Site 1	Republic Road	2.79	2.26	3.09	2.15	3.21	2.38	1.42	0.99	1.46	1.20	2.09	2.20	0.99	3.21	0.80	38
Site 2	Holland St.	2.83	2.25	2.96	2.30	ns	ns	1.65	0.87	1.32	1.11	1.91	1.95	0.87	2.96	0.79	41
Site 3	Camino St.	2.77	2.09	2.91	2.34	ns	ns	1.47	6.98	1.27	0.98	2.60	2.22	0.98	6.98	1.90	73
Site 4	Buena Vista St.	2.77	2.19	2.87	2.39	ns	ns	1.00	6.28	1.07	1.09	2.46	2.29	1.00	6.28	1.73	70
Site 5*	Campbell Ave.	3.75	2.79	3.92	ns	3.31	2.75	2.06	1.13	1.69	1.36	2.53	2.75	1.13	3.92	1.02	41

Total Phosphorus ug/L)

Site #	Location	11/30/04	12/7/04	1/13/05	3/22/05	6/3/05	8/3/05	9/15/05	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
Site 1	Republic Road	24.00	23.00	22.00	21.00	8.00	1.00	0.00	80.42	47.62	58.98	28.60	22.50	0.00	80.42	26.09	91
Site 2	Holland St.	22.00	24.00	26.00	26.00	ns	ns	7.00	60.06	41.59	80.59	35.90	26.00	7.00	80.59	23.84	66
Site 3	Camino St.	19.00	27.00	20.00	35.00	ns	ns	0.00	59.31	46.49	67.92	34.34	31.00	0.00	67.92	22.59	66
Site 4	Buena Vista St.	17.00	22.00	25.00	36.00	ns	ns	15.00	62.70	41.21	72.02	36.37	30.50	15.00	72.02	21.23	58
Site 5*	Campbell Ave.	20.00	31.00	23.00	28.00	11.00	1.00	18.00	79.29	51.39	67.55	33.02	25.50	1.00	79.29	25.18	76

Turbidity (NTU)

Site #	Location	11/30/2004	12/7/2004	9/15/2005	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
1	Republic Road	11.1	54.2	28.2	288	999	68.6	242	61	11	999	385	159
2	Holland St.	10.7	30.1	38.2	223	116	52.8	78	46	11	223	79	101
3	Camino St.	10.7	29.2	29	291	119	72.5	92	51	11	291	105	114
4	Buena Vista St.	10.7	54.2	31.3	303	108	55.4	94	55	11	303	108	115
5	Campbell Ave.	6.8	21.5	42.3	285	145	67.2	95	55	7	285	105	111

pH

Site #	Location	11/30/2004	12/7/2004	9/15/2005	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
1	Republic Road	6.96	7.14	7.07	6.58	7.23	7.6	7.1	7.1	6.6	7.6	0.3	5
2	Holland St.	7.31	7.34	7.13	6.73	7.36	7.59	7.2	7.3	6.7	7.6	0.3	4
3	Camino St.	7.43	7.41	7.11	6.68	7.34	7.56	7.3	7.4	6.7	7.6	0.3	4
4	Buena Vista St.	7.51	7.49	6.84	6.56	7.41	7.57	7.2	7.5	6.6	7.6	0.4	6
5	Campbell Ave.	7.19	7.19	7.06	6.58	7.35	7.42	7.1	7.2	6.6	7.4	0.3	4

Dissolved Oxygen (mg/L)

Site #	Location	11/30/2004	12/7/2004	9/15/2005	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
1	Republic Road	8.28	9.32	8.33	10.95	11.1	5.73	9.0	8.8	5.7	11.1	2	22
2	Holland St.	9.78	10.02	9.32	11.75	12.73	4.34	9.7	9.9	4.3	12.7	2.9	30
3	Camino St.	9.97	9.87	9.1	12.64	12.92	6.64	10.2	9.9	6.6	12.9	2.3	23
4	Buena Vista St.	9.96	10.05	7.72	11.01	12.81	7.11	9.8	10.0	7.1	12.8	2.1	22
5	Campbell Ave.	9.11	8.76	9.06	12.02	12.8	7.18	9.8	9.1	7.2	12.8	2.1	22

Temperature (^{o}F)

Site #	Location	11/30/2004	12/7/2004	9/15/2005	10/31/2005	11/15/2005	3/9/2006	mean	median	min	max	SD	CV%
1	Republic Road	55.7	55.9	68.7	56.9	58.2	53.1	58.1	56.4	53.1	68.7	5	9
2	Holland St.	54.7	55.4	69.3	56.7	57.3	52.8	57.7	56.1	52.8	69.3	5.9	10
3	Camino St.	54.4	55.1	69.4	56.8	57.0	52.8	57.6	55.9	52.8	69.4	6.0	10
4	Buena Vista St.	54.1	54.9	68.8	56.6	57.0	52.8	57.4	55.7	52.8	68.8	5.8	10
5	Campbell Ave.	57.1	56.4	67.3	57.8	58.5	54.1	58.5	57.5	54.1	67.3	4.6	8

Conductivity (mS/cm)

Site #	Location	11/30/2004	12/7/2004	9/15/2005	10/31/2005	11/15/2005	3/9/2006	mean	med	min	max	SD	CV%
1	Republic Road	0.448	0.383	0.257	0.246	0.434	0.399	0.361	0.391	0.246	0.448	0.09	24
2	Holland St.	0.449	0.37	0.277	0.264	0.396	0.378	0.356	0.374	0.264	0.449	0.07	20
3	Camino St.	0.428	0.365	0.282	0.279	0.394	0.379	0.355	0.372	0.279	0.428	0.06	17
4	Buena Vista St.	0.446	0.362	0.207	0.265	0.375	0.383	0.340	0.369	0.207	0.446	0.09	26
5	Campbell Ave.	0.501	0.412	0.336	0.315	0.446	0.383	0.399	0.398	0.315	0.501	0.07	17

Water Chemistry Parameters by Site

Site 1-Republic

Date	TURB (NTU)	pH	DO (mg/L)	COND (mS/cm)
11/30/2004	11.1	7.0	8.28	0.448
12/7/2004	54.2	7.1	9.32	0.383
9/15/2005	28.2	7.1	8.33	0.257
10/31/2005	288	6.6	10.95	0.246
11/15/2005	999	7.2	11.1	0.434
3/9/2006	68.6	7.6	5.73	0.399
minimum	11.1	6.6	5.73	0.246
maximum	288	7.6	11.1	0.448
mean	241.52	7.1	8.95	0.36
median	61.4	7.1	8.825	0.391
SD	384.58	0.3	2.00	0.09
CV%	159	5	22	24

Site 2-Holland

Date	TURB (NTU)	pH	DO (mg/L)	COND (mS/cm)
11/30/2004	10.7	7.3	9.78	0.449
12/7/2004	30.1	7.3	10.02	0.37
9/15/2005	38.2	7.1	9.32	0.277
10/31/2005	223	6.7	11.75	0.264
11/15/2005	116	7.4	12.73	0.396
3/9/2006	52.8	7.6	4.34	0.378
minimum	10.7	6.7	4.34	0.264
maximum	223	7.6	12.73	0.449
mean	78.47	7.2	9.66	0.36
median	45.5	7.3	9.9	0.374
SD	79.39	0.3	2.91	0.07
CV%	101	4	30	20

Site 3-Camino

Date	TURB (NTU)	pH	DO (mg/L)	COND (mS/cm)
11/30/2004	10.7	7.4	9.97	0.428
12/7/2004	29.2	7.4	9.87	0.365
9/15/2005	29	7.1	9.1	0.282
10/31/2005	291	6.7	12.64	0.279
11/15/2005	119	7.3	12.92	0.394
3/9/2006	72.5	7.6	6.64	0.379
minimum	10.7	6.7	6.64	0.279
maximum	291	7.6	12.92	0.428
mean	91.9	7.3	10.19	0.3545
median	50.85	7.4	9.92	0.372
SD	105.10	0.3	2.34	0.06
CV%	114	4	23	17

Site 4-Buena Vista

Date	TURB (NTU)	pH	DO (mg/L)	COND (mS/cm)
11/30/2004	10.7	7.5	9.96	0.446
12/7/2004	54.2	7.5	10.05	0.362
9/15/2005	31.3	6.8	7.72	0.207
10/31/2005	303	6.6	11.01	0.265
11/15/2005	108	7.4	12.81	0.375
3/9/2006	55.4	7.6	7.11	0.383
minimum	10.7	6.6	7.11	0.207
maximum	303	7.6	12.81	0.446
mean	93.77	7.2	9.78	0.34
median	54.8	7.5	10.005	0.3685
SD	107.54	0.4	2.11	0.09
CV%	115	6	22	26

Site 5-Campbell

Date	TURB (NTU)	pH	DO (mg/L)	COND (mS/cm)
11/30/2004	6.80	7.2	9.11	0.50
12/7/2004	21.50	7.2	8.76	0.41
9/15/2005	42.30	7.1	9.06	0.34
10/31/2005	285.00	6.6	12.02	0.32
11/15/2005	145.00	7.4	12.80	0.45
3/9/2006	67.20	7.4	7.18	0.38
minimum	6.80	6.6	7.18	0.32
maximum	285.00	7.4	12.80	0.50
mean	94.63	7.1	9.82	0.40
median	54.75	7.2	9.09	0.40
SD	105.20	0.3	2.14	0.07
CV%	111	4	22	17

APPENDIX G: NUTRIENT LOADING DATA

Discharge Estimates

Site #	Ad (mi^2)	Mean Q (ft^3/s)	Hourly Q (ft^3/hr)	Daily Q (ft^3/day)	Annual Q ($ft^3/year$)	Annual Q (Mgal/year)
1	2.378	2.155	7,758	186,187	67,958,301	509
2	2.691	2.439	8,779	210,694	76,903,191	576
3	2.714	2.459	8,854	212,494	77,560,484	581
4	2.735	2.478	8,922	214,139	78,160,620	585
5	4.966	4.500	16,201	388,816	141,917,967	1,062

Total Nutrient Loading Estimates by Site

Site #	Mean TP (ug/L) ug/L	Mean TN (mg/L) mg/L	Annual TP Load ug/year	Annual TN Load mg/year	Annual TP Load lbs/year	Annual TN Load lbs/year	Annual TP Yield lbs/acre/year	Annual TN Yield lbs/acre/year
1	31.8	2.1	61,163,369,045	4,030,222,816	135	8,887	0.09	5.8
2	35.9	1.9	78,197,251,498	4,160,390,351	172	9,174	0.10	5.3
3	39.2	2.6	86,203,251,353	5,714,406,930	190	12,600	0.11	7.3
4	36.4	2.5	80,497,530,680	5,435,002,668	177	11,984	0.10	6.8
5	33.0	2.5	132,723,288,641	10,153,628,779	293	22,389	0.09	7.0

APPENDIX H: EROSION PIN DATA

Station (ft)	Profile Location	9/21/2005	11/8/2005	11/16/2005	11/21/2005	1/24/2006	1/30/2006	3/14/2006	5/3/2006	5/8/2006	5/10/2006	5/30/2006	Total
686	top	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	1.0	0.0	0.0	**2.3**
846	top	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.8**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.8	0.0	0.0	1.9	0.0	0.0	0.0	0.0	2.4	0.0	3.9	**9.0**
886	top	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	middle 2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.2**
	middle 1	3.5	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.1**
	bottom	0.9	2.5	3.9	2.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	**12.1**
925	top	0.0	0.0	0.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	**14.2**
	middle 3	0.0	0.0	0.0	0.0	15.4	0.0	0.0	3.9	0.0	0.0	0.0	**19.3**
	middle 2	1.3	0.0	0.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	**15.5**
	middle 1	4.1	0.0	0.0	0.7	9.1	0.0	0.0	0.0	2.2	0.0	1.8	**17.9**
	bottom	8.2	2.0	2.4	1.1	17.7	0.0	0.0	0.0	2.4	0.0	0.0	**33.8**
958	top	2.4	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	**8.0**
	middle	2.1	0.0	0.0	0.0	17.7	0.0	0.0	0.0	2.0	0.0	0.0	**21.8**
	bottom	17.7	0.0	1.4	1.8	17.7	0.0	0.0	0.0	0.0	0.0	1.4	**40.0**
984	top	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.1**
	middle	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	**5.7**
	bottom	2.3	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	**5.7**
1066	top	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1145	top	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1407	top	-2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**-2.4**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1440	top	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.1**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.9**

Station (ft)	Profile Location	9/21/2005	11/8/2005	11/16/2005	11/21/2005	1/24/2006	1/30/2006	3/14/2006	5/3/2006	5/8/2006	5/10/2006	5/30/2006	Total
1492	top	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**4.5**
	middle	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.8**
	bottom	2.6	0.9	0.9	0.0	0.0	1.6	4.3	0.0	0.0	0.0	0.0	**10.4**
1597	top	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	3.9	**7.9**
	middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**